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The Antarctic Search for Meteorites:

A model for deep space exploration

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Executive summary

The Antarctic Search for Meteorites (ANSMET) is an annual expedition to the southern continent to collect meteorites. In addition to its goal of gathering extraterrestrial material, it is a realistic model for human space flight. Similarities between ANSMET and Space Shuttle, International Space Station (ISS), and notional future Mars exploration flights include mission duration, major activities, circadian disturbances, a variety of supporting vehicles, small living quarters, allocation of crew time, environmental and systems-related hazards, crew stressors, communication limitations, resupply intervals, and crew involvement in public outreach. Differences include ANSMET's more benign environment, lack of weightlessness, limited crew training, generous personal baggage allowance, reduced physical danger, and absence of a mission control center. The correspondences between ANSMET and space flight make it as valid a model for space exploration as NASA's "analog" projects, which simulate space exploration missions in challenging environments on Earth.

The Principal Investigator of the ANSMET project selects each year's team members from a pool of interested applicants. The resulting teams usually cohere well, suggesting that space commanders should also have a say in the selection of their crews. ANSMET selectees must meet strict medical standards. The expedition begins in late November in Christchurch, New Zealand, where the team is outfitted with protective clothing. A range of available options helps them find good individual solutions for keeping warm. The team then flies to McMurdo Station, Antarctica, for ten days of field training and equipment gathering. In early December, the team flies to its field camp location on the polar plateau. ANSMET work sites have temperatures near -20° C, with wind chill to -40° C. The team spends six weeks searching for meteorites on foot and on snowmobiles. Bad weather may confine the team to camp for days at a time. The team may receive two or more resupply flights during the season. In late January the team pulls out of the field. The participants return to McMurdo and spend three to ten days cleaning and returning equipment. Then they fly to Christchurch, return their borrowed clothing, and travel back to their home countries.

Antarctica is served by a wide range of vehicles, including the C-130, a four-turboprop cargo aircraft, and a variety of motor vehicles equipped for snow roads. A meteorite hunter relies on his or her Ski-Doo snowmobile to drive about 16 km per day (650 km per season), consuming 2.5×10^8 J/day in fuel. Ski-Doos increase the team's search area by a factor of ~100 compared to foot travel. The Twin Otter, a utility aircraft with a payload of ~1000 kg for typical Antarctic missions, resupplies field camps.

ANSMET camps are aligned with the wind to minimize snowdrifts. Campers live in two-person Scott tents with a floor area of 5.7 m^2 and a volume of 4.3 m^3. The tents are double-walled for insulation and ventilated for stoves. The camp includes a latrine tent, and may have additional tents. Each day a camper eats about 1.0 kg of food (about 1000 calories per day more than normal) and drinks 3 liters of water. Varied food helps counteract a monotonous environment. A tent group of two people uses about 1.0 kg of hydrocarbon stove fuel (5.2×10^7 J) per day for heating and cooking. Solar panels provide up to 35 W of electrical power for each tent, corresponding to about 1.5×10^6 J per person per day. Communication with McMurdo and home is via satellite telephone. About 50% of a field camp's footprint consists of logistics, mostly stored outside the tents. The logistics deployed for an eight-person, six-week field season had a mass of 10,742 kg and a volume of 49.6 m^3. Waste is collected in bags for disposal in McMurdo. Striking tents and loading sledges for a camp shift takes time, strength, and skill.

Antarctic explorers navigate with GPS. Future astronauts exploring other solar system bodies will also need accurate navigation, probably via a different technical solution.

ANSMET collects meteorites using a formally established protocol. When the team finds a meteorite, they assign it a number, establish its GPS coordinates, measure and photograph it, record a brief description, and place the sample in a clean bag. They place a marker flag at its location as a backup for the GPS data. At the end of the season, the meteorites are shipped to curators in the United States. ANSMET has collected over 20,000 meteorites since 1976.

Concerns for the people on an ANSMET expedition include team compatibility, staying warm and healthy, maintaining good hygiene, getting enough rest, managing human waste, and keeping a positive attitude despite hardship.

Use of time in ANSMET is similar to that on ISS. Each day, ANSMET participants have an 8.4-hour sleep period (of which 6.9 h is actual sleep). They spend 4.2 h on meals and hygiene, 0.9 h on team coordination, and 7.0 h on scheduled work. They have about 3.5 h of personal time per day. Mental workload approaches saturation on meteorite searches; physical work reaches limits when loading cargo and shoveling snow.

McMurdo Station, a model for a future space settlement, has a summer population of 900 and a winter population of 150-200. The ratio of support workers to scientists is 5:1. Space missions, whose crews must play both roles, should plan for a comparable allocation of work time. McMurdo Station uses about 14,000 liters of water per day. Its power demand averages 1.7 MW. It recycles about 65% of its solid waste. Oceangoing ships resupply it once a year. Logistics occupy about 75% of its geographic footprint. In comparison, the pressurized volume of the International Space Station is only about 20% logistics. Stowage on ISS impedes work and makes it hard to find tools and supplies. Future vehicles should follow Antarctica's example and provide more logistics space.

Comparing ANSMET with real and analog space missions leads to some observations and recommendations. ANSMET's similarity to space flight provides opportunities to learn about the human exploration of deep space at a tiny fraction of the cost of a real mission. It is even more valuable now that other analogs have fallen victim to budget pressure. NASA should support ANSMET and use it to gain more insights for deep space exploration. Astronaut participation in ANSMET is valuable to the astronaut, who gets training in an environment similar to a long-duration space mission, and to his or her teammates, who get a partner trained in survival, operations, and expedition behavior. Astronaut participation in ANSMET should continue.

ANSMET could benefit by adopting some NASA operational techniques. It could cross-train critical crew skills so that the team can still complete all of its tasks with an ill or injured crew member. It could make more explicit contingency plans for the loss of equipment or personnel. It could formally train personnel in leadership, teamwork, and expedition behavior before deploying to the deep field.

ANSMET's lack of a control center makes it an example for the increased crew autonomy that will be necessary for the future human exploration of deep space. The ANSMET PI has the authority to change daily plans, schedules, and task assignments. ANSMET field teams monitor their own status and progress. The ANSMET PI is empowered to make decisions that affect scientific productivity. These are all different from current human space flight techniques, which rely on a control center on the ground. ANSMET is a good place to practice making the best use of limited communications. ANSMET equipment is thoroughly tested and proven to be simple, robust, forgiving of mistakes, and easily repaired. Deep space exploration equipment should be similar. ANSMET crews do their own manifesting and inventory management, rather than relying on the ground as ISS crews do.

It would be possible to conduct an advanced end-to-end Mars mission simulation in Antarctica, using winter stays at the South Pole to simulate the outbound and return legs, and using the Dry Valleys in summer as geological and astrobiological analogs for the surface of Mars.

Glossary and acronyms

Achondrite = uncommon type of meteorite from the Moon, Mars, or a differentiated asteroid

ANSMET = Antarctic Search for Meteorites

ATV = Automated Transfer Vehicle, an unpiloted European cargo spacecraft

AU = Astronomical Unit, 1.496×10^{11} m

Bag Drag = bag check and passenger weigh-in for an Antarctic aircraft flight

Beaker = unflattering slang term for a science grantee in Antarctica

BFC = Berg Field Center, the field equipment depot at McMurdo Station

Big Red = CDC-issued down parka

Bivouac Bag = 40-kg kit containing supplies to make an emergency camp

Boomerang Bag = bag with city clothes, to be returned to an Antarctic traveler if an Ice Flight is aborted

Bunny Boots = CDC-issued white rubber boots

Capcom = Capsule Communicator, the spacecraft communicator in the Mission Control Center

CDC = Clothing Distribution Center in Christchurch, New Zealand

Chondrite = common type of meteorite from an undifferentiated parent body

Crash Pad = closed-cell foam pad, often placed at the entrance of a Scott tent for knee protection

Cygnus = an unpiloted cargo spacecraft built by Orbital Sciences Corporation

DeepWorker = small one-person submersible employed at NEEMO and Pavilion Lake

Dehy = freeze-dried packaged meals that are easily prepared but unpopular for aesthetic reasons

Desert RATS = Desert Research and Technology Studies

Dragon = an unpiloted cargo spacecraft built by Space Exploration Technologies (SpaceX)

ECW = Extreme Cold Weather

EVA = Extravehicular Activity (spacewalk)

Find = a meteorite discovered on the ground, as opposed to one observed falling

Firn = hard, consolidated snow one or more seasons old

Flat Light = overcast weather that makes crevasses, sastrugi, and other snow hazards invisible

Food Pull = selecting, scanning, and packing food for field camp

Freshies = fresh fruits and vegetables, a rare treat in Antarctica

Frostie Boy = the soft-serve ice cream dispenser in McMurdo Station's dining hall

Frost Nip = mild form of frostbite that does not result in tissue death

Galley = (1) the dining hall in Building 155 at McMurdo Station; (2) the water dispenser and food heater on the Space Shuttle

Gear Pull = selecting and testing equipment for field camp

GPS = Global Positioning System

Herc = Lockheed C-130 or ski-equipped LC-130 "Hercules" cargo aircraft

HF = High Frequency (radio)

HTV = H-II Transfer Vehicle, an unpiloted Japanese cargo spacecraft

Hurdy-Gurdy = hand-cranked pump for refueling snowmobiles

Ice Flight = airplane flight from Christchurch, New Zealand to McMurdo Station, Antarctica

ISS = International Space Station

IV = Intra Vehicular crewmember, who guides and monitors an EVA from inside a spacecraft.

Ivan the Terra Bus = 50-passenger all-terrain bus

JSC = NASA Johnson Space Center in Houston, Texas

Komatik Sledge = strong wooden sledge for loads heavier than 500 kg

KSC = NASA Kennedy Space Center near Cocoa Beach, Florida

Lego Box = sturdy, stackable plastic case for tools and spares

LEO = low Earth orbit

Mars DRA 5.0 = NASA Mars Design Reference Architecture 5.0

MCC = (1) Movement Control Center at McMurdo Station; (2) Mission Control Center at Johnson Space Center in Houston

MCM = Three-letter code for McMurdo Station

MEC = Mechanical Equipment Center at McMurdo Station

Meteo-wrong = worthless terrestrial rock that resembles a meteorite

Midrats = midnight rations, a late meal served in the McMurdo dining hall

MLS = Microwave Landing System

Mogas = gasoline for motor vehicles

Mountain Bag = mountaineering rucksack containing ice travel and crevasse rescue gear

Nansen Sledge = lightweight wooden sledge for loads lighter than 500 kg

NASA = National Aeronautics and Space Administration

NBL = Neutral Buoyancy Laboratory, the spacewalk training facility at Johnson Space Center

NEEMO = NASA Extreme Environment Mission Operations

NOAA = National Oceanic and Atmospheric Administration

NPX = Three-letter code for the Amundsen-Scott South Pole Station

NSF = National Science Foundation

Pax = passenger(s)

PI = Principal Investigator

PLRP = Pavilion Lake Research Project

Pole = Amundsen-Scott South Pole Station

PQ = Physical Qualification

Progress = unpiloted variant of the Russian Soyuz spacecraft, used to carry cargo

Raro = sugary drink mix sold in New Zealand

River Box = rigid plastic chest with a locking lid, used to transport and store food and equipment

ROS = Russian Orbital Segment, the Russian parts of the International Space Station

Sastrugi = formations of hardened, wind-carved snow up to a meter in height and a dozen meters long

Ship's Store = the gift shop at McMurdo Station

Shuttle = Space Shuttle

Siglin Sledge = simple plastic sledge for light to medium loads

Sim = space flight training in a simulated mission environment

SIM = Subscriber Identity Module, a pre-paid activation card for the Iridium satellite telephone

Skier = Ski-equipped Lockheed LC-130 aircraft

Ski-Doo = snowmobile

Skua = (1) an Antarctic seabird; (2) an exchange for unwanted but serviceable personal items

Soyuz = Russian spacecraft that carries two or three people

Snow School = outdoor survival training conducted near McMurdo

T-38 = high-performance jet aircraft employed as a cornerstone of astronaut training

Tent Box = wooden box containing supplies for use inside a Scott tent

Triwall = triple-wall cardboard box for transporting about 1.2 m^3 (42 cubic feet) of cargo on trucks and large aircraft

US = United States

USAP = United States Antarctic Program

USOS = United States Orbital Segment, the non-Russian parts of the International Space Station

1. Introduction

In an era of shrinking buying power and reduced flight opportunities, NASA must extract the greatest possible value from all sources of insight into the future of human space exploration. Antarctica is one such source. The history of Antarctic exploration has many political and technical parallels with the development of space, and Antarctica's remoteness and harsh climate make it an excellent proxy for space (e.g., [1,2]). Links between exploration of space and of the Antarctic date back to the International Geophysical Year of 1957-1958, which saw both the launch of Sputnik 1 and the establishment of a station at the South Pole.

The Antarctic Search for Meteorites (ANSMET) is an annual expedition to the south polar plateau to collect meteorites. Although its intent is not to simulate a space mission, the handful of astronauts who have participated in ANSMET agree that it is very similar to a long-duration space flight.

Independently, NASA and other space agencies have simulated deep space exploration missions in "analog" activities at remote field sites on Earth (e.g., [3]). These include NASA Extreme Environment Mission Operations (NEEMO) [4,5], Desert Research And Technology Studies (Desert RATS) [6,7], and the Pavilion Lake Research Project (PLRP or simply Pavilion Lake) [8]. This report focuses on NEEMO, Desert RATS, and PLRP because of the author's firsthand experience with them. Other noteworthy analogs, such as the arctic Haughton Mars Project and the European Space Agency's underground Cooperative Adventure for Valuing and Exercising human behavior and performance Skills (CAVES), are not treated here.

NASA analogs often include fully staffed control centers, astronauts serving as crew, and realistic mission timelines lasting one to two weeks. Analogs have provided key insights into system architectures and operational concepts for the future human exploration of deep space. They have pioneered techniques for human communication with significant speed-of-light delays, for conducting spacewalks on natural objects with negligible surface gravity, and for empowering exploration crews to work with reduced dependence on a ground control center. They have field-tested dozens of emerging technologies including spacewalking tools and full-scale prototype vehicles and habitats. They have provided valuable experience for astronauts preparing for their first space flight, and for flown crewmembers who will take command roles on later flights. Some analogs, especially PLRP, have connected observers in the field with science teams in remotely located control centers to produce high-quality, publishable scientific results. The analogs have accomplished all of this at a tiny fraction of the cost of an actual space flight.

This report treats ANSMET as space flight analog. The chapter following this introduction describes ANSMET in depth. The report then presents data on logistics and crew considerations that may be useful for developers of future human space exploration missions. It offers detailed comparisons between ANSMET and past, present, and future space flights on the Space Shuttle, the International Space Station (ISS), and a proposed Mars mission. Those comparisons are intended to complement the work of Eppler [2], who compares ANSMET to the Apollo moon flights. This report also compares ANSMET with the Desert RATS, NEEMO, and PLRP analogs. It then presents observations and makes recommendations related to ANSMET's value as a simulated space mission. The report ends with a short conclusion.

The remainder of this introductory chapter provides background material to help readers interpret the rest of the report. It gives brief overviews of Space Shuttle and ISS missions along with information on a notional future human flight to Mars. It also presents the general features of three of NASA's space flight "analog" projects. With those points of reference in place, the chapter concludes with an overview of ANSMET.

1.01. Overview of Space Shuttle Missions

Between 1981 and 2011, Space Shuttles launched from Kennedy Space Center (KSC) into low Earth orbit to perform a wide variety of missions. Preparation for a 13-day ISS assembly flight (e.g., [9]), typical of missions late in the Program, began with about 1.5 years of flight-specific training for the seven-person crew, who were led by a commander with a background in military aviation. The mission itself began with launch and ascent to low Earth orbit. There, the crew faced a hostile environment and physical challenges associated with weightlessness. While in space they worked long days on difficult tasks with a high cost of failure. The Mission Control Center was always available on the radio for consultation. In the event of a medical or other emergency, it was possible for the Shuttle to return to Earth within hours to days. Major activities in an ISS assembly flight included launch, heat shield inspections, rendezvous and docking with ISS, multiple Extravehicular Activities (EVAs, or spacewalks), robotic arm operations, exchange of one or more crew members, cargo transfer, undocking, and entry, descent, and landing. The Shuttle usually landed on a dedicated runway at KSC.

1.02. Overview of International Space Station Missions

Crews bound for the ISS launch on Soyuz rockets from Baikonur Cosmodrome in Kazakhstan. The Soyuz carries three crew members: a commander (always a Russian cosmonaut), a flight engineer, and a third person who can be either a second flight engineer or a passenger. The Soyuz may take as long as two days or as little as six hours to rendezvous with the ISS and dock there. Typically there are two Soyuz spacecraft docked to the ISS at a time. Their two three-person crews comprise the six-person complement of the ISS. One ISS crewmember with prior space flight experience is designated as the commander. Missions on board the ISS last six months. Compared to Shuttle crews, ISS crews enjoy a larger habitation volume, but must also endure a longer period of isolation and confinement. Emergency return of an ill crewmember on Soyuz is possible. The pace of work on the ISS is less intense than on a Shuttle flight. Crews spend most of their day doing vehicle maintenance, science, and exercise. There are a few planned EVAs per year, and also rare unplanned ones in response to equipment failures. ISS crews work with the robotic arm to perform various tasks, including the capture and berthing of unpiloted cargo vessels. Flight control centers around the world support ISS operations, with multiple communication channels for voice, video, and data available day and night. ISS crews return home on the Soyuz. They undock, enter the atmosphere, and descend to a parachute landing in a sparsely inhabited region of Kazakhstan.

1.03. Overview of a Reference Future Mars Mission

Many human missions to Mars have been proposed, all subject to the same limitations of physics and technology. This discussion refers to NASA's Human Exploration of Mars Design Reference Architecture 5.0 [10], henceforth called Mars DRA 5.0. The basic structure of a Mars mission will follow that of past and present space flights. There will be a flight crew led by a commander, and a control center on Earth will monitor the flight and provide remote assistance. There will be two major differences with respect to present operations. First, distance and speed-of-light delays will restrict the amount and timeliness of assistance the ground can provide [11]. For a period of weeks around superior conjunction, when the Sun lies between Earth and Mars, there will be no communication at all. Second, the distance between the planets and the geometry of their orbits prohibits crew, cargo, and rescue flights except at specific launch opportunities occurring at 26-month intervals. Responsive resupply and emergency crew return are thus not possible.

The six-person crew will complete a multi-year training flow on Earth. At the same time, a months-long campaign will robotically assemble two large spacecraft in low Earth orbit and send them to Mars. On arrival, one ship (with the ascent vehicle the crew will later use to launch from Mars) will land and manufacture return propellant from local resources, while the other (with a combined lander-habitat module) waits in orbit. A second campaign will assemble the crew's ship in Earth orbit. When it is complete, the crew will launch, dock with the Mars ship, and perform a trans-Mars injection burn, beginning an eight-month interplanetary flight. During the mission they will face isolation, confinement, and no possibility of resupply or early return. Their activities will resemble those of ISS crews, focusing on vehicle maintenance, science, and physical exercise. Arriving at Mars, the crew will leave the interplanetary transit vehicle in orbit and take the pre-emplaced lander-habitat module through entry, descent, and landing on Mars. Depending on the return trajectory, they may remain on Mars a few weeks (for an "opposition-class" mission), or more than a year (for the energetically favorable "conjunction class" mission).

On Mars, the crew will perform EVAs for geological, biological, and resource exploration. Return to Earth will involve launch from the surface of Mars in the pre-deployed ascent vehicle, docking with the interplanetary ship in Mars orbit, a trans-Earth injection burn, and another cruise of about eight months, finally culminating with entry, descent, and landing at Earth. The full mission duration will be about 3 years. That time can be cut in half for the opposition-class flight, at the expense of much additional propellant mass launched from Earth.

1.04. Overview of NEEMO

In NASA Extreme Environment Mission Operations (NEEMO) expeditions [4,5], six-person NEEMO crews lived for about 10 days in the Aquarius underwater habitat, located off Key Largo, Florida, at a depth of about 15 m. Aquarius is an isolated, confined space with an outside environment that does not support human life. It is also a saturation-dive facility, so a quick return to the surface is not possible. NEEMO crews donned diving gear to conduct "EVAs" outside the habitat, taking advantage of the water's buoyancy to simulate reduced or zero gravity. A mobile control center topside in Key Largo assisted and monitored the "aquanauts" via voice, data, and video communication links.

1.05. Overview of Desert RATS

Desert Research and Technology Studies (Desert RATS) [6,7] was a space mission simulation at a geologically interesting field site near Flagstaff, Arizona. Two- and four-person Desert RATS crews drove prototype rovers on one- to two-week missions that simulated traverses on the Moon or Mars, or that mimicked operations at a near-Earth asteroid. Wearing instrumented backpacks, crewmembers performed shirtsleeve 1-g "EVAs" to evaluate tools and techniques for geological exploration. They ate and slept in the rovers, providing insight for designers of future vehicle cockpits and habitation spaces. As in NEEMO, a distant control center assisted in the operation.

1.06. Overview of PLRP

The Pavilion Lake Research Project (PLRP) [8] was a scientific investigation that also served as a space flight analog. It studied unusual stony microbial growths in remote mountain lakes in Canada by employing one-person submersibles that were excellent stand-ins for spacecraft. As in NEEMO, the underwater environment posed real challenges and risks. The submersible "pilots" made science dives typically lasting three to six hours, in close communication with scientists in the boats that tracked the subs. Unlike NEEMO and Desert RATS, the space mission simulation was limited to the dives and did not continue during surface time or off-duty hours.

1.07. Overview of ANSMET

The Antarctic Search for Meteorites (ANSMET) is an annual expedition to Antarctica to collect meteorites for scientific study. ANSMET teams have journeyed to Antarctica every year but one since 1976. They have collected over 20,000 meteorites, including rare and scientifically important specimens from the Moon and Mars. A well-known Antarctic meteorite is ALH 84001, which in 1996 was reported to contain evidence for past life on Mars [12], a claim that remains controversial to the present day. The meteorites that ANSMET collects are permanently curated at the Smithsonian Institution in Washington, D.C. Although meteorites fall no more commonly on Antarctica than anywhere else, Antarctica is the best place to find them. The cold dry climate preserves meteorites, the scarcity of Earth rocks makes meteorites easier to spot, and the flow and erosion of the ice concentrates meteorites in glacial moraines and in certain locations characterized by solid blue ice at the surface. Funding for ANSMET has been provided by the National Science Foundation (NSF) with supplemental funds from NASA in some years. When funding allows, ANSMET may deploy as two groups: a mobile reconnaissance team of four people that explores areas identified from remote sensing as potentially containing meteorites; and an eight-person systematic search team that goes to a place known to be rich in meteorites and collects as many as possible.

An ANSMET mission begins when the team members meet in late November in Christchurch, New Zealand, which hosts the primary logistics support point for the United States Antarctic Program (USAP). Participants convene at the Clothing Distribution Center (CDC) for training and Extreme Cold Weather (ECW) clothing issue. The next day they make their "Ice Flight" to McMurdo Station, Antarctica, on a U.S. Air Force cargo plane, a journey of 4000 km. For the next ten days they stay in McMurdo to gather more field gear; select and pack food for field camp; complete an overnight field training trip on the ice near McMurdo; learn and practice crevasse rescue techniques; and crate, palletize, and document over ten metric tons of equipment and supplies for air transport.

Figure 1. ANSMET field camp at Larkman Nunatak.

ANSMET teams deploy via ski-equipped aircraft to their search sites, typically 1500 to 2500 m above sea level on the south polar plateau (Fig. 1). The sun is above the horizon 24 hours a day. Typical temperatures are near -20° C, with wind chill factors reaching -40° C. When the team arrives at the work area, they set up a field camp of two-person Scott tents. They may use snowmobiles and sledges to traverse to neighboring search areas not directly accessible by aircraft. Team members use snowmobiles to search for meteorites on blue ice, and go on foot to search in glacial moraines. Field seasons typically last six weeks. High wind, snowfall, drifting snow, or thick overcast and flat light that make travel dangerous can prevent searching on a quarter or more of the days the team spends in the field.

ANSMET field camps are autonomous except for satellite telephone communication and aircraft resupply flights. There is no 24-hour control center dedicated to the expedition, as in a space mission. Instead, there are administrators and technicians who support many projects on the continent and who may be reachable by satellite phone during business hours. Resupply flights to the field camp might occur only twice during the season. They deliver critical spares and remove trash and unwanted equipment. Medical evacuation of an ANSMET team member by aircraft has occurred a handful of times in the project's history.

Like an ISS expedition or a flight to Mars, an ANSMET expedition is a months-long expedition far from home with a dangerous outside environment. ANSMET crew members live in cramped quarters with a small group of international co-workers, isolated from family, friends, and the rest of the world. They endure long work days and challenges with basic life functions such as eating and sleeping.

Because of its similarity to a space mission, ANSMET provides potentially useful insights for planners of future human deep space exploration missions. This report presents some of those insights, in the hope that they can inform plans for the human exploration of the Moon, near-Earth asteroids, and the planets.

2. Comprehensive characterization of ANSMET

This chapter presents a full description of ANSMET. It covers the expedition step by step. It then discusses transportation in Antarctica, life in field camp, the process of collecting meteorites, and crew concerns specific to Antarctic field expeditions. This chapter is intended both to give a complete picture of the expedition and to serve as a primer for future ANSMET participants.

2.01. Description of the Mission

This section contains a phase-by-phase breakdown of the ANSMET expedition.

2.01.01. Applying to join the team

Participation in ANSMET begins early in the calendar year with a written request to the Principal Investigator (PI), currently Professor Ralph P. Harvey at Case Western Reserve University in Cleveland, Ohio. The PI hand-picks each year's team based on his knowledge of their capabilities, character, and Antarctic experience. This model works because most ANSMET participants are young American planetary scientists, a pool small enough that the PI can know them all personally or by reputation. Choosing a group that can work together harmoniously is important because the team members have less than two weeks to get to know one another before they deploy to the deep field. Notably successful polar explorers of the last two centuries, such as Fridtjof Nansen [13] and Ernest Shackleton [14], also hand-picked their teams. In human space flight, agency managers select crews who then learn to work as a team during an intense flight preparation syllabus lasting one or more years. This method probably not yield good results with training flows as short as ANSMET's.

The PI announces the upcoming season's team members in June or July.

2.01.02. Medical qualification

The first order of business for an ANSMET selectee is to obtain medical certification for Antarctic duty. Physical Qualification (PQ) is important because an ANSMET participant may be days away from the nearest hospital, which is in Christchurch. Disabilities and medical conditions that could require care beyond the scope of an outpatient clinic are disqualifying for polar duty. The PQ application includes a doctor's examination, a dental checkup, and many pages of health questionnaires. The results go to a medical institution (currently the University of Texas Medical Branch in Galveston, Texas) working under contract to the NSF. PQ paperwork is due in August. In September the contractor announces its rulings on the applicants' fitness for polar duty.

Occasionally the contractor disqualifies an ANSMET selectee. In this case, the PI must find a replacement quickly. In some years, ANSMET has called upon astronauts as late replacements. The strict medical standards that astronauts must meet, and the copious and readily available documentation of their health, make it easy for them to qualify for polar duty. Sometimes ANSMET accepts backup team members who voluntarily go through medical certification one year, in exchange for priority consideration for a place on the next year's team.

2.01.03. Advance mailing

ANSMET participants travel to Antarctica via New Zealand, which enforces strict limits on imports of agricultural products. Experienced travelers bring no such items on their persons or in their luggage. ANSMET participants who want to bring special foods to the field to boost morale can avoid delays in Customs by mailing the food to themselves in Antarctica. McMurdo Station has a US post office which can receive and hold packages for USAP participants. Mail delivery to Antarctica uses the same overseas postal system as the United States Armed Forces. Service to Antarctica is slow and is subject to disruptions for weather and aircraft availability. ANSMET team members expecting to pick up packages in McMurdo when they arrive in early December should ship them in early October. Food items sent by mail must be securely packaged and have at least a two-month shelf life.

2.01.04. Flight to New Zealand

ANSMET team members begin their journey in late November, taking commercial flights to Christchurch, New Zealand. An NSF contractor arranges and pays for air travel from the major US airport nearest to the participant's home. The ANSMET grant may reimburse international participants for their flights to the US. In 2004, the routing for a Houston-based team member was Hobby Airport to Dallas to Los Angeles to Auckland to Christchurch. In 2012, the routing was Hobby to Dallas to Los Angeles to Sydney to Christchurch. The travel time was about 30 hours in both cases. A day is lost in crossing the International Date Line from east to west. In Christchurch, a USAP representative waits beyond Customs to greet Antarctic travelers and direct them to local hotels, where the NSF contractor has arranged reservations (but not payment). ANSMET members may be routed independently from their home airports, but with few exceptions they all arrive at the same hotel in Christchurch on the same day. Ground transportation from the airport is via taxicabs or shuttle vans, the latter equipped with cargo trailers for Antarctic travelers' massive personal baggage.

2.01.05. Christchurch

Christchurch, with a population of about 350,000, is the largest city on New Zealand's South Island. It is located at 43° South latitude and has a cool maritime climate. In the Southern Hemisphere, late November is early summer. The trees and flowers are in full leaf and bloom, a pleasant contrast for travelers from the Northern Hemisphere. The city has many public parks and gardens, and an excellent free museum. From 2010 to 2012 the city was heavily damaged by earthquakes on a previously unknown fault. At the time of this writing, much of the central business district remains cordoned off as a "red zone" unsafe for public entry. Some buildings outside the red zone show evidence of seismic damage. Many hotels have been affected by the earthquakes, which limits options for Antarctic travelers. Reconstruction efforts were still underway in 2013.

ANSMET travelers pay for their own food, lodging, and local transportation expenses in Christchurch. The ANSMET grant, currently administered by Case Western Reserve University, reimburses those costs after the expedition.

The NSF travel coordinators schedule one full day for USAP participants in Christchurch, but "Ice Flights" from there to Antarctica are commonly delayed, sent back, or cancelled outright because of bad weather or aircraft problems. Antarctic travelers may therefore spend extra days in Christchurch waiting for their Ice Flights to be rescheduled. Local recreational options include visiting the Royal Botanic Garden, admiring the native forest in Riccarton Bush, viewing the riverside formal grounds at Mona Vale, going to the beach at New Brighton, and taking the bus to the nearby resort town of Akaroa for day hikes or boat tours.

2.01.06. Clothing issue

The purpose of the scheduled day in Christchurch is for the team to go to the Clothing Distribution Center (CDC), which is located near the airport. The CDC session begins with training videos about the harsh conditions in Antarctica and about the international treaties that protect the continent's flora, fauna, and environment. After the video presentation, the CDC staff hands each participant a checklist and two large orange duffel bags filled with Extreme Cold Weather (ECW) clothing. The traveler must verify each item against the checklist and try it on to make sure it fits. Section 3.09 presents a complete list of CDC gear issued to the author for the 2012-2013 season.

Fit is especially important for boots. The standard issue boots are made of white rubber. They are constructed in two layers with an insulating air space between them. Their cartoonish appearance has earned them the nickname "bunny boots." Bunny boots must fit comfortably over however many layers of socks the wearer plans to use. Loose boots can cause blisters. Tight boots restrict circulation, which leads to cold feet and possibly frostbite.

Another notable ECW item is the bright red Canada Goose down parka. The parka is equipped with many large pockets, a hood with a real fur ruff, and a tag with the wearer's name. Because of its size and distinctive color, the parka is nicknamed "Big Red."

The third major part of the ECW ensemble is a pair of black insulated snow pants with a bib that blocks drafts and provides an extra layer of insulation for the wearer's chest.

Some Antarctic veterans, who may have their own personal arctic clothing, shun the red-black-white ensemble. It indicates to everyone within sight that the wearer is (certainly) a science grantee or "beaker" and (probably) a first-time visitor to Antarctica. Both imply incompetence. Antarctic contract workers are issued insulated Carhartt work clothes, which are brown.

The CDC has lockers available for travelers to store baggage brought to Christchurch but not wanted in Antarctica.

2.01.07. Ice Flight

All travelers must wear their CDC-issued parka, boots, snow pants, hat, gloves, and goggles to board the Ice Flight from Christchurch to McMurdo Station. Each passenger may bring one carry-on bag, typically one of the orange duffels from the CDC. Everything else flies as checked baggage. Once checked, bags are inaccessible until the traveler arrives in Antarctica, with one exception. Each person designates one checked item as a "boomerang bag" to be pulled off the cargo pallet and returned to the traveler if the flight does not take off or is forced to turn back. The boomerang bag should contain street clothes and other essentials for a few days in Christchurch. All bags are x-rayed and examined by dogs trained to detect contraband, especially drugs. As on domestic flights in the US, knives and other sharp objects are not allowed in carry-on luggage. In 2004, each traveler could bring 34 kg of personal baggage (including both checked and hand-carried) to Antarctica. In 2012, the limit was 68 kg.

On the morning of the Ice Flight, travelers gather at the Antarctic Terminal near the CDC to check their baggage. The scheduled check-in time is early enough to allow a quick breakfast at a nearby hotel or at the neighboring International Antarctic Centre. Travelers watch short training videos about the flight and about Antarctica, then take a bus a few hundred meters to the airfield, where they board the plane. Each traveler is given a sack lunch, but must bring his or her own water bottle.

Antarctica is served by aircraft from the US and other countries. In 2004, the author flew to McMurdo on a Royal New Zealand Air Force C-130. In 2012, the author's aircraft was a US Air Force C-17. In both cases the aircraft was filled to capacity with cargo and passengers. US military operations in

Antarctica are termed "Operation Deep Freeze." The name comes from Antarctic missions in 1955-1956 in preparation for the International Geophysical Year of 1957-1958. Antarctic aircrews may wear Operation Deep Freeze insignias on their uniforms. In 2012, C-17 crewmembers wore humorous patches featuring Dr. Seuss's Grinch character and the words "Christmas is cancelled," a reference to the pre-emption of the traditional American winter holiday by the Antarctic summer work season.

"Boomerang" flights, which depart for Antarctica but turn back because of bad weather or mechanical problems, are common. This underscores the importance of the boomerang bag discussed above. In 2004, the author's first Ice Flight turned back for weather after four hours in the air, resulting in a two-day delay in Christchurch.

The 4000-km flight from Christchurch to McMurdo takes about 5 h in a C-17, or 7 h in a C-130. It takes about 8 h in an LC-130, whose bulky skis reduce the plane's cruising speed.

Scenery on the first half of the flight is uninteresting, as the airplane passes over the Southern Ocean. After the halfway point, patches of sea ice may be visible below. The last quarter of the flight offers spectacular views of the mountains and glaciers of Victoria Land, the Antarctic coastline along the air route between Christchurch and McMurdo.

Upon landing, passengers are greeted by freezing temperatures and impressive views of ice and mountains. They transfer to "Ivan the Terra Bus" (described in Section 2.02), Delta vehicles, or 13-passenger vans for transport from the airfield to McMurdo Station proper. There they collect their baggage at the Movement Control Center, pick up their room keys from the housing office, and move into their assigned dormitories.

2.01.08. McMurdo Station

McMurdo Station (Fig. 2) is America's largest installation in Antarctica. It is located at 77.5° South latitude on Ross Island in the Ross Sea. Its placement near historic exploration huts built by Scott and Shackleton is no accident: it is the world's southernmost piece of exposed land reachable by ocean-going ships in summer, when the sea ice is at its annual minimum. New Zealand's Scott Base lies about 2 km away. A graded dirt road connects the two. McMurdo Station was originally established by the United States Navy. Traces of its Navy heritage remain in the ship anchors exhibited outside the chapel, the Seabees mementos that decorate one of the taverns, and the nomenclature of the Galley (dining hall) and the Ship's Store (the firmly land-bound gift shop).

Figure 2. McMurdo Station from Observation Hill.

McMurdo is served by a helipad and three airfields. The helipad lies in the southern section of the station and can accommodate about eight helicopters. For fixed-wing operations, the nearest airfield is a temporary runway on the annual sea ice just offshore from town. It is used in spring and early summer, when the sea ice is still thick enough to support heavy aircraft. It is abandoned later in the summer when the ice thins, then re-established the next year. McMurdo's second aerodrome is Williams Field, located on the permanent McMurdo Ice Shelf about 11 km from town. Williams Field is suitable only for ski-equipped aircraft. Pegasus Field, named for an airplane that crashed there in the 1960s, is about 25 km from McMurdo. It too is located on thick permanent ice, but is machine-groomed for use by both wheeled and ski-equipped aircraft. Warm weather in the summer may make the surface too soft to accommodate heavier wheeled aircraft such as the C-17. Occasionally the runway gets so soft that even C-130 traffic must be stopped. Both Williams Field and Pegasus are reached by multi-lane snow roads based at the sea-ice transition near Scott Base. Warm weather and melting accentuated by dirt that falls from vehicles can make the snow roads badly rutted, increasing travel time and demanding frequent lane closures and resurfacing work.

