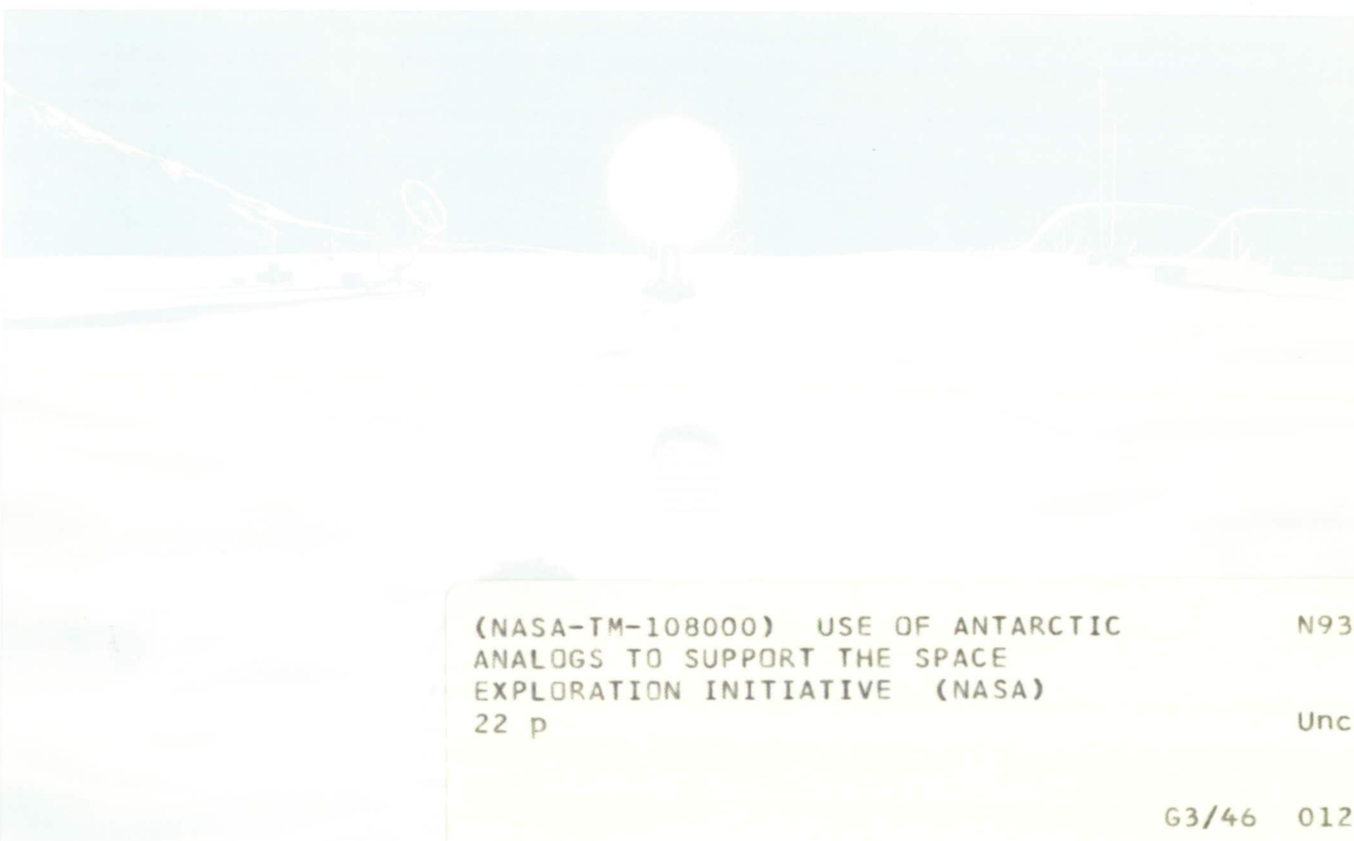
Use of Antarctic Analogs to Support The Space Exploration Initiative



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FOREWORD

In the next 30 years, the U.S. is planning to return human beings to the Moon and to launch piloted missions to Mars. Small numbers of people will live for extended periods of time in spacecraft and on the surfaces of the Moon and Mars, environments hostile to human life. The crews on these missions will need advanced life support systems that allow them to live and work productively in relative comfort. They will also need the capability to leave their habitats to explore planetary surfaces and conduct scientific field work. Machinery, vehicles, and instrumentation that can withstand harsh conditions and rugged terrain must be provided for them. Life scientists will need to understand the human dynamics that develop among individuals who have only their fellow crew members to turn to as colleagues and companions. The logistics involved in resupply will be complex; therefore, conservation and efficiency will be issues of paramount importance.

For more than 25 years, the National Science Foundation has been conducting a program of scientific research on Earth's most hostile continent: Antarctica. Here, too, relatively small numbers of people live for extended periods in an environment that challenges equipment and systems for sustaining human life. In this frigid world, scientists conduct research under conditions that require special protective clothing and sophisticated devices that can operate at temperature extremes. Interesting human dynamics develop among small groups of Antarctic personnel confined in relatively close quarters for long periods of time. Resupply is infrequent because of the difficulty of transportation into Antarctica.

The compelling similarities between these two programs — human exploration of the Moon and Mars and Antarctic research — has led the National Aeronautics and Space Administration and the National Science Foundation to explore the possibility of collaborating and sharing research results. Both agencies concur that strong parallels do indeed exist in operational requirements in the environments of planetary bodies and Antarctica. Further, mutual benefits seem likely to accrue through using the unique conditions of Antarctica to test and verify systems to be used in space, while similarly applying technologies developed for space exploration to Antarctic research stations.

This report offers a preliminary analysis of several ways in which such collaboration might be accomplished. The ideas discussed here will serve as a starting point for developing joint activities over the next few years. Both NASA and the NSF endorse these ideas, and look forward to a productive working relationship as these two exciting national programs continue to unfold.

