EARTH-BASED ANALOGS OF LUNAR AND PLANETARY FACILITIES

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Antarctica contains areas where the environment and terrain are more similar to regions on the Moon and Mars than any other place on Earth. These features offer opportunities for simulations to determine performance capabilities of people and machines in harsh, isolated locales. The Sasakawa International Center for Space Architecture (SICSA) plans to create a facility on Antarctica for research, planning, and demonstrations in support of planetary exploration. The Antarctic Planetary Testbed (APT) will be financed and utilized by public and private organizations throughout the world. Established on a continent owned by no country, it can serve as a model for cooperation between spacefaring nations. APT science and technology programs will expand knowledge about the nature and origin of our solar system, and will support preparations for human settlements beyond Earth that may occur within the first quarter of the next century. The initial APT facility, conceived to be operational by the year 1992, will be constructed during the summer months by a crew of approximately 12. Six to eight of these people will remain through the winter. As in space, structures and equipment systems will be modular to facilitate efficient transport to the site, assembly, and evolutionary expansion. State-of-the-art waste recovery/recycling systems are also emphasized due to their importance in space.

BACKGROUND

The Presidential Directive on National Space Policy released on February 11, 1988, has established, as one goal, "to expand human presence and activity beyond Earth orbit into the solar system." Earlier, the National Commission on Space appointed by President Reagan recommended that a permanent lunar outpost and human visitation of Mars be realized early in the next century.

Enormous program costs required to establish a lunar base or to undertake manned missions to Mars will probably be too expensive for even the wealthiest individual nations to justify. International cost-sharing will enhance economic feasibility and also help to ensure that mission purposes will benefit the world community. Antarctica, an international territory, is an ideal place to demonstrate that such cooperative programs can work.

Exploration of the solar system includes research to yield an improved understanding of planet Earth. The Antarctic Planetary Testbed (APT) facility will support scientific investigations of causes and effects of weather patterns and atmospheric changes that influence our human destiny; forces and evolutionary processes that shape the composition and distribution of planetary resources; and ways to accomplish social progress and prosperity while also protecting fragile ecosystems (Table 1). Such issues are of vital importance to all world populations. Accordingly, APT research should involve scientists from many nations. Living and working together under remote, rugged conditions, the culturally mixed crews can demonstrate that cooperation under difficult circumstances is both possible and essential.

The Sasakawa International Center for Space Architecture (SICSA) is contacting science and technology leaders from many countries to invite their participation. These experts represent government, university, and private organizations spanning a broad range of disciplines and resources.

TABLE 1. Key APT purposes.

Social and Life Sciences
- Psychological and social dynamics experiments involving mixed/international crews under severe, isolated conditions.
- Adaptation and performance assessments under harsh environmental conditions.
- Simulations of food production for self-sufficiency under isolated conditions.

Earth and Planetary Sciences
- Atmospheric, weather, and meteorological studies applicable to Earth/planets.
- Geological, geophysical, and physical chemistry research experiments.

Technology Demonstrations
- Partially closed-loop life support systems.
- Waste reclamation, treatment, and recycling systems.
- Advanced power generation and distribution systems.
- Excavation, mining, and material processing systems/procedures under harsh conditions.
- Construction/assembly systems and procedures under harsh conditions.
- Automation/robotic system versatility and reliability under harsh conditions.

Training Ground for Planetary Missions
- Crew observation for candidate selection and team assignments.
- Crew preparation for long-duration planetary missions under simulated conditions.

International Model
- Create and demonstrate participatory agreements that prepare the goundwork for future international initiatives.
- Encourage participation of international government and private sector organizations in advanced mission planning.
- Demonstrate economic and mission benefits to be gained through international investment and participation.
- Serve as tangible expression of commitment to future planetary initiatives.

SOCIAL RESEARCH EMPHASIS

An important APT function will be to serve as a psychological and social research laboratory. In addition, realistic space mission simulations will afford opportunities for crew training and selection.