All three of McMurdo's airfields use the Microwave Landing System (MLS) as a navigational aid for planes arriving in poor weather. Decades ago, MLS was expected to replace the older Instrument Landing System at airports worldwide, but it never caught on. It is used in Antarctica because the ground infrastructure is easy to relocate. Runway numbering (and indeed all aspects of air navigation) in Antarctica is not based on magnetic directions, which are badly distorted near the magnetic South Pole. True directions are also problematic because of the singularity at the geographic South Pole, where a major airfield is located. Instead, Antarctic air navigation is based on a square grid centered on the South Pole and aligned so that "north" is in the direction of the Prime Meridian. Aircrews use grid directions and coordinates for all their work. Readers interested in Antarctic flying can learn more from a special issue of Aviation Week and Space Technology magazine [15].

McMurdo Station is also a seaport. Workers have constructed a floating pier of ice to moor the cargo ships that serve as McMurdo's primary supply line. If the sea ice does not break up completely, the NSF must hire an icebreaker to cut a path from the open ocean. The resupply ships include a container vessel that brings durable goods and takes away trash and surplus equipment, and a tanker that fills McMurdo's large fuel storage tanks with diesel fuel, automotive gasoline (termed "mogas"), and kerosene fuel for aircraft. Incoming and outgoing cargo is staged in designated zones located inland from

McMurdo's habitation buildings. Logistics yards (Fig. 3) occupy several times more area than the station's dormitories, laboratories, and workshops combined.

Figure 3. Logistics at McMurdo Station.

McMurdo Station tries to minimize its waste stream. This is accomplished largely through recycling. Instead of simple wastebaskets, trash stations in McMurdo consist of a dozen or more labeled receptacles for different recyclable materials. A typical trash station has separate bins for light metal, fabric, food waste, "Skua" (see 2.01.11 below), batteries, aerosols, empty aluminum beverage cans, paper towels, mixed paper, glass, plastic, and non-recyclables. People who seek to avoid sorting their trash by simply dumping it all in the "non-recyclable" bin face criticism. Sorted recyclables are returned by ship to the US for processing. McMurdo recycles about 65% of its waste, twice the percentage of even the greenest US cities.

McMurdo Station is the northern terminus of the South Pole Traverse, a marked and maintained 1,600-km snow road for tractors dragging 50-tonne cargo sledges and fuel bladders to the Amundsen-Scott South Pole Station. The Traverse takes about 40 days to reach its goal. It is valuable because it carries supplies that would otherwise have to be airlifted to the Pole at greater expense.

McMurdo was powered by a nuclear plant from 1962 to 1972, but after persistent leaks the reactor was decommissioned and replaced with diesel generators. McMurdo consumes about 1.7 MW of electricity during peak season. Nearly all of this is provided by the diesels. Three wind turbines installed on the ridge between McMurdo Station and Scott Base provide all of the electricity for the latter, and about 10% of the electricity for the former. At the time of this writing, more wind turbines are on order. Diesel power also runs the desalination plant, which produces 14,000 liters of fresh water daily during peak season. Signs reminding residents to conserve electricity and water are everywhere in McMurdo.

McMurdo has a summer population of about 900. In winter, a smaller community of 100 to 200 endures months of extreme cold, darkness, and physical isolation from the rest of the world. The male-female ratio is about 3:1, and the ratio of support personnel to researchers is about 5:1. Residents live in dormitories. During the busy summer season they may have to share sleeping quarters with two or three roommates. Dorm room windows have blackout shades to block the perpetual summer daylight during sleep periods. The residents of each dorm hallway share lavatories and laundry rooms.

McMurdo has telephone and Internet connections to the outside world via the Black Island telecommunications facility, a suite of dish antennas pointed at satellites in geosynchronous orbit. The satellites are near the northern horizon as seen from there. The Black Island terminal is connected to McMurdo by a microwave link. In 2004 and 2005, McMurdo had only four outside telephone lines. Callers had to enter an electronic queue and often wait for tens of minutes for a turn to make a phone call. In 2012 and 2013, outside phone lines appeared to be unlimited and waiting was not necessary. McMurdo has Internet connectivity, but audio and video streaming are prohibited because the limited bandwidth must be shared among all residents. Computer kiosks are available for residents without computers of their own, and many areas have wireless network coverage. Web browsing is noticeably slower at McMurdo than in the US. Personal computers being brought into McMurdo must have the latest security patches and must be surrendered overnight to USAP Information Technology personnel for virus scans.

The dining hall in Building 155 serves four meals a day: breakfast, lunch, dinner, and "midrats" (midnight rations). The food is excellent. Bread, cereal, hot and cold drinks, and peanut butter and other condiments are available in between the main meal times. "Frostie Boy," the soft-serve ice cream dispenser, is popular at dessert time. Frostie Boy appears to have its own fan club with special T-shirts.

Other points of interest in McMurdo include the post office (open for a few hours three days a week), an interfaith chapel, a barber shop, and a store that carries gifts, toiletries, and incidental items. Two Wells Fargo Automated Teller Machines in Building 155 dispense US dollars. Only one machine is active at a time. Visitors may not interact directly with McMurdo's air traffic control center, fire station, or medical clinic, but may rely on them for support of their projects. Pickup trucks for transporting expedition gear are available for checkout at the Crary Laboratory and at the Mechanical Equipment Center.

2.01.09. Food and gear pull

The team spends much of its ten-day stay in McMurdo gathering food and equipment for the field season. They accomplish this work at the Berg Field Center (BFC), a pair of buildings that serve as storage and maintenance facilities for the materiel used in Antarctic field camps.

The PI divides the team into two-person tent groups. Each tent group spends two or three hours with pencil and paper planning its menu for the entire six-week field season, including reserves, based on a list of the products available at the BFC. When the season's food plan is ready, the tent group "pulls" (selects, scans, and packs) one day's worth of dry and canned food for the overnight snow school trip. This equips them for snow school and also trains them for the much larger job of pulling dry and canned food for the main season. That task occurs later and takes about half a day. Pulling frozen food for the season takes another half day. Food pulls are hard-scheduled so groups won't interfere with one another.

Yet another half day is spent pulling field gear. The BFC issues each ANSMET participant a sleep kit with a sleeping bag, insulating pads, a folding camp chair, and other nighttime necessities. Each participant also gets an ice ax and a "mountain bag," a rucksack with crampons, a first aid kit, and crevasse rescue tools. As a part of gear pull, each recipient checks all of his or her equipment to make sure it fits and is in good condition. See Section 3.09 for a complete list of the gear that the BFC issues to ANSMET team members.

The BFC issues each two-person tent group additional camping equipment. There is a Scott tent, a box of tent stakes, a six-pound sledge hammer for driving the stakes, and two short-handled snow shovels. Each tent group also gets three sturdy wooden "tent boxes." The first contains cooking utensils. The second holds hand soap, matches, paper towels, toilet paper, a fire blanket, a fire extinguisher, hand sanitizer, clothespins, and similar necessities. The third tent box stores commonly used food items such as candy, drink mixes, butter, and spices.

Each tent group also receives a stove box containing two propane stoves, propane hoses, stove boards, a stove platform, a kettle, and a large metal pot for melting snow. Two stoves (of different design) are provided to allow personal choice and backup capability if one fails. The tent group gets an A-frame solar panel and a 40-kg waterproof case with batteries and power conditioners that also serves as a base for the solar array. The group gets two or three "crash pads," old foam sleeping pads commonly placed just inside the tent entrance to protect the knees of people crawling in and out.

Finally, the entire field party has additional gear. There is a separate tent for the latrine. There may be additional tents to store field gear or to provide shelter for snowmobile repair. There are one or more strong, stackable plastic "Lego boxes," which measure about 40×50×50 cm and contain spare parts and tool kits. Noteworthy spares include loss- and failure-prone snowmobile parts (spark plugs, drive belts, springs, windshield attachment fittings, and tow ropes), extra bedding, and a backup radio set. The party carries an emergency shelter and supplies in a 40-kg "bivouac bag." There is an insulated toilet seat and numerous plastic buckets with sealing lids for the latrine, plus large supplies of toilet paper and paper towels for cleanup. For camp shifts there may be Nansen sledges, Siglin sledges, and large and small Komatik sledges. The party is equipped with hundreds of bamboo marker flags. Each participant has his or her own "Ski-Doo" snowmobile. Some Ski-Doos are equipped with panniers for additional cargo and jerry cans for extra fuel. There are 208-liter drums of fuel for the Ski-Doos, wooden drum cradles that allow the fuel barrels to be carried securely on sledges, and two hand-cranked fuel pumps, a prime and a spare. The party carries a large supply of propane bottles for the camp stoves. There are also ice augers and ice chippers used to drill holes for marker flags and to harvest ice for drinking water. The team leader carries a GPS base station that is kept in camp, plus a roving GPS unit to record the positions of meteorites in the field.

The party packs most of their gear into "triwalls," cube-shaped triple-thick cardboard boxes with a volume of about 1.2 m^3 (equal to 42 cubic feet, the units used for aircraft loading calculations). Triwalls sit on wooden pallets so that forklifts can handle them. Ratcheting cargo straps hold the triwalls closed and secure them to their pallets. Cargo strap mechanisms often stiffen or jam because of the cold and the wind-blown grit in McMurdo. The commercial penetrating oil WD-40 frees stuck cargo strap mechanisms. Experienced cargo strap operators keep a can of WD-40 handy. Large items such as tents, Ski-Doos, and fuel drums do not fit in triwalls. The team delivers these things to the Antarctic cargo system separately. Every item sent into the cargo system must be weighed and given a barcode sticker with a unique tracking number. The ANSMET team does much of this work themselves. A cargo list for an ANSMET expedition is presented in Section 3.10.

In addition to selecting and packing BFC-issued supplies and equipment, ANSMET team members must keep their personal gear organized. This takes effort. Different clothes and supplies are needed in Christchurch, in McMurdo, on the snow school trip, and in the field, so a participant may have to repack his or her bags several times. In particular, repacking is unavoidable during the stays in McMurdo at the beginning and end of the season. Dorm rooms in McMurdo lack open floor space for this operation, and it may be necessary to keep the room dark and quiet for day sleepers. Team members may therefore have to repack in the hallway. Despite the 24-hour daylight outside, experienced Antarctic travelers bring a headlamp to help them find things in darkened dorm rooms. They also organize their gear with an eye toward the venue in which each item will be used, perhaps keeping a "Christchurch" bag, a "McMurdo" bag, and a "Field Camp" bag.

2.01.10. Snow school

USAP participants bound for field camps must take an overnight outdoor survival course called "snow school" or "happy camper school." Because of its good safety record, ANSMET is allowed to conduct its own snow school. The ANSMET snow school is led by the same experienced mountaineer who will accompany the party into the field. Snow school begins early on the morning of the fourth or fifth day in McMurdo. Participants collect their personal, tent, and group gear. They use pickup trucks to shuttle their equipment down to the sea ice transition. There they load it all onto sledges and lash it down for travel. Towing the sledges behind their Ski-Doos, they drive to a location about 15 km from McMurdo. In 2004, ANSMET conducted its snow school at a location on Hut Point Peninsula called "Room with a View" for its vistas of Mt. Erebus and the Royal Society Range. In 2012, ANSMET held its snow school on the permanent sea ice near the base of Kiwi Ski Hill.

At snow school, participants develop Ski-Doo driving skills on terrain of varying difficulty, learn and practice crevasse rescue techniques, and set up a field camp. They learn how to use their tents, stoves, and other camping gear. In early December, temperatures in the McMurdo area are near freezing, conditions that make a good transition between the heated buildings of the station and the extreme cold of the polar plateau. The transition is important because some ANSMET participants may have never been camping before.

After spending a night in the tents, the team eats breakfast, strikes camp, re-loads the sledges, and motors back to McMurdo Station. There they unpack their gear and use a truck to return it to the Berg Field Center for cleaning and drying.

2.01.11. Recreation in McMurdo

ANSMET teams spend about ten days in McMurdo preparing for the field. One off-duty day is typically scheduled just before deployment to the polar plateau, but transportation delays may provide team members with more unstructured time in town. There are many options for recreation in and around McMurdo.

Unofficial travel away from the station is generally restricted. Exceptions include a popular hiking trail to the top of nearby Observation Hill. "Ob Hill" offers spectacular views of McMurdo Station and nearby Scott Base. Southward lie White Island, Black Island, and Minna Bluff. To the southwest lies Mount Discovery, a 2681-m stratovolcano. The Royal Society Range forms the western horizon. To the north and the northeast are the two massive volcanoes that dominate Ross Island: Mount Erebus (3794 m) and Mount Terror (3230 m). Mount Erebus is the world's southernmost active volcano. A plume of vapor is commonly visible at its summit. A wooden cross on top of Ob Hill commemorates the Scott party who died on the return from the South Pole in 1912.

Other established hiking trails lead to Cape Armitage, to Scott's historic Discovery Hut, and along the Hut Point ridge in the direction of Arrival Heights. Walking to New Zealand's Scott Base, which has a bar and a gift shop that are sometimes open to visitors from McMurdo, is also popular. Some nearby areas, such as Arrival Heights itself and the explosives storage facility in a volcanic crater above town, are closed to unauthorized entry. When the sea ice is open for travel, ski trips around Cape Armitage are permitted. The ice road to Williams Field is also open for skiers, who can flag down shuttle vans for transportation on land between McMurdo and the ice shelf transition near Scott Base.

Skiing and hiking on the 16-km Castle Rock Loop Trail is permitted when snow and weather conditions allow. Travelers wishing to take that route must attend an outdoor safety lecture, submit an electronic travel plan, and carry a radio. Most importantly, they must check out with the firehouse when they leave McMurdo and check back in when they return. Failure to check in on time results in activation of search and rescue forces. The entire Castle Rock Loop Trail is marked with flags. Emergency shelters are placed at three locations along the route. Over the years, three travelers have fallen to their deaths from cliffs or into crevasses after leaving the marked route, so it's important to stay on the path.

It may be possible to arrange guided tours of the inside of Discovery Hut (which contains artifacts from early 20th-century Antarctic exploration) and the scenic pressure ridges near Scott Base. In 2004, there was an organized motor journey to Scott's rarely-visited Cape Evans Hut, about 30 km from McMurdo, but by 2012 such morale trips had fallen victim to budget pressure. International treaties protect all historic sites in Antarctica.

For USAP participants who prefer indoor exercise, McMurdo offers yoga and aerobics classes. There are two gymnasiums with a variety of aerobic and resistive exercise equipment, and a third for open-court activities such as basketball. McMurdo residents volunteer their time to teach the exercise classes. They also offer other kinds of classes, such as swing dancing.

Interesting volcanic minerals, rocks, and landforms are common in and around McMurdo. Collecting rocks for personal use is not allowed. Observable wildlife includes Weddell seals, and birds such as skuas and penguins. Penguins are rarely seen until after the sea ice breaks up. The Crary Laboratory has a touch tank with interesting marine life from the waters around McMurdo. The Antarctic Treaty protects wild animals from human contact. Scientists investigating Antarctic plants and animals must obtain special permission to interact with the subjects of their studies.

For media-based entertainment, McMurdo has a radio station which residents can listen to or join as disc jockeys. Dorm rooms have television sets with access to locally managed and American Forces Network programming. Dorm lounges are equipped for playing videos of various formats, and libraries of DVDs and VHS tapes for general use.

Building 155 has a craft room with sewing machines and other tools for handiwork projects. Residents sell things they have made at occasional craft sales. McMurdo Station has two libraries, one for general use and another for research, plus informal book exchanges in the dorm lounges. ANSMET participants can borrow books and craft materials to take to the field. McMurdo has a free exchange for unwanted but still serviceable personal goods. Donors place such items in "skua" lockers in the dorms;

people in need can claim donated goods for free at "Skua Central." Strange works of local folk art, including a killer whale made from welded chains and a rusty steel troll lurking under a footbridge, are installed around town. Noteworthy graffiti includes "Seize the day with giant metal hands," advice to people exiting one of the Berg Field Center structures.

McMurdo Station has two bars, Gallagher's and Southern Exposure. Sometimes the bars offer live music of surprisingly high quality and varied range for such a small community. Occasionally, closing time must be enforced externally. In the absence of a police force this service is rendered by the fire department. McMurdo has a coffee shop with a presentation room which is often scheduled for movie showings and open microphone performances.

McMurdo Station and Scott Base each host special events, including both traditional annual parties and one-off cultural events. In the 2004-2005 summer season, McMurdo had an impressive local art show and an evening of dramatic readings of Dr. Seuss. Scott Base sponsored a medical research fundraiser in the form of the Undie 500, a 500-meter foot race conducted outdoors in base-layer clothing. In 2013, McMurdo hosted bingo games and another medical fundraiser in which participants would bid for the right to choose unusual patterns to be sculpted in the facial hair of male volunteers returning unshaven from the field.

A bowling alley, featuring undulating floors and volunteers hand-setting the pins, was available in 2004-2005 but had been decommissioned by 2012.

2.01.12. Put-in flight

When training and cargo preparation are complete, the team is almost ready to deploy to the field. All that remains is to pack personal gear. Each passenger may bring one carry-on bag aboard the aircraft. All other baggage will be checked. Experienced participants keep a few days' worth of clothing and necessary toiletries in their carry-on bag. If the flight is delayed or cancelled, checked bags remain in the cargo system and will be inaccessible to the traveler. ANSMET team members can store items they don't want to bring to the field, including street clothing used in McMurdo that would not be useful in camp, in the "cage," a locked storage space in the rear of the Berg Field Center.

The evening before put-in, travelers gather for "bag drag," reporting to the Movement Control Center at the designated time wearing their ECW clothing and bringing all of their baggage. They prepare tags with their name and flight number for each bag. They deliver their checked bags to be palletized for air transport. Each traveler then steps on a scale with his or her carry-on bag. An attendant records the weight for the aircraft weight-and-balance calculation, then releases the traveler.

Participants can consult television monitors around McMurdo to find scheduled bag drag and transport times, as well as arrival and departure updates for flights to and from McMurdo.

On the day of the put-in flight, team members report to the MCC at the designated transport time. They ride to the active airfield in vans or heavy vehicles. At the field there may be a wait of an hour or more in the passenger terminal, a small heated waiting room with benches. The terminal is mounted on skis so that it can be transported from one airfield to another as conditions change. The restroom is in another movable building.

Deployment to the ANSMET field site may be in stages. In 2004, the author's eight-person team deployed to La Paz Ice Field in two legs. The first was via LC-130 aircraft from McMurdo to the South Pole, a journey of 1400 km accomplished in about three hours (Fig. 4). At the South Pole, the team reconfigured its cargo into smaller units for transport by Twin Otter. Two team members went with a single Twin Otter load of cargo to establish the field camp that same day, while the rest of the team spent the "night" at the Pole. The next day, the rest of the team and most of the equipment were ferried out to La Paz in six Twin Otter flights. A final Twin Otter flight on the third day completed the deployment. A Twin Otter covers the 400 km between Pole and La Paz in about two hours.

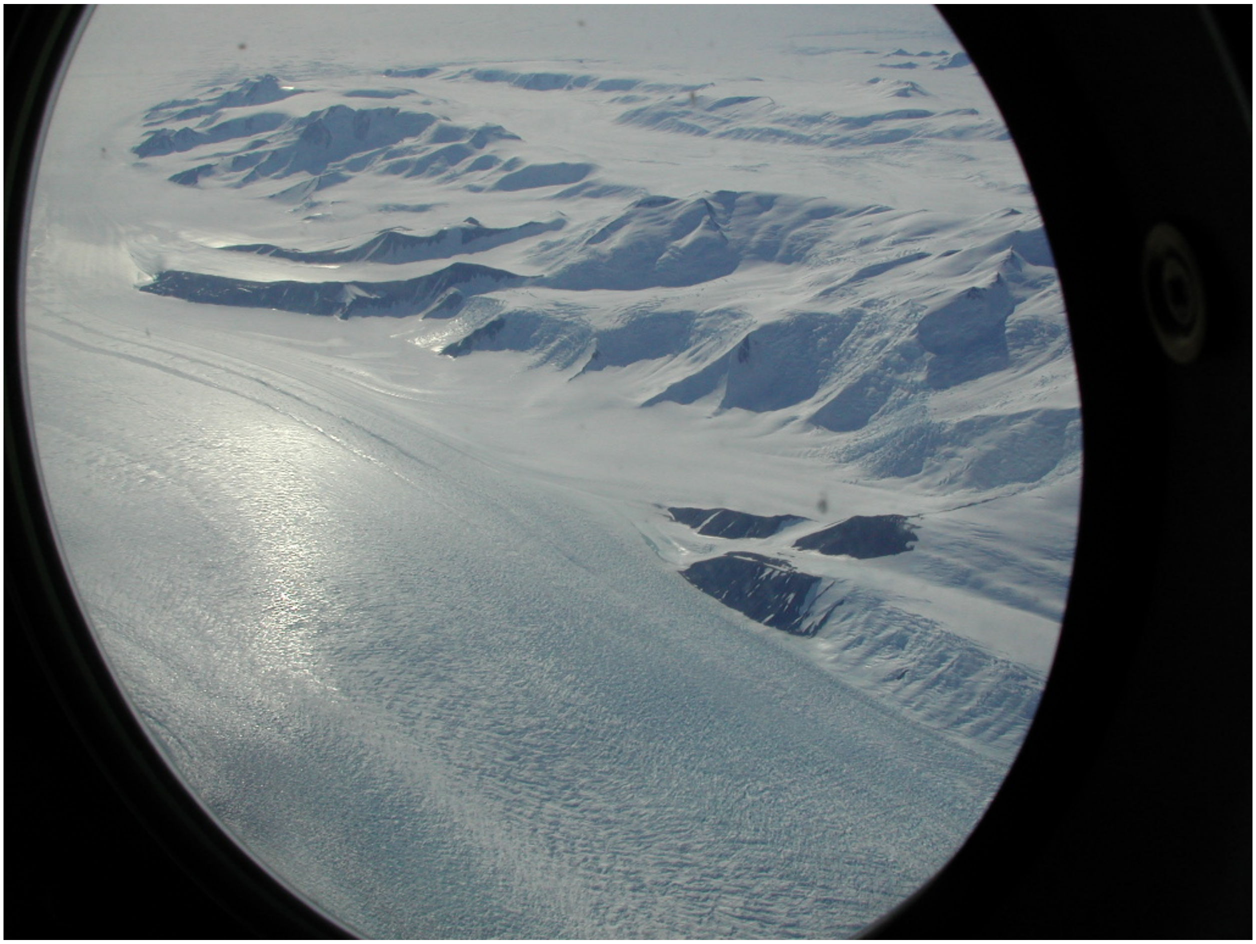

Figure 4. Antarctic vista between McMurdo and the South Pole on an LC-130 put-in flight.

In 2012, the author's eight-person team deployed via LC-130 from McMurdo to the Otway Massif skiway, a 750 km trip accomplished in about two hours. Two LC-130 flights and two Twin Otter flights over a period of four days delivered all of the team's personnel and equipment.

USAP policy requires flight crews to wait with engines running after delivering the first team members to a remote site. When the field team has successfully erected a tent, started a stove, and made radio or satellite phone contact with McMurdo, the plane is allowed to depart.

2.01.13. The South Pole

The Amundsen-Scott South Pole Station (commonly called "Pole") is located at the geographic pole, 2800 m above sea level. Because the low temperature decreases the atmospheric scale height, the air density at Pole is similar to that found at an elevation of over 3300 m in the mid-latitudes. Travelers from McMurdo, which is at sea level, may experience shortness of breath, dizziness, and altitude sickness. The exertion of shifting thousands of kilograms of cargo by hand may make symptoms worse. Air temperatures at Pole in summer are near -35° C. Winds are often light, but wind chill may nonetheless be significant.

Pole has a summer population of about 200, mostly housed in a single large structure that was under construction when the author visited in 2004-2005. By 2013 it had been completed. The new South Pole Station building replaced the 1970s-vintage dome that was gradually being covered in snow. Earlier stations lie buried underneath that one. The new station features an air gap underneath, with extensible legs to allow drifting snow to pass below the structure rather than accumulating around it. The Pole station supports major research facilities for astronomy, high-energy physics, atmospheric science, and other fields of study. It features a cafeteria, a gift shop, and a brightly lighted greenhouse for growing fresh vegetables.

Outside the main station and next to the landing strip (which, oddly, has the three-letter designation "NPX") is a small passively-heated passenger terminal. Like McMurdo, the Pole station is bordered by a large cargo yard for managing logistics. Near the main building there is a candy-striped ceremonial South Pole marker surrounded by the flags of the many countries that participate in Antarctic research. Nearby is the physical South Pole marker, which must be moved about 10 m each year to compensate for the motion of the ice upon which the Pole station is built.

The South Pole station enjoys about four hours of Internet connectivity daily, through an old geosynchronous communication satellite that has run low on stationkeeping propellant and oscillates north and south of the Equator every 24 hours. At its southern extreme, it peeps above the horizon as seen from the South Pole.

A shower at Pole reportedly costs the US taxpayer $50, mostly to transport the fuel needed to melt and heat the water. Toilet flushes cost $20. Because of high logistics costs, the USAP tries to minimize the number of people at Pole.

None of the author's three visits to Pole (in 2004, 2005, and 2013) lasted more than two and a half hours, so a more detailed description is not possible here.

2.01.14. La Paz Ice Field

The 2004-2005 ANSMET systematic search team worked in a large area of blue ice called La Paz Ice Field. The camp was located at S 86° 17.44', W 069° 39.86', 1859 m above sea level. At La Paz, the prevailing wind is from the south. The area has little topographic relief, which makes distances and scales hard to estimate by eye. There is a general downward trend toward the north, expressing itself as flat terraces alternating with slight downslopes on a scale of several km. The tops of the slopes may be decorated with "pinnacles," thorn-shaped excrescences of ice up to 3 m in height that are often associated with crevasses. Small crevasses can be opened safely with an ice axe, and often contain spectacular hexagonal crystals of ice several cm in size. La Paz has a population of several-meter-sized sastrugi (formations of wind-carved snow). At La Paz, "white ice," an intermediate form of ice between firn and blue ice, shows the same rainbow-hued 22-degree halo sometimes observed in the sky around the sun in middle latitudes.

Weather at La Paz was often clear. Temperatures were near -15° C. Clouds sometimes approached the camp from the direction of the Weddell Sea, but they rarely progressed far enough to cover the sky. The La Paz team lost eight full days and seven half-days of work to high winds.

Some of the Ski-Doo and Twin Otter fuel used by the 2004-2005 team was salvaged from prior years' ANSMET camps in neighboring parts of La Paz.

2.01.15. Otway Massif

The 2012-2013 ANSMET systematic search team operated at several locales in the Grosvenor Range, located east of the head of the Beardmore Glacier. The first camp was at Otway Massif, a group of mountains that rise out of the polar ice cap. The massif separates the Mill Glacier, a major tributary of the Beardmore, from the smaller Mill Stream Glacier. The southeast side of the massif, which appears to form a stagnation point between the Mill and Mill Stream Glaciers, is characterized by deep snow, a lack of crevasses, and locally calmer winds. It is a designated LC-130 skiway with the airfield identifier XOM. The camp was located at S 85° 32.74', E 173° 24.66', 2605 m above sea level. A small blue ice field lies near Otway, but it was searched by an ANSMET reconnaissance team in a prior year and was not deemed worthy of further attention.

The weather at Otway was generally calm by Antarctic standards. The massif creates its own weather. Often it was capped by cloud while Mt. Bumstead, 11 km away, enjoyed clear skies.

2.01.16. Mt. Bumstead

The 2012-2013 systematic search team's second camp was located north of Mt. Bumstead at S 85° 36.77', E 174° 15.56', 2559 m above sea level. North and west of Mt. Bumstead lies a blue ice field about 5 km in size. ANSMET searched the ice field, its associated moraines, and the saddle south of the main summit, but collected only five meteorites in four days of searching. Meteorite collection was complicated by the large number of confounding terrestrial rocks, evidently from the steep face of Mt. Bumstead itself. The team also collected geologic samples from the summit of Mt. Bumstead, which is rich in beautiful geodes and other hydrothermally altered rocks.

2.01.17. Larkman Nunatak

Leaving Mt. Bumstead, the 2012-2013 systematic search team moved to Larkman Nunatak, a traverse of about 45 km. "Nunatak" is a native American word for a mountaintop that rises from a glacier. The Larkman Nunatak camp was located at S 85° 43.62', E 178° 59.20', 2608 m above sea level. Larkman was windier than Otway or Bumstead. The snow surface was characterized by small but hard sastrugi which had earned a bad reputation for breaking Twin Otter skis in previous years. For that reason, the team was equipped with a 250-kg hydraulically actuated snow groomer designed to be towed behind a snowmobile to prepare a safe landing strip for the expected mid-season resupply flights. The team's mountaineer spent half a day grooming and marking the airstrip. Two resupply flights and one medical evacuation flight used it without incident.

The terrain around Larkman Nunatak appeared to be a product of scouring by the prevailing southeast winds. An area of ice pinnacles and crevasses lay to the south of camp. The summit of the nunatak was covered with fantastic forms of frost many meters high and evidently condensed directly from the gas phase. To the southeast of camp was a distinctive notch in the nunatak's summit ridge. Airfoil-shaped ridges of ice stretched hundreds or thousands of meters northwest from the nunatak's major prominences. Exploration on a windy day revealed that these structures effectively filled any lee zones downwind of the mountain, leaving no place sheltered from the wind. Within the curve of the nunatak's main ridge was a wind-scoured bowl of blue ice. At the floor of the bowl lay a series of parallel, curved glacial moraines. These contained meteorites, but also diverse other rock types including petrified wood, malachite, and shale with plant fossils. There were also lumps of coal and chert, and many pieces of dolerite, a black, slightly magnetic rock occurring in rounded lumps that often resembled meteorites.

The weather at Larkman is notoriously windy, but the 2012-2013 season logged only three full days and two half days that were too windy to search for meteorites. One afternoon had a few hours of eerily complete calm, during which it was possible to relax comfortably outside in light clothing. Air temperatures at Larkman averaged about -20° C. One day with clear skies and a very thin ice fog produced a spectacular display of rainbow arcs and halos in the sky.

2.01.18. Cecily-Raymond

The 2012-2013 systematic search team expected to conclude its season at the blue ice fields near Mount Cecily and Mount Raymond, about 45 km west-southwest of Larkman. Delays for weather and resupply, plus a medical emergency on the day the party attempted to shift camp, prevented work there. Instead, the team remained for a few more days at Larkman, then traversed back to Otway Massif for pull-out.

2.01.19. Resupply flights

ANSMET camps receive Twin Otter resupply flights during the season. For the reconnaissance team, resupplies coincide with camp moves via Twin Otter, which may happen a half-dozen or more times. For the systematic search team there are typically two resupply flights. In 2004-2005, resupply flights arrived at La Paz Ice Field on December 30 and January 9. The first of those flights also exchanged two members of the reconnaissance team with two from the systematic search team. That exchange ended up taking much longer than planned because the Twin Otter cracked a ski at the reconnaissance team's location (Larkman Nunatak) and had to divert to McMurdo for repairs. The systematic search team members heading for the reconnaissance team were then further delayed in McMurdo by bad weather. In 2012-2013, resupply flights arrived at Larkman Nunatak on December 26 and January 11. The crew of the second flight had made plans to spend the "night" at the field camp, but later decided not to.

Each day when the camp was a primary or secondary destination for an aircraft, the field team phoned in hourly weather observations beginning six hours before the aircraft's scheduled departure time. When field camp members provide weather observations using true directions (based on Sun angle), someone in the McMurdo weather office must transform those observations to grid directions for aircrew use.

Resupply flights carry about 1000 kg of cargo. They bring pre-planned quantities of Ski-Doo and stove fuel, flat and package mail for field team members, packages left in McMurdo by team members explicitly for mid-season delivery to themselves, and critical spares and other items requested by the team via satellite phone a few days before the flight. Thoughtful aircrews may bring a few pieces of fresh fruit as a morale boost for the field team. If there is room on the plane, a USAP employee who otherwise might never get to see the continent beyond McMurdo may ride out and back with a resupply flight.

When it departs a field camp, a resupply flight removes about 1000 kg of trash, empty food boxes, empty fuel containers, broken or unneeded equipment, and sealed buckets of human waste. The last are equipped with sealing lids but may still release odors after several hours in the warm aircraft cabin. The departing plane also takes insulated containers full of meteorites if any are ready to return to McMurdo.

2.01.20. Pull-out flight

At the end of the season, ANSMET teams leave the field via ski-equipped aircraft. As with resupply flights, the field team phones in hourly weather observations before the pull-out aircraft's scheduled departure time. In 2005, the La Paz camp was recovered via Twin Otter to the South Pole, then via LC-130 to McMurdo. The author's flight left camp on January 22. Aircraft schedules and weather constraints had forced the pull-out operation to move forward a few days from the originally planned date. Word that the airplane was on its way and the camp needed to be packed up came as a surprise. The field crew assisted with hand-loading the aircraft at La Paz. After that, all gear except for carry-on bags was managed by the cargo system.

At the end of the 2013 season, the systematic search team established a camp at the Otway Massif skiway to await the arrival of the LC-130. It took several days for the weather and schedule to cooperate so that an airplane could be sent. While waiting, the ANSMET team prepared for pull-out by loading their gear onto Air Force pallets, holding it in place with cargo nets and ratcheting straps. The team's first attempt at this was only partially successful. The team member who had experience preparing cargo for LC-130 transport had left the expedition for medical reasons, and nobody else knew how to do it. When the first pull-out aircraft came on January 18, the plane's loadmaster had to re-strap some of the cargo. The rest of the field team waited another five days for weather and higher-priority missions before they were able to fly back to McMurdo. Some cargo left off the first flight did not make it onto the second flight and remained at Otway to be picked up the following summer.

2.01.21. Trash sorting and gear return

When ANSMET field teams return to McMurdo, they sleep in the dormitories as they did on first arrival. They shower, wash their clothes, and again enjoy dining hall food, including "Frostie Boy." Their field equipment appears in the logistics yard outside the Berg Field Center on the following day. The field team must unpack, sort, clean, and return all the gear they have borrowed from the BFC. The job includes hanging tents up to dry, hand-washing relief bottles, cleaning all cooking and eating utensils, and storing ANSMET-owned field gear in the cage or in a shipping container near the BFC that houses cold- and moisture- tolerant equipment. Any uneaten food in good enough condition to be re-issued must be identified, gathered, and returned to the food room. Team members retain their CDC-issued clothing until they return to Christchurch.

All trash generated in field camp returns to McMurdo in the bags it was thrown into. The field team must sort the trash by hand and place it in the appropriate recycling bins. This is not a trivial task. Much camp trash consists of wrappers, containers, and paper towels contaminated with food residue, which is classed as "food waste." But mixed in with the food waste may be valuable recyclables such as cans, glass, and cardboard. These items must be separated from the rest, cleaned, and recycled.

The systematic search team and the reconnaissance team return to McMurdo at about the same time, but rarely on the same day. Members of the same team may also be split across flights on different days. The result is that personnel and gear return to McMurdo sporadically. Team members already in town help new arrivals take care of their incoming equipment. The complete process may take as long as a week.

2.01.22. Retrograde flight

When all field equipment has been cleaned and returned, the team can fly back to Christchurch. The group does not normally travel together. Instead, different schedules and priorities split the team across multiple retrograde flights. Preparing for the retrograde flight is much like preparing for field camp put-in. Travel coordinators in McMurdo assign passengers to flights. The evening before, the travelers do a bag drag at the MCC to drop off their checked items and to be weighed in ECW with their hand luggage. There is no provision for boomerang bags, so prudent travelers keep a few days' worth of necessities in their carry-on bags. This is important. In 2013, a group of passengers was on Ivan the Terra

Bus, riding out the snow road to Pegasus for their return flight to Christchurch, when a radio call came in saying that the aircraft's weight and balance calculations had been updated and that five people, including two ANSMET participants, were being bumped from the flight. The unfortunates were let off the bus by the side of the road and picked up by an empty passenger van returning from Pegasus. They spent an extra weekend in McMurdo, with only the belongings in their carry-on bags, before successfully flying out.

The author's 2005 retrograde flight was on January 25 in a C-141 with over 120 passengers and a full load of cargo. The flight lasted about five hours. In 2013, the date was January 28 and the plane was an LC-130 with about 35 passengers and no cargo. That flight took eight hours. Both flights arrived in Christchurch after sunset. Darkness was a novel experience after nearly two months of continual daylight.

Buses take deplaning Antarctic passengers across the Christchurch airport to the main international terminal, where they claim their baggage from the carousels, load it on luggage carts, and pass through Customs.