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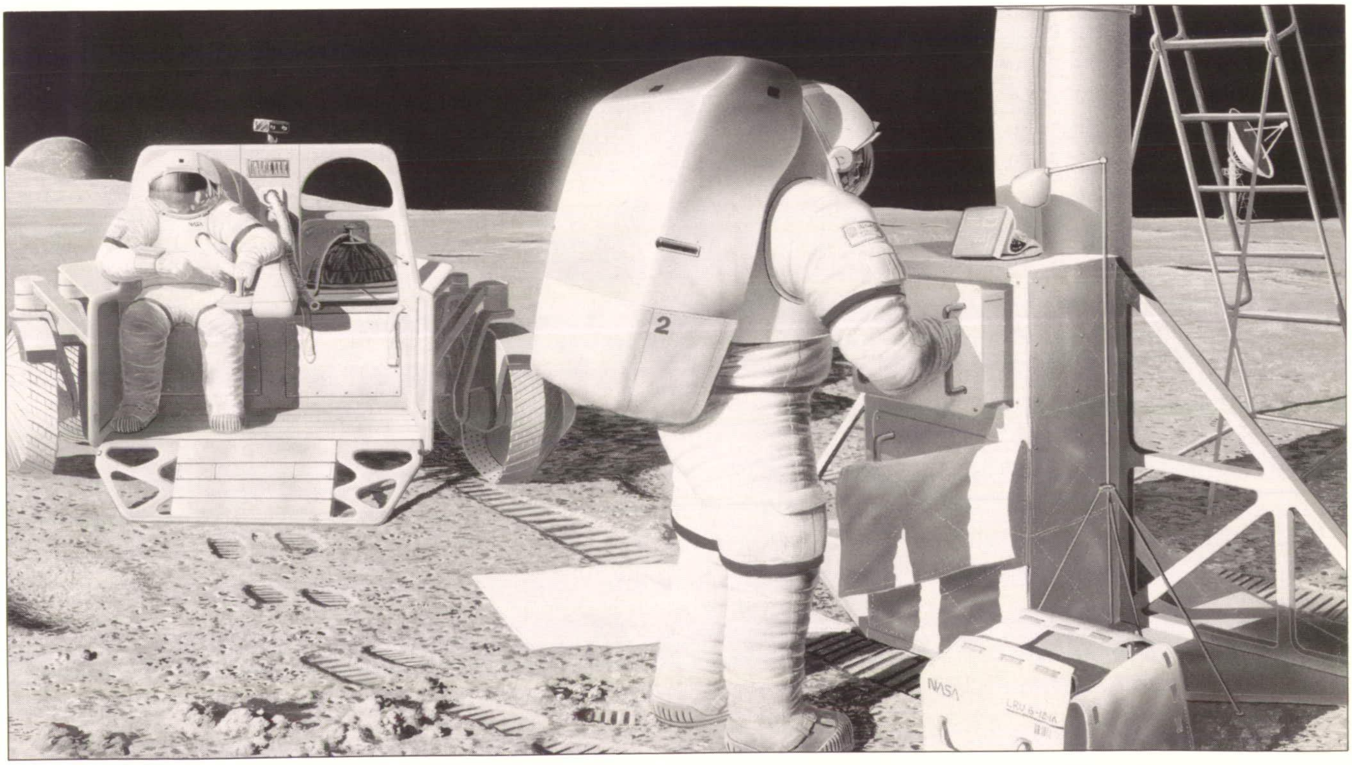
1. INTRODUCTION

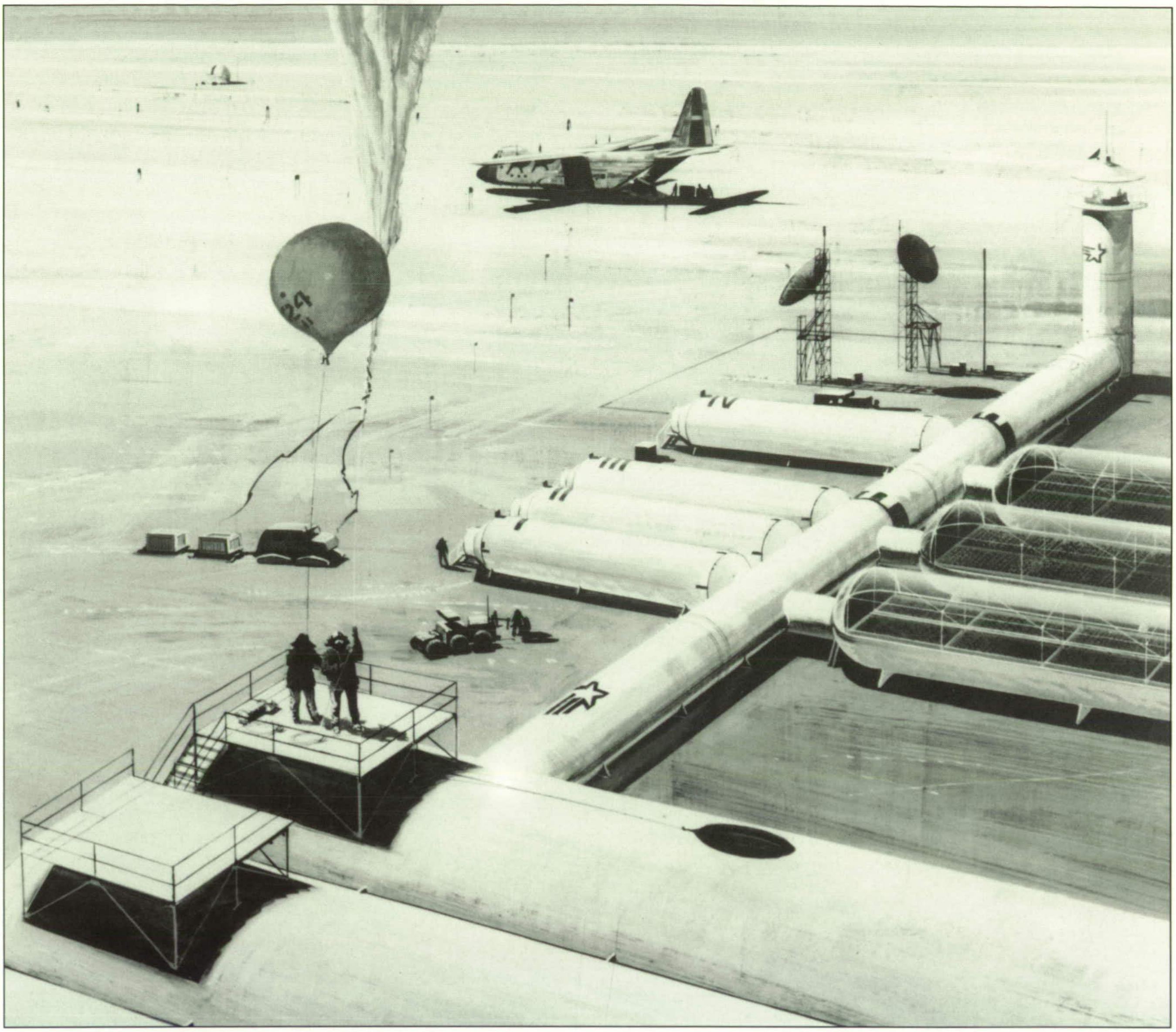
The Space Exploration Initiative (SEI) is a national agenda for the human exploration of space. As detailed by President Bush, the Initiative is a three-decade plan to complete Space Station Freedom in the 1990s, establish permanent human presence on the Moon in the early 2000s, and land a crew on Mars before 2019. With the oversight of the National Space Council, NASA is the lead agency for the SEI, with the Departments of Defense and Energy playing important roles. Other Federal agencies and scientific organizations are also expected to participate in the definition and implementation of the SEI.

Human exploration of the Moon and Mars will pose a complex array of scientific and technical challenges. The Nation's substantial investment in these missions, the inherent logistical constraints, and the limited accessibility of lunar and Martian environments make advanced planning and research imperative. Productive crew activities in extremely remote, intrinsically hazardous, and comparatively unfamiliar settings require understanding, to the greatest possible extent, the operational, physiological, and psychological challenges that will be encountered. A well-planned and sustained program of ground-based research and testing in environments analogous to the Moon and Mars is a proven, rational method to reduce the risks associated with human space missions of unprecedented duration, distance, and complexity. Many characteristics unique to Antarctica make it an appropriate Earth analog for lunar and Martian outposts: physical remoteness, isolation, hostile environments, rugged terrain, logistical constraints, and limited human contact.