Extended lunar surface missions and long manned voyages to Mars and other planets will pose great psychological and physiological demands on crews. Abilities of the crew to work well as individuals and as members of a team under these prolonged, difficult circumstances is an urgent concern.

U.S. and Soviet space missions to date demonstrate that social interactions are often complex and problematic. Successful team efforts require that individuals like, respect, and adjust to one another on a very personal basis. Learning to depend upon each other's judgement and technical knowledge is also essential. Such vital group "chemistry" is difficult to predict based exclusively upon psychological profiles of crew candidates.

Most available data pertaining to group dynamics under extended, harsh, isolated conditions is anecdotal and unreliable. While many Soviet space station crew experiences have been of relatively long duration, very little information revealing scientific details about crew interaction, adaptation, and performance has been released. Submarine isolation data is not directly applicable since neither the characteristics or size of the crew populations are comparable. Lessons derived from conventional Arctic and Antarctic experiences have similar limitations due to differences in population groups and the nature of their activities.

APT research and demonstration programs will select crew populations and activities to match real mission conditions and objectives as closely as possible. The participants will be international in composition to reveal insights about the ways cultural differences and preferences can be successfully accommodated.

SPECIAL EARTH SCIENCE BENEFITS

Use of the APT facility for research that is not exclusively space-related can help to cover costs for program implementation and operations. While several nations currently maintain research stations in Antarctica, the APT will be unique as an international base, affording living and work accommodations for a wide variety of cooperative ventures.

A representative APT use is to provide a laboratory for field measurements of seasonal changes in the Earth's upper atmosphere, the stratosphere in particular. Purposes will be to advance our understanding of physical, chemical, and meteorological processes that influence perturbations in ozone above Antarctica that were first observed by the British above their Halley Bay Station during the mid 1970s. Since that time, the October mean ozone level measured at Halley Bay has dropped between 40% and 50%. Potential enlargement of the 12-million-km^2 "hole" is viewed with alarm because atmospheric ozone is responsible for screening out more than 99% of the solar ultraviolet radiation that reaches the Earth's atmosphere. APT research can focus international attention on natural and man-made ozone influences and countermeasures.

APT research can also direct international resources and concerns to other issues of global importance. The Antarctic continent is a major forcing system driving the Earth's weather systems. Accordingly, APT research can investigate and monitor air and ocean transport of radioactive particulates and toxic chemicals, magnetospheric phenomena and their relationship to the solar wind magnetosphere system, and influences of ice and other surface features upon past, present, and future climatic conditions.

APT studies of the Antarctic plate can expand knowledge about the evolution of the Earth's crustal and upper mantle structures. This can lead to a better understanding of the way mineral resources are distributed throughout our planet, whether or not they are to be exploited.

TECHNOLOGY DEMONSTRATION APPLICATIONS

Severe environmental conditions on the Moon and Mars will pose hardships for people and machines. Failure to validate procedures and systems under realistic conditions is likely to be costly in terms of human life and/or failed missions. The APT facility will offer a valuable environment for realistic simulations and assessments (see Table 2).

TABLE 2. Antarctic-planetary analogs.

Environmental Characteristics
- Antarctica, which averages approximately 8000 ft above sea level, is the Earth's highest and driest continent with atmospheric pressure most like Mars.
- Antarctica receives relatively high levels of solar radiation similar to conditions on the Moon and Mars.
- Antarctica, having temperatures as low as -100°F and even colder at the South Pole, has similarities to the Moon and Mars.
- Coastal Antarctic winds range from a 15 mph average to 200 mph and more. Snow storms in these locations have similarities to dust storms on Mars.
- Antarctica and the Moon have locations with long days/nights that affect surface operations; as many as 3 months of darkness/extreme cold on Antarctica and 14 days on the Moon.