2.01.23. Clothing return

The CDC lies about 500 m from the Christchurch International Airport passenger terminal. Returning Antarctic travelers may take their airport luggage carts through the parking lot and across the street to the CDC, following boot prints and penguin footprints painted in blue on the sidewalk. At the CDC they return the clothing and bags they collected at the beginning of the season. In 2005, an attendant used a checklist to make sure all of the gear (except for the used socks) was returned. In 2013, there was no formal check-in process. Travelers simply dumped everything (including the used socks) in a heap, presumably for CDC personnel to sort out later.

2.01.24. Return to the United States

Returning Antarctic travelers stay one or two nights in Christchurch, including the night of their arrival, before flying back to the United States via commercial air. USAP personnel in McMurdo make the lodging and flight reservations. In 2005, the author's flight home was on January 27 and the routing was Christchurch to Auckland to Los Angeles to Dallas to Hobby. In 2013, the flight was on January 30, and the routing was Christchurch to Sydney to Dallas to Hobby. The day lost in crossing the International Date Line on the outbound journey is regained on the return.

Some ANSMET participants delay their post-season commercial flight to the US in order to tour New Zealand, Australia, or other southern-hemisphere countries that would be difficult to reach directly from home.

2.02. Transportation To, From, and Within Antarctica

As in a space mission, many aspects of an Antarctic expedition are shaped by transportation constraints. The USAP uses a variety of vehicles to support its operations. This section describes the vehicles that ANSMET participants are most likely to encounter.

2.02.01. Lockheed C-130 "Hercules" aircraft

The mainstay for hauling cargo and passengers to, from, and within Antarctica is the venerable "Herc," a medium-size four-engine turboprop airplane. Passenger accommodations are minimal. The aircraft is equipped with tube-and-webbing seats. It is so noisy that all passengers are advised to use foam earplugs. Some wear earmuff-style hearing protection in addition to the earplugs. In 2004, the Royal New Zealand Air Force C-130 that carried the ANSMET team to Antarctica was configured with four rows of seats in the forward part of the cargo bay. Facing pairs of passengers had to interlock their knees, making any change of position difficult. On takeoff the passengers slid aft, making the crowding worse toward the rear of the plane. The C-130 has basic lavatory facilities isolated from the cabin by a plastic curtain. A few small side windows allow passengers to see outside. After the plane reaches cruising altitude, the loadmaster permits passengers to leave their seats. Antarctic aircrews may allow one or two visitors on the flight deck on a non-interference basis during cruise.

C-130s in Antarctica carry GPS and other customary navigation tools, but crews also use a sextant built into the ceiling of the flight deck to sight the Sun as an aid to navigation. Cruise speed for a

C-130 is about 510 km/h (280 knots, in the units used by aircrews). A typical crew complement is a pilot, co-pilot, flight engineer, and navigator on the flight deck, plus a loadmaster in the cargo compartment. A typical load for a Herc on an Antarctic mission is about 12,000 kg.

2.02.02. Foremost all-terrain bus ("Ivan the Terra Bus")

Most air passengers arriving at McMurdo get a ride on Ivan the Terra Bus as their first ground transportation experience in Antarctica. Ivan is an all-wheel-drive off-road bus originally designed by a Canadian company for use on tundra. Its six wheels have low-pressure tires about 1.5 m in diameter. Cargo lockers along the sides of the bus, accessible from the outside only, provide stowage space for hand luggage. Despite the high cabin, boarding is easy via stairs at the forward door. The bus can seat about 50 passengers. It can travel about 40 km/h on ice and dirt roads. At speeds above about 30 km/h the ride is very bouncy.

2.02.03. Delta

A Delta is a four- or six-wheeled transport, hinged behind the two-wheeled driver's cabin. Like Ivan, Deltas have low-pressure tires 1.5 m in diameter. Their high suspension gives them superior ground clearance. The aft section can be a heated compartment for passengers or a flat bed for cargo. In the passenger configuration, which seats about 20 people, the floor of the compartment is high off the ground and can only be reached by a folding metal ladder in the rear of the vehicle. People in the passenger compartment communicate with the driver's cabin via radio. Delta wheels do not have fenders, so the windows of a Delta are usually opaque with spattered mud. Like most heavy vehicles in McMurdo, the Deltas have individual names, such as "Dawn," stenciled on the cab.

2.02.04. Utility truck

Bright red Ford F-350 pickup trucks, with standard or flat beds, are available for light-duty hauling and errands in and around McMurdo. Besides snowmobiles, these are the only vehicles that

ANSMET participants are likely to drive themselves, and then only after attending a one-hour class that highlights the special considerations of driving in Antarctica. All drivers must carry a valid license. The trucks are equipped with fat low-pressure tires and engine-block heater cords that can be connected to electrical outlets at their parking spaces. The heaters are not needed in summer. The trucks have a special hand-operated parking brake that replaces the normal foot-operated brake. The Crary Laboratory has two trucks available to science grantees for 45-minute checkout. The Mechanical Equipment Center has several more trucks that are available on a first-come, first-served basis. The day's first driver is required to perform a thorough check of all the vehicle's systems and fluid levels and to record the results on a checklist kept in the cab. A Hobbs meter on the dashboard records engine hours, which the driver must also record on the checklist.

2.02.05. 13-passenger van

Ford E-350 13-passenger vans operate as passenger shuttles that link McMurdo Station with Scott Base and the surrounding airfields. They run on a schedule that shifts according to daily demands. The primary "bus stop" in McMurdo is Derelict Junction, a parking area west of Building 155. With prior coordination, a group of people travelling together to a specific destination may be able to arrange dedicated van service. Many van drivers are volunteers. It is a challenge to cram 13 people, fully garbed in ECW clothing and carrying large bags for air travel, into a shuttle van. Like the pickup trucks, the vans are equipped with low-pressure tires to reduce rutting on snow roads in warm weather. As with the Deltas, shuttle van side windows are often covered with spattered mud and impossible to see through. Passengers wishing to admire the scenery should ride shotgun.

2.02.06. Bombardier "Ski-Doo" Snowmobile

The Ski-Doo (Fig. 5) is one of the most critical items of equipment the field team uses. ANSMET participants spend half or more of their meteorite searching time riding on snowmobiles. A participant with a broken Ski-Doo cannot effectively search for meteorites.

The Ski-Doo greatly increase a meteorite hunter's operational radius. If limited to foot travel, which is slow on slippery ice and tiring with bulky ECW gear, searches would be limited to a radius of about two kilometers. The field team would clear that area in a few days. Ski-Doos increase the area available for searching by about two orders of magnitude. In the 2012-2013 season, the author logged about 650 km on his Ski-Doo, collecting meteorites and shifting camp (see Section 3.6).

The machine itself weighs about 300 kg and is powered by a lightweight "Rotax" engine designed for ultra-light aircraft. It seats one rider comfortably and can carry a passenger as well. ANSMET Ski-Doos are equipped with steel-tube cargo racks on the hood, and large wooden storage boxes mounted behind the rider. Some have additional fittings for GPS antennas. Storage for smaller items, such as a tool kit, spare drive belt, spill kit, and tow ropes, is available underneath the seat, which is hinged on the left side. A reinforced cable loop at the front of the frame allows a disabled Ski-Doo to be towed, and a cotter-pinned trailer hitch at the rear enables it to tow other loads. A Ski-Doo can tow about 900 kg on properly loaded sledges.

Figure 5. Bombardier "Ski-Doo" snowmobile, fully loaded and towing two sledges for a camp shift.

A wide drive tread moves the machine forward. Two unpowered forward skis are attached to the steering assembly for directional control. On the left part of the dashboard is a transmission lever with neutral, reverse, and first and second gears. Top speed in first gear is 55 km/h (35 mph on the English-unit speedometer). There is no operational reason for an ANSMET team member to drive faster than that. The rider controls speed with a thumb-actuated throttle lever on the right handlebar. A responsive brake lever is on the left, along with the headlight switch and a small lever that locks the brakes. The throttle lever and handlebars have electric heaters for rider comfort. In spite of the heaters, hands and especially thumbs do get cold. Fatigue is also a factor for the thumb controlling the throttle, especially during systematic meteorite sweeps that can last for hours. Besides the speedometer, the dashboard has an odometer (including a resettable trip odometer), a switch for the handlebar heaters, an engine priming pump, and a lever-lock choke switch. New Ski-Doos have dual rear-view mirrors. Unfortunately, USAP Ski-Doos are not new. Many have only one mirror remaining, and a few have none. A detachable clear plastic windscreen protects the rider from the worst of the relative headwind and associated cold.

Ski-Doos burn "premix," a 40:1 mixture of unleaded automobile gasoline and two-stroke engine oil. Fuel use is about 3 km per liter (6 miles per gallon). The capacity of the fuel tank is 36 liters (10 gallons). The gas cap has a probe and float designed to provide fuel level indication on a rotary dial built into the top of the cap. It does not work reliably. The only way to be certain of the fuel level is to look inside. The contrast between the bright sun and snow outside and the dark interior of the tank makes this difficult. An operator fills the gas tank using a hand-cranked "hurdy-gurdy" pump that feeds from a 208-liter (55 gallon) steel fuel drum. Filling a Ski-Doo without causing a fuel spill is an acquired skill. In Antarctica, fuel spills are serious. All spills must be thoroughly cleaned up and reported to the USAP. Wise workers hold an absorbent pad around the mouth of the gas tank while fuelling to catch any small spills. They may also keep a dedicated pair of leather mitts for fuelling only, to keep from contaminating their gloves. Overfilling a Ski-Doo gas tank can cause a small fuel leak via a vent line under the hood.

Starting a cold Ski-Doo engine is an involved process. Before starting, it's worth verifying that the transmission is in neutral and that the kill switch on the right handlebar has not been pushed down. The MEC-recommended starting procedure is three pumps of the primer, five full cycles of the starter pull-rope, two more pumps of the primer, choke switch on, ignition key on, then pull the rope until it starts. The electric starter works if the engine is already warm. Once started, the engine must be revved for about one minute before it can be left to idle without stalling. Too much priming, or too heavy a hand on the throttle, can flood the engine and make it impossible to start. A flooded engine will dry out if left alone for about fifteen minutes. An impatient rider can fix a flooded engine faster by lifting the forward cargo rack and hood, removing the spark plugs, and pulling the starter rope about twenty times to dry out the cylinders. After putting the machine back together, the operator can try again to start it.

There are three ways to turn off a Ski-Doo engine: the keyed ignition switch, the kill switch, and a second dedicated switch on a lanyard designed to clip to the rider's clothing and kill the engine if the rider falls off. The lanyard can come loose inadvertently, causing a mysterious engine failure. The kill switch is easy to press accidentally, especially if handlebar muffs are installed, resulting in an engine that will not start until the problem is recognized and remedied.

Riders are cautioned not to defeat the spring feature of the throttle lever, which returns to idle when released. A rider once decided to alleviate thumb fatigue by slipping a cardboard toilet paper tube over the end of the handlebar to provide constant pressure on the throttle lever. That worked until the machine hit a bump. The rider fell off without injury, but the machine motored away and would have gone on until it ran out of gas if a fast-thinking and fast-driving teammate had not chased it down, reached over, and hit the kill switch.

The drive tread is made of a strong synthetic rubber with metal cleats for traction on ice. The tread rolls on idler wheels and slides on aluminum rails. The interface between the tread and the rails is intended to be lubricated with snow. Long operation at high speed on snow-free ice can create enough heat to melt the tread and weld it to the rails.

Although they are commercial-off-the-shelf products that have been tested by thousands of users over millions of miles, Ski-Doos are not immune to the effects of the harsh Antarctic environment. ANSMET often operates at high elevations, where the low density of the air makes engines run fuel-rich. A rich mixture fouls the spark plugs with soot, which in turn causes the engine to lose power or quit unexpectedly. A fouled plug can be cleaned by placing the spark gap in the flame of a camp stove for an hour. Adjusting the fuel-air mixture so that plugs will not foul requires pulling apart the engine's two carburetors and repositioning a tiny metal clip on the steel pin that controls the fuel jet, an operation that takes about an hour for an inexperienced worker, or fifteen minutes for an experienced one. In both the 2004-2005 the 2012-2013 seasons, the best efforts of the MEC to pre-set the carburetors for the expected altitude and temperature resulted in constant plug fouling, and the systematic search team had to adjust all of the carburetors (sixteen total) in the field.

Ski-Doo windshields are held on by thick rubber bands that grasp flanges on the windscreen which fit through slots in the hood. The rubber bands are prone to breaking or falling off. In the cold the bands stiffen and are hard to manipulate. Some of the flanges are in places difficult to reach by hand. In the 2004-2005 season, all eight of the systematic search team's Ski-Doos lost so many rubber bands that the team had to secure their windshields with freezer tape. In the 2012-2013 season, the team carried a large number of spare rubber bands. They were able to replace the few that were lost during the season and keep their windshields on without freezer tape.

The undercarriage of a Ski-Doo has springs to smoothen bumps and hinged brackets to transmit loads from the chassis to the tread. The extreme cold and hard bumpy ice cause springs and brackets to break, the latter usually at the welds. They must be replaced with spares using hand tools, a job that takes two people several hours. The work is complicated by the cold conditions, which demand gloves. Undercarriage work can take all the strength the worker can muster. In the 2004-2005 season, the systematic search team had no spare parts to repair broken undercarriages. By the end of the season they had two unusable machines. Riders had to double up or remain in camp, reducing the party's search efficiency. In 2012-2013 the systematic search team suffered one broken spring and one broken bracket, but had the spares and skills to repair them and finished the season with eight working machines.

Some Ski-Doos used by ANSMET have welded steel fixtures on the rear to hold GPS antenna poles. In 2004-2005, two of these fixtures broke at the welds and fell off.

Unplanned Ski-Doo repair and maintenance consumed about 32 person-hours of time in the 2012-2013 field season.

In 2012-2013, the MEC recommended that riders check all four suspension springs and tighten all the idler wheel bolts at the end of every day of riding, in an attempt to reduce (or at least promptly detect) mechanical problems. This operation made use of three crescent wrenches from the Ski-Doo's onboard tool kit, and took about five minutes to complete.

2.02.07. Ski-equipped Lockheed LC-130 aircraft ("Skier")

The Herc can be fitted with skis for takeoffs and landings on snow or ice runways or even unimproved snow (Fig. 6). Thus equipped, the aircraft is designated an LC-130 and has a "Skier" callsign. The 109th Airlift Wing of the New York Air National Guard, based in Schenectady, New York, operates the LC-130s that support the USAP. The skis add weight and drag to the aircraft, slowing its cruise speed by about 20 km/h to 490 km/h (270 knots). The skis fit over the wheels. The skis and wheels can be hydraulically raised and lowered independently so that the aircraft can land on both snow and concrete. This capability is especially important for flights between Antarctica and Christchurch.

Skiers are frequently employed for flights to the South Pole. The cold temperatures there demand that the engines be kept running while the plane is on the ground, even during refueling. Passengers are not allowed on board during hot-refueling.

At unimproved landing strips such as Otway Massif, aircrews unload LC-130 cargo using combat airdrop techniques. The plane lands, then taxis forward at a few km/h. The loadmaster and crew maneuver loads strapped to aluminum Air Force pallets along rollers built into the floor of the cargo hold, then down the lowered ramp at the rear of the plane and onto the snow. The entire plane can be emptied this way in less than one minute.

Loading the plane at an unimproved site without forklifts or other heavy equipment is difficult. Cargo must be secured to Air Force pallets with side nets and ratcheting cargo straps, and staged near the landing strip. The plane lands, taxis into position, and lowers the cargo ramp. Ground crew members (for ANSMET, the participants themselves) use snowmobiles to tow the loaded pallets into position behind the plane, where they are subjected to the heat, noise, and fumes of the engines. Heavy or asymmetrically loaded pallets may dig into the snow or fishtail when towed. Once the pallets are in place, the aircraft loadmaster winches them aboard the plane and secures them. The entire process, including possible reconfiguration of the cargo, snowmobile operations, and getting the pallets on the plane, can take an hour and a half.

Figure 6. LC-130 ski-equipped Lockheed "Hercules" cargo aircraft at the South Pole.

In 2013, the systematic search team's first pull-out flight had difficulty taking off. The plane made an unsuccessful 13-km takeoff attempt, then taxied back for a second try, this time using Jet Assisted Take Off units, single-use solid rocket motors strapped to the aft fuselage to help the plane achieve takeoff speed on soft snow or at high elevation. LC-130s in Antarctica carry eight JATO bottles. A crew member must exit the aircraft while on the ground to arm them for firing. When activated, the JATO units produce considerable noise and smoke, and yield a noticeable shove forward, but only boost the plane's forward speed by about 10 km/h (5 knots). Often, that boost is enough to break the nose ski free of the snow and allow the plane to become airborne.

In the 2013 flight, the extra thrust from the JATOs lifted the nose ski off the snow, but it immediately slapped back down, and that takeoff attempt had to be aborted. The aircraft then taxied back to camp. The aircrew, with some urgency, unloaded much of the cargo, shifting everything remaining (including the passengers and their hand baggage) to the extreme rear of the plane. The third takeoff attempt was successful, but after so long on the ground with engines running, the aircraft lacked fuel reserves to fly directly back to McMurdo. It had to divert to the South Pole to refuel. This gave the passengers an unexpected but appreciated visit to the Pole. While the plane was hot-refueling at Pole, the flight engineer was working behind the engines and got fumes in his eyes. The resulting irritation made him unable to work the rest of his shift. He stayed on the couch in the aft part of the cockpit for the flight to McMurdo. When the plane arrived at about 0200 local time, an ambulance was waiting to take him to the clinic.

2.02.08. Pisten Bully

A Pisten Bully is a medium-sized tracked vehicle used in and around McMurdo to transport passengers and light cargo. The heated cabin can accommodate about eight people. There is a luggage rack on the roof.

2.02.09. de Havilland DHC-6 Twin Otter

Like the C-130, the turboprop-powered Twin Otter (Fig. 7) is an important Antarctic workhorse. With a working radius of about 500 km carrying a load of about 1000 kg, a ski-equipped Twin Otter can land in many places where an LC-130 cannot. Its load capacity is appropriate for camp resupply flights, which do not demand the large cargo capability of an LC-130. Its cruise speed is about 280 km/h (150 knots). For deliveries to remote field sites, cargo capacity is limited by the need to carry one or more 208-liter drums of AN-8 turboprop fuel. While the plane is on the ground, the crew transfers the fuel to the plane's tanks using a gasoline-powered pump. Twin Otters are also used for responsive air transportation, such as medical evacuations. The crew usually consists of a pilot, a copilot, and a loadmaster.

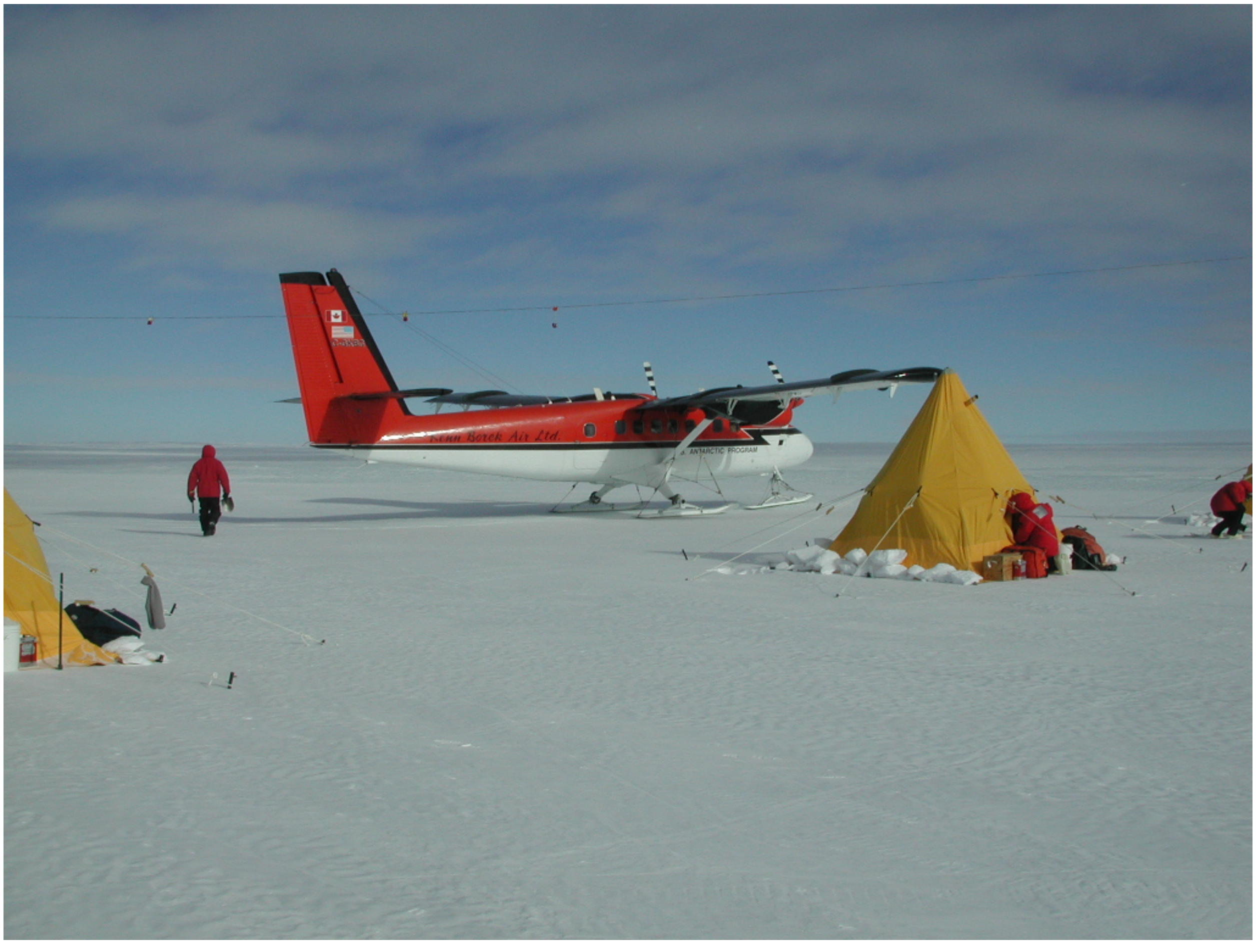

Figure 7. De Havilland DHC-6 Twin Otter aircraft at an ANSMET field camp.

Kenn Borek Air, a Canadian airline, operates the Twin Otters under contract for the USAP. In January 2013, during the author's second ANSMET season, a Kenn Borek Twin Otter crashed in the Transantarctic Mountains. The crew and a single passenger died.

2.02.10. Lockheed C-141 Starlifter

A 1960's-era military cargo plane powered by four jet engines, C-141s provided Antarctic support for the USAP until 2005. The United States retired its C-141 fleet in 2006, replacing the aircraft with the C-17.

2.02.11. Boeing C-17 Globemaster III

The C-17 is a large, modern airlifter with four jet engines. It can carry heavier and bulkier loads than the C-130, but is relatively expensive to operate. The USAP leases its C-17s from the 62nd Airlift Wing of the Air Mobility Command, stationed at McChord Air Force Base near Tacoma, Washington. C-17s fly primarily at the beginning and end of the Antarctic summer, when traffic to and from the continent is at its peak. In addition to heavy cargo, C-17s carry fresh vegetables and package mail, both of great psychological importance to Antarctic workers. In 2012-2013, warm weather made the Pegasus runway too soft for the C-17, and the continent had to go without "freshies" and packages for many weeks. Some care packages mailed to the ANSMET field team that season never made it to Antarctica and were returned to their senders in the US months later.

The seats on the C-17 were designed for paratroopers and are no more comfortable than those of the C-130, but the plane nevertheless offers a much more pleasant ride. The interior lighting is brighter, the windows are larger, the climate control is more responsive, and the interior noise level can be made comfortable with only a single layer of hearing protection. Although it is a larger airplane than the C-130, the standard crew complement appears to be the same: four on the flight deck, plus a loadmaster.

2.03. Field Camp

This section describes an ANSMET field camp, which might be analogous to an early outpost on the Moon or Mars.

2.03.01. Orientation and layout

The wind affects all work done in ANSMET, beginning with the layout of camp. Any obstruction on the ground causes downwind turbulence, which in turn creates dunes of drifted snow that may grow to be meters high and tens of meters long. Although the snow is fluffy when first deposited, after a few days it consolidates into a material tough enough to make shoveling difficult. Keeping tents and supplies clear of drift is an endless battle.

The only advantage Antarctic campers enjoy in the struggle against drift is the consistency of the wind direction, which makes it possible to align the camp to minimize the problem. The team places habitation tents in a line perpendicular to the wind direction, spaced five to ten meters apart. Ski-Doos and supplies such as food boxes are arranged in lines along the wind direction, downwind of the tents and their turbulent wakes. The latrine tent is located downwind of the center of camp. The team places the Ski-Doo fuelling station further downwind or off to one side of camp, with the fuel drums placed in a line along the wind direction.

Even with careful layout of the camp, episodes of high wind or snowfall can force the team to spend half a day digging equipment and supplies out of the drift. At the end of the season, they must invest more time and effort to dig out the tents and their stabilization lines and stakes.

Placing an ANSMET camp demands attention to more than just the wind. The best substrate for a Scott tent is firn: hard, consolidated snow that is more than one season old but has not been compressed to form white or blue ice. Firn has material properties similar to polystyrene foam. Unlike ice, which shatters when struck and will not hold a tent stake, and fresh snow, which is too weak to retain a stake with a load on it, firn is both compliant enough to accommodate a stake and strong enough to hold it under load. Firn can be excavated with vigorous shoveling to make holes for the tent legs and to provide ballast for the tent skirt.

Experienced campers pitch their tents on firn that is smooth and flat. Tent floorboards, if used, can flatten out bumps, but slopes cannot be compensated and result in uncomfortable living conditions.

While blue ice is a poor choice for tent placement, it is the best source of drinking water. An ideal ANSMET campsite places the tents on firn, with a nearby exposed patch of blue ice for collecting water.

2.03.02. Food

The hard work and cold conditions in ANSMET make food a consideration of utmost importance. Food provides energy to keep the body warm. In Antarctica, a person may need to eat a thousand calories more than his or her normal daily intake in order to stay healthy. In particular, the sugar and fat that are reviled as unhealthy under normal conditions are essential in Antarctica for short- and long-term energy respectively. A wide variety of good food also provides important psychological support for people in monotonous surroundings and difficult working conditions (e.g., [13]).

ANSMET teams transport and store their dry and canned food in "river boxes," rigid plastic chests measuring about 30×45×100 cm. River boxes are not insulated, but they do have a locking, sealing lid that helps keep the drift out. The seal is not perfect, so ANSMET crews line the river boxes with plastic trash bags so that the drift that does enter won't spoil food packaged in cardboard. Dry goods for two people for six weeks fill three river boxes.

Dry goods include rice, pasta, crackers, energy bars, candy, cookies, dried fruits and vegetables, jerky, nuts, oatmeal, dry cereal, granola, pancake mix, bread mixes, powdered milk, other dry beverage mixes, sugar, and spices. Juice boxes and canned fruits and vegetables are also popular. All food taken to the field must be able to withstand rough handling and freezing, so metal containers are preferable to glass. Mayonnaise is bad field food: if frozen, it separates irreversibly into unappetizing components. Each tent group brings about a week's worth of "dehy," commercially available freeze-dried backpacking food packaged in foil or plastic envelopes. Dehy is lightweight and easy to prepare, generally needing only the addition of boiling water. But it is very high in sodium and has poor flavor and consistency, so it is generally reserved for emergencies. Most of the dehy brought to the field goes uneaten and is returned to the food room at the end of the season.

Because summer temperatures in McMurdo may rise above 0° C, frozen food, which will spoil if thawed, must be handled separately from the dry goods. ANSMET teams transport and store their frozen food in steel coolers measuring about 40×40×70 cm. Three or four coolers are needed to contain the frozen food for two people for six weeks. Immediately after the frozen food pull, ANSMET participants load their full coolers onto pallets and secure them with cargo straps. A forklift takes the loaded pallets to McMurdo's cold storage facility, where they await loading onto the aircraft that will take them, still frozen, to the field. In camp, frozen food can be safely stored outside because temperatures on the polar plateau never approach thawing.

Popular frozen foods include beef, chicken, pork, sausage, fish, bacon, shrimp, scallops, frozen fruit, frozen vegetables, bagels, sliced bread, tortillas, and products such as chiles rellenos and breaded chicken patties. Butter is a key staple. It is used liberally in Antarctic cooking, including the "La Paz Heart Attack" breakfast, which consists of bacon and English muffins fried in butter. ANSMET participants suffering chronically from the cold may find relief by eating more butter. The author heard an anecdotal report of a woman who skied from the Antarctic coast to the South Pole using only the supplies she hauled behind her on a sledge. One-third of the weight of her loaded sledge at departure consisted of butter. One pound of butter per week per tent group is a typical consumption rate in ANSMET.

The total mass of dry and frozen food for a two-person tent group for a six-week expedition is about 80 kg, or 1.0 kg per person per day. The diet provides 3500 to 5000 calories per person per day.

The Berg Field Center can provide a cookbook for Antarctic field camps. The National Outdoor Leadership School's camp cookbook [16] is instructive as well. Also, past ANSMET participants have contributed recipes to "The ANSMET Cookbook for Hungry Hunters" [17], an unpublished document which veterans may be able to provide. Section 3.15 presents an example of an ANSMET camp recipe.

Most meals in camp are prepared by frying or boiling. Both options provide opportunities to add butter to the diet. Boiling meat, vegetables, and starchy foods together results in a complete, balanced meal using only one pot, an important consideration given that the dishes can only be "washed" by wiping them with paper towels. Baking requires a camp oven. In 2012-2013, the camp had a propane oven large enough to roast a 6.5-kg turkey for the Christmas feast. In 2004-2005, one participant brought a small camp oven designed for use with a single-burner camp stove. It could bake small pizzas and cakes. Campers appreciated fresh-baked goods after several weeks of eating only frozen, dried, and canned food.

The BFC issues each camper a bowl, cup, plate, knife, fork, and spoon. Some participants with camping experience bring their own mess kits. The cooking kit for each tent includes a kettle, frying pans, pots and lids of different sizes, kitchen knives, mixing bowls, spatulas, a corkscrew, a cheese grater, and a camp toaster.

2.03.03. Water

ANSMET camps are surrounded by water in solid form. Snow can be melted for water, but its low density means that a container full of snow yields less than a quarter container of water. A container filled with ice chunks produces about half a container of water. Chipping ice for water is a daily chore in camp, and melting ice is the first step in preparing a meal.

Melted ice or snow is essentially distilled water. It contains no dissolved minerals and has no taste. Most people find it too bland to drink without additives such as tea, coffee, chocolate, or "Raro," a powdered drink mix that resembles Kool-Aid. In 2012-2013, the systematic search team camped downwind of the exposed rock of Larkman Nunatak. Every pot of melted ice ended up with a few grains of windblown grit in the bottom which had to be thrown out.

ANSMET participants may add chips of blue ice to adult beverages traditionally served "on the rocks." In this case the "rocks" are hundreds of thousands of years old and contain bubbles of air that have been pressurized by long burial at depth. As the ice melts, the bubbles crackle and pop.

2.03.04. Clothing

Clothing is key for ANSMET participants. The chief concern is to wear enough windproofing and insulation to keep warm in wind chill factors below -20° C. A typical outfit includes a windproof fleece hat with ear flaps, a neck gaiter, and ski goggles for the head; light gloves plus heavy mittens for the hands; an undershirt, a long-sleeved thermal shirt, a fleece jacket, and Big Red for the upper body; undershorts, medium weight long johns, and windproof insulated bibbed snow pants for the lower body; and sock liners, heavy wool socks, and bunny boots for the feet.

Inside the tent, conditions are much milder. Hats, goggles, gloves, Big Red, and bunny boots are rarely necessary. Most people also remove the fleece jacket and exchange the heavy bibbed snow pants for lighter wind pants while in the tent.

The standard clothing issued by the CDC offers enough total insulation and layering flexibility so that most people can find a combination that keeps them comfortable. A disadvantage of CDC gear is that it is often outdated. Antarctic veterans may bring their own higher-end clothing to supplement what they get from the CDC. Another disadvantage of the CDC-issued gear is that the supply of base-layer underwear and socks is limited. The CDC provides only one set of underwear and as few as two pairs of socks for a six-week field season. People desiring a change of base layer clothing must bring their own. In camp it is possible to hand-wash small clothing items. Campers who wash their underwear can bring fewer sets to the field.

The trickiest part of dressing for the Antarctic is eye protection. Participants who wear corrective lenses face an even greater challenge. The two competing effects are cold and fogging. Eye covering that keeps the wind out is likely to fog up on the inside. Eye covering with enough ventilation to prevent fogging is likely to be intolerably cold. There are as many solutions to this conundrum as there are Antarctic workers, a sure sign that no ideal answer exists. Motorcycle helmets, paintball masks, side-shielded glacier sunglasses, and ski goggles all have their adherents. Some people swear by commercial antifogging products, others swear *at* them. The specific scheme chosen is not important. What matters is its effectiveness. Meteorite hunting is done entirely by eye, and eyes that are peering through foggy lenses or tearing from the cold spot fewer meteorites. The author tested a half-dozen different arrangements, including equipment borrowed from the CDC, the BFC, and the ANSMET project, plus personal glasses and goggles. His preferred option was a pair of Oakley A-Frame polarized ski goggles used without antifogging solution.

2.03.05. Warmth

Proper clothing and plenty of good food are necessary but not sufficient to keep a person warm in Antarctica. The chief provider of heat is the camp stove in the tent. In 2004-2005, each tent had two small Optimus stoves designed for backpacking. These stoves burned white gas. They were prone to throttle malfunctions which made the flame level hard to adjust and sometimes made the stove impossible to turn off. The fuel tank was small and had to be filled one to three times a day. For safety reasons, campers had to refuel the Optimus stoves outside the tent. At subzero temperatures, white gas causes frostbite instantly on contact with bare skin, so caution was required when refueling stoves. Starting a cold Optimus stove required the user to ignite a measure of messy preheat paste on the burner before lighting the stove itself. All of these disadvantages combined to make the Optimus stoves unpopular.

In 2012-2013, each tent group got two dual-burner camp stoves, which came from different manufacturers to provide dissimilar redundancy. These stoves burned propane from 9-kg net-weight cylinders that lasted for 8 to 10 days of normal use. Changing propane cylinders in the cold does not expose the operator to frostbite risk as does pouring liquid stove fuel. Propane stoves also do not need preheat paste, so they are safer and easier to light. Eliminating preheat paste also reduces the number of hazardous materials that have to be airlifted to and from camp. A white-gas stove user who switches to propane never changes back.

A camper who has trouble staying warm at night can fill a Nalgene container with hot water, wrap it in clothing or the BFC-issued bottle insulation jacket, and place it in his or her sleeping bag as a hot water bottle.

Finally, each ANSMET participant is issued two vacuum-insulated metal flasks to carry hot liquids during the workday. Both the 2004-2005 team and the 2012-2013 team used their vacuum flasks and their insulated Nalgene water bottles every day.

2.03.06. Shelter

Shelter in an ANSMET camp is provided by the Scott tent (Fig. 8), based on a design used by the eponymous Captain Robert Scott. It is a pyramid-shaped structure supported by four aluminum poles. It weighs about 40 kg. It measures about 2.4 m on a side when set up. The internal volume is about 4.3 m^3, and the floor area is about 5.7 m^2.

The Scott tent has inner and outer walls separated by an air gap. The outer wall has a skirt about 30 cm wide that is designed to be spread out on the ground. Campers shovel snow onto the tent skirt to hold it down. This is a strenuous task, but it is important for two reasons. First, the snow provides weight and stability which may be needed in high winds. Second, snow helps to seal the gaps between the skirt and the ground. Even a tiny crack provides a path for drifting snow to enter and fill the space between the tent's inner and outer walls, effectively eliminating the insulation value of the double-wall construction.

Figure 8. Interior of a Scott tent, as seen from the entrance.

The Scott tent is anchored to the ground by guy lines about 1 cm in diameter. The tent stakes are 40-cm sections of 2.5-cm steel pipe with rebar crosspieces welded across their tops to secure the tent lines. About twelve stakes hold down the tent skirt; about nine more anchor the guy lines, including the crucial one that runs to the peak of the pyramid from the upwind side. A securely anchored Scott tent is said to be able to withstand winds up to 150 km/h (80 knots).

Near the peak of the tent, the walls are pierced by two rigid vent tubes that allow stove exhaust to escape. This helps prevent the buildup of carbon monoxide. The vents extend in different directions to keep wind-blown drift from blocking both at the same time. Because the risk of carbon monoxide poisoning is still not zero, ANSMET observes the rule that a stove cannot operate in the tent unless at least one person is present and awake to watch it.

Entry to the tent is gained through cloth tunnels sewn into the inner and outer walls. Each has its own drawstring to cinch it closed. When both occupants are inside or outside the tent, the doors can be tied off with the drawstrings, which reduces drafts.