The scientific research conducted in Antarctica during the International Geophysical Year (1957 to 1958) led to the establishment of the U.S. Antarctic Program (USAP) in 1959. For more than 25 years, the National Science Foundation (NSF) has spearheaded the program, which encompasses a broad spectrum of disciplines, including glaciology, biology, biomedicine, Earth science, atmospheric sciences, and ocean sciences. (Recent Antarctic research, for



Human exploration of the Moon and Mars will require advanced systems, such as those pictured here, to allow crew members to move about freely and work productively. (Artwork by Pat Rawlings/SAIC, design by Chuck Simonds, Lockheed © LMSC 1989.)



Antarctic research stations, such as the one depicted here, share many characteristics with lunar and Martian exploration. (Painting courtesy of Lockheed, © 1990.)

example, includes comprehensive studies of the depletion of Earth's ozone layer.) Over its 30-year history, the program has been extended to encompass the responsibility for managing all related operational activities. This research program has placed the United States in a unique position of scientific preeminence and diplomatic leadership.

The NSF's program presents strong parallels with the SEI, particularly in the research, human, and operational aspects of working in a remote and hazardous environment. In addition, both programs focus on scientific exploration and discovery. Access to the Antarctic environment and to the NSF's rich history of experience could provide an opportunity to test and verify proposed approaches to critical planetary surface systems and operational techniques. The U.S. Antarctic Program, in turn, could benefit from developed and proposed NASA data, systems, and technologies that might increase the efficiency of operations or enhance the research program.

Because of its remote and hostile nature, Antarctica may provide an ideal setting for testing critical technologies (habitat design, life support, and advanced scientific instrumentation), studying human factors and physiology, and conducting basic scientific research similar to and directly relevant to the scientific research planned for the Space Exploration Initiative. Antarctica is a compelling place in which to conduct these tests, because the individuals engaged in Antarctic science are doing the same type of research that will be conducted on the Moon and Mars: exobiology, geology, astrophysics, and basic biology. Crews of Antarctic bases and outposts must be largely self-sufficient because these sites are remote and isolated, although they may be accessible enough for rescue in the event of an emergency. Individuals and groups experience stresses that are, in many respects, similar to those that will be experienced by crews on long-duration space missions: isolation, confinement, forced socialization, harsh environments, extremes of light and dark, and dependence on life support.

Studies in the Antarctic can yield information on human behavior and performance, human-machine interfaces, communications, medical care in remote locations, health maintenance, and physiology under long-term, stressful conditions. Along with operational considerations, questions of social psychology and interpersonal interaction will assume paramount importance on future human missions to the Moon and Mars. For Mars, these missions could involve up to 2 years in flight, in addition to time spent on the planet. Space travel has a range of physiological effects, some of which could be amenable to study in analog settings in Antarctica. For example, conditions of isolation are known to compromise the immune system, and personnel in Antarctic bases could serve as subjects for immunodepression studies. Ambient conditions in Antarctica could also be conducive to studies of sleep cycle, seasonal affect disorder, and adaptation of circadian rhythms to cycles of light and darkness.

The broad discipline of space human factors will become increasingly important as planning for human exploration proceeds. Crews on Mars will spend long periods in confined conditions at vast distances from Earth's familiar environment. Positive psychosocial interactions and crew cohesiveness are important to the success of these high-investment missions. Antarctic bases can provide a testbed for studying operational techniques, human factors, and small-group dynamics in harsh conditions. As an added advantage, these studies will consist of meaningful tasks in discrete disciplines, much like those to be performed on the Moon and Mars, as opposed to simulations of actual tasks that have limited operational extrapolability. Information gathered in Antarctica could help in formulating standards for crew selection and skill mix for space missions. Command and control structure, crew coordination and communication, and questions of leadership, all critical to the success of space operations, can be studied in Antarctic outposts.

An additional synergism between the two programs lies in the fact that Antarctic science may help to answer questions about Mars science, particularly those concerning the possible emergence and fate of life on Mars. At one time in the history of the solar system, conditions on Mars and Earth were probably quite similar. Particularly noteworthy is the evidence that liquid water once flowed on Mars, which suggests that life may have had the opportunity to evolve. Then, for reasons not well-understood, the Martian atmosphere began to disappear; temperatures dropped, and Mars became the frozen desert that it is today.

In the dry valleys of Antarctica, similar types of conditions prevail. The only permanently ice-covered lakes on Earth are found in the dry valleys; in effect, they are also a frozen desert region. Scientific research in the dry valleys seeks to understand how life would adapt itself to these conditions. The tools and techniques developed to search for signs of past or present life in the dry valleys of Antarctica can be adapted to tools and techniques developed to search for signs of past or present life on Mars.

This report provides an overview of the results of efforts addressing potential approaches to using the Antarctic in these ways as an analog for the lunar and Mars exploration of the SEI. (These efforts include a joint NASA/NSF workshop held on May 2, 1990.) Sections 2 and 3 describe in more detail the SEI and U.S. Antarctic Program. Section 4 elaborates on the unique conditions of two particularly promising Antarctic sites. Section 5 discusses a possible approach to implementing a joint NASA/NSF effort, and Section 6 summarizes conclusions.

2. THE SPACE EXPLORATION INITIATIVE (SEI)

The SEI is a national commitment to expand human presence in the solar system. The SEI near-term strategy, which builds on the results and insights of 20 years of studies, encompasses three major, interdependent phases:

1. Establish policy direction.
2. Determine mission architecture options.
3. Analyze architectures and program implementation approaches.

The specific approach to implementing the SEI is still in its formative stages, and this will continue to be the case for the next several years. However, some features can be inferred from past and current planning activities. For example, a lunar outpost may evolve from a small research base to a permanently occupied facility. Crew members will conduct in situ and telerobotic scientific research, and an observatory may ultimately be built on the lunar farside. On Mars, a similar evolutionary strategy is likely to be used. Scientific research will be intimately tied to the exploration of the Martian surface, and field disciplines, such as geology and exobiology, will be key in defining scientific requirements.

While development of the SEI strategy proceeds, NASA is operating within a 5-year plan to support a wide range of potential architectures, preserve early milestones, and maintain the flexibility to be redirected to incorporate architecture options developed through ongoing studies.

An initiative of the magnitude and scope of the SEI mandates new technologies and innovative operational approaches to living and working in space and on planetary surfaces. Research and development activities must be initiated and paced to prepare for program milestones. For instance, basic research on human behavior and medical support systems on long-duration space missions is necessary to support habitat design and crew selection, training, and health. Precursor robotic missions will provide key engineering data to support site selection and system design studies. In addition, the development of technologies (e.g., regenerative life support systems, automation and robotics, etc.) that significantly enhance mission efficiency must be timed to allow necessary advances as mission plans evolve in ambition and complexity.

Focusing on those aspects of the SEI related to research and operations on planetary surfaces, this section discusses possible approaches to ensure that the systems that support these efforts are designed and operated efficiently and effectively. Key requirements that must be accommodated as exploration architectures mature are presented. The role of a test and verification strategy that would use Earth-based analogs to evaluate system hardware and operational techniques is then discussed. The advantages and disadvantages of Earth-based analogs are then identified, with specific emphasis on Antarctica.

2.1 Key Mission Considerations

To organize and systematically examine the range of options for human exploration, it is important to understand the considerations associated with emplacement and evolution of lunar and Martian surface infrastructures. Planetary surface systems, which in this report refer to the totality of systems (e.g., facilities, vehicles, research tools, etc.) that would fulfill human and robotic mission objectives on the surfaces of the Moon and Mars, pose a unique set of challenges. The development of robust, reliable systems for living and working in remote environments represents a new dimension of the national space endeavor in which NASA's knowledge base must be strengthened through extensive research and testing on Earth and in space.