Geological Features
- Antarctica is a large, mostly virgin land mass, about the size of the U.S. and Mexico combined. It has a variety of landscape features from which to select sites for planetary mission simulations.
- Antarctica's rock bed terrain includes areas with sterile soils devoid of any life forms, similar to conditions on the Moon and Mars.
- Polar ice caps on Antarctica and Mars are rare in our solar system. Earth and Mars are the only planets possessing these features.

Program Priorities
- Antarctica, like the planets, belongs to no nation. Current and future treaties governing its use can provide a model for cooperative international space initiatives.
- The Antarctic ecosystems must be respected and protected. Similar conservation priorities apply in planning orbiting and planetary habitats.
- Antarctica's remoteness imposes space-like living, work, and resupply constraints. Facilities should be easy to construct, and self-sufficiency should be optimized.

The APT initiative will also provide incentives to advance valuable technologies for terrestrial uses. For example, critical APT performance and reliability requirements under extreme climatic and working conditions will offer demanding tests and testimonials for companies developing commercial products. The APT's remote location and extended-duration crew duty cycles will encourage innovations to achieve high-yield, efficient food and energy production. APT's space-applicable methods to treat and recycle wastes will demonstrate that human settlements can be nonpolluting and environmentally responsible.

A key technology development and demonstration objective will be to realize a high level of self-sufficiency through local growth and processing of food sources. Severe limitations upon environmentally conditioned volume and manpower will demand careful selection of nutritious, rapid-growth plants and animals that are easy and efficient to attend. Hydroponic agriculture and controlled pond fish and shrimp farming are candidate approaches. Organic wastes will be recycled for reuse to the extent possible.

Another priority will be to implement and evaluate autonomous power generation and storage systems. Candidate technologies include biomass systems that produce gas from organic wastes, fuel cells that produce electricity through a reverse osmosis process, wind turbines, and small nuclear generators.

APT operations will provide challenging applications for robotic and other automated systems. Experiments will include excavation to obtain and process mineral resource samples, *in situ* material processing, and construction techniques.

SITE SELECTION/DEVELOPMENT

An important APT planning and implementation priority is to minimize man-made disturbances to Antarctica's environment and ecosystems. This will be accomplished through careful site selection, avoidance of large transportation and construction equipment requiring extensive roadbeds, limitations on crew population size, and emphasis upon reprocessing, reuse, and control of waste materials. Similar considerations apply in planning orbiting and planetary habitats.

The site selection process will correlate key lunar and martian mission simulation objectives with environmental, geological, and programmatic features of various candidate locations. Final selection will be made following studies to determine prudent restrictions on placement, development, and operations to protect wilderness areas. These investigations will be conducted by an international body of scientists and planners committed to ensuring that terrestrial as well as planetary objectives are recognized.

The APT site development plan will adhere to comparable guidelines for hardware and practices appropriate to transportation, construction, and operational procedures on a planetary surface. For example, construction equipment and elements will be sized to be transported to and within the site using relatively small vehicles. Building components and interior systems will be modular, designed for simple and rapid assembly by small crews. This modular approach facilitates evolutionary expansion of site structures: additions, upgrades, reconfigurations of equipment, and changeouts of components for periodic and emergency servicing.

APT will demonstrate state-of-the-art technology to collect, treat, and recycle waste materials to the maximum extent possible. This will help to reduce storage and resupply requirements and prevent the creation of undesirable contaminants. These priorities are also of importance in planning long-term manned space missions.

CONSTRUCTION PRECEDENTS

The initial APT development will be constructed by a crew of approximately 12 people during the Antarctic summer. Six to eight members of this international group will winter-over to establish permanent base-camp operations. Later expansion stages may ultimately produce a small settlement of about 50 people. Tables 3 and 4 present key facility construction guidelines and elements.

There are presently more than 40 manned scientific stations in Antarctica. The largest is the U.S. McMurdo Station, a scientific base and transit center that can accommodate more than 200 people during the winter and more than 1000 during the summer. The Antarctic stations vary in size, facilities provided, and construction.