Inside, the top of the tent is equipped with clotheslines. These are extremely useful, but the built-in clotheslines do not provide enough space for all the boots, hats, gloves, socks, goggles, thawing meat packages and juice boxes, and other items that need the warm conditions near the peak of the tent. Campers often rig extra clotheslines to provide more heated storage space. Finding anchor points for new clotheslines can be a challenge.

Additional stowage space, albeit unheated, is provided by a row of pockets sewn onto the Scott tent's inner wall. Campers use these pockets to store items they use frequently. The tent design could be further improved by adding a second row of pockets, and by fabricating the pockets out of clear plastic or mesh cloth so that the contents could easily be seen.

The typical internal arrangement places tent supplies, cooking utensils, the stove, and a food box in a line up the center of the tent, beginning about 40 cm inside the door and running to the rear wall of the tent. The two inhabitants set up their sleeping pads and sleep kits on either side of the central stores, allowing them both to reach the food, utensils, supplies, and stove. During the day they roll up their sleeping bags and place them against the rear wall of the tent to make a comfortable backrest.

The floor of the Scott tent is a waterproof tarp that provides no padding, rigidity, or insulation. Without extra flooring, the boards that support the cook stove slowly melt their way down into the ice beneath them. A warmer, flatter, and more stable floor can be had by installing floorboards: 60×240 cm sheets of plywood with bubble wrap covering one side. These can be slid under the tent walls before all the stakes are installed, then covered with the waterproof tarp. Protecting the entire tent floor this way takes four boards, which together weigh about 40 kg. An extra layer of foam crash pads under the area just inside the door and beneath the central line of boxes and the stove board makes the tent noticeably warmer. The inhabitants' sleeping pads provide more than enough floor insulation for the sleeping areas.

A tall person cannot stand up in a Scott tent. The only place high enough is the center, which is usually full of hanging laundry and is directly above the stove and the tent boxes, which do not afford a place to stand.

Some newer Scott tents have vestibules: projections in the front outer wall of the tent which give the occupants extra storage space that is not heated but is sheltered from wind and drift. The vestibule is supported by additional metal poles. Its ceiling is high enough for short people to stand up straight, but taller people must dig the floor down about 30 cm if they want to stand comfortably. The additional storage space in a tent with a vestibule comes at a price: about 5 kg of extra weight and some loss of insulation.

The most important thing a Scott tent provides is shelter from the wind. But the double wall construction also makes the tent much warmer than the outside air temperature, which in field camp is usually -20 to -15° C (-5 to +5° F). With the stove lit, the temperature at the floor of the tent is near freezing. At the peak of the tent, where the vents and the clotheslines are, it can be 25° C. Half a meter above the floor, chest level for a seated occupant, the temperature is about 10° C. With the stove off for sleep during the "night" or while the occupants are out, the temperature drops to slightly below freezing. On a sunny day with no wind and an outside temperature near freezing, conditions that might be experienced at snow school, a Scott tent can be uncomfortably warm.

2.03.07. Electrical power

Power for battery-operated equipment such as cameras is best provided by lithium batteries, which work well in the cold. Alkaline cells perform poorly in low temperatures. Devices powered by alkaline batteries work inside a tent. If taken outdoors, they can be used if they are kept in an inside pocket and brought out into the cold for only a few seconds at a time. The USAP recommends rechargeable batteries to reduce waste, but an ANSMET field season is short enough that a supply of expendable batteries for the entire expedition can be carried easily.

For equipment without replaceable batteries, and for larger power loads, ANSMET camps have ancillary electrical power systems. In 2004-2005, the leader's tent had electricity provided by a wind turbine and a solar panel. An electrical equipment box contained a storage battery and an inverter to provide 110 V, 60 Hz power. The system generally worked, but was subject to sporadic outages. In 2012-2013, each tent had a two-panel solar array that could be bolted to the top of a 40-kg battery and inverter box. The system provided about 35 W of 110 V, 60 Hz power. It, too, was subject to mysterious failures, one of which electrified an array frame so that it delivered a painful shock when touched. That unit had to be retired and exchanged for a spare. Other electrical failures resolved themselves just as mysteriously as they arose.

2.03.08. Communication

Three systems provide communication in an ANSMET camp. The first, used in the 2012-2013 season but not in 2004-2005, was a set of walkie-talkies that enabled tent groups to converse without going outside. They were useful when the weather was bad. The second was a High Frequency (HF) radio set with a wire antenna many meters long that had to be deployed perpendicular to the direction of the intended receiving station, not a trivial task in camp. In 2004-2005 the HF radio was not able to reach either McMurdo or South Pole, but it could receive BBC World Service news transmissions. In 2012-2013 the team set up the HF radio, made a successful test call to McMurdo Station, then disassembled it and packed it up again. The equipment remained in camp as a backup.

The camp's primary long-distance communication tool during both seasons was the Iridium satellite telephone. In 2004-2005 the systematic search team had two Iridium handsets. In 2012-2013 there were three. Each phone saw 5 to 60 minutes of use per day. The Iridium phone was used for daily check-in calls to McMurdo, longer discussions with equipment specialists in McMurdo, personal calls to family and friends in America and elsewhere, and hourly reports to Mac Weather on days when an aircraft was expected. In 2013 the Iridium phone played a crucial role when one team member developed a medical problem during a camp move when no other communication resources were available.

Iridium calls normally costs about $2.00 per minute. A user must have a pre-paid Subscriber Identity Module (SIM) card to activate the phone. In 2004-2005, each ANSMET participant had to buy his or her own SIM card. In 2012-2013, the ANSMET grant paid for an unlimited SIM card which covered all of the team's Iridium phone use.

An Iridium phone draws about 6 W during its 8-hour recharge period. When fully charged it provides one to two hours of talk time.

Because of poor satellite viewing geometry in Antarctica, Iridium calls may fail when dialed, or may drop unexpectedly in mid-conversation. When either occurs, redialing a few seconds later is almost always successful.

Iridium handsets can receive, but not send, free text messages of up to 120 characters. Senders can log onto a website to transmit their messages. Despite their brevity, text messages from friends and family at home can provide important morale support for meteorite hunters.

2.03.09. Logistics

Organization of logistics in field camp is at the discretion of the camper. There is limited room in the tent for stowing items that are frequently used or too delicate to leave outside. Typically, campers keep electronics, everyday clothing, a small assortment of food, and cooking and cleaning supplies in the tent. Inhabitants of tents with vestibules use the extra storage volume for the propane tank, trash bags, extra frozen food, and additional clothing. Tents without vestibules have enough space between the front inner and outer walls for the propane tank and trash bags.

Outside, campers stow personal bags near the entrances of their tents. They arrange their food boxes, spares, tools, fuel, and other group gear in lines along the wind direction beside or downwind of the tents. Toilet supplies stay in the latrine tent. Overall, about half of the camp's total footprint consists of logistics.

Material slated to leave camp on a departing resupply flight is stored in a dedicated cargo line a few dozen meters from the tents, in a location accessible to the Twin Otter.

2.03.10. Trash

Trash generated in field camps must be sorted into categories compatible with the McMurdo recycling system when the team returns at the end of the season. An easy arrangement that honors the spirit of the recycling program is for each tent to maintain two trash bags. The first is for recyclables: glass, cardboard, large pieces of paperboard, steel and aluminum cans, and recyclable plastic, all with the worst of the food residue removed. These are easily sorted by hand into the proper bins in McMurdo. The second is for paper towels that have been used to clean dishes, probably the largest trash item by volume. These, along with any other trash contaminated by food, can be bagged up together and thrown into McMurdo's "Food Waste" bins.

Small trash items that are difficult to recycle, including dead batteries, are best kept by the participant and discarded after returning to the US.

2.03.11. Shifting camp

In 2004-2005, the systematic search team stayed at one camp site for the entire season. In 2012-2013, the systematic search team shifted camp from Otway to Bumstead, from Bumstead to Larkman, and from Larkman back to Otway. An attempted shift from Larkman to Cecily-Raymond had to be aborted. Each camp shift required loading all of the camp's equipment onto sledges to be towed behind snowmobiles. Because changing conditions may delay or halt a camp move, packing takes careful thought.

Moving an ANSMET camp is strenuous and time-consuming. It also adds risk. The team cannot seek shelter from the wind or make hot food when their tents and stoves are packed up and lashed to sledges. Good weather is a requirement.

Some non-essential equipment, such as reserve food boxes, rarely-used personal gear, and solar power units, can be packed the day before a camp shift, but most of ANSMET's gear is needed for basic survival and cannot be taken down until the morning of the move.

Each tent group is responsible for packing its own gear and loading it onto sledges. They begin with non-essential gear, then handle the bedding, personal gear, and kitchen equipment from the tent. Last comes the tent itself, which travels in a canvas cover. Groups who finish their own packing can go to work on group gear, including the latrine tent and its contents.

All equipment must be loaded onto the team's Siglin, Nansen, and Komatik sledges. The heaviest equipment goes toward the rear of the sledge for better towing characteristics. Lateral balance is important as well. Unbalanced loads can capsize during the traverse.

Loaded sledges must be lashed down to make a compact load that will not shift or spill. A Nansen sledge has a canvas cover that goes over the load. Metal hooks sewn into the cover allow a long lashing line to cross back and forth. Two people work together, one on each side of the sledge. They cinch the line tight after each turn. When the entire load has been sewn up, they repeat the process, pulling each turn of the lashing line as tight as their strength allows. Without two stages of tightening, the load will work itself loose as the sled travels over the uneven snow.

Siglin sleds have a concave shape that makes loading and retaining equipment easier, but no canvas cover. Instead there are side ropes with multiple hooks for the same kind of lashing line that is used on the Nansen. Large, sturdy Komatik sleds carry the heaviest equipment, such as Lego boxes, which weigh over 50 kg when full, and fuel drums, which weigh up to 180 kg. Crews use cargo straps to secure loads on Komatik sleds.

Striking the camp and loading sledges takes about four hours of hard physical work. An inexperienced team may take longer.

The ANSMET mountaineer usually leads the traverse. He is responsible for navigation and for selecting a safe travel route through terrain that may have steep icy slopes and hidden crevasses. Speed of travel is rarely greater than 15 km/h. Traverses can be slowed further when poorly secured cargo shifts or spills, when sledges overturn, and when snowmobiles malfunction. Even if no stops are needed for cargo or Ski-Doo problems, the team halts to rest, eat, and verify their navigation every hour or so. In 2012, the 11-km shift from Otway to Bumstead took one and a half hours to complete. The 45-km traverse from Bumstead to Larkman took about four and a half hours. In 2013, the 56-km move from Larkman all the way back to Otway took the team, who by then was more experienced, only three hours.

When the team arrives at a new location, they search for a camp site with level firn for pitching the tents and a nearby patch of blue ice for drinking water.

With the site selected, the team builds a new camp, a process that takes about three hours. It is essentially the reverse of striking camp. The team puts up their tents; installs flooring; sets up their stoves and fuel bottles; emplaces the boxes that contain their food, utensils, and tent supplies; arranges their sleep kits; and stows their personal bags. They set up the latrine tent. At this point they have warmth, shelter, food and drink, and a bathroom. They will have been up and moving for at least eight hours, so they may pause for a hot drink and a meal. After that they establish new cargo lines for less essential gear and install secondary systems such as solar power units.

The systematic search team moves to new camp sites infrequently. The reconnaissance team, on the other hand, may shift camp a half-dozen times during a season, either by snowmobile traverse or by aircraft. Either operation requires striking camp as described above, and making camp again at the new location.

2.04. Collecting Meteorites

This section describes the main work of ANSMET: gathering meteorites. Collecting Antarctic meteorites follows an established protocol that balances the challenges of working in the harsh environment against scientific priorities such as protecting the samples, recording location data, and mapping searched areas.

2.04.01. Preparing to search

Preparation for a day of Antarctic meteorite hunting begins with breakfast and hot drinks. About fifteen minutes before the work day is scheduled to start, a meteorite hunter fills an insulated bottle with a hot drink, puts on his or her full ECW gear, loads a parka pocket with granola bars, candy bars, jerky, and other portable food, applies lip balm, and puts sunscreen on any exposed skin (generally not a large area). He or she checks to make sure that ancillary items, such as a pen for marking location flags or a magnet for testing whether an ambiguous sample might be a meteorite, are in their proper places. When these tasks are complete, the meteorite hunter leaves the tent.

Once outdoors, the meteorite hunter prepares his or her Ski-Doo for work. The cover comes off and goes into the rear cargo box. If there has been windy weather since the last ride, it might be necessary to dig the Ski-Doo tread out of the snow and to scoop windblown snow out of the engine compartment. Each searcher normally carries a half-dozen marker flags on the snowmobile. If many flags were used on the previous work day, the rider may have to fetch more from storage. The insulated beverage container can travel in the rear cargo box or under the seat.

One or two team members carry meteorite collection kits, which are contained in 49-liter mountaineering rucksacks. Before a day's search, the responsible person checks to make sure that his or her collection kit has plenty of Teflon bags and metal sample tags, plus sterile tongs, freezer tape, and scissors. The collection kit also contains a hand-held counter with grey-scale patches and a centimeter scale that is held near each sample for in-situ photos. Collection kits usually ride in the metal panniers installed on some of the Ski-Doos.

Starting a Ski-Doo may take some effort as described in 2.02.06 above, and is best done a few minutes before the day's work is scheduled to begin in case there are unforeseen problems. A hundred-meter test drive, to make sure that the vehicle operates properly, may also be worthwhile.

At the appointed time, usually 0900, the team members leave their idling Ski-Doos and gather to discuss the day's work plan. These meetings take about ten minutes. They may be even shorter late in the season when the team knows its tasking well and has less tolerance for standing around in the cold.

When the team is briefed and ready, they leave camp together to commute to the day's work area.

2.04.02. Search methods

ANSMET teams work on snowmobiles or on foot. Ski-Doos are used for large stretches of blue ice (Fig. 9). To search on ice that is rich in meteorites, the team lines up their Ski-Doos eight abreast, 10-30 m apart and facing parallel or anti-parallel to the wind direction. On a hand signal from the leader, they drive forward at 5-8 km/h, scanning the ice by eye and trying to maintain spacing between their teammates to the left and right. The Ski-Doos usually create a "U" formation, with the leader on one flank. A designated team member, who accepts the responsibility of maintaining the other end of the formation at the expense of not being able to devote as much attention to meteorite searching, takes the other flank.

The team member on the wing of the formation that borders on unsearched ice stops periodically to plant marker flags indicating the boundary of the searched area. These flags are recovered on the next sweep, and other flags placed to mark the new boundary. Double flags mark the upwind and downwind limits of the search. These are recovered later in the season when the tracks from the GPS unit on the leader's Ski-Doo have been downloaded and there is no longer a danger of forgetting which areas have been searched. Recovering flags may take the team several hours a handful of times during the season. Recovering flags allows them to be re-used and reduces unwanted pollution of the continent.

Figure 9. Searching for meteorites on blue ice.

"Formation flying" on Ski-Doos is challenging. The rider must circumnavigate patches of snow where meteorites are not found. Paying more attention to the ice means paying less attention to lateral spacing, which creates the possibility of gaps and overlapping search swaths. Some drivers go faster than others. Some searchers stop for a closer look at every bit of rock they pass, which causes delays if the rocks turn out to be terrestrial. Coordinating the search so that it proceeds efficiently and equitably takes effort from all participants.

There is anecdotal evidence that small meteorites, which are easily be blown by the wind, accumulate at the downwind margins of blue ice fields. In such areas, Ski-Doo searchers may go slower, tighten up formation, or even get off the machines and search on foot.

In areas of blue ice that are being explored for the first time, or that are expected to have few meteorites, or that have already been searched but may possibly have meteorites that were missed the first time, Ski-Doo searchers may adopt a "loose" formation with a separation of 30-100 m between machines. No attempt is made to maintain precise spacing or ordering, and riders may S-turn left and right of course to scan for rocks. Loose sweeps are conducted at higher speed, 15-25 km/h.

In glacial moraines, where the rocks are too large for Ski-Doos to safely traverse and too plentiful for a human searcher to evaluate at any speed above a very slow walk, ANSMET teams park their Ski-Doos and search on foot. As with motorized searches, foot searches are a team effort. The participants line up facing upwind or downwind, moving slowly forward and trying to keep a constant spacing of 3-5 m between searchers. Their walking speed is about 0.5 km/h. The people on the left and right wings of the formation place flags or build rock cairns to mark which areas have been searched. They tear down the cairns or remove the flags when no longer needed.

Some moraines are poor in meteorites, or in need of only a cursory reconnaissance, or have already been searched but are worth a quick second look. In these cases the team may assume a "loose" foot formation with greater spacing, faster walking speed, and less rigid control of course and lateral order.

The team may take a short break after completing an upwind or downwind sweep. Bathroom stops are best taken at the downwind limit of the sweep, since that operation must face downwind and it's better if that direction is away from the rest of the group. On full workdays, lunch breaks are taken in the lee of snowmobiles or terrain to reduce wind chill. Because inactivity makes people cold, lunch stops usually last 30 minutes or less.

2.04.03. Wind considerations

Except in loose search patterns conducted during commutes, or on traverses constrained by fixed beginning and ending locations, ANSMET searches are aligned with the prevailing wind. With the wind coming from behind, bodies stays warmer and goggles stay clear of fog. On upwind legs, the Ski-Doo windshield provides shelter, but small distortions in the plastic make it harder to spot meteorites. On days with moderate wind, both upwind and downwind sweeps may be practical. On days with higher wind, the team may choose to search for meteorites while heading downwind only, and then hunker down behind the windshield for fast upwind transits to the starting point of the next sweep.

Crosswind sweeps are uncomfortable, with the wind on the side of the face and no protection from the windshield. ANSMET teams avoid crosswind work when possible.

2.04.04. Collecting samples

When an ANSMET participant spots a meteorite, he or she may take a moment to make sure it's not a "meteo-wrong:" a worthless terrestrial rock that resembles a meteorite. Diagnostic features of meteorites include rounded corners; regmaglypts (depressions that look like thumbprints); and the ability to attract a small magnet held nearby. The best diagnostic for meteorites is fusion crust, a thin layer of black material coating the outside of the rock. Fusion crust is an artifact of a meteorite's high-temperature passage through the Earth's atmosphere. Meteorite diagnostics can be mimicked by terrestrial processes, so identification is not always positive.

If the discoverer believes that the rock really is a meteorite (a "find" in planetary science parlance), he or she stands up and waves both arms overhead to attract the attention of the rest of the team. Searchers focused on driving a tight search pattern and scanning the ice for meteorites may take some time to notice, especially if the discoverer is lagging behind. When the others realize that someone is waving, they stop their machines, mark their places with flags, ice chippers, or ice axes, and then converge on the find. The discoverer moves his or her Ski-Doo so that the team leader, with the GPS-equipped Ski-Doo, can drive up to the meteorite and get an accurate position measurement.

At this point the team moves into coordinated action, honed over all past finds of the season (Fig. 10). The minder of the collection kit brings the backpack over, opens it, and pulls out the sterile tongs, the hand-held counter, a roll of freezer tape, and a pair of scissors. The designated photographer lies prone on the ice, facing the meteorite with the sun at his or her back, and readies the camera. The collection kit minder pulls out a metal tag with a unique sample number on it and announces it to the party. The leader records the number in a field notebook. Another party member clicks the counter's thumbwheels to display the sample number, then uses the centimeter scale on the counter to estimate the size of the meteorite in three orthogonal axes. The same person then holds the counter near the meteorite for the photograph. A team member prepares a marker flag, writing the sample number on the flag pole with a permanent pen. Yet another party member pulls from the collection kit a clean Teflon bag to contain the meteorite. The bags are available in a variety of sizes to handle larger and smaller samples, but they are infamously hard to open with gloved fingers. Often someone must expose a bare hand to the cold to open the bag. Most people can tolerate bare hands for only a few seconds.

When the photo has been taken, a party member (often the discoverer) takes the tongs, picks up the sample, looks at it from all directions, announces what percentage of its surface is covered by fusion crust and whether it is a chondrite or an achondrite, and places it in the bag. Using the tongs is also a bare-hand task. Achondrites and especially fragile meteorites may be wrapped in aluminum foil before being bagged. When the sample is in the bag, the holder folds the bag around it, slips the metal sample tag into the fold so that it does not directly contact the sample, and holds the bag up for a teammate to tape it closed. Peeling the end of the tape from the roll, and using the scissors to cut the tape after the bag is sealed, are also bare-hand tasks. When the sample is safely bagged, another team member moves in with an ice chipper or ice auger to drill a hole to plant the marker flag. The bagged meteorite goes into the collection kit along with the various collecting tools. The collection kit itself is then returned to its minder's Ski-Doo.

An experienced team can accomplish all of this in little longer than the one minute it takes the leader's GPS unit to establish a position fix. The first meteorites of the season may take much longer, because task distribution may not yet be established and because everyone wants to look at the samples. If the team finds a big meteorite early in the season, everyone wants his or her picture taken with it.

When collection is complete, the team members return to their Ski-Doos and drive back to the position markers they left behind. Etiquette stipulates that searchers driving to and from the collection activity stay clear of unsearched areas in their teammates' lanes to avoid "poaching" meteorites that should rightfully have been found by someone else.

Collecting a meteorite during a foot search is much like collecting one during a motorized search. Team members wave to indicate a find. The rest of the team walks over to that location. The leader marks the meteorite's position using a hand-held GPS unit. Collection proceeds as described above, and the team resumes their positions in the search pattern. Team members must hand-carry the collection kit, marker flags, and ice auger. In moraines that are very rich in meteorites, the team may save time by marking all the finds during the foot pass, then returning later to collect all of the meteorites.

Figure 10. Collecting a small meteorite.

2.04.05. Marking locations

The collection process includes recording GPS location data for each meteorite. The party also places a flag at the location of each find. The flags are brightly colored synthetic cloth rectangles, about 20×30 cm, attached to 2.4-meter bamboo poles. A flag allows the team to return and re-take a meteorite's position data if there is a problem with the original GPS data take.

Information on meteorite positioning is important for pairing studies, which aim to understand how the pieces of a meteoroid that breaks up during atmospheric entry get distributed across the ground. Antarctic meteorites are often paired with one another based on their composition, but it can be difficult to unravel how the initial trajectory, fragmentation in flight, aerial separation because of different ballistic coefficients, and differences in transport by ice flow, wind, and slopes all contribute to a meteorite's discovery location.

2.04.06. Returning to camp

At the end of the work day, the team returns to camp. They line up at the fuel barrels and take turns with the pump to refuel all of the snowmobiles. It takes 20 to 30 minutes to service a fleet of eight. Each team member then parks his or her machine, unloads trash, empty drink containers, and any other items that don't spend the night on the Ski-Doo, tightens the idler wheel bolts and checks the suspension springs, and covers the Ski-Doo to reduce drifting snow in the engine compartment if the weather should turn windy.

The minders of the collection kits have additional duties. They take the full kits to the "isopods," insulated metal cases that are used to transport the meteorites out of the field and back to the US. They verify the number and identity of all the collected samples and cross-check them against the records in the leader's notebook. They then store the samples in the isopods. To save time the next morning, they may replenish the supplies of Teflon bags and freezer tape in the collection kit.

The leader has yet another task at the end of the day, which is to download the data on the team's search area and on the location of each sample from the GPS unit on his or her Ski-Doo to a portable computer. Once the data is safely stored on the machine, the marker flags for those samples are no longer needed and the team can remove and reuse them as needed.

2.04.07. What happens to the meteorites?

If the team fills an isopod container ahead of a mid-season resupply flight, the container may travel back to McMurdo aboard the Twin Otter along with the other items leaving camp. Otherwise the isopods return to McMurdo as priority science cargo on the same flight that brings the field team home. Because the meteorites often have snow and ice adhering to them, and because liquid water may alter them in ways that reduce their scientific value, the meteorites are kept frozen in transit. In McMurdo, the science cargo handlers keep the meteorites in refrigerated storage. Late in the Southern summer the meteorites are shipped, still frozen, back to the US. They arrive via Federal Express at the astromaterials curation facility at JSC, usually in late April.

Scientists at JSC make an initial assessment of each specimen and assign it a permanent sample number. They reject any meteo-wrongs (less than a few percent of the collected rocks), and identify any unusual meteorites. The samples stay at JSC for months or years [18], but eventually become the property of the Smithsonian Institution in Washington, D.C. for permanent curation there.

An initial description of the most interesting meteorites from an ANSMET field season may appear the following summer in NASA's Antarctic Meteorite Newsletter. About one year after the end of an ANSMET field season, the scholarly journal Meteoritics and Planetary Science publishes a more comprehensive list of the season's finds. Planetary scientists all over the world use these bulletins to select and request samples of Antarctic meteorites for study.

2.04.08. How many meteorites does ANSMET collect?

ANSMET returns an average of several hundred meteorites per season. In 2004-2005, a near-record year, the systematic search team collected about 400 meteorites, and the reconnaissance team about 800. In 2012-2013 the systematic search team collected about 330 meteorites, and the reconnaissance team about 70. Since it began in 1976, ANSMET has collected over 20,000 Antarctic meteorites [18].

2.04.09. Tent days

ANSMET field teams do not rest on the weekend. They take one or two half-days off at Christmas and New Year's, but otherwise any day in the field is fair for work.

Nevertheless, field teams rarely have to work more than seven days in a row. The reason is the weather. High winds, drifting or falling snow that covers meteorites, or "flat light" that hides crevasses and other hazards can halt work. So can Ski-Doo problems or illnesses which prevent one or more team members from traveling. A participant who cannot work is never left in camp alone. Another team member stays with them.

A day without collecting is spent in the tent. On tent days, team members may read, write, draw, listen to music, play games (card games and tabletop games such as Settlers of Catan are popular), watch movies on suitably equipped laptop computers, bathe, wash clothes, call friends and family on the satellite telephone, go for short walks near camp, repair equipment, take pictures, cook special meals, or take naps.

One tent day after a succession of work days is a welcome opportunity to rest. Two consecutive tent days are more than enough. Three or more are tedious. In 2012-2013, bad weather confined the reconnaissance team to their tents for 13 days in a row.

2.04.10. Public outreach

ANSMET makes an effort to inform the public about its activities. Participants take turns writing entries for a daily blog. In McMurdo, they post blog entries directly to the Internet. In the field, they transmit their blog entries, along with small accompanying image files, via the Iridium phone. A contact in the US posts them to the Internet.

In 2012-2013, the systematic search team participated in a popular question-and-answer session on the Reddit website. The event was complicated by the lack of direct Internet connectivity in the field.

To get around this, the field team called an associate in North America on the Iridium phone. The associate, looking at the Reddit front page, read questions from his computer screen to the field team over the phone. The team answered the questions verbally, and the associate transcribed their responses onto the website. In 2004-2005, the author coordinated with JSC's education office to conduct weekly satellite telephone conferences with classrooms while in the field.

ANSMET maintains a website with photos and text describing the project's mission and environment. ANSMET also hosts an evening event at the Lunar and Planetary Science Conference (held every year in mid-March in Houston, Texas) in which the latest season's participants talk about their experiences for an audience of interested astronomers and geologists. ANSMET participants may also talk about their experiences at their own institutions and other venues.

2.05. Crew Concerns

Like a space mission, an ANSMET expedition demands a lot from its human participants. This section describes challenges of Antarctic work that relate specifically to the crew.

2.05.01. Crew composition and selection

ANSMET team members must adapt to hard work and uncomfortable living conditions. They must work well as a team and live in close proximity with a tent mate. They must cope with isolation and with separation from family and friends. Not everyone has these skills. The ANSMET PI selects team members from a pool of interested people (mostly planetary scientists), based on his knowledge of their character and capabilities. Half of the members of each team are veterans of past ANSMET expeditions. Veterans are especially valuable as they require less training in the field, and can help teach the rookies. They also self-select as participants who liked their Antarctic experience well enough to seek another.

2.05.02. Self care

Despite the excellent clothing and field equipment, maintaining physical health and well-being in an Antarctic field camp is a challenge. The primary concern is keeping warm. Wearing the issued clothing, eating plenty of energy-rich food, drinking hot fluids, and engaging in vigorous physical activity are good ways to keep warm. As an illustration of the last point, the author volunteered for the task of drilling the hole for the marker flag at each meteorite find, largely because the effort needed to turn the ice auger provided a warming physical workout.

The face, feet, and hands are most susceptible to discomfort or injury from the cold. Faces in particular are subject to cold injury. In 2012-2013 at least three team members suffered from "frost nip," a mild form of frostbite that does not result in tissue death, on parts of their faces that were exposed to the wind for only a few minutes. The safest practice is to keep all skin covered. This also reduces the likelihood of sunburn. Sunburn is a hazard in on the polar plateau, given the high elevation, the glare of snow and ice, and the reduced column density of stratospheric ozone (the "ozone hole") over the southern continent. Exposed skin that can withstand the cold still must be protected with sunscreen. The combination of hat, goggles, and neck gaiter (which can be pulled up to cover the mouth and nose) provides good protection against both sunburn and frost nip.

For cold hands, heavily-insulated gloves that do not to hinder circulation seem to be the best solution. The handlebar warmers on the Ski-Doo are also helpful, especially if used proactively. If the rider's hands are already chilled, it can take a long time for the heat to penetrate heavy gloves and warm the hands. For cold feet, wool socks provide a good defense. Clean socks are warmer than dirty ones. One past ANSMET participant brought over 40 pairs of socks to the field, in order to have a clean pair every day. Another way to ensure warm feet is to choose boots that are roomy enough to accommodate extra layers of socks without impairing blood circulation. Physical activity also helps keep both hands and feet warm. If these methods are insufficient, participants can use chemical heat packs. When exposed to air, these packets generate temperatures over 38° C for several hours. Some ANSMET participants use four or eight packets a day in their gloves and boots.

While cold is the primary health concern in Antarctica, minor conditions can also cause problems. A common issue is dry skin. The combination of extreme cold and low humidity can make skin so dry that it cracks open painfully. This is most common, and debilitating, on the hands. Hands suffer additionally from the alcohol-based hand sanitizer that must replace soap and water in camp. Ordinary skin moisturizers (which must be protected from freezing) can prevent dry hands from cracking. After cracks develop, the victim can mend them with skin glue, reducing pain and the likelihood of infection.

People working hard at high elevation in cold, dry conditions easily become dehydrated. At the same time, field team members may not want to drink water, which means chipping and melting more ice, and making more trips outside the comfort of the tent to use the urine dump. Alcohol and coffee, both popular in camp, have diuretic effects which increase the risk of dehydration. The flat taste of melted ice makes the water unappealing to drink. In all, it takes a conscious effort--plus monitoring of the color of the product when using the urine dump or a relief bottle--to maintain a healthy level of hydration in an Antarctic camp.

Another potential self care challenge in camp is hemorrhoidal discomfort. This condition is exacerbated by dehydration, a cold environment in the latrine, a diet poor in fresh fruits and vegetables, and limited options for keeping that area of the body clean. Baby wipes (which must be protected from freezing) and over-the-counter medications can help prevent and treat hemorrhoids.

2.05.03. Hygiene

It's hard to keep clean in the field. The best possible arrangement, not deployed in all camps, is a dedicated shower tent. If available, the shower tent has a stove for warmth, a water bag with a spray nozzle that can be suspended from the ceiling, and a platform to protect bare feet from the cold ice of the floor. A simpler solution is to take a sponge bath in the habitation tent. Either way, washing is time-consuming. It takes about an hour to melt ice, heat water, bathe, and clean up afterward. Bathing is a good activity for a tent day when outdoor work is not possible. Each participant must decide how often to wash, balancing the effort of bathing against the discomfort of being dirty. For the author, six days was an acceptable interval between baths.

Campers can wash their hair by leaning over a large plastic basin. Short hair is easier to wash and dry than long hair, so some participants cut their hair short before deploying to the field.

ANSMET campers dispose of used bath water at the camp's urine dump or pour it down a small crevasse. To the author's best knowledge, this practice is not technically forbidden. But it also harms the Antarctic environment and is another reason not to bathe too often.

Most men choose not to shave facial hair while in the field. Shaving is unnecessary. It can also generate more waste water, and it removes valuable insulation on a part of the body that is often exposed to the cold.

Clean underwear is another item taken for granted in ordinary life that is a rare luxury in an Antarctic field camp. There are no facilities for washing clothes in camp. One solution is to bring enough clean underwear to last for six weeks. Another is to forget about clean underwear. There are jokes about old Antarctic explorers who simply turn their base-layer clothing inside-out halfway through the season. The author alternated between two sets of synthetic underwear, wearing one set and hand-washing the other. This system minimized the amount of clothing brought to the field and demanded little extra effort. The second layer on the upper body had to be added to the washing rotation to reduce odors. ISS crews have tested base-layer clothing made with silver threads as a biocide. This underwear reportedly remains odor-free for extended periods without laundering. It could be useful in Antarctica.

Oral hygiene is important in Antarctica. An energy-rich diet is likely to be sugar-rich as well, and the nearest dentist is 5000 km away. It is easy for campers to brush their teeth, but hard for them to spit out toothpaste suds without leaving the warm tent or polluting Antarctica. Space Shuttle crews, lacking a sink as do Antarctic campers, spat into rags which they hung to dry in the toilet compartment. This provided a fresh minty scent in the latrine, but it was best not to think too hard about the source of the pleasant smell. Antarctic team members can spit into wet-trash bags destined for a Food Waste container in McMurdo. A tidier option is to use fluoride-free toothpaste (available in US supermarkets but not in McMurdo) that is safe to swallow in small quantities.

2.05.04. Sleep

It can be hard to get restorative sleep in Antarctica. At McMurdo Station there are comfortable beds and blackout shades to block the perpetual daylight outside, but 24-hour activities and the comings and goings of roommates at all hours can interfere with sleep.

In camp the situation is even more challenging. Early in the season there may be stress about the living environment. The walls of the Scott tent admit a lot of light. In winds above 35 km/h (20 knots) the tent shakes loudly. The ground insulation, padding, and covering provided in the sleep kit may require a lot of rearrangement to yield a comfortable bed.

Environmental stress often eases after a few days. Adjusting the pads and sleeping bag over the first few nights produces suitable results for almost everyone. If necessary, additional or different bedding can be requested on the first resupply flight. Light and noise problems, on the other hand, demand technical solutions. Every ANSMET team member should bring a rigorously light-proof eyeshade that will stay in place all night and that is comfortable in any sleeping position. Sleep masks distributed for free on airliners are not effective, but neck gaiters work well. Effective, comfortable earplugs (with backups in case they fall out during the night and get lost in the bedding) are also crucial.

Notably absent from the BFC sleep kit is a comfortable pillow. Each camper should bring his or her own, preferably tested before leaving home. It may also be possible to borrow a pillow from the Housing Office in McMurdo.

2.05.05. Human waste

Urine and feces are handled separately in ANSMET camps. Until the time of this writing it has been permissible to dump urine into the Antarctic environment. This policy may be tightened in the future to make it consistent with the rules for the ecologically sensitive Dry Valleys, where both liquid and solid human waste must be collected and shipped back to McMurdo. But in 2004-2005 and 2012-2013 each ANSMET field camp established one or two outdoor urine dumps, marked with flags. Men could use these as urinals. Women used collection devices in the tent or other protected environment, then emptied their "pee bottles" (issued by the BFC and marked with a prominent "P") into the urine dump. Both men and women used relief bottles during the sleep period to avoid dressing up and going outside. Campers emptied their pee bottles at the urine dump in the morning. Woe to the camper who neglected that chore, only to wake in the middle of the next sleep period with a full bladder and a pee bottle with no ullage. When the party left a camp site, it buried the urine dump in snow to reduce its visible impact.

For collecting feces, each team established a "poop tent" downwind of the habitation tents. The toilet was a wooden box that contained a gray plastic bucket lined with plastic bags. A styrofoam seat covered the top of the box and the bucket. After the season the seat, inevitably somewhat contaminated, was discarded in the trash at McMurdo. The poop tent also held supplies of toilet paper, paper towels, and empty buckets. Next to the toilet, team members placed alcohol-based hand sanitizer and some creature comforts such as books, scented candles, or plastic flowers. When a bucket became full, a conscientious camper would pull it out of the box, hammer a sealing lid onto its rim, and put a fresh bucket lined with plastic bags into the box. The cold conditions in the poop tent largely, but not completely, controlled offensive odors. A marker flag was kept next to the poop tent so that an entering occupant could signal that it was occupied. With the flag up, other prospective users could tell at a glance that they had to wait their turn. Chronically forgetting to take down the flag upon leaving the poop tent earned a camper the wrath of his or her teammates.

2.05.06. Illness

Minor medical issues arise from time to time in camp. Headaches are common, especially early in the season when team members are acclimatizing to the altitude. Dehydration and poor sleep can also cause headaches. Campers manage headaches with over-the-counter medications they bring themselves.

In 2012-2013 a team member contracted a mild case of food poisoning. It is common for food taken to the field to be somewhat past its expiration date, but this is the only case of illness caused by expired food that the author is aware of.