Table 1 identifies three SEI mission considerations that fundamental research, advancements in state-of-the-art technology, and extensive test and verification of candidate systems must

TABLE 1. SEI SYSTEM AND OPERATIONAL CONSIDERATIONS

Designing Surface Systems
• Provide habitats, utilities, surface vehicles, and processing plants that have long lifetimes, are reliable, and can be maintained with very limited crew intervention.
• Establish and evolve capabilities that minimize reliance on Earth for vital supplies or services (propellant, life support, waste management, etc.).
• Incorporate and apply autonomous and robotic technologies to enhance operational effectiveness.
• Provide responsive, capable support for field exploration and science.
Providing for Human Needs
• Maintain crew health.
• Protect the crew from the effects of long-term exposure to low gravity and radiation.
• Maximize the stability and productivity of small groups.
Developing Optimal Operational Strategies
• Develop an integrated, cost-effective support strategy.
• Identify and evolve servicing, maintenance, and repair concepts as the outpost matures.
• Maximize human-machine roles in system operations.
• Optimize commonality in designs and operations.
• Design to accommodate autonomous operations.
• Develop robotic construction, maintenance, and operations procedures.

address. To address these considerations, NASA has adopted the following goals:

- Develop and verify reliable, robust facilities and systems that can be maintained and operated with limited human involvement.

- Conduct extensive human factors and technology research to develop autonomous and telerobotic systems and the tools and techniques needed to support scientific investigations.

- Understand the psychological and medical aspects of remote, long-duration, and isolated human activities through significant research in simulated environments with relevant work tasks.

The sections that follow outline alternative strategies that will support the achievement of these goals.

2.2 Test and Evaluation Options

A rigorous test and evaluation effort, which proceeds in tandem with hardware design and development, is critical to reducing mission and program risks, accelerating schedules, relaxing design and operational requirements, and reducing life-cycle costs. A test and evaluation strategy for the SEI will evolve as the mission architecture and implementation concept are defined. Experience on past and current NASA programs shows that such a strategy typically embraces a wide spectrum of geographically dispersed facilities and laboratories to support related research, verify system requirements, and test hardware. As in all aerospace programs, the test and evaluation strategy will be designed to confirm engineering and operational requirements in simulated environments. For the SEI, the strategy will also incorporate the results of studies on human physiology and behavior, group dynamics, and human-machine interfaces into ongoing design and development phases.

No known test facility can simultaneously replicate all environmental, engineering, and operational parameters. Therefore, a number of factors, including the complexity of the system, its criticality to the mission, technology status, and resource requirements (funding, personnel, facilities, and equipment), must be considered as NASA evaluates testing options for large and small facilities.

A balanced and cost-effective strategy will emerge as the result of a thorough planning process that includes three key activities: (1) a comprehensive determination of test and verification requirements (i.e., facilities, equipment, and personnel that will be necessary at each milestone), (2) an evaluation of current and planned capabilities, and (3) an assessment of the feasibility and value of using such facilities. NASA has initiated such an approach in preparing for the SEI and will continue to evaluate and update its plans as additional knowledge becomes available.

The use of testbeds will be an important part of this approach. Generally speaking, a testbed is a physical and/or analytical representation of a "system" that is used to model, simulate, verify, and validate the system's functional, operational, and performance-related capabilities. Testbeds will be used to verify system requirements, acquire data to support design activities, provide a basis for selecting alternative systems, and validate the performance and operational capabilities of science instruments, human support systems, and planetary surface elements that must operate and evolve over several years. A variety of settings can be used as testbeds, including an onsite (e.g., a laboratory) or remote facility, or even the space environment. Capabilities to support these evaluation activities (e.g., environment simulators, anthropometrics laboratories, materials testing laboratories, thermal testbeds) are currently available within NASA, other government agencies, and the aerospace and academic communities.

High-fidelity simulations in appropriate environments must be used throughout all phases of the Initiative. Access to such capabilities will accelerate understanding of key technologies and human factors issues, determine the reasonableness of and ensure compliance with system requirements and specifications, and reduce development and mission risk. The discussion that follows argues for the use of the Antarctic as a high-fidelity simulator or planetary analog to complement SEI's overall development strategy.

2.3 Use of an Antarctic Planetary Analog as a Testbed

Within the context of the discussions in Sections 2.1 and 2.2, several environments are of particular interest to the SEI, either for their value as possible research and testing locales or for the application of experience gained through their use as research facilities. These environments include:

- Space
- Laboratories
- Polar areas (Antarctic and Arctic)
- Subaquatic environments (submarines, submersibles, diving chambers)
- Underground
- Others (remote mining operations, offshore drilling, etc.)

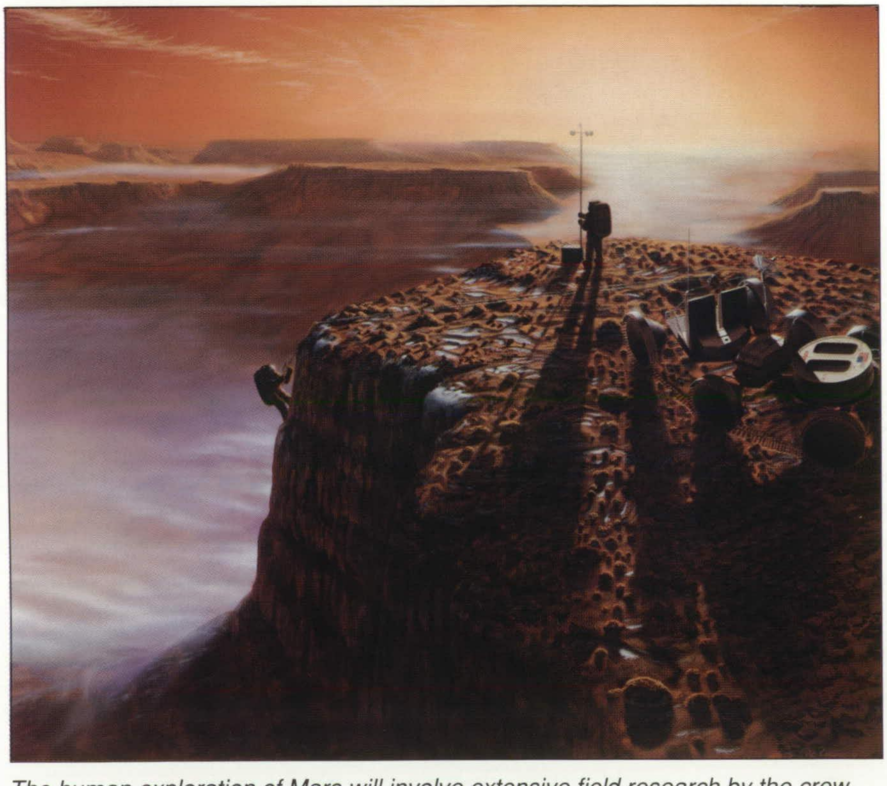
The open literature includes comparative analyses of these environments for their potential advantages to human space exploration. In one such assessment relating specifically to SEI, the environments were compared according to a number of criteria. The results, in corroboration with other related studies, indicate that Antarctica would be an extremely high-fidelity planetary analog in which to test numerous human exploration concepts. The following discussion focuses on how Antarctica offers exceptional capabilities for SEI requirements and system verification in three areas: fidelity, versatility, and relevance.