During the International Geophysical Year, 50 Antarctic stations were operating, including 47 year-round facilities. The cost of establishing and maintaining these stations ran as high as $1 million/person for the Amundsen-Scott base in 1957. Construction approaches differed with national preferences: British and Norwegian expeditions favored conventional frame buildings, the French used prefabricated pressed steel huts, while American, Australian, and Soviet huts were typically built on rock sites using prefabricated aluminum or plywood panels clamped together to form flat-roofed box-like buildings.

Typical heating systems apply ducted hot air, sometimes using waste heat produced by diesel power generators. Trash management often involves sealing garbage in empty oil drums that are left on sea ice. Some larger stations have heated and insulated sewage pipes.

The largest interior base in Antarctica, the Byrd Station, provides power with a nuclear reactor. The base has 15 buildings (including a hospital) with winter accommodations for 40 people.

TABLE 3. Design and construction guidelines.

Safety

- Design and select materials to reduce fire hazards in the dry Antarctic climate.
- Securely anchor building to withstand high wind speeds.
- If located in a locale with snow, provide means to raise the structure or another device to prevent blockage of entries.
- Design for snow loads (if appropriate).
- Provide emergency health care equipment and supplies.
- Provide a safe haven with emergency rations separate from the main crew living facilities.
- Provide backup power and communication systems.
- Design for easy maintenance and repair of all life/safety-critical systems.
- Provide means for emergency crew evacuation by air and/or land.

Economy

- Emphasize modular and easy to assemble construction systems.
- Size modules and other construction/equipment elements for transport by most economical means.
- Provide economical, local energy source heating and power systems.
- Provide means to treat and recycle waste materials to the extent possible.

Mission Simulation Applicability

- Size and configure facility modules to conform with shuttle payload limitations.
- Provide means to reconfigure interior spaces and equipment for changing demonstration requirements.
- Simulate and provide facilities for simulating construction/assembly procedures to the extent possible.
- Duplicate space habitat environment and functions to the extent practical.

TABLE 4. Initial facility elements.

Building Systems and Equipment
- Modular enclosure(s) of design and size to afford simple and rapid construction.
- Modular interior equipment systems enabling easy change-outs and expansion.
- All elements designed for transport by relatively small air and surface vehicles.
- State-of-the-art systems to collect and recycle waste materials.

Living Accommodations
- Crew quarters for 12 people (summer) and 6-8 people (winter).
- Means to reconfigure living spaces for planetary simulation experiments.
- Galley and wardroom comparable to size and menu provisions of space station.
- Basic exercise, toilet, shower, and laundry equipment.
- Small health maintenance facility for routine and emergency medical care.

Research Accommodations
- Facilities for human, animal, and plant life science research.
- Utility interfaces to accept standardized space station-like experiment racks.
- Data buses and computing systems to control and monitor experiments.
- Laboratory space with work benches, information resources, and storage.
- Maintenance and parts room with basic tools and calibration equipment.

Grounds and Ancillary Structures
- Greenhouse/biosphere for plant growth.
- Staging area and equipment for Earth and planetary science experiments.
- Mining and material processing/sample return simulation area.
- Space construction and assembly simulation area.
- Vehicle repair and storage facilities.
- Helipad and fuel storage depot.

CANDIDATE POWER SYSTEMS

Important power system selection objectives are to minimize dependence upon imported fuel sources, environmental pollution, and maintenance. Systems with potential value for planetary applications will be tested on a continuing basis and used when feasible.

Biomass systems can process organic wastes through anaerobic biochemical fermentation to produce gas for combustion generators. Basic equipment includes a digestor tank and pipeline. An attractive feature of this process is its ability to beneficially use by-products of daily activity that normally present a disposal problem. Since a minimum 95°C temperature must be present for anaerobic processing to occur, the digestor must be well insulated and may require special heating.