In 2012-2013 a team member suffered an injury to the hand while working with three other people to unload a 200-kg sledge from a cargo pallet. Although not threatening to life or limb, the injury made operation of the Ski-Doo throttle uncomfortable for the entire season. This injury could have been prevented if the team had coordinated their lifting better.

In 2004-2005 two team members suffered unspecified illnesses that prevented them from working for a day or two. On those days they remained in camp along with their tent mates.

The ANSMET mountaineer or team leader is entrusted with a combination-locked plastic case stocked with prescription medication from the clinic in McMurdo. All the medications are inventoried and labeled clearly. The intent is for the medications to be available in camp, but used only under direction of the physician in McMurdo via satellite telephone. The prescription medication container was used during the 2012-2013 season (see 2.05.07 below). An unforeseen operational difficulty arose when the cold inactivated the glue on the medications' paper labels. The labels promptly fell off the plastic bags and scattered on the wind, causing a litter problem and making the medicine more difficult to identify.

2.05.07. Medical evacuation

A medical emergency arose on the systematic search team in early 2013. The occasion was a camp move that had been delayed many times for weather and logistical reasons. When the move finally became possible, the team worked all morning to strike camp and then began a 45-km traverse across potentially crevassed terrain to a new work area. Early in the traverse a team member became disoriented and behaved erratically. The team halted, and the leader called the clinic in McMurdo on the satellite phone. The physician on duty could not positively identify the problem, but because the possible causes included potentially life-threatening conditions, the physician called for a medical evacuation. The team decided to return to the camp site they had just left, which was known to have a safe place for a Twin

Otter to land. Throughout the episode, the victim claimed to be feeling fine and resisted the change in plan.

Once back at the original campsite, the team set up a tent for the victim and lit a stove for warmth. Two team members stayed in the tent and cared for the victim while others rebuilt the camp and retrieved Ski-Doos and cargo that had been temporarily abandoned on the traverse route in order to transport the victim. The team leader called McMurdo every 30 minutes with updates on the local weather (for the rescue aircrew) and the status of the victim (for the medical experts).

A Twin Otter from the South Pole Station, carrying the Pole's only physician and an emergency medical technician, arrived in camp about five hours after the first call to the clinic. By then the victim's symptoms were beginning to resolve. The aircraft carried the victim to McMurdo. The victim remained in the clinic there until the next available flight to Christchurch, which was two days later. By that time the illness had apparently resolved completely. A full medical workup in Christchurch revealed no physiological problems. The root cause of the illness remains unknown, but an accidental overdose of medication is one possibility.

Given the remoteness of the field camp and the limited number of aircraft and medical personnel in Antarctica, the infrastructure's response time was commendably fast. The physician on the evacuation flight praised the ANSMET team for its effective handling of the situation.

2.05.08. Psychological concerns

Like physical health, psychological well-being can suffer in an Antarctic field camp. Stressors include apprehension about the dangerous environment, separation from family and friends, inability to help with problems arising at home, lack of privacy, close living quarters, variable levels of effectiveness in finding meteorites, uncertain and changeable travel plans, and physical discomfort. In stretches of bad weather, sitting in the tent for days on end can cause significant stress. Despite having no special training, and possibly little experience living and working outdoors, most ANSMET participants are able to cope with the stress. Some are more successful than others. In a past year, an ANSMET participant had to be evacuated from the field for psychological reasons. But the many ANSMET veterans who return for additional seasons constitute clear evidence that the psychological challenges do not overwhelm the positive aspects of the experience.

2.05.09. Psychological countermeasures

Many countermeasures are available to help ANSMET participants meet the psychological challenges of life in camp. ANSMET schedules two group events, a holiday gift exchange and a New Year's celebration, expressly to support crew morale. The morning following each celebration (usually Christmas Day and New Year's Day) is usually granted as off-duty time to allow the group to stay up for the celebration and sleep late the next day.

ANSMET reconnaissance teams and systematic search teams may gather in the evening for satellite phone conversations between the two parties. This provides an informal get-together for both teams, and also a chance for everyone to hear some fresh voices.

Smaller gatherings, where one tent group invites another over for dinner, are common. A tent group may "go out to dinner" or "have guests over for dinner" once or more per week. Informal visits to other tents may happen daily, depending on individual gregariousness.

"Game nights," where two or more people get together to play games, are also important for psychological support.

Most ANSMET team members bring removable decorations to personalize their tents and Ski-Doos. Holiday tent decorations to be displayed at the appropriate season are popular. So are flags flown from Ski-Doos. Snowmobile decorations have practical value as well. They can help team members identify each other from a distance, a hard task when almost everybody is riding a yellow Ski-Doo and wearing black snow pants, white bunny boots, and a red parka.

Care packages from family and friends are also good for morale. Former ANSMET participants who recall the importance of care packages during their own time in Antarctica often send similar gifts to the team. Letters and gifts from family are especially valued. Participants who want to receive mail in the field should provide the address and mailing instructions (including allowing for long delivery times) to their contacts before leaving home.

Over the years, ANSMET has accumulated a small library of books, DVDs, and games. These items are stored in the cage in McMurdo. Most teams bring some library items to the field during put-in, or designate some for delivery in a later resupply flight. Personal books, movies, puzzles, and music are also helpful for psychological support. A common error in packing is to bring too many books. Team members should realize that everybody brings a book or two, and that they can easily borrow and trade with others instead of bringing a large personal library.

When time and weather allow, Antarctic campers can take walks to get some private time. This can be important after living with a tent mate less than a meter away for many days. Anyone leaving camp alone must first tell someone which direction they are going and what time they will return.

The JSC psychological support community provided some additional recommendations to the author in preparation for the 2004-2005 season. These included meditation or prayer, not fixating on issues, and controlling things that can be changed while accepting those that can't.

One more psychological support mechanism available in Antarctica is probably the most popular. Alcohol is allowed in field camps. Temperatures in ANSMET camps are cold enough to freeze beer and wine, causing them to burst their containers. Consequently most alcohol brought to the field is in the form of hard liquor, which is available at the store at McMurdo Station.

In camp, moderate drinking is commonplace. Many old Antarctic hands add a little liquor to their hot chocolate at the end of a long cold day of work. Less moderate drinking occurs during holiday celebrations. Typical consumption of liquor in field camp is two to four bottles per person for the 40-day season.

Alcohol use is common in McMurdo. Two official bars offer it for sale. The line of shoppers waiting for the store to open on Saturday morning, when the alcohol is restocked for the week, is surprisingly long for such a small community. Alcohol appears to be tolerated officially for its value as a stress reducer, but the safety authority in McMurdo recognizes its negative effects, educating USAP participants about the role of intoxication in past fatal accidents around the station.

2.05.10. Interpersonal concerns

The significant stresses of life in camp can lead to interpersonal problems. The risk of conflict is increased because most ANSMET participants have no prior training in expedition behavior. There is inadequate time to provide that training before put-in. In 2010-2011 and 2011-2012, a team of research psychologists from Michigan State University studied interpersonal interactions among ANSMET participants in a voluntary journal-based study. They concluded that social behavior among the team members was generally good, but that it could be improved if the team got some training before entering the field.

In 2012-2013, the ANSMET PI addressed the researchers' recommendation for training by granting the author permission to teach the team some of the expedition behavior guidelines presented to astronauts during their preparations for space flight. The five main principles, compiled from National Outdoor Leadership School and NASA Astronaut Office sources, form an acronym, CHARM, which stands for "take CARE, HELP others, take ACTION, RESPECT your teammates, and serve the needs of the MANY." The following paragraphs explain each point.

"Take CARE."—Mom. Take good care of yourself, physically and emotionally, so that you'll be happy and won't be a drag on the team. Take good care of your teammates too. Watch them. Check on how they are doing. Offer all assistance. Remind them to take care of themselves.

HELP others. "Won't you please, please help me?"—The Beatles. Help pull the group toward its goal; don't retard progress. Watch what the leader is doing and try to make his job easier. Do your share of the work, and more if you're able. If you are not busy and see someone who is, offer to help even before they ask. If you need help, ask for it. Your teammates want to help!

Take ACTION. "We need to be the change we wish to see in the world."—Gandhi. Take charge of your interactions with others, don't just passively wait for good chemistry to happen. An expedition like this can be a highlight of your life, or a horrible grind. The thing that will make the most difference is how we choose to act toward each other.

RESPECT your teammates. "My mother used to say to me...'In this world, Elwood, you must be oh so smart or oh so pleasant.' Well, for years I was smart. I recommend pleasant. You may quote me."—Elwood P. Dowd. Give. Share. Take turns. Praise others. Say "please" and "thank you." Make your comments constructive, not critical.

"The needs of the MANY outweigh the needs of the few, or the one."—Spock. Group goals come before personal goals. Do what's best for the team, not what's best for you. Don't chronically make others wait for you; it's selfish. Treat everyone equally; playing favorites splits the team.

3. Data from ANSMET

This chapter presents data collected during the 2004-2005 and 2012-2013 ANSMET expeditions that allow comparisons with analog space missions and actual space flights. It is arranged by topic, and then by year for topics with data from both seasons. Topics include day-by-day overview calendars, examples of daily timelines, use of time in field camp, fatigue and sleep, distance traveled by date and mode, packing lists for personal and NSF-issued gear, bills of lading for aircraft transport, use of volume and consumable commodities in camp, crew workload and exertion, general data on McMurdo Station as a model for a settlement in space, an informal method for estimating wind speed without instrumentation, and a recipe for a popular camp dinner.

3.01. 2004-2005 ANSMET Calendar Overview

2004 Nov. 27.......... Depart United States
2004 Nov. 28.......... Lost to International Date Line crossing
2004 Nov. 29.......... Arrive Christchurch
2004 Nov. 30.......... CDC clothing issue
2004 Dec. 1............ Aborted Ice Flight to McMurdo
2004 Dec. 2............ Off duty (day trip to Akaroa)
2004 Dec. 3............ Ice Flight to McMurdo
2004 Dec. 4............ Food pull, Delta trip to Cape Evans
2004 Dec. 5............ Mountaineering class
2004 Dec. 6............ Driving school, move gear for snow school
2004 Dec. 7............ Snow school at Room with a View
2004 Dec. 8............ Return from snow school, move gear
2004 Dec. 9............ Pack and palletize gear, South Pole medical brief
2004 Dec. 10.......... Fieldwork training
2004 Dec. 11.......... Off duty (Castle Rock ski trip)
2004 Dec. 12.......... Drive Ski-Doos to Williams Field, bag drag
2004 Dec. 13.......... Put-in for part of team by LC-130 to South Pole, then by Twin Otter to La Paz
2004 Dec. 14.......... Put-in for rest of team
2004 Dec. 15.......... Set up camp, practice collecting meteorites
2004 Dec. 16.......... School teleconference, fuel sortie, half day collection
2004 Dec. 17.......... Tent day for high wind
2004 Dec. 18.......... Morning in the tent, afternoon fuel sortie
2004 Dec. 19.......... Tent day for high wind
2004 Dec. 20.......... Full day collection
2004 Dec. 21.......... Full day collection
2004 Dec. 22.......... Full day collection
2004 Dec. 23.......... Full day collection
2004 Dec. 24.......... Full day collection
2004 Dec. 25.......... Half day collection, holiday party
2004 Dec. 26.......... Full day collection
2004 Dec. 27.......... Full day collection
2004 Dec. 28.......... Half day collection
2004 Dec. 29.......... Full day collection
2004 Dec. 30.......... Twin Otter resupply and swap of two team members
2004 Dec. 31.......... Full day collection

(continued)

3.01. 2004-2005 ANSMET Calendar Overview (continued)

2005 Jan. 1 .... Full day collection
2005 Jan. 2 .... Tent day for high winds
2005 Jan. 3 .... Full day collection
2005 Jan. 4 .... Full day collection
2005 Jan. 5 .... Morning in tent, half day collection
2005 Jan. 6 .... School teleconference, full day collection
2005 Jan. 7 .... Tent day for high winds
2005 Jan. 8 .... Morning collection, afternoon in tent
2005 Jan. 9 .... Morning in tent, afternoon Twin Otter resupply
2005 Jan. 10 .... Morning in tent, half day collection
2005 Jan. 11 .... Full day collection
2005 Jan. 12 .... Tent day for wind and drift
2005 Jan. 13 .... School teleconference, tent day for wind
2005 Jan. 14 .... Tent day for wind
2005 Jan. 15 .... Morning in tent, half day collection
2005 Jan. 16 .... Full day collection
2005 Jan. 17 .... Morning in tent, half day collection
2005 Jan. 18 .... Full day collection
2005 Jan. 19 .... Full day collection
2005 Jan. 20 .... School teleconference, full day collection
2005 Jan. 21 .... Pack up camp, Twin Otter cargo pickup
2005 Jan. 22 .... Pull-out by Twin Otter to South Pole, LC-130 to McMurdo
2005 Jan. 23 .... Clean and return gear
2005 Jan. 24 .... Return gear, bag drag
2005 Jan. 25 .... Return gear, fly to Christchurch
2005 Jan. 26 .... Off duty in Christchurch
2005 Jan. 27 .... Return to United States

(end)

3.02. 2012-2013 ANSMET Calendar Overview

2012 Nov. 26.......... Depart United States
2012 Nov. 27.......... Lost to International Date Line crossing
2012 Nov. 28.......... Arrive Christchurch
2012 Nov. 29.......... CDC clothing issue
2012 Nov. 30.......... Ice Flight to McMurdo
2012 Dec. 1............ Gear pull, menu planning
2012 Dec. 2............ Fieldwork training
2012 Dec. 3............ Fieldwork training, snow school gear staging
2012 Dec. 4............ Snow school
2012 Dec. 5............ Return from snow school, gear staging
2012 Dec. 6............ Dry food pull, gear packing
2012 Dec. 7............ Frozen food pull
2012 Dec. 8............ Science, psychology, and operations training
2012 Dec. 9............ Off duty (Discovery Hut, pressure ridges), bag drag
2012 Dec. 10.......... Put-in for part of team by LC-130 to Otway Massif
2012 Dec. 11.......... Gear unpacking and staging
2012 Dec. 12.......... Put-in for rest of team by LC-130
2012 Dec. 13.......... Fuel delivery, shift camp to Mt. Bumstead
2012 Dec. 14.......... Morning camp setup, half day collection
2012 Dec. 15.......... Full day collection
2012 Dec. 16.......... Full day collection
2012 Dec. 17.......... Ski-Doo repair, prep for camp move
2012 Dec. 18.......... Shift camp to Larkman
2012 Dec. 19.......... Morning camp setup, half day collection
2012 Dec. 20.......... Full day collection
2012 Dec. 21.......... Half day collection
2012 Dec. 22.......... Tent day for wind, cold
2012 Dec. 23.......... Full day collection
2012 Dec. 24.......... Full day collection
2012 Dec. 25.......... Morning off duty, half day collection
2012 Dec. 26.......... Full day collection, resupply flight
2012 Dec. 27.......... Half day collection, holiday party
2012 Dec. 28.......... Morning off duty, half day collection
2012 Dec. 29.......... Full day collection
2012 Dec. 30.......... Full day collection
2012 Dec. 31.......... Full day collection

(continued)

3.02. 2012-2013 ANSMET Calendar Overview (continued)

2013 Jan. 1 .... Morning off duty, half day collection
2013 Jan. 2 .... Tent day for flat light and high wind
2013 Jan. 3 .... Morning in the tent, half day collection
2013 Jan. 4 .... Full day collection
2013 Jan. 5 .... Full day collection
2013 Jan. 6 .... Tent day for wind, Ski-Doo repair
2013 Jan. 7 .... Half day collection, afternoon in tent
2013 Jan. 8 .... Morning prepare for resupply, half day collection
2013 Jan. 9 .... Morning camp chores, half day collection
2013 Jan. 10 .... Morning camp chores, half day collection
2013 Jan. 11 .... Prepare for camp shift, resupply flight
2013 Jan. 12 .... Aborted camp shift, medical evacuation of team member
2013 Jan. 13 .... Off duty
2013 Jan. 14 .... Prepare for camp shift
2013 Jan. 15 .... Shift camp to Otway
2013 Jan. 16 .... Load cargo pallets for LC-130
2013 Jan. 17 .... Stage cargo for LC-130
2013 Jan. 18 .... Pull-out for part of team by LC-130 to McMurdo via South Pole
2013 Jan. 19 .... Return gear, sort trash
2013 Jan. 20 .... Off duty
2013 Jan. 21 .... Off duty
2013 Jan. 22 .... Clean and return gear
2013 Jan. 23 .... Gear return, pull-out for rest of team
2013 Jan. 24 .... Clean and return gear
2013 Jan. 25 .... Clean and return gear, bag drag
2013 Jan. 26 .... Bumped from Christchurch flight
2013 Jan. 27 .... Off duty
2013 Jan. 28 .... Fly to Christchurch
2013 Jan. 29 .... Off duty in Christchurch
2013 Jan. 30 .... Return to United States

(end)

3.03. Example Daily Timelines

This section contains complete timelines for typical and noteworthy days. The times, accurate to 5 to 10 minutes, are taken from the author's notebooks for both the 2004-2005 and 2012-2013 ANSMET expeditions. The date in the heading of each subsection indicates which trip yielded the data.

3.03.01. Collecting ECW gear at the CDC (2012 Nov. 29)

0000-0600	sleep period
0600-0640	off duty
0640-0710	prepare for science talk in McMurdo
0710-0730	write in journal
0730-0800	breakfast with team at hotel
0800-0900	wait for bus to CDC
0900-0910	bus to CDC
0910-0930	CDC training videos
0930-1130	collect, try on, and pack ECW clothing
1130-1145	bus to hotel
1145-1300	lunch at local restaurant
1300-1500	shop for food and supplies
1500-1900	walking tour of Christchurch
1900-2100	dinner at local restaurant
2100-2130	off duty
2130-2150	write in journal
2150-2230	prepare for sleep
2230-2400	sleep period

3.03.02. Ice Flight (2004 Dec. 2)

0000-0500	sleep period
0500-0600	breakfast
0600-0630	van ride to Antarctic Terminal
0630-0720	wait in terminal
0720-0800	bus to airplane, embark airplane
0800-1500	fly from Christchurch to McMurdo on RNZAF C-130
` 1500-1600	disembark airplane, bus from ice runway to McMurdo
1600-1730	McMurdo arrival briefings
1730-1800	occupy dorm room
1800-1830	dinner
1830-2100	off duty
2100-2200	prepare for sleep
2200-2400	sleep period

3.03.03. Gear and food pull (2004 Dec. 4)

0000-0600	sleep period
0600-0700	off duty
0700-0800	breakfast
0800-0900	team meeting
0900-1000	McMurdo arrival briefings
1000-1200	check out cooking and sleeping gear
1200-1300	plan field menu over lunch
1300-1700	food pull at Berg Field Center
1700-1800	dinner
1800-1900	staging for recreational trip to Cape Evans
1900-2400	recreational trip to Cape Evans

3.03.04. Snow school (2004 Dec. 7)

0000-0530	sleep period
0530-0600	wash and dress
0600-0700	breakfast
0700-0730	move baggage to Berg Field Center
0730-0800	educational teleconference with classroom in the US
0800-1000	move equipment to ice edge, load sledges
1000-1200	drive to camp site at Room with a View
1200-1300	set up camp
1300-1800	roped travel and crevasse rescue training
1800-2100	Ski-Doo driving practice
2100-2230	dinner
2230-2400	sleep period

3.03.05. Field camp put-in (2012 Dec. 10)

0000-0645	sleep period
0645-0745	breakfast
0745-0825	errands and dorm chores
0825-0830	write in journal
0830-1100	off duty
1100-1135	lunch
1135-1200	pack and dress for transport
1200-1225	muster at Motion Control Center
1225-1315	van ride to Pegasus Airfield
1315-1445	wait in passenger terminal
1445-1500	embark LC-130
1500-1730	fly from McMurdo to Otway Massif
1730-2030	unload LC-130, unpack equipment, set up camp
2030-2200	dinner
2200-2230	prepare for sleep
2230-2400	sleep period

3.03.06. Full day collecting meteorites (2013 Jan. 4)

0000-0710	sleep period
0710-0840	breakfast
0840-0900	prepare for work
0900-1710	Ski-Doo search for meteorites on blue ice
1710-1840	fuel Ski-Doos, gather food for group dinner
1840-2100	group dinner
2100-2145	group board games
2145-2215	write in journal
2215-2230	off duty
2230-2245	prepare for sleep
2245-2400	sleep period

3.03.07. Half day collecting meteorites (2005 Jan. 17)

0000-0745	sleep period
0745-0900	breakfast
0900-0930	off duty
0930-1025	camp chores
1025-1030	write in journal
1030-1115	lunch
1115-1130	phone call with family
1130-1200	prepare for work
1200-1700	Ski-Doo search for meteorites on blue ice
1700-1900	dinner
1900-2120	off duty
2120-2140	write in journal
2140-2200	prepare for sleep
2200-2400	sleep period

3.03.08. Resupply flight (2012 Dec. 26)

0000-0700	sleep period
0700-0830	breakfast
0830-0900	prepare for work
0900-0920	camp chores
0920-1210	Ski-Doo search for meteorites on blue ice
1210-1330	lunch in camp
1330-1600	foot search for meteorites in moraine
1600-1730	receive Twin Otter resupply flight, camp chores
1730-1900	dinner
1900-2000	write team blog entry
2000-2100	camp chores
2100-2105	write in journal
2105-2145	off duty
2145-2200	prepare for sleep
2200-2400	sleep period

3.03.09. Holiday in field camp (2012 Dec. 31)

0000-7000	sleep period
0700-0840	breakfast
0840-0900	prepare for work
0900-1530	foot search for meteorites in moraine
1530-1800	off duty
1800-2200	group dinner
2200-2215	write in journal
2215-2400	holiday party

3.03.10. Field camp pull-out (2005 Jan. 22)

0000-0005	write in journal
0005-0015	prepare for sleep
0015-0630	sleep period
0630-0800	breakfast
0800-1015	strike camp
1015-1045	load Twin Otter
1045-1215	fly to South Pole on Twin Otter
1215-1300	unload Twin Otter, visit South Pole Station
1300-1330	wait for LC-130
1330-1630	fly to Williams Field on LC-130
1630-1700	bus ride from Williams Field to McMurdo Station
1700-1800	reconfigure gear, dormitory chores
1800-1830	shower
1830-1930	dinner
1930-2030	shave
2030-2300	off duty
2300-2330	prepare for sleep
2330-2400	sleep period

3.03.11. Gear cleaning and return (2013 Jan. 23)

0000-0120	off duty
0120-0145	prepare for sleep
0145-0845	sleep period
0845-0930	breakfast
0930-0940	laundry
0940-1015	write in journal
1015-1100	write team blog entry
1100-1120	laundry
1120-1220	off duty
1220-1300	lunch
1300-1440	clean and return gear at Berg Field Center
1440-1455	finalize team blog entry
1455-1800	off duty
1800-1840	dinner
1840-2220	off duty
2220-2240	write in journal
2240-2300	prepare for sleep
2300-2400	sleep period

3.03.12. Retrograde flight (2005 Jan. 25-26)

(2005 Jan. 25)

0000-0700	sleep period
0700-0730	breakfast
0730-0800	team meeting
0800-0900	reconfigure gear
0900-1000	off duty
1000-1020	show and tell about meteorites at Heavy Machine Shop
1020-1130	off duty
1130-1300	lunch
1300-1315	team meeting
1315-1355	sort trash and unpack gear at Berg Field Center
1355-1415	dress for travel, dormitory chores
1415-1430	wait for transportation to Pegasus Airfield
1430-1845	ride Delta to Pegasus Airfield, wait for C-141, board C-141
1845-2345	fly to Christchurch on C-141
2345-0000	disembark C-141

(2005 Jan. 26)

0000-0115	claim baggage and pass through customs
0115-0130	walk to CDC with baggage cart
0130-0215	return ECW clothing
0215-0230	taxi ride to hotel
0230-0300	prepare for bed
0300-0900	sleep period

3.04. Use of Time in Camp

This section presents data on how an ANSMET participant spends time in field camp, broken down by category. The data come from the author's journals, with all activities for the entire field season recorded and timed with 5 to 10 minute accuracy.

Pre- and post-sleep includes washing, dressing, brushing teeth and other nighttime and morning hygiene activities, plus time awake during the sleep period. Logistics includes time spent in transit and packing, unpacking, and managing equipment. Personal time is unstructured and spent at the discretion of the participant. Team activities include meetings and other mandatory group activities. Work includes searching for meteorites, recording information in journals, and public outreach activities. Some columns may have small rounding errors.

3.04.01. 2004-2005 camp time breakdown

	total hours	percentage	hours per day
Actual sleep	273.5	27.8	6.7
Pre- and post-sleep	63.17	6.4	1.5
Meals	164.98	16.8	4.0
Logistics	110.18	11.2	2.7
Personal	189.92	19.3	4.6
Team	27.5	2.8	0.7
Work	154.75	15.7	3.8
Total	984.00	100.0	24.0

3.04.02. 2012-2013 camp time breakdown

	total hours	percentage	hours per day
Actual sleep	282.92	29.5	7.1
Pre- and post-sleep	84.32	8.8	2.1
Meals	158.57	16.5	4.0
Logistics	146.58	15.3	3.7
Personal	92.17	9.6	2.3
Team	41.52	4.3	1.0
Work	153.91	16.0	3.8
Total	965.99	100.0	24.0

3.04.03 Combined 2004-2005 and 2012-2013 camp time breakdown

	total hours	percentage	hours per day
Actual sleep	556.42	28.6	6.9
Pre- and post-sleep	147.49	7.6	1.8
Meals	323.55	16.6	4.0
Logistics	256.76	13.2	3.2
Personal	282.09	14.5	3.5
Team	69.02	3.6	0.9
Work	308.66	15.9	3.8
Total	1943.99	100.0	24.1

3.04.04. Discussion of use of time in camp

The biggest difference between the 2004-2005 and 2012-2013 seasons is in the personal time category. About twice as much unstructured time was available in the earlier season. The difference is attributable to weather. There were more tent days at La Paz Ice Field than at Larkman Nunatak. Logistics occupied more time in 2012-2013 because of the camp moves that year. In both years, meals took about 4 hours a day. The amount of work focused on expedition goals (meteorite searches, recordkeeping, and public outreach) was consistent at a little less than 4 hours a day. The author averaged about 7 hours of sleep per night during an average sleep period of 8.4 hours.

3.04.05. Comparison of ANSMET and ISS time use

As noted throughout this report, crews on the ISS face conditions comparable to ANSMET. ISS crew workdays are rigidly scheduled according to published guidelines. The sleep period spans 8.5 hours but most crew members do not actually sleep that long. ISS crews are scheduled for 2.5 hours of physical exercise per day to help keep their bones and muscles strong in weightlessness. Logistics chores are divided into scheduled work tasks and a daily "prep work" activity during which crew members gather tools and supplies for the day's activities. Daily planning conferences and plan familiarization time on ISS correspond to team coordination activities on ANSMET.

The following table compares typical workdays on ISS and in ANSMET. For ease of comparison, ANSMET times are tallied differently than in the tables above. The sleep period is the time set aside for sleep, not the amount of time actually spent asleep. Meal times includes time for dressing and personal hygiene. Because scheduled work time on ISS includes stowage and maintenance tasks in addition to science activities, it makes sense to combine ANSMET work on both logistics and science in that category.

ANSMET and ISS time use

	hours per day	
	ISS	ANSMET
Sleep period	8.5	8.4
Meals and hygiene	4.5	4.2
Team coordination	2.0	0.9
Scheduled work	6.5	7.0
Personal	0.0	3.5
Exercise	2.5	0.0
Total	24.0	24.0

The table shows that ISS and ANSMET crews spend time in a similar way. The times reserved for sleeping, eating, and working are almost identical. This correspondence between expeditions that have no common history suggests that future exploration missions, in space and on Earth, should plan for similar crew time usage.

The main differences between ISS and ANSMET are that no personal time is scheduled for workdays on ISS, and that ANSMET participants are not scheduled for exercise. (ISS crews do get unstructured time on weekends.) Less time is needed for team coordination on ANSMET because the tasks are simpler and because all the participants are located together in camp rather than being distributed in control centers worldwide.

3.05. Fatigue and Sleep in Camp

Sleep disruptions and fatigue are common on space missions. For comparison with space travel, the author collected the following data on fatigue and sleep in an Antarctic field camp during the 2012-2013 season. The fatigue ratings use a 10-point scale which has been employed in some space flight analogs. The scale is defined as follows:

JSC Fatigue Rating Scale

1-2 No fatigue. Performance not compromised.
3-4 Minor fatigue. Performance not compromised.
5-6 Moderate fatigue. Performance will likely be compromised if continued.
7-8 Significant fatigue. Performance is compromised.
9-10 Extreme fatigue. Unable to continue with adequate performance.

The following table gives the author's fatigue ratings for each morning and evening of the field season, along with the duration of each night's sleep period and how long the subject actually slept. Each line of the table gives the evening fatigue rating, then data on sleep during the night, and then fatigue rating for the following morning.

The average sleep period was 8.4-hours, during which the participant averaged 6.9 hours of sleep.

3.05. Fatigue and Sleep in Camp (continued)

Night of	PM fatigue	Sleep period (h)	Actual sleep (h)	AM fatigue	Notes
Dec. 10-11	5	8.0	5.0	5	Dec. 10 field camp put-in
Dec. 11-12	4	9.0	7.5	1	
Dec. 12-13	4	9.1	6.5	3	
Dec. 13-14	8	8.0	5.5	5	Dec. 13 camp shift
Dec. 14-15	4	9.0	8.0	1	
Dec. 15-16	3	9.2	8.5	1	
Dec. 16-17	3	8.8	8.0	1	
Dec. 17-18	4	8.5	6.5	2	
Dec. 18-19	6	8.5	5.5	4	Dec. 18 camp shift
Dec. 19-20	3	7.5	5.8	5	
Dec. 20-21	5	8.7	6.3	2	
Dec. 21-22	3	8.7	7.8	2	Dec. 21 afternoon nap 0.7 h.
Dec. 22-23	3	8.5	7.5	2	
Dec. 23-24	3	8.8	8.0	2	
Dec. 24-25	5	8.0	6.5	2	
Dec. 25-26	6	9.1	6.3	3	
Dec. 26-27	6	9.0	7.8	3	"sleep interruptions"
Dec. 27-28	5	8.2	6.0	--	AM fatigue data missing
Dec. 28-29	5	7.7	7.3	5	
Dec. 29-30	4	8.3	7.1	--	AM fatigue data missing
Dec. 30-31	5	8.8	6.8	4	
Dec. 31-Jan. 1	5	8.7	6.0	4	
Jan. 1-2	5	8.8	7.5	3	"minor sleep interruptions"
Jan. 2-3	3	8.9	6.3	4	
Jan. 3-4	3	9.0	7.8	3	"minor sleep interruptions"
Jan. 4-5	4	8.4	7.0	4	
Jan. 5-6	4	8.7	7.5	3	"minor sleep interruptions"
Jan. 6-7	3	9.2	7.0	4	"some sleep interruptions"
Jan. 7-8	3	8.8	6.5	4	
Jan. 8-9	4	10.2	7.5	2	
Jan. 9-10	3	10.0	8.0	2	
Jan. 10-11	2	9.4	8.5	1	
Jan. 11-12	5	8.8	6.0	4	
Jan. 12-13	7	9.5	7.0	3	Jan. 12 team medical emergency
Jan. 13-14	2	9.1	6.3	4	
Jan. 14-15	5	8.0	6.0	2	
Jan. 15-16	5	10.2	7.0	4	Jan. 15 camp shift
Jan. 16-17	5	9.8	6.8	3	
Jan. 17-18	2	9.2	6.8	3	
Jan. 18-19	8	4.5	4.0	4	Jan. 18 field camp pull-out
Averages		8.4	6.9		

(end)

3.06. Daily Distance Travelled

To guide plans for the future exploration of the planetary surfaces, the author collected data on transport distances during the 2012-2013 season. Of particular note are the long distances covered by Ski-Doo, which illustrate the importance of motorized transportation for exploring more than one or two kilometers from camp. In the table below, all values are in kilometers.

Date	Air	Auto	Ski-Doo	Foot	Notes
Nov. 26	2367	29	0	0.8	depart United States
Nov. 27	Lost to dateline crossing				
Nov. 28	12059	5	0	1.1	
Nov. 29	0	10	0	10.5	
Nov. 30	4100	29	0	1.3	Ice Flight
Dec. 1	0	0	0	4.5	
Dec. 2	0	0	0	0	
Dec. 3	0	2	0	2.9	
Dec. 4	0	0	20.0	0	snow school
Dec. 5	0	0	8.7	0	
Dec. 6	0	0	0	6.4	
Dec. 7	0	0	0	1.6	
Dec. 8	0	0	0	4.5	
Dec. 9	0	5	0	9.7	
Dec. 10	760	24	0	1.6	field camp put-in
Dec. 11	0	0	0	0	
Dec. 12	0	0	0	0	
Dec. 13	0	0	11.3	0	camp shift
Dec. 14	0	0	15.1	0	
Dec. 15	0	0	20.9	0	
Dec. 16	0	0	40.9	0	
Dec. 17	0	0	0	0	
Dec. 18	0	0	32.8	0	camp shift
Dec. 19	0	0	14.6	0	
Dec. 20	0	0	28.6	0	
Dec. 21	0	0	20.8	0	
Dec. 22	0	0	0	0	
Dec. 23	0	0	15.0	0	
Dec. 24	0	0	50.2	0	
Dec. 25	0	0	34.3	0	

(continued)

3.06. Daily Distance Travelled (continued)

All values are in kilometers.

Date	Air	Auto	Ski-Doo	Foot	Notes
Dec. 26	0	0	40.5	0	
Dec. 27	0	0	8.4	0	
Dec. 28	0	0	17.5	0	
Dec. 29	0	0	8.7	0	
Dec. 30	0	0	8.2	0	
Dec. 31	0	0	9.0	2.4	
Jan. 1	0	0	26	0	(data estimated)
Jan. 2	0	0	0	0	
Jan. 3	0	0	11.6	0	
Jan. 4	0	0	42.6	0	
Jan. 5	0	0	30.6	0	
Jan. 6	0	0	0	0	
Jan. 7	0	0	12.4	0	
Jan. 8	0	0	24.4	0	
Jan. 9	0	0	9.0	1.6	
Jan. 10	0	0	21	2.4	(data estimated}
Jan. 11	0	0	0	0	
Jan. 12	0	0	11.3	0	team medical emergency
Jan. 13	0	0	0	0	
Jan. 14	0	0	0	0	
Jan. 15	0	0	55.7	0	camp shift
Jan. 16	0	0	0	0	
Jan. 17	0	0	0	0	
Jan. 18	1790	0	0	0	field camp pull-out
Jan. 19	0	26	0	0	
Jan. 20	0	6	0	2.3	
Jan. 21	0	0	0	1.6	
Jan. 22	0	0	0	1.3	
Jan. 23	0	0	0	5.8	
Jan. 24	0	0	0	1.6	
Jan. 25	0	0	0	6.4	
Jan. 26	0	21	0	1.6	
Jan. 27	0	0	0	1.6	
Jan. 28	4100	26	0	2.4	retrograde flight
Jan. 29	0	14	0	11.3	
Jan. 30	16315	26.5	0	0	return to United States
Totals	41491	217.5	650.1	87.2	

(end)

3.07. 2004-2005 Personal Gear Packing List

On space missions, allowance for personal belongings is extremely limited. Antarctica is more lenient. The following is a list of the personal equipment the author brought to Antarctica for the 2004-2005 season.

Camping Gear: compression straps, camp chair, relief bottle, parachute cord, small cord, dromedary bag, pocket knife, Leatherman, knee pads, mess kit, extra space blanket, extra closed-cell foam pad, day bag, extra duffel bags, extra stuff sacks, garbage bags, trash compactor bags.

Laundry: laundry bag, wash basins, soap, clothespins, safety pins, sewing kit (needle, thimble, thread).

Diversions: cards, cribbage board, Hoyle's Rules, writing, drawing, journal, books, tent decorations, CD player, CDs.

Hygiene and Comfort: razors, soap, soap dish, comb, shaving brush, shaving mirror, synthetic body towel, synthetic face towel, synthetic washcloth, handkerchiefs, hand sanitizer, shampoo, toothpaste, toothbrush, dental floss, deodorant, nail clippers, ear plugs and backup ear plugs, eye shade, multivitamins, lip balm, sunscreen, hand moisturizer.

Spice Kit: salt, pepper, onion, garlic, cinnamon powder, cinnamon sticks, ginger, vanilla, cloves, cumin, chili, curry, oregano, sage, rosemary, basil, mustard powder, Tabasco.