Fidelity

Fidelity, as used in this report, is the degree to which an environment reproduces lunar or Martian conditions or activities. From this standpoint, Antarctica is considered high fidelity in that it can simulate physical, operational, human factors, and biomedical elements of the SEI rather closely. For example:

- Parallels exist in physical environment:
  - Degree and extent of isolation.
  - Harsh environmental conditions.
- Base architectures and operations have the same requirements:
  - Scientific research must be facilitated.
  - Systems must operate under extreme, hostile conditions and be maintainable and reliable.
  - Operational strategies reflect limited opportunities for resupply.
- Human and biomedical factors are similar:
  - Number of crew (from 4 to 30 or more).
  - Activities (science, medical care, health maintenance, psychological interaction, etc.).
  - Mission durations (3 months to 1 year or longer).

Physical Environment. Some of Antarctica's physical attributes — the harsh, cold environment, geologic processes, and isolation from populated areas — are particularly applicable to testing and developing SEI systems. Although the atmospheric pressures of Mars and Earth are significantly different, temperature patterns are similar. Comfortable, low-bulk environmental protection is necessary in both environments for activities outside the habitat. In addition, tools and techniques for scientific research must accommodate harsh and rugged environmental conditions.



The human exploration of Mars will involve extensive field research by the crew members. (Painting by Pat Rawlings for NASA.)

Operations. The similarities in base architecture and operations are quite striking. The design approaches for both planetary and Antarctic environments reflect the need for simple, modular construction with the built-in capability for growth and evolution. Tools and techniques must be available for the effective performance of scientific research. Operational strategies must involve sufficient resiliency and pragmatism to accommodate the isolated conditions experienced by personnel. Logistics and resupply conditions are constrained, and a philosophy must be developed to efficiently use and conserve limited resources. In addition, it is desirable to optimize the capability to support scientific field activities. Thus, both Antarctica and the planned lunar and Martian outposts share similar operational requirements and constraints and must be designed to be safe and sustainable.

Human Factors and Biomedicine. Human dynamics and physiological conditions in Antarctic environments provide perhaps the highest degree of fidelity. Planetary environments will impose extreme isolation and confinement on small groups of people operating complex systems for 1 year on the Moon and up to 3 years on Mars; in the Antarctic, the same conditions apply for small and large groups for up to 1 year. In both cases, optimal crew selection, mix, and training are essential; a strong understanding of organizational, group, and individual dynamics is critical. In addition, parallels exist between the two programs in terms of health maintenance and medical care concepts, which must respond to the complex and not well-understood interaction between human physiology, psychology, and social conditions.

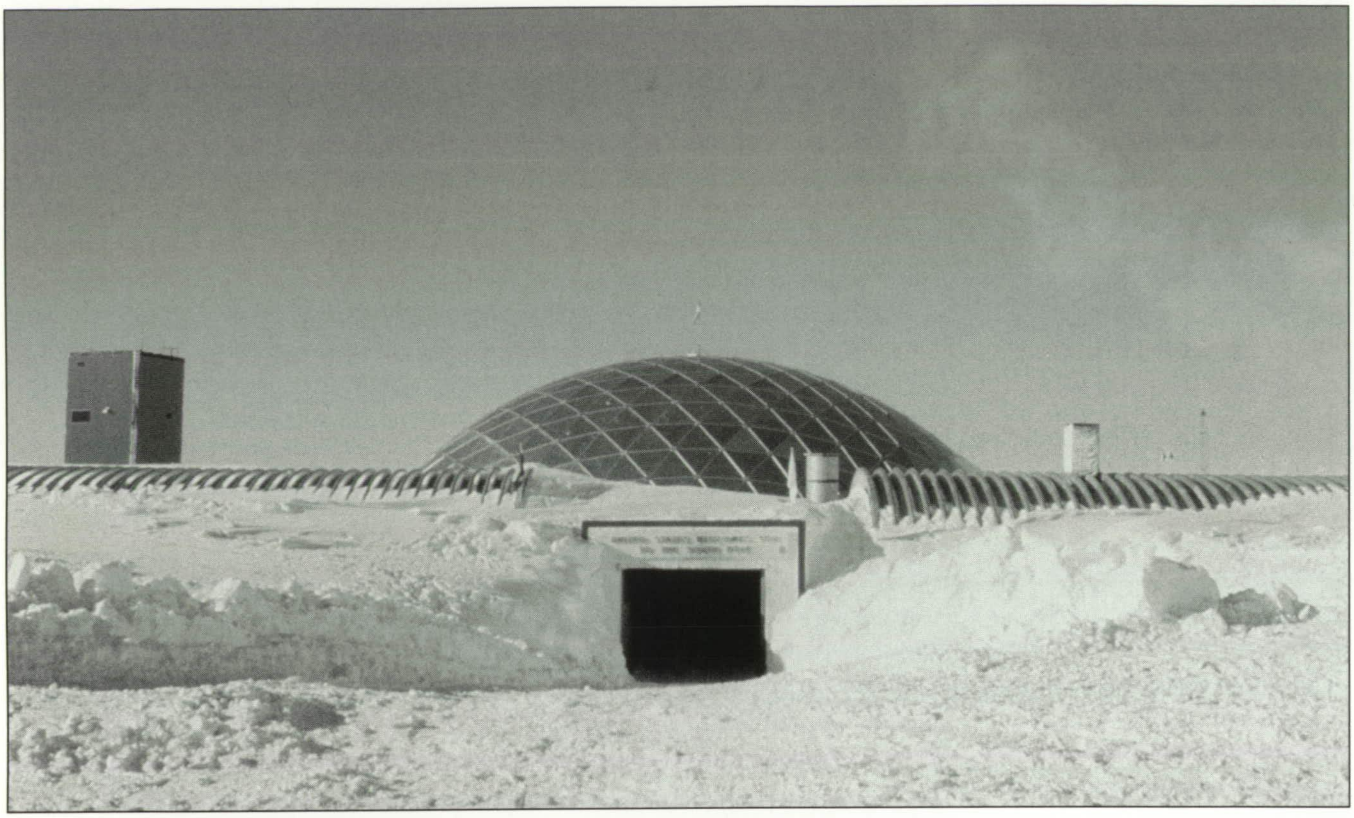
Versatility

Of all potential testbed environments, Antarctica is the most versatile. A substantial portion of hardware, software, operations, human factors studies and simulations, crew training, human physiology research and medical care concept evaluation, and science experimentation testing (e.g., telescience concepts) could be simulated in an Antarctic setting that approximates the psychological and physical conditions on planetary surfaces. Few other simulators, if any, can simultaneously accommodate such a wide range of test requirements with such high fidelity.