Fuel cells convert water into constituent hydrogen and oxygen atoms through reverse osmosis for storage, then back again producing electricity as needed through a chemical reaction. Fuel cells, unlike dry cells, do not require recharging. They will continue to operate as long as hydrogen and oxygen are supplied, producing low-voltage, high-amperage direct current (DC). Practical voltages require stacks of these cells. Alternating current (AC) is obtained by adding a power converter (inverter). Normal conversion efficiencies range from 40-60%. Air pollution is 1000 to 10,000 times less than produced by traditional combustion systems.

Wind turbines represent a potential power option in Antarctica since winds are usually present. While oscillation between maximum and minimum wind speeds is typically high, the frequency between them is short. Electricity can be stored in batteries during calm periods. Wind turbines are easy to transport and require little maintenance. Rotor icing can occur when exposed to blizzards unless electrical resistance heaters are provided. The "fuel source" is locally abundant and free.

Nuclear power generation is clean and reliable but may be most applicable for use in facility operations that exceed the APT in size (e.g., the Byrd Station). Current systems generally require replacement after about two years of use.

PRIORITY TECHNOLOGIES

As in space, high transportation costs, restrictions on cargo payload volumes, and limitations on periods of site accessibility pose serious logistic constraints. These constraints impact the design of facilities and major equipment elements, resupply of consumables, and crew rotation cycles. Stringent conservation measures are necessary to conserve fuel for power and heating (a dominant logistic burden) and to protect the environment.

The APT can serve as an operational testbed for new or improved waste management recovery technologies that can be beneficial in space and remote terrestrial settings. Representative types of systems that are being given consideration include: (1) vapor compression distillation to recover potable water from urine and other sources; (2) thermoelectric integrated membrane evaporation to distill and recover water under a partial vacuum; (3) vapor phase catalytic ammonia removal to recover water from urine using high temperatures; (4) reverse osmosis to remove suspended macromolecules, ionized salts, and certain low-molecular-weight species; and (5) multifiltration, which flows waste water through a series of particulate filters, adsorption beds, and ion exchange resin beds to recover potable water.

The APT will apply advanced power technologies developed by different nations when and where possible. New NASA programs such as the Civilian Space Technology Initiative (CSTI) and Pathfinder program are supporting aggressive efforts to develop advanced power systems for the future. Improved systems created through these enterprises may offer clean and efficient options to replace the fossil-fuel-driven systems used throughout Antarctica today.

Current research involving photovoltaic (PV) systems is aimed at improving solar conversion efficiency above 20% and increasing capacities of electrochemical storage systems. Major studies involve refinements of indium phosphide, amorphous silicon, and gallium arsenide solar cells. (Gallium arsenide arrays have attained efficiencies of 23.5% with projected specific powers of 88 W/kg.) Special emphasis is also being directed to improving battery and fuel cell technologies. The "next generation" battery appears to be the Na/S battery that is being developed by the Air Force's Wright Patterson Aero Propulsion Laboratory (PAPL). Fuel cell improvements are aimed at developing single unit regenerative H_2O_2 cells.

Advanced solar dynamic (ASD) systems can be competitive with PV technologies in very small sizes, but are even more attractive for higher power applications (50 to 100 kWe) where increased efficiency is important. NASA's aggressive ASD technology development program for space station *Freedom* is aimed at providing a factor of 5 or 6 increase in the specific power that will be afforded by the initial PV system. (The 773-m^2 ASD system on space station *Freedom* will be about one-fourth of the array area size of the PV system.)

NASA's advanced nuclear system developments are based upon use of the SP-100 reactor. Special research and development emphases are advanced Stirling and thermoelectric energy conversion systems and space environmental effects safeguards. Radiation protection possibilities for future space applications include shields manufactured from lunar soil. An objective is to enable 80 W/kg space power systems in 500 to 800 kWe modular units.