Necessaries: pens and pencils, watch and instructions, camera, film or memory cards, lithium batteries, cash, traveler's checks, passport, driver's license, credit cards, plane tickets, sunglasses, calendar, Iridium phone card, standard phone card, envelopes, stamps, address book.

Medical Kit: over-the-counter medications, band-aids, skin glue, extra lip balm, extra skin moisturizer, antiseptic wipes.

Treats to Share: chewing gum, chocolate, holiday gifts, mulled cider.

Clothes: New Zealand: sleep shorts, loose jeans, belt, t-shirts, nice shirt, running shoes, light waterproof jacket, pile jacket, workout shorts, workout shirt, denim shorts, socks, underwear, wool cap, swimsuit.

Clothes: McMurdo: hiking shoes, long underwear, warm shirt, wind pants, wool socks, gloves, pillow stuff sack, puffy clothes to make the pillow.

Clothes: Field Camp: glacier glasses, baseball cap, down booties, synthetic sock liners, synthetic glove liners, synthetic undershorts, synthetic undershirts, extra wool socks, hats, face masks, extra long underwear.

3.08. 2012-2013 Personal Gear Packing List

The following is a list of the personal equipment the author brought to Antarctica for the 2012-2013 season. It reflects lessons learned from the 2004-2005 season.

Field Mess Kit: large non-insulated mug, dipping cup, large plastic bowl w/ lid, Banks fry-bake pan, channel-lock pliers, hot pad, plastic spoon, high-rim plate.

Field Gear: 1-liter relief bottle, small collapsible wash basin, large basin for hair and clothes, clotheslines (indoor & outdoor), laundry (compression) straps ×4, clothespins, big safety pins, Kill-A-Watt, thermometer, space blanket, gray foam pad for tent floor, plenty of extra parachute cord, wire ties, cable ties, sewing kit.

Field Health & Medical Supplies: toiletries organizer, large tube of hand sanitizer, swallow-safe toothpaste, SPF 50+ sunscreen (stick & alcohol), mirror, over-the-counter medications, baby wipes, second toothbrush, band-aids (incl. butterflies), extra lip balm, skin moisturizer, alcohol swabs, Ace bandage.

Field Treats and Diversions: chewing gum (50+ sticks), decorations, playing cards, cord for knots, holiday presents, puzzles, books, candy, mulled cider ingredients.

Field Camp Clothing: down booties, base layer, expedition-weight shirts ×2, good bibbed snow pants, good warm gloves, extra wool socks, expedition-weight long johns ×2, light-weight polypro shirt, light-weight long johns, extra base layer, extra synthetic glove liners.

Bath Kit: shampoo, Ivory soap, soap dish, synthetic washcloth, synthetic body towel.

Daily Necessities: cafe bag, official papers, water bottle, phone card & instructions, reading material, journal, MP3 player, earphones ×2, portable speaker, tablet computer & keyboard, charging cables, pencils, pencil leads, erasers, ballpoint pens, Sharpie, reading glasses & case, passport, small wallet, cash, driver's license, credit card, watch & instructions, sunglasses & retention strap, camera, batteries, SD cards.

Christchurch: Aviator bag, Southern planisphere, sleep shorts, loose jeans, shirts ×6 +crew polo +workout, running shoes, cotton socks, underwear, electric razor-trimmer & charger, small flashlight, light rain jacket, pile jacket, belt, shorts, C-130 ear protection, travel pillow.

Stationery Pouch: holiday cards to send, envelopes & stamps, address book, writing paper.

Overnight: TSA liquids bag, fluoride toothpaste, small refillable hand sanitizer, deodorant, sunscreen, lip balm, zipper pouch, toothbrush, sleep ear plugs and backups, multivitamins, pain reliever, comb, nail clippers, tweezers, handkerchiefs.

McMurdo: duffle bag for cage storage, expedition behavior notes, laundry bags ×2, hiking shoes with stow bag, pair of thick socks, wind pants, warm cap with ear flaps, neck gaiter (= eye shade), ski goggles & spare lenses, convertible mittens, snow school base layer (polypro sock liners, mid-weight socks, microfiber briefs, microfiber undershirt), Leatherman, pocket knife, square water bottle, spare sunglasses, DVD case with movies, flip-flops, lithium batteries, dead battery bag, spare watch battery.

3.09. List of NSF-Issued Field Gear

The following are complete lists of the equipment issued to the author by the Clothing Distribution Center in Christchurch and by the Berg Field Center in McMurdo for the 2012-2013 ANSMET field season.

<u>From the CDC in Christchurch</u>
"Big Red" down parka, "Little Red" wind breaker, insulated snow pants, bunny boots, orange duffel bags ×2, additional orange duffel bag with two full-body down suits as backup gear for the party, heavy grey wool socks ×4 pair, lightweight synthetic long johns, mid-weight synthetic long johns, heavy polar fleece pants, polar fleece jacket, leather mittens, wool mittens, leather insulated work gloves, giant bear-paw mitts, lightweight synthetic glove liners ×2 pair, lightweight long-sleeve synthetic undershirt, mid-weight long-sleeve synthetic undershirt, windproof cap with ear flaps and chin tie, fleece neck gaiter, ski goggles.

<u>From the BFC in McMurdo</u>
"Yazoo" hat with ear flaps and velcro at chin (replacement for ineffective CDC-issued windproof cap), large duffel bag for sleep kit, one-liter pee bottle (suitably marked), "Arctic Storm Long" down sleeping bag, stuff sack for sleeping bag, polar fleece sleeping bag liner, closed-cell foam sleeping pads ×2, "Thermarest" sleeping pad, large vacuum flask, small mountaineering rucksack, chemical hand-warmer packs ×50, first aid kit, signal mirror, "Stabilicer" ice crampons, small vacuum flask, cloth bag with assorted climbing gear, snow stakes ×2, bag of bungee cords, extra Ski-Doo tow rope, ice ax, ice chipper (steel chisel welded to end of steel rod), rock hammer.

3.10. Field Equipment Weight and Cube

The following pages list the 2012-2013 systematic search team's equipment for camp put-in, as documented by the Antarctic cargo system. The lists establish priority for various items and guide aircraft weight and balance calculations. Following Antarctic convention, the tables give weight in pounds and cube (volume) in cubic feet. The total weight of equipment delivered to the field, excluding the field team members themselves and the aviation fuel carried by the Twin Otter flights (which was used by the delivery aircraft, not the field team), was 23,682 pounds or 10,743 kg. The total volume, excluding passengers, aviation fuel, and the snowmobiles (for which volume was not recorded), was 1753 cubic feet or 49.6 m^3.

3.10. Field Equipment Weight and Cube (continued)

First LC-130 flight

LBS	CUBE	REMARKS
452	30	FLOOR BOARDS
22	3	DANGEROUS GOODS IN APPARATUS
2	1	MATCHES, SAFETY
1510	48	GASOLINE, PREMIX
1510	48	GASOLINE, PREMIX
140	39	SLED
140	39	SLED
37	2	PROPANE
37	2	PROPANE
37	2	PROPANE
37	2	PROPANE
37	2	PROPANE
570	152	SNOW GROOMER
135	38	NANSEN SLED
135	38	NANSEN SLED
37	7	RED TOOL BOX
104	7	BROWN SPARES BOX
22	1	FIRE EXTINGUISHERS
600	42	FOOD
621	42	FOOD (6 RIVER BOXES)
385	42	PERSONAL GEAR
385	42	PERSONAL GEAR
65	31	SIGLAN SLED
65	31	SIGLAN SLED
93	15	SCOTT TENT
87	15	SCOTT TENT
83	6	CAMPING GEAR/FOOD SUPPLIES
91	6	RADIOS/PHONES
450	42	PERSONAL GEAR BOX #2
490	42	FROZEN FOOD
700		SKI-DOO
700		SKI-DOO
700		SKI-DOO
700		SKI-DOO
1000		4 PAX
TOTAL		12179

(continued)

3.10. Field Equipment Weight and Cube (continued)

Second LC-130 flight

LBS	CUBE	REMARKS
700		SKI-DOO
700		SKI-DOO
700		SKI-DOO
700		SKI-DOO
155	8	COLLECTION MATERIALS
88	7	COLLECTION MATERIALS
40	2	PETROLEUM DISTILLATES
275	21	BAMBOO FLAGS
505	70	TENTS (3)/SIGLIN SLED (3)
170	40	OVEN/TP
265	44	BUCKETS/LIDS/DRUM CRADLES
22	3	DANGEROUS GOODS IN APPARATUS
24	4	GASOLINE
825	54	SOLAR UNITS/SOLAR PANELS/SKI-DOO PARTS
42	8	PANNIER
42	8	PANNIER
655	125	KOMATIK SLEDS (2)
140	39	NANSEN SLED (1)
1510	48	GASOLINE
370	42	PERSONAL GEAR
140	39	SLED
140	39	SLED
140	39	SLED
70	8	TP/PAPER TOWELS/SPILL KITS
999	88	PROPANE
78	5	SCIENCE SPARES
2	1	ETHANOL PURELL
105	15	SCOTT TENT
79	15	SCOTT TENT
515	42	GPS/METAL DETECTOR
1	1	CONSUMER COMMODITY
51	3	BAJA - BECK
360	28	FROZEN FOOD
405	42	PERSONAL GEAR
1000		4 PAX
TOTAL		12013

(continued)

3.10. Field Equipment Weight and Cube (continued)

Delivered later by Twin Otter

LBS	CUBE	REMARKS
1490	48	GASOLINE PREMIX
1633	48	FUEL, AVIATION, TURBINE ENGINE
1633	48	FUEL, AVIATION, TURBINE ENGINE

(end)

3.11. Use of Volume and Consumables in Camp

The crew's requirements for food, water, energy, and living and storage volume drive the design of space vehicles, habitats, and power systems. The following data from Antarctica may help guide calculations for future space missions.

3.11.01. Habitable volume

Living space aboard a spacecraft is expensive to design, build, and launch. But insufficient living space can cause psychological problems for the crew. The minimum necessary habitable volume for a given crew size and mission duration is not well understood.

ANSMET can provide some guidance in this area. The "habitation module" of an Antarctic field camp is the Scott tent. It houses two people in an internal volume of 4.3 m^3, with a floor area of 5.7 m^2. The experience of the 2012-2013 reconnaissance team, which was plagued by poor weather, demonstrates that 4.3 m^3 is enough space for two people to share for at least 13 consecutive days without causing interpersonal difficulties. Note, however, that the camp did have separate quarters, comparable in size to a Scott tent, for the latrine.

The 2004-2005 systematic search team did not have a dedicated tent for team gatherings. The 2012-2013 team did. Comparing the two suggests that there is a psychological advantage to having "neutral ground" for group activities. Thus, a space crew of 8 persons on a 40-day expedition might deserve a 4.3 m^3 volume, separate from their living quarters, for meetings and other gatherings. The 2012-2013 systematic search team also benefited from, but did not strictly require, yet another 4.3 m^3 Scott tent that was used variously as a bath house and as a shelter for Ski-Doo maintenance.

3.11.02. Stowage space

About half of the footprint of an ANSMET field camp is devoted to stowage of equipment and supplies that can endure the cold and that are rarely used inside the tent. This suggests that, for a 40-day expedition, stowage space should make up about half of the usable volume, with habitation space occupying the other half. Estimating the same quantity another way, the 2012-2013 systematic search team brought about 50 m^3 of logistics to the field (Section 3.10), while its tents provided about 30 m^3 of habitable volume. These figures yield a logistics fraction of about 60%.

Longer missions, with greater stores of equipment and supplies, might need a greater proportion of stowage volume. As noted in Section 3.13, McMurdo Station, which has major resupply opportunities once a year, devotes about 75% of its space to logistics.

3.11.03. Food

Packaged food for two people for a 40-day Antarctic field season, with reserves of about 30%, weighs about 80 kg and occupies about 0.5 m^3. This matches the National Outdoor Leadership School's recommendation of 2.0 to 2.5 pounds of food (0.9 to 1.1 kg, 3500 to 5000 calories) per person per day for moderate work in extremely cold conditions [16]. On a space mission with a controlled environment and strenuous daily exercise, NOLS guidelines suggest 1.75 to 2.0 pounds of food (0.8 to 0.9 kg, 3000 to 3500 calories) per person per day.

3.11.04. Water

A person in Antarctica consumes about 3 liters of water per day (6 liters for a two-person tent group), mostly for cooking and beverages.

3.11.05. Stove fuel

A two-person ANSMET tent group uses about 1.0 kg of propane fuel per day for heating and cooking. The combustion of propane yields about 50 MJ/kg. The time-average thermal energy use is thus about 300 W per person, or 2.6×10^7 J per person per day. Comparing fuel use on tent days (when the stove operated all day) and outdoor work days (when the stove ran only at mealtimes) suggests that about half of the thermal energy was used for cooking and the other half for space heating. On outdoor work days, the stove ran for about 1.5 hours at the morning meal and again at the evening meal, implying a peak thermal energy rate of about 2400 W for the two-person tent group. Cooking larger meals for four or eight people used a similar peak rate, but for longer times. Thermal energy use in the 2004-2005 season, which used white gas instead of propane, was similar.

3.11.06. Electrical power

In 2012-2013, electrical power use ranged from about 5 W to about 35 W for a two-person tent group. The higher value, corresponding to about 1.5×10^6 J per person per day, was the maximum the solar power units could deliver. The electricity was used for personal electronics and for the laptop computers and GPS units used to record and locate meteorite. Continuous daylight meant that no energy was needed for lighting.

3.11.07. Transport fuel

The 2012-2013 systematic search team burned about 2300 liters of pre-mix in their Ski-Doos, or about 7.2 liters per person per day. Using that fuel, each of the eight team members traveled about 650 km during the season (Section 3.06), or about 16 km per day. Gasoline contains about 35 MJ per liter. Transport energy consumption was thus about 2.5×10^8 J per person per day. For comparison, maximum electrical energy use was 1.5×10^6 J per person per day (about 200× less than transport), and stove energy use was 2.6×10^7 J per person per day (about 10× less than transport). Transportation thus consumed the overwhelming majority of the energy used in the field.

3.11.08. Summary of ANSMET volume and consumables use

Habitation volume, 4 people for 13 days .... 2 hab tents + latrine = 12.9 m^3
Habitation volume, 8 people for 40 days .... 4 hab tents + latrine + commons = 25.8 m^3
Stowage volume for 40 days .... 50 - 60% of camp, roughly equal to habitation volume
Food for one person .... 1.0 kg and 0.0063 m^3 per day
Water for one person .... 3 liters per day
Propane fuel for one person .... 0.5 kg per day
Thermal power (time average) .... 300 W per person
Thermal peak power .... 2400 W for a two-person tent group
Thermal energy .... 2.6×10^7 J per person per day
Thermal energy allocation .... half for cooking, half for space heating
Electrical power (time average) .... 2 - 18 W per person
Electrical energy (high limit) .... 1.5×10^6 J per person per day
Transport fuel .... 7.2 liters per person per day
Transport energy .... 2.5×10^8 J per person per day

3.12. Workload and Exertion

In space exploration and in space flight analogs, many tasks demand high mental workloads and strenuous physical exertion. Safely maneuvering a robotic arm using limited camera views is an example of the former. Manipulating massive pieces of equipment while maintaining body stabilization during a spacewalk is an example of the latter. Some space flight analogs have used the Likert scale to measure mental workload and the Borg rating to measure perceived exertion. Both scales are given below.

Likert Workload Rating Scale

1-2	Insignificant workload. Insignificant mental effort. Significant spare capacity remaining.
3-4	Light workload. Light mental effort. Desirable spare capacity remaining.
5-6	Moderate workload. Moderate mental effort. Enough spare capacity remaining.
7-8	Significant workload. Significant mental effort. Very little spare capacity remaining.
9-10	Maximum workload. Maximum mental effort. No spare capacity remaining.

Borg Rating of Perceived Exertion

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

(continued)

3.12. Workload and Exertion (continued)

Using the above scales, the author estimated workload and exertion for common tasks. The high elevation and bulky clothing contributed to the perceived exertion.

Workload and Exertion by Task

	Mental Workload		Physical Exertion	
	Average	Peak	Average	Peak
Cooking a meal in camp	2	5	7	9
Packing equipment	5	7	7	13
Chipping ice for water	1	1	9	11
Pulling food from camp storage	3	5	9	11
Fuelling Ski-Doo with hand pump	3	6	7	13
Ski-Doo daily maintenance	2	4	8	15
Ski-Doo undercarriage repair	4	7	13	20
Digging tent out of snow drift	1	2	15	19
Loading or unloading cargo plane	4	5	15	19
Shifting cargo	2	7	12	17
Loading cargo sledge	3	7	13	18
Setting up Scott tent	3	7	14	20
Ski-Doo traverse	1	6	7	12
Searching for meteorites on Ski-Doo	6	8	7	11
Searching for meteorites on foot	7	9	12	14
Collecting a meteorite	4	7	9	15

(end)

3.13. Data on McMurdo Station as a Model Space Settlement

Because of its extreme environment, its isolation, and its focus on operations, McMurdo Station is a good model for a future settlement on a celestial body. The following data on McMurdo may be useful for designers of those installations. The amount of area devoted to logistics is driven by the population, the amount of science and support activity, and the frequency of cargo ship visits (currently once per year).

Summer population (November through February)	900
Winter population (March through October)	150-200
Ratio of support staff to scientists	5:1
Ratio of males to females	3:1
Fresh water use (desalinated seawater)	14,000 liters per day
Average electrical power use (90% diesel, 10% wind)	1.7 MW
Fraction of solid waste that is recycled	65%
Major resupply interval	1 year
Storage and logistics space	about 75% of total settlement area

3.14. Informal Wind Speed Measurement Technique

As emphasized in this report, all outdoor activity in Antarctica is constrained by the speed and direction of the wind. For expedition members without instruments designed to measure wind speed, the following table may prove useful for making estimates in the field.

Urine Stream Anemometry*

Wind speed	Effects
Calm	Stream is steady, makes a hole in the snow about 1 cm across.
5 knots	Stream is unsteady, makes a hole a few cm across with a halo of droplet impacts.
10 knots	Stream breaks up before contact with snow. No defined hole. Instead, a scatter pattern of droplet impacts with a central tendency, a width of several cm, and significant downwind elongation.
15 knots	Stream breaks up after 30 cm of travel. Large irregular impact pattern.
20 knots	Stream breaks up after 20 cm of travel. Droplets whirl in turbulence downwind of subject. Unavoidable contamination of boots and pant cuffs.
25 knots	Extensive field of downwind and downhill surfaces sprinkled.
30+ knots	Outdoor urination not advisable.

*Calibrated for male subjects facing downwind.

3.15. An ANSMET Camp Recipe

"Polar White-Out" Seafood Chowder, field-tested at La Paz Ice Field and Larkman Nunatak, has plenty of calories to stoke the fires. It's easy to make. You can adjust the relative quantities of the ingredients and it will still taste good. The quantities given here make a main dish for a party of four.

Bacon, 1/2 pound
Butter, 1/2 stick = 4 tbsp. = 1/4 cup
Water, 1 quart
Frozen shrimps, 1/2 pound
Frozen scallops, 1/2 pound
Frozen cut corn, 1/2 pound
Powdered milk, 1 cup
Powdered or flaked potatoes, 1-2 cups for desired consistency
Powdered onion, 2 tbsp. or to taste
Powdered garlic, 1 tbsp. or to taste
Ground black pepper to taste
Optional spices: salt, Sazon Goya (monosodium glutamate), Tabasco sauce

Cut the bacon into little pieces. Set the stove to medium heat. Put a big cook pot on the stove and drop in the half stick of butter. When the butter has melted, dump in the bacon pieces and fry them in the butter, stirring periodically.

When the bacon is browned, add the quart of water. Add the frozen scallops, frozen shrimps, and frozen cut corn. Turn the heat up to bring the cold water and frozen ingredients to near boiling.

When the soup starts to boil, turn the heat down to avoid burning. Add the powdered milk, powdered onion, and powdered garlic.

Add the powdered or flaked potatoes, a little at a time, stirring thoroughly with each addition. Potato makes the chowder thicker, so if you want runnier soup use only 1 cup of potato. After the potato is in, keep the heat low and stir often to keep the soup from burning to the bottom of the pot, which makes a nasty cleanup job. If the bottom does burn while it's cooking, the soup will still taste fine as long as you don't mix the burned stuff into the rest of the soup.

Add ground black pepper to taste.

When the shrimps and scallops are done (about 10 minutes after they reached a boil), the chowder is ready to serve.

Optional: With all that bacon in there, you may not need any more salt, but you can add it if the soup tastes bland. Sazon Goya (monosodium glutamate) makes the chowder extra delicious. Glutamate is a neurotransmitter that causes unwanted side effects in some people. Check with your dining partners before adding it. A splash of Tabasco sauce also livens up the chowder.

4. Comparing ANSMET to space flight and to space flight analogs

This chapter describes three space missions (the Space Shuttle, the ISS, and a notional Mars mission) and three of NASA's space flight analogs (Desert RATS, NEEMO, and Pavilion Lake, all of which the author has participated in) in a format that invites comparison with ANSMET. Areas of interest are environment, mission duration, mission activities, habitats and vehicles, transportation, crew characteristics, crew training, crew equipment, typical crew day, risks and stressors, communication, resupply, remote participants, and public outreach. For the analogs, additional considerations are the ways in which they do and do not resemble space flight. Tables at the end of the chapter provide point-by-point comparisons of ANSMET to the missions and analogs. Eppler [2] gives similar comparisons between ANSMET and the Apollo moon missions.

4.01. Space Shuttle

This discussion is based on the author's experience as a crew member of Space Shuttle flight STS-122 (ISS assembly flight 1E) and as a Capcom in the Mission Control Center for many other Shuttle flights.

4.01.01. Environment

The Space Shuttle flew its missions in low Earth orbit at altitudes near and above 300 km. There, sky is black and the Earth rolls by underneath at an angular rate comparable to the view from an commercial airliner (which flies 30 times slower, and 30 times lower). The outside environment is airless and can be tolerated with the help of a 160-kg space suit. Unfiltered sunlight can cause eye damage in seconds. The solar day-night cycle is the same duration as the orbit period, about 90 minutes. People and objects in orbit are weightless. Shuttle crews lived in artificial surroundings for the full duration their missions.

4.01.02. Duration

Space Shuttle missions lasted 5-17 days. Typical ISS assembly flights were about 13 days long.

4.01.03. Mission priorities and major activities

Space Shuttle mission priorities varied according to the flight manifest. For ISS assembly missions, key priorities were to dock with the ISS, exchange ISS crew members, join new modules to the station using the ISS and Shuttle robotic arms, conduct spacewalks for assembly and repair, and transfer cargo to and from ISS. Major flight activities included ascent, heat shield inspection using the Shuttle's robot arm, rendezvous and docking with ISS, three or more two-person spacewalks, robot arm operations for assembly and for moving spacewalkers, undocking, a second heat shield inspection, and entry and landing.

4.01.04. Habitats and vehicles

Space Shuttle crews lived in the limited volume of the crew compartment. Most crew members slept in the middeck, which also contained the galley and the toilet. While docked, some crew members chose to sleep on the ISS, which offered more space and privacy. Spacewalkers had to sleep in the ISS airlock the night before an EVA at reduced air pressure as part of the protocol to reduce dissolved nitrogen in their bodies.

4.01.05. Getting there and back

The Space Shuttle served as its own transfer vehicle for space missions. Crews boarded the vehicle at Kennedy Space Center after a week of quarantine at JSC and KSC. They arrived at KSC by government air (usually T-38) from Ellington Field, midway through the quarantine week. Return from the landing site, either KSC or Edwards Air Force Base in California, was by government air (Gulfstream jet).

4.01.06. Crew size, composition, and roles

Space Shuttles typically carried crews of 6 or 7 people. Two, the Commander and Pilot, were military test pilots with primary responsibility for leading the mission and flying the vehicle. The rest were Mission Specialists whose background was in engineering or science and who focused on spacewalking, robotics, and flight engineer tasks. One person was designated as crew medical officer, receiving extra medical training if not already a physician. Before the 1986 Challenger accident, Space Shuttles sometimes carried Payload Specialists in place of one or more Mission Specialists. Payload Specialists were responsible for specific science or engineering experiments on their missions.

4.01.07. Crew training

Training for a Shuttle mission normally lasted 12 to 18 months, but could be longer for exceptionally challenging flights or when delays arose. A typical training week was 40 hours, but could be longer as the launch date approached. Training included single-system lessons; simulations ("sims") with and without the Mission Control Center for ascent, orbit, and rendezvous; robotics and EVA simulations in computer rendered environments; spacewalking training in the Neutral Buoyancy Laboratory (NBL); aviation and crew coordination experience in the T-38; teambuilding exercises including the possibility of a NOLS expedition; visits to facilities where flight hardware was being prepared for the mission; hands-on interaction with flight hardware; and physical fitness training.

4.01.08. Important crew equipment

Each Shuttle astronaut had an assigned middeck locker drawer to hold their clothing and a bare minimum of personal gear, usually limited to a flashlight, clipboard, pocket knife, and basic toiletries. Each crew member was allowed to carry a notebook with reminders and reference information gathered during their training. Crew notebooks often contained information that for one reason or another could not be included in the vehicle's official documentation. Crews chose their own menus for the flight from an assortment of available dishes. Food was stored in a community locker but, the packets had colored stickers to identify which crewmember they belonged to. Each crew member had an assigned launch and entry suit. Spacewalking crewmembers each had a customized space suit or shared a suit with another crewmember and reconfigured it between spacewalks. Crewmembers could bring a limited number of mementos to give to friends and family after the flight.

4.01.09. Typical crew day

Shuttle crews worked 16-hour days. Although mission timelines provided generous "post-sleep," "midday meal," and "pre-sleep" periods (respectively, 1.5 to 2.5 hours for breakfast and morning hygiene, 1 hour for lunch, and 1.5 to 2.5 hours for dinner and personal time), in practice crews often worked through all of these. All midday meals, and some breakfasts and dinners, were eaten on the fly. Personal time was less than one hour per day, and often taken in lieu of sleep. The sleep period was scheduled for eight hours but many crew members did not sleep that long.

Daily activities included Shuttle systems maintenance and reconfiguration, robotic operations, EVAs, orbit adjustment burns, "proximity operations" such as docking and undocking, satellite deployments and captures, work with onboard payloads and experiments, cargo documentation and transfer, and public outreach activities.

4.01.10. Major risks and stressors

Major risks on a Space Shuttle flight were many and varied. Shuttle accidents in 1986 and 2003 killed crews on ascent and entry. Orbital debris posed a significant hazard, as did collision and fire. Spacewalking crewmembers faced a risk of decompression sickness. Radiation was monitored but posed little health hazard for Shuttle missions, which were short and restricted to low orbit. The risk of death on a Shuttle flight was about 1 in 60.

Besides physical danger, major stressors included isolation, confinement, public visibility, the knowledge that every action was being evaluated, poor sleep, close quarters, lack of privacy, difficulty keeping clean, a challenging workload, separation from family and friends, additional timeline pressure when tasks ran long, operations with fragile and irreplaceable flight hardware, and lack of unstructured time.

4.01.11. Communication

Voice communication channels to the Mission Control Center were open almost continuously. About half of the time a video downlink channel, via the high-rate Ku-band system, was available as well. Work-related and personal communication via e-mail was possible, with the mail uplinked and downlinked about three times per day, but crews had little time to type long messages. Data files could be uplinked and downlinked through the Ku system as required. Each crewmember had one or two private medical conferences during the flight. Unscheduled medical consultations could be set up as needed. Private family communication sessions via video teleconference were scheduled for each crewmember once or twice per mission.

4.01.12. Resupply

Resupply to a Shuttle in flight was not possible. The Shuttle itself functioned as a resupply vehicle for the ISS.

4.01.13. Remote participants

Remote participants in Shuttle missions included the Mission Control Center, ground control entities for various Shuttle payloads, and space stations such as ISS and Mir along with their own control centers.

4.01.14. Public outreach

The media eagerly followed Shuttle flights, with hundreds of reporters present at launches, dozens at landings, many daily news stories during flights, continuous real-time coverage on NASA TV during flights, and two or more live media interviews with Shuttle crewmembers on most missions. NASA produced press kits and provided accommodations for reporters at KSC and JSC.

4.02. International Space Station

This discussion is based on the author's ISS crew training, duties as the Crew Support Astronaut for the crew of ISS Expedition 18, experience as a Capcom for many ISS expeditions, and seven days at ISS during STS-122.

4.02.01. Environment

The ISS operates in the same low Earth orbit environment as did Shuttle, about 320 km high. The key attributes are airlessness, weightlessness, and 90-minute orbital and day-night cycles. Crews live in engineered surroundings for the full duration of the mission.

4.02.02. Duration

The shortest ISS crew stays occurred during the Shuttle era and lasted as little as 30 days. Today's ISS crews remain there for about 180 days. Tourists and guest astronauts who travel to the ISS on an upcoming Soyuz and then return with the crew of an older Soyuz stay for 7-10 days.

4.02.03. Mission priorities and major activities

While the ISS was under construction, its crews focused on assembly tasks. Now that the ISS is complete, crews work on maintenance and payload science. Several times a year, crews do spacewalks to reconfigure or repair equipment outside. The robot arm captures and berths some visiting vehicles. Major events also include the arrival, unpacking, repacking, and departure of unpiloted cargo ships, such as the Russian Progress vehicle, the European Automated Transfer Vehicle (ATV), the Japanese H-II Transfer Vehicle (HTV), and the commercial Dragon and Cygnus capsules.

4.02.04. Habitats and vehicles

ISS crews live and work in its pressurized modules. At the time of this writing, the habitable volume includes the Russian Service Module; the Functional Cargo Block; Nodes 1, 2, and 3; the Airlock; the US Lab; the European Columbus module; the Japanese Kibo module; stowage modules attached to Node 1 and Kibo, and airlock and docking modules attached to the Service Module and Functional Cargo Block. Crewmembers from the US, Japan, Europe, and Canada, and Russia sleep in Node 2, in dedicated sleep quarters measuring about 1×1×2 meters. The sleep stations have doors, soundproofing, extra radiation shielding, and a few comfort items. Russian crewmembers occupy two "kayuta" sleep stations in the Service Module that have small individual windows. The Service Module also has a galley, a dining table, and a toilet. The United States Orbital Segment (USOS) has its own eating and waste management accommodations in Node 1 and Node 3 respectively.

Many different vehicles visit the ISS. During construction, Space Shuttles docked to the ISS for about seven days of intensive assembly work. Soyuz spacecraft ferry crewmembers up and down, remaining docked for six months at a time before returning to Earth. Management of docking ports may require a Soyuz to relocate to a different port partway through its stay in orbit. Progress cargo ships dock to the Russian Orbital Segment (ROS) for several weeks. During that time, crews unload the goods they carry. Their breathing gas and propellant reserves may be transferred to the ISS, and their thrusters may be used to reboost the ISS. When a Progress is empty, the crew fills it with trash. At the end of its life, the Progress is undocked by remote control and incinerated during re-entry over the southern Pacific ocean. European ATVs have a similar mission profile. Japan's HTVs also carry cargo and remove trash, but they are not used for reboost. Their docking scheme requires them to fly close formation with the ISS where the crew can capture them with the robotic arm and berth them to the ISS. SpaceX Dragon and Orbital Sciences Cygnus cargo vehicles are also berthed using the arm. Uniquely among the unpiloted ships that visit the ISS, Dragon capsules re-enter the Earth's atmosphere and land intact. They can return cargo to the ground.

4.02.05. Getting there and back

During construction, crews rode to and from the ISS on Space Shuttles launching from and normally landing in Florida, and on Soyuz vehicles launching from Baikonur Cosmodrome in Kazakhstan and landing on the sparsely-inhabited steppes of the same country. Since the retirement of the Shuttle, the Soyuz has been the sole provider of ISS crew transportation.

4.02.06. Crew size, composition, and roles

The nominal ISS crew size is six people: three Russian cosmonauts, two American astronauts, and one Canadian, European, or Japanese astronaut. The Soyuz launch and landing schedule sometimes leaves only three people on the ISS for a period of weeks. One crewmember is always designated as Commander. The others are Flight Engineers. Command rotates among the international agencies, with a Russian in command half the time, an American a little less than half the time, and occasional commanders from Canada, Europe, and Japan. On the USOS, one crewmember is usually designated as the lead for the robot arm, one as the lead spacewalker, and one as the crew medical officer.

4.02.07. Crew training

Training for a 180-day ISS mission takes about two and a half years, but took up to four years for the first ISS crews and may be reduced to about two years for veteran flyers. Training is scheduled for about 40 hours a week. About half of the training for US crewmembers occurs overseas, mostly in Russia. Major training topics include spacewalking, robot arm operation (including track-and-capture for visiting vehicles), systems knowledge for all US and international partner modules, crew coordination in the T-38 and in expedition settings, scientific payloads, cold-weather and water survival training in Russia, and physical fitness.

4.02.08. Important crew equipment

Strict mass and volume limitations keep ISS crewmembers from bringing much personal equipment. They choose their food and wardrobes before flight. These items are brought to ISS on cargo ships before or after their own launch. ISS crews carry personal notebooks much like Shuttle crews did. They have access to laptop computers on orbit and may carry a considerable store of electronic media because it is easily transported. Each crewmember is issued a Sokol suit and a custom-fitted seat liner for launch and entry on Soyuz. EVA suits are assembled for each crew member as needed from the store of components on ISS. Crewmembers can carry a limited number of mementos for friends and family.

4.02.09. Typical crew day

ISS crews work slightly less aggressive schedules than Shuttle crews did, in keeping with the longer duration of their missions. As discussed in Section 3.04 above, the daily schedule allocates 8.5 hours for the sleep period; 2.5 hours for mandatory physical exercise; 4.5 hours for meals and self- care; 2.0 hours for daily planning conferences, work preparation, and plan familiarization; and 6.5 hours for scheduled work.

Work on the ISS is a mix of science payload operations and systems maintenance. Adjustments to the vehicle's orbit and attitude are commanded from the ground. Spacewalks are uncommon. Robotic operations in support of visiting vehicles occur every few weeks. Media and education events are scheduled several times a week. Because of the long duration of ISS training flows and missions, crews engage in some on-board training to refresh their skills.

4.02.10. Major risks and stressors

Major risks on ISS are similar to those on Shuttle, including collision and fire. Radiation is a larger concern because of the longer duration of the flight. Crews have had to take temporary refuge in shielded parts of ISS during high radiation events, and have had to suit up and shelter in the Soyuz for predicted close encounters with orbital debris that were recognized too late to schedule an avoidance maneuver.

ISS crews face stress related to high cost of failure, public visibility, continual evaluation, high workload (compounded by the long flight duration), and a potentially uncomfortable living environment. Additional stressors include protracted confinement in a limited volume and long-term isolation from family and friends.

4.02.11. Communication

The ISS stays in communication with ground control centers in the US and Russia almost continuously. Additional centers in Europe and Japan also support the ISS. At least seven independent voice channels exist. The ISS sends four channels of video to the ground about half the time. Private and work-related e-mail is exchanged with the ground at least three times a day, and an unmonitored Internet-protocol phone is available for the crew's private use. The phone uses the same communication assets that carry the ISS video downlink. Data files are uplinked and downlinked as needed. The crew enjoy a live, if slow, Internet connection for official and personal use. Private medical conferences and private family conferences are scheduled weekly. At the end of each work week the crew have a private conference with the leaders of their support staff on Earth, in which all parties can communicate candidly about how the mission is going.

4.02.12. Resupply

Resupply to the ISS is an ongoing concern, with manifests planned months to years in advance. Progress, HTV, ATV, Dragon, and Cygnus vessels bring cargo to station. Trash-filled Progresses, HTVs, ATVs, and Cygnuses are incinerated during entry over the south Pacific. Dragon capsules return cargo intact to the ground. As of 2013, each year the ISS receives about six visiting vehicles: four Progresses, one HTV or ATV, and one Dragon or Cygnus. Payload capacities of these vehicles vary from about 2.5 to 7 tons. HTV and Dragon can carry both pressurized and unpressurized cargo.

4.02.13. Remote participants

Remote participants in ISS missions include major control centers in Houston, Moscow, Huntsville (Alabama), Tsukuba (Japan), and Munich (Germany). Huntsville and Munich are in turn served by numerous subsidiary research centers responsible for science investigations on ISS.

4.02.14. Public outreach

ISS crews speak with media entities and educational institutions several times a week, but the mass media do not cover ISS activities on a daily basis as they did for Space Shuttle flights. Each expedition has press releases and media kits. A moderate level of news coverage accompanies Soyuz launches and landings. The financial, logistical, and bureaucratic demands of traveling to Kazakhstan and gaining access to Baikonur limit Western press attendance at Soyuz launches.

4.03. A Future Mars Mission

As in Section 1.03, this discussion is based on Mars DRA 5.0 [10].