Relevance

The relevance of research and testing activities refers to the degree that the data generated, research conducted, or technology tested has utility to NASA, or under the best of circumstances, to other agencies, such as NSF. Because of their interest in similar technologies and issues, both NASA and the NSF would accrue a large data base of information on research and testing results that would directly apply to their needs. For example, simulated science experiments could be conducted in the Antarctic dry valleys using prototype equipment and protocols that might be adapted to research on Mars. Simulation of exobiology-related investigations using robotics and telescience is particularly advantageous since science experiments of relevance to the USAP could be performed in dry valleys or on the high plateau, thereby serving the interests of both NASA and the NSF. Another instance where using Antarctica as a testbed for the SEI would be highly relevant to both agencies is an evaluation of NASA's waste management system technologies. Such a focused testbed could be directly applied, during actual tests, to reduce or mitigate the environmental effects of waste generation and disposal in Antarctica.

From a technical viewpoint, then, sufficient merit warrants the continued exploration of the role of Antarctica as a testbed in support of the SEI. Near-term activities would focus on further definition of test and evaluation requirements, and detailed assessments of the potential compatibility of Antarctica and other environments with these needs. A key factor in this analysis would be the evaluation of the mutual benefits of collaboration, including identification of ways to accommodate the programmatic differences and unique capabilities of both NASA and the NSF in the overall strategy. In addition, small-scale activities that will eventually be useful within an SEI-specific program can begin now, within the context of the ongoing U.S. Antarctic Program.



Amundsen-Scott South Pole Station. (Photograph courtesy National Science Foundation.)

Perennially ice-covered Lake Vanda, located in Wright Valley, one of several dry valley regions of Southern Victoria Land, Antarctica. (Photograph by Dr. Robie Vestal.)

3. THE U.S. ANTARCTIC PROGRAM (USAP)

The United States has maintained a continuous, active presence in Antarctica over the past three decades. In accordance with Presidential directives (Memorandum 6646), this presence has focused on the "conduct of scientific activities in major disciplines; year-round occupation of the South Pole and two coastal stations; and availability of related necessary logistics support." Research conducted in Antarctica encompasses a broad spectrum of disciplines, including glaciology, biological and biomedical research, Earth sciences, atmospheric sciences, and ocean sciences.

Major year-round USAP research stations are McMurdo Station, the Amundsen-Scott South Pole Station, and Palmer Station. McMurdo is the largest Antarctic station, and it is located near the ice-free dry valleys of Victoria Land. The remote field camp is also a critical component of the scientific program in Antarctica. At these temporary camps, scientists often come into direct contact with the material or environments that they are studying.

The NSF has overall funding and management responsibilities for all U.S. activities in Antarctica. The NSF obtains support, on a reimbursable basis, from the Departments of Defense and Transportation for logistics-related services (e.g., operational communications, air transport of crew and supplies, staging facility operation, channel breaking, etc.). Logistics and facilities support constitute the major portion of NSF's funding.

This section highlights aspects of the NSF program that might benefit from NASA technologies and testbeds. Aspects of the Antarctic Program where NASA might capitalize on current systems or apply its hardware and personnel in full-scale simulations are also discussed.

3.1 Goals and Objectives

As a leader in the international community, the NSF adheres to and promotes the principles of the Antarctic Treaty, which is the legal foundation for activities in the area south of 60° S. The NSF's goals focus on creating conditions that will enhance the scope and content of ongoing and anticipated scientific research. These goals, enunciated below, impact the potential role of the NSF in the SEI program, since SEI-related activities in Antarctica must either contribute to or not conflict with them.

- Plan and conduct scientific and engineering research.
- Enhance the ability of the USAP to support scientific research.
- Minimize impact on the Antarctic environment.
- Further the principles of the Antarctic Treaty.
- Increase public awareness of, involvement in, and commitment to the USAP.

For the five goals presented above, the NSF has articulated a series of related objectives to be considered as NASA examines the potential role of Antarctica in planning and implementing the SEI. **Table 2** lists these objectives, several of which relate to key USAP operational and research problems and issues.

3.2 Critical Operational and Research Issues

During the 1990s, the NSF will focus its program and plans on achieving three key objectives: (1) enhancing scientific research and related support capabilities, (2) improving the effectiveness and efficiency of operations, and (3) mitigating or eliminating environmental impacts. These objectives are discussed in more detail below. The SEI program requirements and technologies are then overlaid to project the role and contribution a joint program would have in resolving key issues or augmenting USAP capabilities.

Enhancing Scientific Research and Related Support Capabilities

Projects in Antarctica involve basic research on marine and terrestrial life, oceanic processes,

TABLE 2. NSF GOALS AND OBJECTIVES

Plan and Conduct Scientific and Engineering Research

- Support research on the Antarctic environment, including the oceans south of 60° S latitude
- Support research that will benefit from unique physical characteristics of the Antarctic environment

Enhance the Ability of the USAP to Support Scientific Research

- Develop "telepresence" and autonomous systems for aiding research at Antarctic sites at both manned stations and unmanned observatories
- Make more efficient use of logistical resources
- Improve electrical power capability, particularly at inland stations, by using alternative energy sources (solar, wind, nuclear, etc.), increasing efficiency, and implementing advanced energy storage technologies
- Develop alternative energy sources for heating and for producing water
- Improve living conditions
- Improve the selection process for Antarctic winter-over personnel
- Improve communications
- Improve waste management
- Optimize operations to minimize use of critical resources

Minimize Impact on the Antarctic Environment

- Ensure compliance with all applicable U.S. and international laws, agreements, conventions, and regulations
- Improve waste management systems with a view toward reducing waste disposal and emissions at Antarctic sites to nearly zero
- Develop advanced recycling techniques
- Improve electrical power capability, particularly at inland stations, by using alternative energy sources (solar, wind, nuclear, etc.), increasing efficiency, and implementing advanced energy storage technologies
- Develop alternative energy sources for heating and for producing liquid water
- Optimize operations to minimize use of critical resources

Further the Principles of the Antarctic Treaty

- Promote scientific investigations
- Promote international cooperation
- Continue to exchange operational and scientific plans and research results with other treaty nations
- Provide free access for purposes of inspection to duly designated observers from other treaty nations

Increase Public Awareness of, Involvement in, and Commitment to the USAP

- Encourage research, including research supporting the SEI
- Involve a wide range of participants in the program
- Inform the public on plans and progress
- Implement public relations and media campaigns, as appropriate

geologic and glacial characteristics, the atmosphere, solar-terrestrial physics, and astrophysics. These areas of scientific inquiry have attracted leading researchers, but the pace of scientific work is often frustrating due to the rigorous demands that the environment places on the tools and capabilities needed to obtain results. Among the capabilities that enable Antarctic scientific research are:

- **Research and Analysis Equipment and Tools** - State-of-the-art instruments and tools must function well in the harsh, polar environment, especially for research in geology, astronomy, and biology. Progress is hindered when sampling and measuring devices break down, lock up, or fail to meet targeted performance standards.

- **Support Capabilities** - Several related issues fall within this category. For instance, Antarctic stations must adequately support research activities. The availability of computer equipment and improved communications links with research colleagues are illustrative of simple yet vital requirements for improving the research environment. These accommodations can be enhanced by incorporating automation and robotic capabilities in the experimental phases of a project and by having access to automated information systems to assist in data analysis.