TRANSPORTATION TO APT SITE

The APT's remoteness will create access problems that are similar in principal to circumstances encountered in planning future planetary bases. This isolation and the requirements it imposes upon the APT's development and operations are intentional, bringing levels of realism to the program that will maximize its value.

Important factors influencing transportation alternatives are (1) the specific APT site location, (2) minimum payload size requirements for initial base establishments and resupply, (3) seasonal weather and ice conditions restricting schedules, (4) emergency rescue accommodations, and (5) environmental safeguards governing acceptable modes for personnel and cargo delivery to the base. Minimization of damage to the natural setting is highlighted as a priority concern.

The maximum size for a cargo item is assumed to correspond with capacities afforded by the shuttle orbiter's 60-ft-long, 14-ft-diameter payload bay. This restriction is imposed to support compliance with existing standards applied to space systems.

APT transportation scheduling will be strongly influenced by severe weather conditions. Short summer "access windows" are analogous to space mission constraints. Large freight ships with ice-strengthened hulls can travel to Antarctica from about mid-December to early March. Other marine freighters, under escort by Coast Guard icebreakers have access to some Antarctic ports from late November to April. Air travel is less dependent upon seasonal weather conditions but is more expensive. Popular Antarctic aircraft are the Lockheed C-130 Hercules, Lockheed C-141 Starlifter, and Antonov An-22 Cock.

Access to the APT site from the nearest ship port and/or airfield constitutes the most challenging problems. Helicopters offer versatility and require minimum site accommodations but are hampered by extreme weather conditions. Accordingly, supply and crew rotation events are planned to be limited primarily to warm summer months.

APT ORGANIZATION OPTIONS

The APT program is conceived as an initiative that involves international organizations in its management and/or use. The specific management structure and operating rules remain to be determined based upon future sponsor interests in compliance with appropriate government laws and policies.

Two general sponsorship and organization approaches are being explored: an internationally financed initiative governed by a Board of Owners; and U.S. Government-sponsored and -owned operation that invites international use.

The multinational Board of Owners approach has a precedent in other international space organizations such as Intelsat and Inmarsat. These organizations provide at least one body that decides issues on a one-nation, one-vote basis (traditional international law) and a second body that apportions power and profits based on share ownership (a flexible, more capitalistic and less statist approach). Intelsat, created in 1965 largely as a U.S. initiative, serves as a successful and continuing model for organizations that desire to develop and share resources and other benefits in a multinational extraterritorial format.

The U.S. Government-sponsored approach envisions a U.S. facility that would invite international use in exchange for financial and in-kind service support. Key organizing sponsors might be NASA and the National Science Foundation (NSF). This approach, provided that such sponsors are interested, will probably be the easier of the two to implement and manage, but is limited as a model for future international partnerships in space.

Program financing for both organizational approaches can be provided through a combination of government grants and user fees. Properly located, outfitted, and operated, APT will represent a valuable real estate investment as well as an important asset to advance world progress and benefits in space (Table 5).

TABLE 5. Benefits for APT participants.

Government Sponsors
- Reflects a national/agency commitment to advance progress towards solar system exploration.
- Facilitates and demonstrates development of advanced systems for space and terrestrial uses.
- Encourages and directs private sector participation and investment in space initiatives.
- Brings nonaerospace organizations and technologies to light that represent new capabilities.
- Produces new knowledge and experience to reduce risks and costs for future space initiatives.
- Fosters and symbolizes a commitment to international cooperation.
- Offers potential model for future international space initiatives.

Commercial Organizations
- Provides opportunities to demonstrate and publicize current technologies and capabilities.
- Provides means for organization to better understand and prepare for future government and commercial space business opportunities.
- Creates a service market for APT construction and operations support.

Research Organizations
- Affords extended access to Antarctica for space and other research.
- Provides opportunities and means to conduct unique research.
- Provides opportunities for networking and participation with other government and private research organizations and sponsors to advance science objectives.
- Presents occasions to share experiences and knowledge with people from other nations/cultures.