4.03.01. Environment

The crew of a future Mars mission will operate in a variety of environments: low Earth orbit, interplanetary space, Mars orbit, and the surface of Mars. None of these has a breathable atmosphere, so leaving any vehicle or habitat will require a full pressure suit. Extremes of cold occur on the surface of Mars. A hot environment is possible if the interplanetary trajectory passes inside the orbit of Earth. In space, crews are weightless. Mars has partial gravity, about 0.38 times that of Earth. Mars mission flight and surface environments both have more radiation than low Earth orbit. During interplanetary transit the vehicle will be in constant sunlight. Crews will experience light-dark cycles when in orbit around a planet. On the surface of Mars, the day-night cycle lasts 24 hours and 39 minutes. The division between light and dark time varies with latitude and season. The crew will inhabit artificial environments for the duration of the mission. They will experience natural surroundings during EVAs on Mars.

4.03.02. Duration

Mars missions may take about 600 days for an opposition-class flight, or about 1000 days for a conjunction-class flight. There are advantages and disadvantages to both types of mission, as discussed in Mars DRA 5.0 [10].

4.03.03. Mission priorities and major activities

Mars DRA 5.0 describes systems dedicated to sending a crew to Mars and bringing them back safely. Major activities to accomplish that goal include construction of three large spacecraft in low Earth orbit; Earth departure; interplanetary transit; storage in Mars orbit or entry, descent and landing on Mars of the unmanned first and second craft; launch of the crew to LEO; rendezvous with the third craft, which carries the crew to Mars; Earth departure; interplanetary transit; Mars orbit operations; entry, descent, and landing at Mars; human surface activities including geology, biology, other science, and EVAs; crew launch from Mars; a second interplanetary transit phase; and entry, descent, and landing at Earth. Life science research, with the crew as subjects, will be a major activity during transit.

4.03.04. Habitats and vehicles

In Mars DRA 5.0, the crew launches from Earth in a small capsule, rides to Mars in a habitat module that remains in orbit around Mars, and lands on Mars in a combined descent module and surface habitat. They launch from Mars in a separate ascent vehicle, cruise back to Earth in the same habitat in which they rode out to Mars, and land on Earth in the capsule in which they launched.

4.03.05. Getting there and back

The Mars architecture serves as its own suite of transfer vehicles. The Mars crew will presumably launch from KSC, to which they will travel via government air. Landing sites on Earth may be constrained by the geometry of the return trajectory from Mars. After landing, the crew will return to their home institution by government air.

4.03.06. Crew size, composition, and roles

To assure an adequate mix of skills, to accommodate astronauts from US and international partners, and to reduce adverse social dynamics that can occur in isolated, confined groups, the preferred size of a Mars crew is six. One will be designated as mission commander. A crew physician and a lead planetary geologist are also likely to be named. Other crewmembers will be assigned as needed. Providing backups for critical skills will be an important consideration in crew selection.

4.03.07. Crew training

Crew training for a Mars flight is likely to last three or more years. Given the long transit times and the finite residence time of knowledge in a person's brain, Mars crews may also train during interplanetary cruise. Training may both develop new skills refresh old ones, and may cover spacecraft systems; launch, rendezvous, entry, and landing at both Earth and Mars; and Mars surface activities.

4.03.08. Important crew equipment

As in Shuttle and ISS missions, crew members will have personal suits for launch and entry and for EVA. Because of the long flight duration and the impossibility of responsive resupply, crews may want to bring more personal effects than have been allowed on Shuttle or ISS. Personal clothing and favorite foods will be psychologically important, but will also contribute to crew system mass.

4.03.09. Typical crew day

A typical crew day during transit to and from Mars will probably resemble a day on ISS, with sleep, meals, exercise, science, and maintenance activities. On Mars, daily tasking will focus on EVAs to explore the planet.

4.03.10. Major risks and stressors

Risks on a Mars flight will include ascent and entry accidents, fire, collision, system failure, radiation, decompression sickness, physiological effects of weightlessness, psychological pressure, and hazardous natural materials on Mars. Stressors beyond the physical danger will include long confinement, separation from loved ones, monotony, operations with irreplaceable flight hardware, public visibility, constant evaluation, poor sleep, close quarters, lack of privacy, difficulty keeping clean, a challenging workload, and timeline pressure. The long mission duration and impossibility of rapid return to Earth increase the likelihood and consequences of serious illnesses and psychological problems.

4.03.11. Communication

Communication with the ground control center via voice, video, and electronic files will be pervasive on a Mars flight, but speed-of-light time delay will limit the bandwidth and timeliness of all communication [11,19].

4.03.12. Resupply

Because of the geometry of planetary orbits, responsive resupply is not possible for Mars missions. The only resources available will be those brought along with the crew and robotically pre-emplaced on Mars.

4.03.13. Remote participants

The ground control center will be the main remote participant in a Mars flight. Other entities on Earth may interact with the crew, but only through the main communication link with the control center.

4.03.14. Public outreach

Public involvement with a Mars mission will be pervasive but managed by the ground. A large media presence, encouraged by NASA press kits and accommodations for reporters, is likely at launch and landing. Live interviews with the crew will be impossible during most of the flight because of communication delays [11], but NASA and the public will eagerly follow blogs and pre-recorded messages sent by the crew.

4.04. NASA Extreme Environment Mission Operations (NEEMO)

NASA conducted numerous NEEMO missions (Fig. 11) over many years, with variation in their durations and priorities. This discussion is based on NEEMO XVI, which was conducted in June, 2012. The author participated in NEEMO XVI as a Capcom and as a pilot of DeepWorker 2000 submersibles.

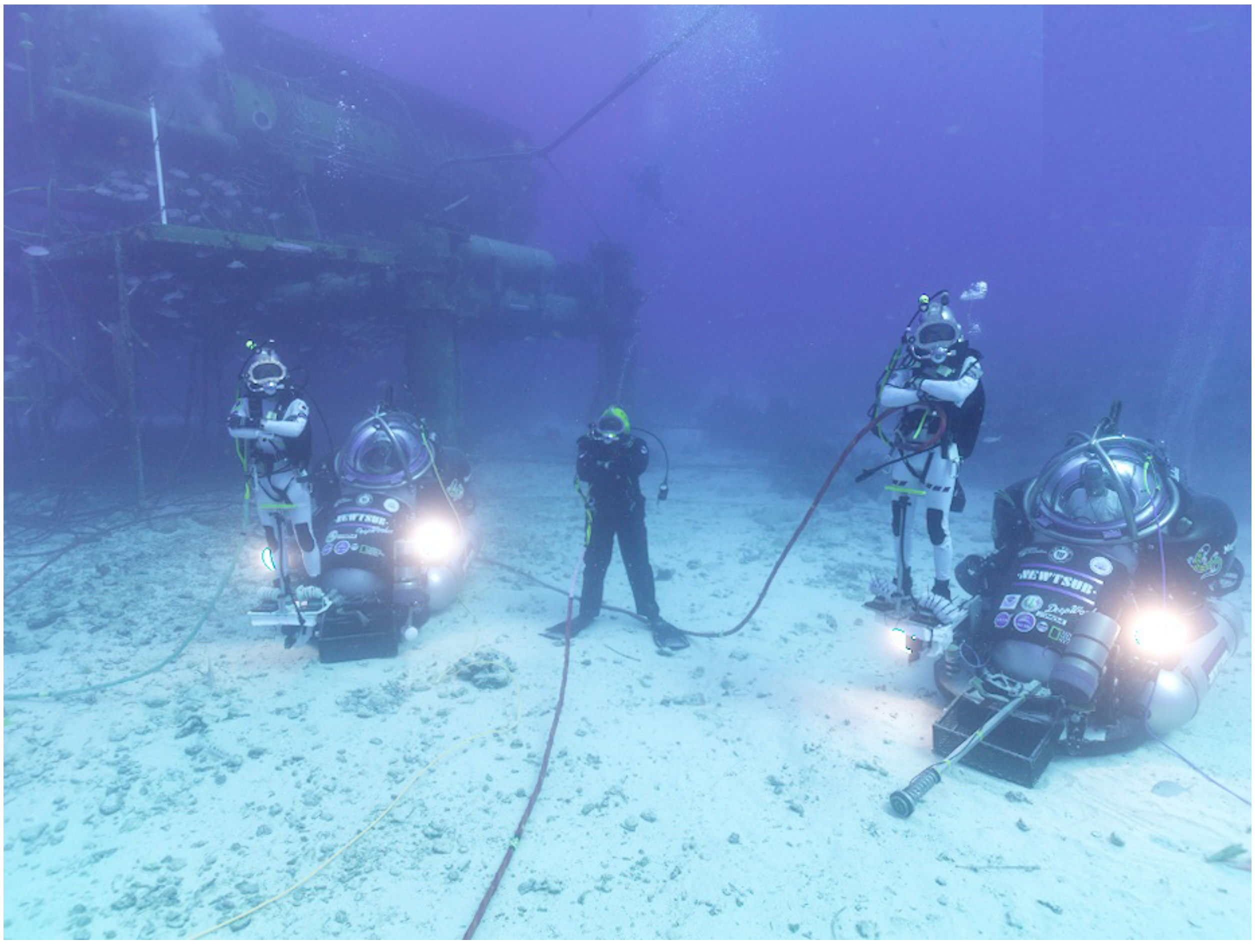

Figure 11. DeepWorker subs, "EVA" astronauts, and the Aquarius habitat at NEEMO.

4.04.01. Environment

NEEMO used the Aquarius underwater habitat, located at a depth of 14.5 m in the sea off Key Largo, Florida. Except during the one-day decompression period at the end of the mission, the air pressure in the habitat matches the water pressure outside, about 2.5 atmospheres. Fast return to the surface would cause dangerous decompression sickness. The air in the habitat is the same temperature as the water outside (about 25° C) and humid. The underwater environment outside does not support human life. The day-night cycle is normal, with light and dark periods that alternate on a 24-hour cycle. Outside the habitat, NEEMO "aquanauts" were effectively weightless because of the buoyancy of the water. With added weights they could simulate working on the Moon or Mars. The habitat is an engineered environment. Crews worked in both artificial and natural environments when outside.

4.04.02. Duration

A NEEMO mission lasted about 10 days.

4.04.03. Mission priorities and major activities

NEEMO mission priorities have varied. NEEMO XVI focused on human exploration of asteroids. Crews spent several hours a day on "EVA" excursions outside the habitat, testing tools and techniques for work on solar system bodies with negligible gravity and irregular surfaces. They also interacted with DeepWorker submersibles that acted as small, maneuverable "spacecraft." An artificial time lag was introduced into communications with the shore station to mimic the speed-of-light delay for operations in deep space. Major activities included "splashdown" and taking up residence in the habitat. There were multiple EVAs on most days. At the end of the test, there was a 17-hour decompression period with hatches closed, followed by "splash-up" to the surface.

4.04.04. Habitats and vehicles

NEEMO crews lived in the Aquarius habitat. The habitat receives air, power, and communications from the Life Support Buoy, a diesel-powered installation moored above it. In NEEMO

XVI, DeepWorker submersibles aided in the test. Surface support ships launched and recovered the subs. NEEMO XVI employed the Lana Rose, a commercial boat, and later the Liberty Star, a former Space Shuttle solid rocket motor recovery ship from KSC. Divers and workers traveled between the shore facility in Key Largo and the habitat on Conch Reef using an assortment of NASA and NOAA small craft, including Latency, an aluminum landing craft from KSC, and the George F. Bond, a NOAA dive boat with an onboard recompression chamber.

4.04.05. Getting there and back

Participants in NEEMO flew commercial air to southern Florida, then drove rental cars to Key Largo. The boats discussed above provided transportation to and from the work area. Crew members entered and left the habitat using scuba equipment.

4.04.06. Crew size, composition, and roles

NEEMO crews consisted of six people, the maximum capacity of the Aquarius habitat. Two crew members were technicians responsible for the operation and maintenance of the facility. They played little or no role in NASA activities. The remaining crewmembers were engineers and astronauts from NASA and other ISS partner agencies. One aquanaut, generally an astronaut with space flight experience, was designated the commander. The others were flight engineers.

4.04.07. Crew training

The saturation dive environment of NEEMO demanded more training than NASA's other space flight analogs. Crews had to pass a challenging swim test and participate in a week of training at their home institutions before travelling to Florida. They arrived in Key Largo a week before splashdown for further training before the mission.

4.04.08. Important crew equipment

As in a space mission, NEEMO crews had personal "EVA" equipment: wetsuits and dive helmets. They could bring laptop computers to the habitat, and also some clothing and other personal items. In NEEMO XVI each crew member also had an iPad for communicating and for viewing electronic procedures.

4.04.09. Typical crew day

Crew time in NEEMO was focused on EVA. Crews woke at 0600 for morning hygiene and breakfast. They participated in a daily planning conference with the control center topside in Key Largo, then prepared for the first spacewalk of the day, in which two NASA aquanauts went outside with one of the habitat technicians as a safety observer. The other two NASA personnel stayed in the habitat, one working as IV and the other monitoring the operaton and taking care of other indoor tasks such as writing the day's public blog entry. At midday the first team of spacewalkers returned to the habitat and secured their dive gear. The crew then ate a meal together. In the afternoon the crew members swapped roles, with the morning EVA crew assuming the IV and habitat responsibilities, and the others taking their turn outside. The second EVA ended late in the afternoon and was followed by another daily planning conference with the control center. After the conference, the crew shared an evening meal, then had some personal time for keeping journals, taking pictures, and communicating with friends and family via e-mail.

4.04.10. Major risks and stressors

Major risks in NEEMO included drowning, habitat leaks, system failure, hazardous ocean currents, and poisonous and carnivorous wildlife. A NOAA diver drowned while working near Aquarius in 2009. Other stressors in NEEMO included confinement, isolation, high workload, public visibility (including being on camera for much of the day), and lack of privacy.

4.04.11. Communication

NEEMO XVI participants had audio and video communication with the control center most of the time, but the link included a built-in delay of 50 s each way to simulate operations at a near-Earth asteroid 0.1 Astronomical Units (AU) away. Data files traveled to and from the habitat the same way. Mission communications during work hours resembled that of a real space flight. A real-time voice channel with the topside Watch Desk was always available in case of emergency.

4.04.12. Resupply

Aquarius is resupplied via "potting." Topside crews place goods in a sealed metal container and lower it down to the sea floor, where a diver swims it to the habitat. Pots travel up and down daily. Topside personnel are available to gather items as needed and bring them to the Watch Desk to be potted down the next day. Resupply is thus responsive, but limited in quantity. Trash and items no longer needed in the habitat are potted back up to the surface.

4.04.13. Remote participants

NEEMO tests involved the crew in the habitat, the habitat's Watch Desk, a "flight control" team in the control center, and a "flight following" control center at NASA Johnson Space Center. The crew participated in outreach events with media and educational partners across the United States. The NEEMO XVI crew spoke on audio loops with the crew of the ISS.

4.04.14. Public outreach

The public outreach effort surrounding a NEEMO mission was similar to that of a space mission, but smaller in scale. For NEEMO XVI, NASA provided press kits and issued press releases, and made accommodations for media representatives. Crews spoke with reporters and schools. NEEMO support personnel gave media interviews in Key Largo. Local schools brought busloads of children to the control center to observe the operation and ask questions.

4.04.15. How it resembled space flight

NEEMO's main similarity to space flight was its underwater environment, which was hostile to human life and simulated weightlessness. Mission durations were similar to a Shuttle flight. Other similarities were system maintenance activities, EVAs with their attendant preparatory and recovery work, dependence on artificial life support systems, confinement in a limited volume, the impossibility of quick return to a safe and normal environment, crew size and composition, and limited personal equipment,. NEEMO daily schedules were similar to those of ISS. Risks and stressors for the crew were milder than those on a space flight, but similar in quality. Communication with the surface accurately mimicked a space mission. There was a formal mission control center. Public outreach was similar to a space flight.

4.04.16. How it did not resemble space flight

NEEMO demanded much less training than space flight. Mission durations were much shorter than an ISS expedition or a Mars flight. Resupply was easy and responsive.

4.05. Desert Research and Technology Studies (Desert RATS)

Desert RATS (Fig. 12) began in the 1990s and has been conducted irregularly ever since, usually at geologically interesting sites in Arizona. This discussion is based on Desert RATS 2010, which was conducted in September of that year. The author participated as the driver of one of the test's two prototype rovers.

4.05.01. Environment

Desert RATS took place at various venues in Arizona over its history. The 2010 test explored the Black Point Lava Field at Parker Ranch, north of Flagstaff, Arizona, at elevations around 2000 m. The climate was arid. Daytime high temperatures reached 35° C, with nighttime lows near 20° C. The terrain was rolling plains, interspersed with recent lava flows and volcanic cinder cones. Vegetation at the lower elevations was limited to grass and sagebrush, with juniper at higher elevations. Day-night cycles were normal for the season. The outside environment was not hazardous. In 2010, Desert RATS crews lived and slept inside vehicles that were prototypes for future pressurized rovers. They thus spent most of their time in an engineered environment. A natural setting was always visible outside the windows, and crews spent two or more hours a day outside on shirtsleeve "EVAs".

Figure 12. Rover and crew at Desert RATS.

4.05.02. Duration

Desert RATS 2010 was a 14-day effort, but the crews changed halfway through, so each crew spent seven continuous days in the simulation. Other Desert RATS tests have lasted 7-14 days.

4.05.03. Mission priorities and major activities

Desert RATS tested tools and techniques for planetary surface exploration under simulated mission conditions in a geologically relevant setting. Desert RATS 2010 focused on the "Space Exploration Vehicle," a prototype crew cabin that could be mounted on electrically-driven wheels to explore the Moon or Mars, or on a propulsive sled for weightless environments. Crews also tested geological sampling tools and wrist-mounted information displays. Major activities included driving between geological work sites, describing the geology of the area, conducting three 30-60 minute "EVAs" per day, and operating and maintaining ancillary systems in the rover. The air conditioner demanded a noteworthy amount of repair effort. Each day the crew spent about one hour completing questionnaires about the human-factors properties of the rover and other test equipment. Desert RATS 2010 also explored how the mission's scientific productivity depended on whether communication with the ground was available continuously or only twice a day, and on whether the rovers traveled separately or close together.

4.05.04. Habitats and vehicles

Desert RATS 2010 crews lived in their rovers. They also spent one day working in a prototype Deep Space Habitat. Four-wheel-drive pickup trucks accompanied the rovers, carrying generators to recharge the batteries that powered the rovers' drive wheels and ancillary systems.

4.05.05. Getting there and back

Desert RATS 2010 crews flew commercial air to Phoenix, Arizona. They drove rental cars to Flagstaff and then to a base camp near the work site.

4.05.06. Crew size, composition, and roles

The typical size of a Desert RATS crew was 4 persons. In the 2010 test, each seven-day session employed two rover crews, each of which consisted of one astronaut and one geologist, for a total of four people. A second seven-day session with different crews brought the total number of participants to eight.

Each rover had a commander. One of the two rover commanders was also designated overall team commander.

4.05.07. Crew training

Crew training for Desert RATS varied. For the 2010 expedition, there was one week of dedicated training at Johnson Space Center before the test. The training week included an overnight stay in the rover. Additional training sessions occurred at intervals before and after the main training week. The most valuable training for the crew, and for the rest of the mission team, was provided by the "dry run" on the first day in the field. Many unanticipated problems were discovered and solved on that day.

4.05.08. Important crew equipment

Desert RATS crews were permitted a small amount of personal gear, mostly clothing. Unlike Space Shuttle and ISS missions, the 2010 Desert RATS expedition allowed little crew input into the menu. Each crewmember had a dedicated EVA backpack. Crew members were issued laptop computers for mission purposes and could bring their own computer for personal use.

4.05.09. Typical crew day

The crew day in Desert RATS 2010 began with wakeup at 0600, plan review and breakfast until 0800, and a daily planning conference with the control center. Following the conference was a 30-minute period of rover activation and checkout. Over the course of the day, the rovers would drive 10-15 km, usually with three stops for terrain imaging and geological exploration "EVAs." An hour was usually scheduled for lunch, but on most days that time was used to recover from earlier delays and the crew had to eat on the fly. At the end of the work day, usually around 1700, the crew would park the rover for the night, prepare and eat dinner, fill out questionnaires, and then enjoy a limited amount of personal time for movies or journal writing before lights-out at around 2200.

4.05.10. Major risks and stressors

Risks in Desert RATS 2010 were small compared to space flight or NEEMO, because the outside environment was benign and there were no systems upon which the crew's lives depended. Heat illness, sun exposure, and rattlesnakes were the greatest threats. Stressors included isolation, confinement, close quarters, high workload, and poor odor control in the onboard toilet. Crews were also under camera surveillance for the entire workday.

4.05.11. Communication

In Desert RATS 2010, the rovers communicated with a control center at base camp. Depending on the conditions being tested, communication was either continuous or limited to the morning and evening. Rover crews had direct lines to the support personnel following the rovers. Communication with the control center was sometimes lost because of the hilly terrain. Transfer of data files proceeded both with radio and with physical media handed in and out of the rover. At one overnight parking site near a highway, cellular network coverage allowed crews to call home. Mission communication during working hours resembled that of a real space flight.

4.05.12. Resupply

The rovers carried supplies for the duration of the mission. Resupply of necessary parts and spares was accomplished on demand. Items not readily available at the field site could sometimes be fetched from shops in Flagstaff within a few hours.

Trash and latrine waste were unloaded from the vehicle via a "suit port transfer module." This was a container that interfaced with the mechanism used to connect space suits to the back of the vehicle, allowing material to pass in and out. Crews took the trash out about every three days.

4.05.13. Remote participants

Desert RATS 2010 crews interacted with a control center at base camp, and with a separate Science Backroom located in Flagstaff.

4.05.14. Public outreach

Desert RATS expeditions were not as vigorously publicized as NEEMO tests, but enjoyed some local and national media coverage. NASA issued press releases about the tests. Desert RATS crews participated in little or no public outreach during the mission.

4.05.15. How it resembled space flight

The duration of a Desert RATS mission was comparable to that of a Space Shuttle flight. The living quarters were cramped and there was little privacy. Daily schedules were filled with challenging work, and unstructured personal time was rare. Communication during working hours was flight-like.

4.05.16. How it did not resemble space flight

The environment at Desert RATS was not hazardous. A reassuringly normal scene was always visible out the window. The focus of Desert RATS was to test hardware and operational techniques. In that sense it was more like a test flight than an operational space mission. Transportation to and from the work area was easily accomplished through familiar means. Crew sizes were smaller than for modern space missions. Training lasted only about a week. Desert RATS tests were much shorter in duration than an ISS increment or a Mars flight. The crew had little personal technical gear. No crew equipment was critical for life support. The levels of risk and stress were much lower in Desert RATS than in a real space mission. Communication outages were common. Resupply was easy and responsive. Public outreach was less pervasive and the crew was almost entirely insulated from it.

4.06. Pavilion Lake Research Project (PLRP)

The Pavilion Lake Research Project (Fig. 13), a cooperative endeavor led by the Canadian Space Agency and NASA, conducted extensive field investigations in 2009-2011. The project centered on scientific investigation of interesting coral-like "microbialite" structures that grow in Pavilion Lake, which is located in the mountains near Kamloops, British Columbia. Goals related to space exploration were secondary to the science. This discussion is based on the 2010 field season of PLRP, in which the author participated as a "scientist-pilot" in the same DeepWorker 2000 submersibles that supported NEEMO.

4.06.01. Environment

The aspect of PLRP that resembled space exploration was the underwater operations in the DeepWorker submersible. Pavilion Lake is about 60 meters deep. Below a shallow thermocline, the water temperature is a uniform 4° C. The environment is thus hostile to human life. Sub pilots needed warm clothing to prevent hypothermia in the unheated cockpit. A DeepWorker pilot manually controls the composition and pressure of the cabin atmosphere, under verbal guidance from an expert on the chase boat. An error in managing the cabin's partial pressure of oxygen could have serious consequences.

4.06.02. Duration

A field season at Pavilion Lake lasted about ten days. During that time, sub pilots could expect about four half-day dives and four half-day shifts as Capcoms or Science Communicators.

4.06.03. Mission priorities and major activities

The goal of PLRP was to study the microbialite structures in the lake. Cameras, sensors, and manipulators on the submersibles collected data and samples. The specific goals of each sub dive were driven by the kind of data to be collected. Many investigations relied on the observational powers of the pilot, whose task was to notice features of interest, image them with the sub's camera, and provide running commentary on what he or she was seeing. The DeepWorker dives were the main activity of the work day. Other participants operated remotely-controlled submersibles or conducted bench-top science on samples recovered by the subs.

Figure 13. DeepWorker pilots and crew at Pavilion Lake.

4.06.04. Habitats and vehicles

PLRP participants lived in rented cabins. Many slept on couches or bunk beds, four or more to a bedroom. The close quarters and limited privacy were thus flight-like, but the rustic setting was not. The DeepWorker submersibles resembled spacecraft. Other important vehicles were the twin-pontoon chase boats and a special barge with a central well and an overhead chain hoist to launch and recover the subs. The barge had a modular design so that it could be trucked to Pavilion Lake. The barge was moved by pushing it with an aluminum utility boat, also brought in by truck.

4.06.05. Getting there and back

People working at Pavilion Lake flew commercial air to Kamloops, then drove rented cars to the lake. Many of the participants, in particular the staff who supported the DeepWorker, lived in Vancouver and simply drove the five or six hours to the lake.

4.06.06. Crew size, composition, and roles

TheDeepWorker submersible seats one person, who serves as pilot and scientist. Most of the sub pilots were scientists who had to develop piloting skills, but some were astronauts whose challenge was to learn scientific observing skills.

4.06.07. Crew training

Training for Pavilion Lake consisted of two or three days in North Vancouver B.C at Nuytco Research, the company that built and operates the subs. The training focused on the safe and effective operation of the DeepWorker. Further preparation for the field season, in particular the guidelines for scientific observation of microbialites, came through reading and self-study on the pilot's own time. A pilot's first science mission served as real-time training, which reduced the scientific value of that dive.

4.06.08. Important crew equipment

The only personal equipment a DeepWorker pilot brings into the submersible are clothing, a kneeboard with mission information, and data storage media. Everything else--emergency gear, a flashlight, a fire extinguisher, drinking water, and a pee bottle--is provided by Nuytco. After the pilot has entered the vehicle, he or she stows the loose gear in the cabin according to personal preference. Shoes are not allowed in the sub, so pilots fly in stocking feet.

4.06.09. Typical crew day

Work days at Pavilion Lake were long, but much time was lost to coordination and overhead. Meals were taken together and followed by lengthy meetings. After breakfast came the first dive shift. Pilots prepared for their missions, collected their clipboards and data sticks, and reported to the dock to ride out to the mission start point. They then "flew" their missions. If the mission was short, they returned to shore and a different pilot took the sub for a short afternoon dive. If the dive was long, the sub's batteries could not be recharged quickly enough for a second mission that day. Pilots not flying missions worked on the chase boats as Capcoms or Science Communicators. A midday meal was taken if time allowed. Every evening there was a large group dinner followed by more team meetings. Some evenings had time for unstructured socializing.

4.06.10. Major risks and stressors

Risks at Pavilion Lake were minor, and all related to working in the submersible. Drowning and asphyxiation were possible but very unlikely. The presence of a second submarine for rescue operations, the very large safety factors in life support commodities, and the existence of multiple independent methods of returning the sub to the surface made the operation very safe. High workload and lack of sleep were the primary stressors.

4.06.11. Communication

Communication with a submersible at the surface is accomplished through standard marine radios. During a dive, the sub communicates with the chase boat using an ultrasonic through-water communication system that transmits voice and a few key telemetry parameters. In the 2010 season, science data were not transmitted from the submersibles, but were recorded on board for later analysis. Later seasons did include transmission of science data to a control center, both in real time and with a delay to simulate the speed-of-light lag from a near-Earth asteroid.

4.06.12. Resupply

Resupply to a DeepWorker in the water is not possible. If a failure occurs, the sub returns to the surface where the topside crew hoists it out of the water and services it on the barge. Personnel from Nuytco Research bring to the field a selection of spare parts and consumables such as Sodasorb for removing the carbon dioxide exhaled by the pilot.

4.06.13. Remote participants

Except for media contacts, all of the people involved in the 2010 Pavilion Lake field season were present at the site. Other seasons did include a distant control center.

4.06.14. Public outreach

Public outreach for PLRP was extensive in both the US and Canada. The project maintained a website. Both NASA and the Canadian Space Agency sent outreach representatives to document and publicize the activity. Crew members posted blogs to the Internet. The team hosted a "community night" where they met in an informal setting with area residents and with children from local Native American groups.

4.06.15. How it resembled space flight

Sub drivers at Pavilion Lake operated in an environment hostile to human life and depended on engineered systems for life support. Underwater, the submarines were neutrally buoyant, and could be flown in three dimensions as if they were spacecraft. The cockpit was similar to that of an aerospace vehicle. Crew work schedules were long and there was little time for sleep. Communication between sub pilots and topside controllers was similar to communication on a space mission. Pavilion Lake maintained a vigorous public outreach component.

4.06.16. How it did not resemble space flight

Although the duration of the field season at Pavilion Lake was comparable to a Shuttle flight, the time spent in the space-like underwater environment was only a few hours on only a few days. The mission duration was much shorter than an ISS increment. PLRP focused on science, not engineering; except for the operation of the subs, there was little similarity to any human space mission. Transportation to and from the field site, and accommodations there, were not flight-like. Subs carried a single crew member, a situation that is rare in modern space flight but possibly analogous to a spacewalk. Training for Pavilion Lake took only a few days. Sub pilots carried almost no personal equipment except for their clothing. The long workdays were flight-like, but many activities occurred on flexible schedules, and interpersonal coordination, team meetings, and large communal meals expanded to fill much of the day. Risks at Pavilion Lake were minor and well controlled. Science data were not always transmitted from the subs to the surface, and vehicle telemetry was sparse. Resupply to a submerged DeepWorker was not possible. Resupply to a sub on the barge was immediate. Pavilion Lake did not involve major off-site participants.

4.07. Comparison of ANSMET Field Camp to Space Missions

Attribute	ANSMET	Shuttle	ISS	Mars
Environment	cold constant daylight natural surroundings	airless 90-minute orbit artificial surroundings weightless	airless 90-minute orbit artificial surroundings weightless	airless or low pressure constant daylight in transit 2-hour orbit around Mars 24h 39m day on Mars zero or partial gravity
Duration	40 days	13 days	180 days	1000 days
Major activities	transport logistics shifting camp meteorite hunting resupply public outreach	ascent and entry docking and undocking robotics EVA system operation payload activities public outreach	ascent and entry docking and undocking robotics EVA vehicle maintenance payload activities physical exercise visiting vehicles public outreach	ascent docking and undocking Mars transit physical exercise Mars landing EVA vehicle maintenance surface exploration Mars launch Earth transit Earth landing
Habitats and vehicles	Scott tent C-17 LC-130 Twin Otter snowmobile trucks, vans, buses	Orbiter	ISS Progress ATV HTV Dragon Cygnus	Earth launch and entry capsule transit habitat Mars landing habitat Mars ascent vehicle cargo vehicles surface rovers
Travel to and from	commercial air government air	Orbiter	Soyuz	ascent and entry vehicles transit vehicles

(continued)

4.07. Comparison of ANSMET Field Camp to Space Missions (continued)

Attribute	ANSMET	Shuttle	ISS	Mars
Crew composition	4 or 8 people 1 leader 1 mountaineer other participants	7 people 1 commander 1 pilot mission specialists	6 people 1 commander flight engineers	6 people 1 commander 1 physician 1 planetary scientist other participants
Crew training	3-4 days duration beginning of season	1.5 years duration before flight	2.5 years duration before flight onboard training	3 years duration before flight onboard training
Crew equipment	ECW clothing snowmobile sleep kit many personal items	launch and entry suit EVA suit few personal items	Sokol suit EVA suit few personal items	launch and entry suit EVA suit personal items
Typical crew day	8.4 h sleep period 4.2 h meals 7.9 h work period 3.5 h personal	8.0 h sleep period 4.0 h meals & self care 12.0 h work period	8.5 h sleep period 4.5 h meals & self care 6.5 h work period 2.0 h work coordination 2.5 h exercise	8.5 h sleep period 4.5 h meals & self care 8.5 h work and coordination 2.5 h exercise
Risks	crevasses cold fire UV exposure carbon monoxide	high speed vacuum fire orbital debris system failure radiation	high speed vacuum fire orbital debris system failure radiation	high speed vacuum fire orbital debris system failure radiation illness psychological dysfunction

(continued)

4.07. Comparison of ANSMET Field Camp to Space Missions (continued)

Attribute	ANSMET	Shuttle	ISS	Mars
Stressors	cold ennui isolation small group lack of privacy hygiene challenges	weightlessness very high workload isolation small group lack of privacy hygiene challenges high cost of failure public scrutiny very little personal time constant evaluation physical danger	weightlessness high workload isolation small group lack of privacy hygiene challenges high cost of failure public scrutiny little personal time constant evaluation physical danger	weightlessness high workload isolation small group lack of privacy hygiene challenges high cost of failure public scrutiny constant evaluation physical danger long separation from Earth
Communication	satellite telephone short-wave radio	radio links e-mail video downlink private conferences video teleconferences	radio links e-mail video downlink private conferences video teleconferences Internet link private telephone	radio links e-mail video downlink speed-of-light delays limited bandwidth
Resupply	Twin Otter two week interval	none	various vehicles two month interval	none
Remote participants	McMurdo	Mission Control Center	multiple control centers	Mission Control Center
Public outreach	daily blogs telephone interviews	major media coverage audio and video events	some media coverage audio and video events	major media coverage pre-recorded events

(end)

4.08. Comparison of ANSMET field camp to NEEMO, Desert RATS, and PLRP

Attribute	ANSMET	NEEMO	Desert RATS	PLRP
Environment	cold constant daylight natural surroundings	underwater normal day-night natural surroundings weightless	hot and dry normal day-night natural surroundings	underwater normal day-night natural surroundings weightless
Duration	40 days	10 days	7 days	10 days
Major activities	transport logistics shifting camp meteorite hunting resupply public outreach	splashdown "EVA" gear maintenance public outreach decompression splashup	driving "EVA" maintenance science observation human factors forms public outreach	sub piloting Capcom work public outreach science observation
Habitats and vehicles	Scott tent C-17 LC-130 Twin Otter snowmobile trucks, vans, buses	Aquarius habitat dive boats DeepWorker	prototype rovers habitat module support trucks	rental cabin DeepWorker chase boats utility boat support barge
Travel to and from	commercial air government air	airline, rental car	airline, rental car	airline, rental car

(continued)

4.08. Comparison of ANSMET field camp to NEEMO, Desert RATS, and PLRP (continued)

Attribute	ANSMET	NEEMO	Desert RATS	PLRP
Crew composition	4 or 8 people 1 leader 1 mountaineer other participants	6 people 1 commander 2 hab techs flight engineers	4 people 1 commander 2 rover drivers 2 geologists	1 sub pilot
Crew training	3-4 days duration early in season	2 weeks duration before mission	1 week duration before test	3 days duration before season
Crew equipment	ECW clothing snowmobile sleep kit many personal items	wet suit scuba gear few personal items	few personal items	few personal items
Typical crew day	8.4 h sleep period 4.2 h meals 7.9 h work period 3.5 h personal	8 h sleep 4 h meals 10 h work 2 h other	8 h sleep 4 h meals 10 h work 2 h other	7 h sleep 5 h meals 10 h work 2 h other
Risks	crevasses cold fire UV exposure	drowning system failure currents bites & stings	heat rattlesnakes	drowning asphyxiation

(continued)

4.08. Comparison of ANSMET field camp to NEEMO, Desert RATS, and PLRP (continued)

Attribute	ANSMET	NEEMO	Desert RATS	PLRP
Stressors	cold ennui isolation small group lack of privacy hygiene challenges	confinement isolation lack of privacy high workload public visibility hygiene challenges	confinement isolation lack of privacy high workload public visibility hygiene challenges	high workload lack of sleep
Communication	satellite telephone short-wave radio	audio video data files e-mail	audio video data files	through-water audio through-water telemetry
Resupply	Twin Otter, 3 week interval	"potting," daily, as needed	on-site stores, as needed	on-site stores, as needed
Remote participants	McMurdo	control center Watch Desk	control center science backroom	none
Public outreach	daily blogs	blogs media interviews	little or none by crew	talks with locals blogs

(end)

5. Observations and recommendations

This chapter presents key observations and recommendations regarding ANSMET as a model for space exploration. Many of them address the potential for ANSMET to guide the development of systems and operational techniques for future space missions, especially in the area of crew autonomy. Others speak to NASA policy. A few suggest ways to improve ANSMET based on NASA's human space flight experience.

5.01. ANSMET Resembles Space Flight. NASA Should Treat It as a Space Flight Analog.

Five different astronauts (including the author) have participated in six ANSMET expeditions. All have pronounced it a good proxy for space flight. Its stress, confinement, isolation, long duration, high workload, hostile environment, limited resources, scheduling of crew time, and dependence on mechanical systems are all comparable to a real space mission. Like space crews, ANSMET participants contribute to public outreach.