Improving the Effectiveness and Efficiency of Operations

The logistics chain is indisputably the most vital factor in the success and safety of scientific research in Antarctica. It is also the most resource-intensive element, and a top-priority issue for the NSF is to find innovative, practical ways to reduce the logistics burden. Numerous technologies and techniques could improve the flow of supplies. For instance, diesel-powered generators are the major source of power at the South Pole Station. For every gallon of diesel fuel shipped to the Station, several gallons are burned by the major transporter, the LC-130 aircraft. The large power use imposes a substantial cost on the USAP. Estimates of the cost of fuel at the South Pole Station, for example, range from \$8 to \$12 per gallon. The USAP would benefit greatly from the use of alternative power (derived from solar, wind, and nuclear sources) that would reduce the flow of fossil fuels, eliminate the release of atmospheric contaminants, and improve system reliability and maintainability.

Additional areas where NASA technologies, techniques, and experience could streamline operations are briefly discussed below.

- **Environmental Control and Life Support** - Technologies and techniques to reduce the volume of stored waste and improve treatment processes not only would optimize operations but also would alleviate the impact on the environment. Sewage and trash disposal are two key areas that would benefit from NASA technologies. Methods to improve the efficiency of water production at the South Pole Station, where potable water is produced by melting snow and treating it, are also desirable. An additional area includes the possible incorporation of food growth capabilities at the stations.
- **Communications** - Support and scientific personnel communicate with the "outside world" frequently through a variety of channels. Satellite communication is currently available, and updated plans for maintaining continuous coverage are expected as satellites are retired. Given the South Pole Station's location and the limited availability of satellite coverage, the problems in that area are especially acute. Mechanisms to improve two-way communication are essential to the well-being of research and support personnel and to the conduct of safe operations.
- **Habitats** - Improving the layout and design and interior accommodations of the habitable environments continues to be of high priority for the psychological health and productivity of personnel based in Antarctica. The translation of NASA technology, experience, and insight may have significant benefits for station operations.
- **Human Factors and Biomedicine** - The NSF continually strives to find ways to improve the personnel selection and training process and to understand the psychological aspects of individual and group dynamics. In addition, a more comprehensive suite of medical support capabilities, including supplies and diagnostic and treatment capabilities, would enhance a physician's response in acute and chronic health care situations. These concerns are also of interest to NASA as it plans for the long-duration missions of the 21st century.

Mitigating or Eliminating Environmental Impacts

The NSF plans and conducts its operations to minimize the use of local resources and eliminate or control the release of contaminants into the air, land, or water to the extent practical and feasible. Improving operations in Antarctica will require the introduction of new or modified technologies, many of which could reduce the environmental impact of Antarctic research. The NSF will consider these technologies for reducing environmental impact as well as for improving performance and reliability.

4. ANTARCTIC ANALOGS

Antarctica, Earth's southernmost continent, is also by far its most remote. Its nearest neighbor, South America, lies across the 1,000-kilometer Drake Passage. Antarctica is almost entirely within the Antarctic Circle, and its average elevation, about 3,000 meters, is the highest in the world. At 14.2 million square kilometers, Antarctica is approximately the size of the United States and Mexico combined. Temperatures on the polar plateau average -60° C, with annual precipitation less than 5 cm (water equivalent) as snow. Most of the continent is covered by an ice cap several kilometers thick; only a small portion, mainly near the coast, remains ice-free. This unique combination of characteristics makes Antarctica a very suitable analog environment for planetary exploration.

As **Table 3** indicates, numerous Antarctic locales and USAP staging facilities would readily accommodate research and testing of facilities and technologies relevant to the SEI. In particular, the environmental characteristics of two distinct locales — the ice-free dry valleys and the polar plateau — would make them appropriate sites for simulation facilities. Research and test opportunities that would exploit these characteristics to benefit the SEI are discussed in the following subsections, in addition to examples of analogs to meet the unique challenges of human missions to the Moon and Mars. Other strategies, which might use other Antarctic stations, could involve testing one or more focused technologies, or developing a simulation facility relevant to both lunar and Martian environments. These and other strategies would be explored during joint NASA/NSF studies.

TABLE 3. ANTARCTIC LOCALES FOR CONDUCTING SEI TESTBED ACTIVITIES

Representative Test and Evaluation Needs	Candidate Antarctic Locales		
	Year-Round Stations[1]	Summer Camps[2]	Staging Facility[3]
Science Support (Planetary Science, Geology, and Exobiology) • Methodology, equipment, and tool evaluation • Telepresence demonstration	X	X	
Systems and Operations • Technology demonstrations[4] • Subsystem/system testing[4] • Integrated system verification • Operations analyses • Operations and logistics simulations	X	X	X
Human Needs • Crew selection and training • Human psychology, behavior, and performance studies • Habitability evaluations • Medical support systems and procedures testing	X	X	

1 McMurdo, South Pole, Palmer, and the proposed High Plateau.
2 Field camps, huts, and tents in various locations in ice regions and dry valleys.
3 Located at Christchurch, New Zealand and Puerta Arenas, Chile.
4 Power, life support (air, water, food, waste management systems), and constructible/rigid habitats.

Artist's concept of a Mars analog habitat located next to an ice-covered lake in the dry valleys of southern Victoria Land, Antarctica. The dry valleys are considered by many to be the best terrestrial analog to the planet Mars. Ice-covered lakes similar to the one shown may have once existed on Mars and provided a suitable location for life. From such a facility, mission planners could test and evaluate habitat design, critical technologies, and conduct studies on human performance and behavior in an extremely remote, and demanding environment. Ongoing basic research relevant to Martian exobiology could also give the occupants of this habitat meaningful tasks. (Illustration courtesy of Robert S. Murray/Martin Marietta, 1990 ©)

4.1 The Dry Valleys

The dry valleys of southern Victoria Land, approximately 4,000 square kilometers located between 160° and 164° E longitude and 76° 30" and 78° 30" S latitude, are the largest and best known of the ice-free "oases" located around the Antarctic continent. The dry valleys are free of ice primarily because glacial flow from the polar plateau is obstructed by the Transantarctic Mountains. The potential evaporation greatly exceeds the annual snowfall, producing an extremely arid environment. The mean annual temperature is about -20° C, but temperatures range from -50° C to 10° C. During the winter months, strong winds from the polar plateau buffet the valleys. The dry valleys receive about 4 months each of sunlight, twilight, and darkness.

The Antarctic dry valleys are Earth's most Mars-like environment. The climate and the physical processes shaping the surface are similar to those on Mars. Therefore, the dry valleys are suitable for testing some of the hypotheses that planetary scientists have about the Martian surface, and they may also be used to test some of the techniques and equipment that may one day be used to study the surface of Mars.

Recognizing the dry valleys as an area in which life has adapted to extreme conditions with little available liquid water, scientists in the late 1960s conducted biological investigations there in preparation for the Viking missions to Mars. Since then, research activities relevant to planetary science (exobiology and geology) have continued in the dry valleys. The systematic study of the physical and biological processes occurring in the dry valleys is facilitating a better understanding of conditions on Mars, as well as helping to develop a scientific rationale for future exobiological and geological investigations of that planet. Studies in the

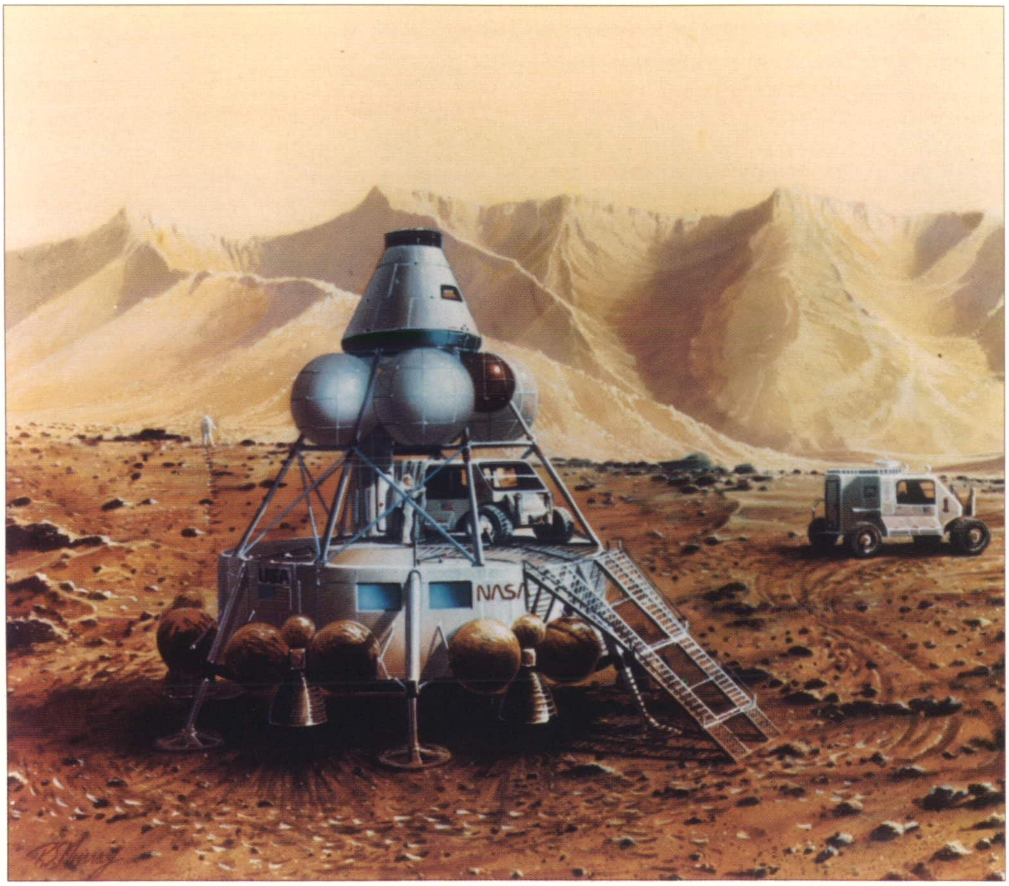
Antarctic, therefore, which are scientifically beneficial in and of themselves, will have additional value in their relevance to the actual work to be conducted on Mars.

A facility in the dry valleys of Antarctica could simulate a research outpost on Mars. This facility could be tailored to the types of science that are expected to be a part of the human exploration of Mars. This is essentially field science; that is, the occupants leave the habitat frequently to conduct field studies of the Martian environment. This factor will impact the design of the facility and the way in which the habitat accommodates the crew.

4.2 The Polar Plateau

In contrast to the ice-free dry valley regions, very little field research is conducted on the polar plateau. Research efforts at these facilities are oriented toward observational science, such as upper atmospheric physics, solar astronomy, and infrared, submillimeter, and millimeter astronomy, conducted primarily from the confines of a structure placed on the plateau. Therefore, sites on the plateau, such as the South Pole Station, or perhaps another facility high on the polar plateau, might be valuable for simulating conditions to be encountered in spacecraft (rather than on planetary outposts) during long-duration flights or at an astronomical observatory located on the Moon.

Crews on SEI missions, including a lunar outpost, will work in close cooperation in intrinsically hazardous conditions. As on Mars, crews on the Moon will require provisions and procedures for on-site medical care, probably involving teleconsultation with physicians on Earth. Crew members will be continuously exposed to wholly artificial environments and will be totally dependent on life support. For the Moon, some resupply is feasible, although the costs and logistics involved dictate the advisability of at least partial closure of life support systems. As in the Antarctic, extreme cycles of light and dark will alter circadian rhythms of crew members placed in such an environment. These issues could be addressed in the Antarctic, giving mission planners valuable insight prior to the final design phase of a lunar outpost.



Habitat and vehicles for humans on Mars. (Illustration courtesy R. S. Murray/Martin Marietta.)

5. POSSIBLE IMPLEMENTATION APPROACH

The preceding discussions have indicated areas in which both NASA and the NSF might benefit from collaborating on and sharing in the results of research, technology evaluations, and experience with living in and operating facilities in remote and isolated environments. Such an effort could include an evolutionary strategy to use Antarctica to test and evaluate proposed and alternative in situ and remote science and human support systems and techniques to be used on the Moon and Mars. The strategy would encompass three phases. This phased approach allows work to be incrementally initiated, yet it permits objectives, schedules, and budgets to be revisited before beginning subsequent phases. These three phases and their features are described below.

- **Phase 1:** The initial focus would be on relatively simple experiments and systems and the generation of essential data to support technical and design decision points:
  - Human needs in isolated and confined environments
  - Innovative scientific research (telescience and robotics)
  - Operational and logistic correlations and analogs
  - Research and development on subscale systems.
- **Phase 2:** The program would expand and evolve to include more intensive, lifetime testing of interdependent systems and technologies:
  - Subsystem demonstrations (power, life support, waste management, etc.)
  - System lifetime tests and failure signatures
  - Human-machine interfaces and automated reconfiguration
  - System-automated health monitoring and reconfiguration test and evaluation.
- **Phase 3:** The program would conclude with a full, integrated outpost engineering and operations verification test:
  - Analog facilities
  - Robotic and telerobotic construction
  - Outpost mission operations with simulated logistics.

A schedule to accommodate these program phases would include key milestones for the generation of results that will provide the science and engineering community with confidence that proposed hardware and techniques will operate reliably and effectively. Especially noteworthy is the fact that the Antarctic research program benefits could proceed in tandem with space exploration accomplishments. This opportunity to share technology and experience and contribute materially to each organization's respective program is perhaps the most striking feature of this approach.

6. CONCLUSIONS

This report has discussed the Space Exploration Initiative and the U.S. Antarctic Program in the context of assessing the potential rationale and strategy for conducting a cooperative NASA/NSF effort. Specifically, such an effort would address shared research and data on living and conducting scientific research in isolated, confined, hostile, and remote environments. A review of the respective goals and requirements of NASA and the NSF indicates that numerous opportunities exist to mutually benefit from sharing relevant technologies, data, and systems. Two major conclusions can be drawn:

- **The technologies, experience, and capabilities existing and developing in the aerospace community would enhance scientific research capabilities and the efficiency and effectiveness of operations in Antarctica.** The transfer and application of critical technologies (e.g., power, waste management, life support) and collaboration on crew research needs (e.g., human behavior and medical support needs) would streamline USAP operations and provide the scientific community with advancements in facilities and tools for Antarctic research.

- **Antarctica is the most appropriate Earth analog for the environments of the Moon and Mars. Using Antarctica in this way would contribute substantially to near- and long-term needs and plans for the SEI.** Antarctica is one of the few ground-based analogs that would permit comprehensive and integrated studies of three areas deemed critical to productive and safe operations on the Moon and Mars: human health and productivity; innovative scientific research techniques; and reliable, efficient technologies and facilities.

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