For decades, NASA's space science community has valued ANSMET as a provider of extraterrestrial samples. NASA should also recognize ANSMET's value as a space flight analog. This is especially important as Desert RATS, NEEMO, and other major analogs projects have been cancelled, eliminating those sources of insight for future space exploration.

At the time of this writing, the NSF has decided to terminate its direct support of ANSMET. NASA should step in and fund ANSMET.

5.02. Astronaut Participation in ANSMET is Mutually Advantageous. It Should Continue.

Because ANSMET is so similar to a space mission, astronauts who participate in ANSMET gain experience for space. That experience would be most valuable for astronauts who have completed basic training, including a NOLS course, and are awaiting their first flight assignment.

Astronaut participation also helps ANSMET. Although they are not meteorite experts like most of their teammates, astronauts contribute their wilderness survival, expedition behavior, and operational experience to the team. Furthermore, astronauts must meet strict medical requirements for their jobs, which makes it easy for them to qualify for polar duty.

To maintain the focus of the expedition on meteorite science, no ANSMET team should include more than one astronaut.

5.03. Surface Mobility Enables Exploration. Future Missions Should Provide It.

A two-kilometer walk in Antarctic ECW gear is tiring. Despite the reduced gravity, the mass and bulk of a pressure suit is likely to produce the same result on the Moon or Mars. A spacewalk on a low-gravity asteroid will proceed at a rate no faster than an ISS EVA. With such restricted range and speed, an exploration team working on foot would exhaust the opportunities for discovery near the landing site after only a few days.

ANSMET invests considerable resources of money, time, mass, cube, and energy in its Ski-Doos. They are worth it, as proven by the many hundreds of kilometers the team drives during a season. Ski-Doos expand the team's search range by factor of 10, which corresponds to a factor of 100 in search area. Ski-Doos also enable the group to shift camp. Without that capability, the 2012-2013 systematic search team would have been limited to its first camp site, which yielded only five meteorites.

All of the above arguments lead to the conclusion that explorers on the Moon, Mars, or asteroids must have vehicles for surface mobility or risk a very low return for a very expensive flight.

5.04. Surface Navigation Enables Exploration. Future Missions Should Provide It.

ANSMET crews need to know where they are. They must navigate around hazards, sometimes in poor visibility. They must precisely locate meteorite finds. They must keep track of where they have and have not searched, often in terrain that provides few visual landmarks. ANSMET relies on GPS for these functions, using multiple roving GPS sets, plus a highly accurate base station, to accomplish them.

Explorers on the Moon, Mars, and asteroids will face similar navigation needs and challenges, but may have to meet and solve them without a dedicated, multi-billion-dollar satellite constellation. Small, cheap radio beacons, or remotely sensed albedo and elevation maps used in combination with optical navigation, might work. Whatever the technical solution, effective exploration will depend on solid navigation.

5.05. Good, Varied Food is Key for Health and Morale. Space Missions Should Provide It.

For explorers working hard in difficult living conditions, food is crucial. Notably successful explorers, going back at least as far as Nansen [13], have recognized and respected this simple fact. The USAP in general, and ANSMET in particular, also recognize the need for abundant, flavorful, varied food. The prevalence of fan club T-shirts for the soft-serve ice cream machine in McMurdo provides solid, if humorous, evidence of the importance of food. ANSMET field parties appreciate both personal favorite foods brought by team members unexpected goodies arriving in care packages.

The controlled environment of a spacecraft does not demand large numbers of calories, but the need for tasty, varied food is no less. NASA invests substantial effort to provide good food for ISS crews. That work should continue, and may be even more important, for future missions beyond low Earth orbit.

Related to food is alcohol. ANSMET participants use alcohol in moderation during off-duty hours in the field without affecting safety or productivity. NASA strictly prohibits alcohol on all space flights. The Agency may wish to revisit this policy for deep space missions lasting more than a year.

5.06. ANSMET Provides a Wide Variety of Clothing. Deep Space Missions Should Too.

ANSMET participants have access to a wide range of available clothing and eye protection, from the CDC, the BFC, the ANSMET project, and their own personal supplies. Although not prohibitive in weight and volume, the variety allows almost everyone to find a combination that works for them.

In space, crew members have very few choices for the design and materials of their clothes. The benign environment in the spacecraft cabin makes clothing less critical, but on deep space exploration missions crews will appreciate a broader range of choices for comfort and convenience.

One area where NASA might inform ANSMET is underwear. The ISS has no laundry facilities and the mass of supplies that can be sent there is severely restricted. ISS crews have tested underwear woven with silver threads that kill bacteria. Reportedly, the silver-thread garments remain odor-free much longer than standard cotton. Such underwear might be similarly beneficial in Antarctica.

5.07. Logistics Occupy 50-75% of a Remote Site.

About 50% of the footprint of a 40-day Antarctic field camp is logistics. About 75% of McMurdo Station, which receives its major resupply once a year, is logistics. Antarctic campers keenly feel the need for logistics space when they have to explode and repack their gear in the limited floor space of a McMurdo dormitory room. Even the venerable Scott tent, with its thoughtfully provided clotheslines and stowage pockets, would benefit from more of both. Making the pockets transparent, so their contents could easily be seen, would be a further improvement.

Inadequate stowage volume is a perennial problem on ISS, where only about 20% of the pressurized modules are devoted to logistics. Excess supplies are strapped to walls, floors, and ceilings, sometimes interfering with other equipment and functions. The late addition of a dedicated stowage module to the ISS reduced but did not eliminate the problem. Designers of future spacecraft might avoid repeating the errors of ISS by using Antarctica as a guide for estimating logistics volume.

5.08. Support Takes Five Times as Much Work as Science.

The USAP employs about five support personnel for every scientist working on the continent. A similar ratio of effort should be expected in the similarly challenging and systems-intensive environment of a space mission.

The ISS Program prioritizes science work from the crew, who are also responsible for all on-board support tasks in addition to meeting basic human needs for sleep, food, and so on. At the time of this writing, the goal on ISS is to get 35 hours of science work per week from a USOS crew of three, out of about 120 hours per week of available work time. This corresponds to a ratio of about 3.5 to 1, which is ambitious in comparison with the 5:1 ratio in Antarctica, even allowing for the support provided to ISS crews by the Mission Control Center.

Planners of future deep space missions should expect science to occupy from 17% to no more than 28% of the effort of the crew, who will otherwise be busy keeping themselves and their critical flight systems functional.

5.09. As in ANSMET, Space Mission Commanders Should Have a Say in Crew Selection.

The ANSMET PI hand-picks the members of the expedition, as did Shackleton and Nansen. This selection method successfully compensates for the limited amount of time the crew has to practice working together before they go into the field.

NASA gives crew commanders little or no say in crew selection, relying on the lengthy pre-flight training period to develop team cohesion. This has been successful for past missions. But for future deep space flights with durations of one or more years, crew interactions are even more important. The Agency could help its future commanders forge coherent teams during preparation for flight by giving them some say in who makes the trip with them.

5.10. ANSMET Cross-Trains Some Critical Crew Skills. It Should Train Even More.

Space crews cross-train one another's skills, so that at least two people on board can accomplish any critical task. The resulting back-up capability was used on many Shuttle missions, especially in the first days of each flight when some crew members suffered from nausea and could not complete their planned work.

ANSMET practices some cross-training. For example, the team assigns and trains a primary and a secondary meteorite photographer. But the mountaineer has no back-up. In the 2012-2013 season, the systematic search team's mountaineer fell ill in the field and had to be evacuated. The remaining team members had enough Antarctic experience to navigate safely to the point where their pull-out flight would meet them, but did not know how to palletize their cargo for LC-130 transportation. Only the absent mountaineer had that skill. The poor packing job caused a substantial delay in loading the plane. That delay, with engines running, may have contributed to an expensive diversion of the aircraft for refueling and a related injury to a member of its crew. ANSMET would be better positioned to handle off-nominal situations if it formally trained backups for all important scientific and operational tasks.

5.11. ANSMET Plans for Some Contingencies. It Should Consider Even More.

NASA famously tries to plan for every possible failure. Events still take it by surprise, as tragically demonstrated in the 1986 Challenger accident, when the Agency had no plan to transport the grief-stricken families of the crew away from the launch site while shielding them from the media. But such exceptions are rare. The success of almost every human space mission has ridden on the foresight and planning that prepare operators to respond appropriately to most problems.

ANSMET responds to many problems reactively, usually with good success. The team deals with minor illnesses as they arise. When equipment fails, they use spares or do without. But the unforeseen evacuation of the mountaineer from the 2012-2013 systematic search team raised important questions that nobody in camp knew how to answer, including, critically, whether or not the reduced team was authorized to traverse to their pull-out point. It took days for the affirmative answer to come from McMurdo. ANSMET teams would be better prepared for the field if they formally planned how they would respond to the loss of key party members or critical equipment.

5.12. Most ANSMET Participants Have No Expedition Behavior Training. They Should.

NASA takes pains to teach its astronauts how to work together in isolated, stressful conditions, employing NOLS courses, flight-like simulations, the T-38 trainer jet, the underwater environment at the NBL, and a variety of other methods. The rarity of interpersonal conflicts on space missions is evidence that this approach works.

The scientists who make up the majority of an ANSMET party are not trained in expedition behavior. Those who are Antarctic veterans may have gained some insight on the topic during their previous expeditions. They may even use good practices, such as giving small presents to their teammates at the beginning of the season and cooking and sharing good food, but they generally lack formal training in the subject. The team of Michigan State University psychologists who have studied interpersonal interactions in the 2010-2011, 2011-2012, and 2012-2013 seasons of ANSMET recommended in each of their reports that ANSMET participants should get some formal expedition behavior training before deploying to the field. There is at least anecdotal evidence that the 30-minute brief on expedition behavior (see 2.05.10) that the 2012-2013 team received at the start of the season had a positive effect on behavior that year.

Accordingly, ANSMET should make formal expedition behavior training a standard part of field preparations. If a NOLS-trained astronaut participates in ANSMET, he or she might be a good choice to lead that activity.

5.13. As in ANSMET, Space Crew Commanders Should Adjust Crew Tasking.

Future deep space missions will travel great distances from Earth, which means that communication with the ground control center will be delayed and diminished [11]. This in turn will force the crew to assume some tasks and functions currently performed by the Mission Control Center, while isolating them from the assistance the ground provides to today's ISS crews. Crew autonomy in space flight has been the subject of some recent work [20-23] but much remains to be learned. ANSMET, which operates in an environment resembling space without a control center, suggests ways to help future space exploration crews to be more autonomous. This section, and sections 5.14 - 5.19, discuss crew autonomy as practiced in ANSMET. For a more complete treatment, see Love and Harvey [24].

On ISS today, crewmembers are specifically trained for the tasks they will do on orbit, with limited flexibility for adaptive reassignment during the mission. When reassignment is necessary, the decision is usually made in the Mission Control Center. Because a deep space mission will have a longer duration and a greater variety of tasks, it will include more changes to pre-planned crew tasking than an ISS expedition. The deep space crew commander will need the same authority as the ANSMET team leader to make those changes without consulting the ground, especially when there will not be enough time for time-delayed radio conversations.

5.14. ANSMET Monitors Its Own Progress. So Should Deep Space Crews.

On ANSMET, the PI and the mountaineer jointly monitor the team's progress each day and throughout the field season. On the ISS, that function is largely performed on Earth. Because communication latency will impair the control center's situational awareness and delay its advice, retaining it as the primary monitor of daily operations on a deep space flight will waste much time and effort. As in ANSMET, a deep space crew member should take the role of primary monitor for the progress of the team's work, keeping an eye on the clock and the schedule in addition to his or her other tasks.

5.15. As in ANSMET, Deep Space Crews Should Make Decisions Affecting Science.

In ANSMET, the PI makes decisions that trade competing science goals against one another (such as where to search next), or that trade science against other priorities (such as whether or not to search in marginal weather conditions). The ANSMET team leader constantly adjusts science tasks and priorities in real time, efficiently responding to changes in schedule, weather, terrain, equipment readiness, and other factors. This is the "adaptive-exploratory" approach discussed by Mader et al. [25]. This is a far cry from ISS where all such decisions are made on Earth. On a deep space flight where advice from the control center is less readily available, a crew leader should have the authority to make decisions affecting science.

5.16. ANSMET Operates With Limited Bandwidth, As Will Deep Space Missions.

On ISS, crews benefit from an essentially unlimited capability to exchange text, data, and still imagery with the control center. On a deep space mission, the bandwidth for such communication will be much smaller. Here again, ANSMET provides a good model. The limitations imposed by satellite telephone communication force team members and their correspondents to make every transmitted byte count. For example, even a short 120-character text message can provide great morale support to the field team. Future deep space crews and their correspondents might benefit from communication practice under conditions similar to ANSMET.

5.17. ANSMET Uses Simple, Tough, Forgiving, Fixable Gear. So Should Space Missions.

As in space flight, ANSMET carefully selects the equipment that will support the expedition, but the choices it makes are radically different.

All of the gear on an ANSMET expedition is operated by the crew themselves, who may arrive at McMurdo Station with no expertise or even familiarity with the equipment they will trust their lives to. Training before deployment to the field is limited to a few lectures and the overnight snow school trip. ANSMET teams manage this skill deficit by including Antarctic veterans (who know what to do and can teach the rookies) and by selecting equipment that has been tested under brutal field conditions and proven itself to be easy to operate, hard to break, tolerant of user errors, and easy to fix when it does fail.

In contrast, much hardware on the ISS is extremely complicated. It is not as reliable as Antarctic equipment. It is easily endangered by user errors. Failure recovery can be very involved. The ISS works under these constraints because it is mostly operated by flight controllers on Earth, whose collective knowledge of the systems greatly exceeds that of the crew. Even the small number of system tasks that the crew does perform are guided by detailed instructions from experts on the ground. Whenever things do not go according to plan, crews call the Mission Control Center for real-time consultation.

Reduced and delayed voice and telemetry from a deep space ship will force more system operations to be performed by the crew, who cannot possibly carry the knowledge of an entire flight control team. This will demand a shift away from the hardware philosophy of ISS (complex, fragile, unforgiving, hard to fix) and toward the norm for Antarctica (simpler, stronger, more forgiving, and more maintainable).

5.18. ANSMET Does Its Own Manifesting and Stowage. So Should Deep Space Crews.

Except for a few crew-preference items such as clothing and personal mementos, the ground plans and prioritizes all cargo manifests for flights to the ISS. The longer duration of a deep space expedition will mean more, and more kinds of, crew-preference items will be flown. The crew will play a greater role in defining the cargo manifest. Here ANSMET provides an extreme example. The team leader and the mountaineer choose almost everything that goes into the field. Each two-person tent group makes its own food selections for the field season, and each team member chooses his or her own personal clothing and entertainment items. Individual ANSMET team members also enjoy some latitude to select their USAP-issued field gear. The freedom to choose those few things, trivial in terms of mass and volume, appears to confer a big psychological benefit for people working in otherwise highly constrained and difficult conditions. With appropriate adjustments for mission duration, deep space crews might assume the primary role for selecting analogous types and mass fractions of their ship's manifest.

ISS crews and ground controllers invest substantial effort to keep track of where items on board the vehicle are stowed. Future exploration missions that manage inventory remotely will be further hampered by long communication delays. They would benefit from a more efficient system. ANSMET suggests some possibilities for improvement. ANSMET field teams pack all their own gear for transport to the field, then unload it and stow it in camp themselves. Inventory is tracked with human memory and personal written notes. Although there is an occasional search for a tool or a food packet, serious problems are uncommon. Future deep space exploration crews will be able to use their inventory more readily if they arrange and track it themselves, with help from intelligently designed labels and stowage hardware.

5.19. ANSMET Manages Its Own Daily Schedule. So Should Deep Space Crews.

On ISS, the ground creates and updates the daily schedule. On a deep space mission, waiting tens of minutes for the ground to respond to a schedule problem will only make the situation worse. ANSMET teams effectively manage daily schedule changes without consulting a control center. If the day runs late, the PI decides which tasks will and will not be completed.

Deep space mission crews will need similar short-term planning authority. (Long-term, strategic planning may still be done efficiently on Earth.) If an electronic schedule is maintained on board, the crew will need to manage it, preferably using software that does not itself consume much valuable work time. At the time of this writing, the ISS Program is beginning to explore crew self-scheduling [26].

5.20. Antarctica is a Good Place to Simulate a Mars Mission.

Much important work remains to be done with terrestrial spaceflight analogs such as ANSMET. Someday, however, we will make the transition to real human exploration of deep space. With that transition in mind, it is worth asking what ultimate terrestrial analog might best prepare NASA for the leap to near-Earth asteroids, the Moon, or Mars. One possible answer to that question is to simulate a Mars flight in Antarctica.

The great challenges of space operations include inaccessibility, isolation, a hostile physical environment, and the absence of outside assistance in case of emergency. Antarctica offers comparable challenges. The South Pole can be reached only from October through February. The rest of the year it is effectively isolated from the rest of the planet. During winter, temperatures reach -80° C. Antarctica thus offers people and equipment a tough challenge, and excellent preparation for deep space.

Coincidentally, the duration of the Antarctic winter is about the same as predicted flight times to Mars. This suggests a possible simulated mission concept. Preparation for the mission would begin in Austral summer with deployment of the test team and hardware to the South Pole Station. People and lightweight equipment can travel by air from Christchurch to McMurdo, then to the South Pole. Heavier equipment travels from Hobart, Tasmania to McMurdo on a cargo ship. It then goes to the South Pole on an aircraft or on a tractor-drawn sledge via the South Pole Traverse. Packaging test hardware for transportation aboard a C-130 is analogous to preparing it for launch on a rocket and could provide valuable insights.

The test hardware might include a habitat module with systems for communications, life support, and thermal control. Solar energy systems will not work during the 6-month polar night, but non-solar power systems can be tested year-round. Crew systems--food, water, clothing, exercise equipment, living quarters, work facilities, and so on--are good candidates for testing in Antarctica. Crew psychological effects can be studied as well.

During the summer the test team unpacks, assembles, and checks out the habitat and its associated equipment. At the close of the season, when the hardware is ready, the "flight crew" can move in.

The Pole closes for the winter in February. The Mars analog flight crew spends the winter simulating a journey to Mars. In their enclosed habitat, separated from the main base, they would experience isolation comparable to being in deep space. Conditions outside the habitat will be harsh. There will be no direct contact with other people. This will provide an excellent test of the psychological pressures of small crews, enclosed quarters, and lack of external contact.

If a control center is included in the simulation, increasing communication delays can be implemented as if the crew and habitat were really on the way to Mars. This will provide a challenging test of communication protocols and operational concepts for delayed telemetry from the spacecraft.

During the simulated flight, the crew will operate and maintain the equipment in the habitation module. If engineering and human research objectives are not enough to keep the crew busy, they can work (potentially with the control center and with field scientists around the world) to plan their traverses and science activities in the upcoming field season at the destination.

If a major failure makes the test module uninhabitable, the crew has the option of evacuating to the main South Pole Station, which operates (with reduced staffing) all winter. It provides an important safety backup, allowing more aggressive testing of new systems and equipment than would be possible where no such emergency capability exists.

In October, the Pole once again becomes accessible. This milestone marks the crew's "arrival" at "Mars." Now they deploy out to the Dry Valleys, a region along the Antarctic coast near McMurdo

Station. The Dry Valleys are a good analog for Martian terrain. Here the crew lives and works through the Austral summer doing real, peer-reviewed scientific research in fields such as geology, glaciology, and astrobiology. Meanwhile, the crew could test surface systems including habitats, rovers, suits, and tools in a setting more challenging than the sites of today's analog studies. Underwater operations in ice-covered lakes could provide an excellent simulation for suited work on the Martian surface. Protocols for communication with scientists outside Antarctica, similar in concept to the "science back-room" of the Apollo program, could be tested to maximize science return.

Close cooperation between simulation planners and academic and government scientists independently engaged in research in the Dry Valleys would ensure that the crew's field work contributed to the state of current scientific knowledge. This kind of cooperation, the rudiments of which exist today, will be essential to broaden the base of support for future deep space exploration.

At the close of the Antarctic field season in February, the crew returns to South Pole and spends the eight-month winter simulating the return flight to Earth. The total duration of the mission would thus be about 20 months. Alternatively, this last part of the test could be skipped if there were no further test objectives to be achieved.

An important feature of this concept is that it offers many opportunities for cooperation beyond the NASA Human Spaceflight community. Cooperation with the wider Antarctic science community (to ensure that the work done in the field is relevant to current research) and with experts in robotic deep space exploration (to deal with communication delays) would be crucial for the success of the mission. So would partnership with the NSF. The NSF would gain the use of the crew for significant, cutting-edge science, while NASA would gain experience in science-driven human exploration which its current engineering-based efforts provide only at a modest level.

This concept also offers possibilities for wider partnering. Antarctica is already a model for international cooperation on research in a challenging environment. In fact it may provide a successful framework for international exploration and use of the Moon, asteroids, and other planets. Because this concept can test so many engineering, scientific, and operational concepts at once, it provides many opportunities for partner agencies to contribute as much or as little as they wish. A simple electronic checklist viewer, a more complicated atmosphere-revitalization system, or an entire habitat module would all add value to the undertaking.

The preceding paragraphs have outlined a concept for testing equipment, personnel, and operational concepts for the future human exploration of deep space under the toughest conditions on Earth. It includes the potential for cooperation with other communities, agencies, and nations. It offers a great challenge to space exploration methods and machines. Those that meet the challenge could be confidently applied to Mars.

6. Summary and conclusion

This report has described ANSMET in detail and compared it to real and simulated space missions. Chapter 1 introduced ANSMET and the space missions and space flight analogs it resembles. Chapter 2, which could serve as a primer for future ANSMET participants, described an ANSMET expedition step by step, listed the vehicles that support operations in Antarctica, discussed living arrangements in an ANSMET field camp, provided a detailed picture of collecting meteorites in Antarctica, and enumerated the leading crew concerns. Chapter 3 presented data from ANSMET for comparison with similar data from real and simulated space flights. The data included day-by-day overview calendars, daily timelines, allocation of time in camp, fatigue and sleep, distance traveled, equipment lists, use of volume and commodities in camp, crew workload and exertion, and data on McMurdo Station as a model for a future settlement in space. Chapter 4 provided in-depth descriptions of representative past, present, and future space missions, as well as three major space flight analogs, in a consistent format which invites comparisons to ANSMET. That chapter concluded with tables that make those comparisons explicitly. Chapter 5 gave observations of ANSMET from the perspective of human space flight, and of human space flight from the perspective of ANSMET. The observations suggest recommendations that might improve both.

6.01. Key Results of This Work

The following paragraphs summarize the most important points of this report.

6.01.01. Description of ANSMET

An ANSMET expedition begins with applying to join the team. Selectees must pass a strict medical qualification. In late November, ANSMET teams fly to New Zealand and spend one day in Christchurch getting outfitted with Extreme Cold Weather clothing. They make their Ice Flight to McMurdo Station, where they spend about ten days selecting and packing food and field equipment, and completing field training that includes an overnight snow school. Once equipped and trained, the teams fly to their field camp locations, possibly via the South Pole. The systematic search team, with eight people, deploys to a site known to be rich in meteorites, while a mobile four-person reconnaissance team may search for new meteorite deposits in another region. Camp sites on the polar plateau typically have an air temperature near -20° C, with wind chill down to -40° C. Establishing the camp takes one or more days, after which the team spends about six weeks searching for meteorites on foot or on snowmobiles, or remaining tent-bound if the weather is bad. Two Twin Otter flights during the season resupply the systematic search team. The reconnaissance team may fly to new locations many times. Teams celebrate Christmas and New Year's Eve in camp. In mid to late January, the team pulls out of the field. They return to McMurdo and spend three to ten days cleaning and returning equipment. Then the team members fly to Christchurch, turn in their ECW gear, and travel back to their home countries.

Antarctica is served by a wide range of vehicles. The main workhorses are the Lockheed C-130 "Hercules," a four-turboprop cargo aircraft, and its ski-equipped variant, the LC-130. The larger C-17 sometimes augments the C-130 fleet. Ground transportation in McMurdo is provided by trucks, buses, and vans equipped for snow roads. The Ski-Doo snowmobile is a key piece of field equipment without which a meteorite hunter cannot work effectively. A typical ANSMET team member drives 650 km on his or her Ski-Doo during the season, averaging about of 16 km/day and consuming 2.5×10^{8} J/day in the form of hydrocarbon fuel. The Twin Otter is a smaller utility aircraft that makes resupply flights to ANSMET camps and relocates the reconnaissance team.

ANSMET field camps are aligned with the prevailing wind to mitigate drifting snow. Two campers share a sturdy Scott tent, which is double-walled for insulation and ventilated for stoves. Its habitable volume is about 4.3 m^3 and its floor area is about 5.7 m^2. Each camp includes a latrine tent. Optionally, a camp may have a science tent, a bath tent, or both. Each day, a camper eats about 1.0 kg of energy-rich food and drinks 3 liters of water that is melted from ice. A tent group of two people uses about 1.0 kg of hydrocarbon stove fuel (5.2×10^{7} J) per day for heating and cooking. A tent group's solar power panels, batteries, and inverter provide up to 35 W of continuous 110 V, 60 Hz electrical power, corresponding to about 1.5×10^{6} J per person per day. Communication with McMurdo and home is via satellite telephone. About 50% of a field camp consists of logistics, mostly stowed on the ice outside the tents. Trash is collected in bags for sorting and recycling in McMurdo. Striking camp and loading sledges for a camp shift takes time, strength, and skill.

A formally established collection protocol protects meteorite samples while recording their locations and mapping the boundaries of the area searched. ANSMET teams use snowmobiles for searching on blue ice. They search moraines on foot. In both cases, the searchers usually work in formations with even spacing, making sweeps aligned with the wind direction. When the team finds a sample, they give it a number, establish its GPS coordinates, measure and photograph it, estimate its percentage of fusion crust, determine whether it is a chondrite or achondrite, and use sterile tongs to place it in a clean Teflon bag along with a metal tag bearing its sample number. They place a marker flag near its location as a backup for the GPS data. At the end of the season, the meteorites are shipped to JSC for initial characterization. They are curated permanently at the Smithsonian. ANSMET has collected over 20,000 meteorites since 1976.

ANSMET engages in public outreach via its website, participant blogs, special sessions at science conferences, and other avenues.

Concerns for the people on an ANSMET expedition include team compatibility, staying warm and healthy, maintaining good hygiene, getting enough rest, managing human waste, and keeping a positive attitude despite hardship.

6.01.02. Spaceflight-relevant data from ANSMET

Use of time in ANSMET is similar to that on ISS. Each day, ANSMET participants have an 8.4-hour sleep period. They spend 4.2 h on meals and hygiene, 0.9 h on team coordination, and 7.0 h on scheduled work. They have about 3.5 h of personal time per day. For comparison, ISS crews have an 8.5-h sleep period. They spend 4.5 h on meals and hygiene, 2.0 h on team coordination (especially with the Mission Control Center), 6.5 h on scheduled work, and 2.5 h on exercise.

In the average 8.4-hour sleep period, one team member averaged 6.9 hours of sleep per night. Days with high exertion, or with poor sleep the night before, generated significant levels of fatigue. Mental workload was highest in meteorite searches, especially in the crowded environment of a moraine. The greatest demands for physical work came with lifting and loading cargo, fixing Ski-Doo undercarriages, and shoveling snow.

Equipment and supplies for the 2012-2013 systematic search team of eight people for 40 days had a mass of 10,743 kg and a volume of 49.6 m^3.

McMurdo Station, a model for a future space settlement, has a summer population of 900 and a winter population of 150-200. For every scientist, there are five support workers. For every female, there are three males. The station uses about 14,000 liters of desalinated seawater per day. Its power load averages 1.7 MW, supplied by diesel generators and wind turbines. It recycles about 65% of its solid waste. Oceangoing ships resupply it once a year. Logistics occupy about 75% of its geographic footprint.

6.01.03. Comparing ANSMET to space flight and to space flight analogs

As discussed in Sections 4.01-4.03 and 4.07, ANSMET is comparable to Shuttle, ISS, and notional future Mars missions. It features circadian rhythm disruptions, but does not involve weightlessness and does not have such a hostile environment. Its duration is near the logarithmic mean of Shuttle and ISS mission durations, but well short of a Mars flight. Major activities in ANSMET include transportation, science, public outreach, and managing logistics, but no scheduled physical exercise. ANSMET uses a variety of different vehicles and has small living quarters, but ANSMET crews do not drive many transport vehicles themselves. ANSMET and space missions have similar crew sizes. ANSMET requires very little crew training in comparison with a space mission. It is similar in terms of crew personal items and protective clothing, but its more generous mass allowance permits more personal gear. Both have environmental and systems-related risks, but the overall physical danger in ANSMET is much lower. ANSMET crews face stress from isolation, lack of privacy, lack of hygiene, a harsh physical environment, and a small group size, but need not bear such a high cost of failure or as much public exposure. Communication bandwidth in ANSMET is limited compared to Shuttle or ISS, but probably greater than that of a Mars mission. The importance of resupply and the resupply interval are comparable to ISS. ANSMET operates without a control center. Public outreach work done by ANSMET members resembles that of space mission crews.

As shown in Sections 4.04-4.06 and 4.08, ANSMET also compares with space flight analogs like NEEMO, Desert RATS, and Pavilion Lake. Its work is done outdoors, but it features disrupted circadian rhythms and is not conducted underwater like NEEMO and Pavilion Lake. ANSMET lasts longer than these analogs. It has similar science, vehicle operations, and outdoor work in special clothing, but ANSMET focuses more on transportation and logistics. All involve a variety of different vehicles and use cramped living quarters. Crew sizes are similar, except in Pavilion Lake where the space analog is limited to individual submersible pilots. Crew training for ANSMET is similar to Pavilion Lake but somewhat shorter than Desert RATS or NEEMO. Personal equipment and items in ANSMET are greater in number and variety than in NEEMO, Desert RATS, or Pavilion Lake. The times allocated for sleep, work, and meals are similar in all four. The risk level in all four is comparable. Stressors include isolation, small group size, lack of privacy, and hygiene challenges, but ANSMET has a very cold environment and less public visibility. ANSMET has less communication with the outside world than the analogs. Resupply in ANSMET is less frequent and less responsive than in the analogs. Unlike the analogs, ANSMET has no control center. ANSMET crews engage in public outreach about as much as NEEMO and Pavilion Lake crews, and much more than Desert RATS crews.

6.01.04. Observations and recommendations from ANSMET

A number of observations and recommendations arise from comparing ANSMET with real and analog space missions. The first of these is ANSMET's similarity to space flight, which provides opportunities to learn about the human exploration of deep space at a tiny fraction of the cost of a real mission. ANSMET is even more valuable now that other analogs have been cancelled for budgetary reasons. NASA should support ANSMET and use it to gain more insights for deep space exploration.

Astronaut participation in ANSMET is valuable to the astronaut, who gets training in an environment similar to a long-duration space mission, and to the team, who get a teammate trained in survival, operations, and expedition behavior. Astronaut participation in ANSMET should continue.

Surface mobility is crucial for exploration and discovery. Compared with foot travel, it multiplies the searchable area around a base camp from a few square km to a few hundred square km. With wide ranging exploration comes the need for precise navigation, which is easy on Earth with GPS. Navigation on other solar system bodies will demand new technical solutions.

A wide variety of good food is important for physical and mental health, both in Antarctica and in space. Similarly, a variety of clothing is important so people can find the solution that works best for them.

McMurdo Station is about 75% logistics. An ANSMET field camp is about 50% logistics. The pressurized volume of the ISS allots only about 20% to logistics. On ISS, equipment and supplies are stowed everywhere, impeding work and making it hard to find things. Future space vehicles should have more, and more intelligently arranged, logistics space.

Maintaining and operating a remote outpost in a hostile environment requires about five times the effort that can be devoted to science activities at that outpost. Deep space exploration missions should plan accordingly.

For long space expeditions, the crew commander should have a role in crew selection.

ANSMET could benefit by adopting some NASA operational techniques. It could cross-train critical crew skills so that the team can still complete all of its tasks even if any member becomes ill or injured. It could make explicit contingency plans for the loss of equipment or personnel. It could formally train personnel in leadership, teamwork, and expedition behavior before deploying to the deep field.

ANSMET works without a control center. Future human deep space exploration missions will have less ability to rely on mission control because of the delays and bandwidth restrictions imposed by great distance from Earth. Their crews will have greater autonomy. Some aspects of space crew autonomy could use ANSMET as a model. For example, the ANSMET PI has the authority to change tasking and task assignments. ANSMET field teams monitor their own status and progress. The ANSMET PI is empowered to make decisions that affect scientific productivity. These are all different from current space flight techniques, which rely on the Mission Control Center.

Antarctic field camps have limited communication bandwidth, unlike Shuttle or ISS but like a crew on Mars. It might be a good place to practice making the best use of limited communications.

ANSMET equipment is thoroughly tested and proven to be simple, robust, forgiving of mistakes, and easily repaired. Deep space exploration equipment should be similar, despite aerospace engineering practices that often produce hardware that is complicated, fragile, unforgiving, and hard to fix.

ANSMET crews do their own manifesting and stowing. On ISS these functions are led by the ground. Mars crews will want a greater say in personal equipment brought on the journey, and will find things more readily if they stow and track them onboard rather than passing that job to a distant control center.

ISS schedules are managed by the ground. ANSMET, on the other hand, manages its own schedule. Like an ANSMET crew, a Mars crew will have to do more of its own scheduling to avoid inefficient back-and-forth exchanges with the control center.

It would be possible to conduct an advanced end-to-end Mars mission simulation in Antarctica, using winter stays at the South Pole to simulate the outbound and return legs, and using the Dry Valleys as geological and astrobiological analogs for science on the surface of Mars.

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References

[1] Hoffman, S.J., and Voels, S.A., Antarctic exploration parallels for future human planetary exploration: The role and utility of long range, long duration traverses. NASA CP-2012-217355, (2012) National Aeronautics and Space Administration, Houston, TX.

[2] D. B. Eppler, Analysis of Antarctic logistics and operations data: Results from the Antarctic Search for Meteorites (ANSMET), austral summer season, 2002–2003, with implications for planetary surface operations, in Garry, W.B., and Bleacher, J.E., eds., Analogs for Planetary Exploration: Geological Society of America Special Paper 483 (2011) 75–84, doi:10.1130/2011.2483(06).

[3] M.L. Reagan, B.A. Janoiko, J.E. Johnson, S.P. Chappell, A.F. Abercromby, NASA's analog missions: Driving exploration through innovative testing, AIAA 2012-5238, AIAA Space 2012 Conference and Exposition, Pasadena, CA, 11-13 September, 2012.

[4] S. Chappell, A.F.J. Abercromby, M.L. Gernhardt, W. Todd. Final report of NEEMO 14: Evaluation of rover, cargo lander, and crew lander during simulated partial gravity exploration and construction tasks. NASA Technical Report TP-2011-216152.

[5] S.P. Chappell, A.F.J. Abercromby, M.L. Reagan, M.L. Gernhardt, NEEMO 16: Evaluation of systems for human exploration of near-Earth asteroids, International Conference on Environmental Systems, Vail, CO, 15-19 July, 2013.

[6] A.F.J. Abercromby, S.P. Chappell, M.L. Gernhardt, Desert RATS 2011: Human exploration of near-Earth asteroids. Global Space Exploration Conference, Washington, DC, 22-24 May, 2012.

[7] A.F.J. Abercromby, S.P. Chappell, H. Litaker, M.L. Reagan, M.L. Gernhardt, NASA Research and Technology Studies (RATS) 2012: Evaluation of human and robotic systems for exploration of near-Earth asteroids, International Conference on Environmental Systems, Vail, CO, 15-19 July, 2013.

[8] D.S.S. Lim, A.L. Brady, A.F. Abercromby, D.T. Andersen, M. Andersen, R.R. Arnold, J.S. Bird, H.R. Bohm, L. Booth, S.L. Cady, Z. Cardman, A.M. Chan, O. Chan, C. Chénard, B.R. Cowie, A. Davila, M.C. Deans, W. Dearing, M. Delaney, M. Downs, T. Fong, A. Forrest, M.L. Gernhardt, J.R. Gutsche, C. Hadfield, A. Hamilton, J. Hansen, I. Hawes, J. Heaton, Y. Imam, B.L. Laval, D. Lees, L. Leoni, C. Looper, S. Love, M.M. Marinova, D. McCombs, C.P. McKay, B. Mireau, G. Mullins, S.H. Nebel, P. Nuytten, R. Pendery, W. Pike, S.B. Pointing, J. Pollack, N. Raineault, M. Reay, D. Reid, T. Sallstedt, D. Schulze-Makuch, M. Seiber, R. Shepard, G.F. Slater, J. Stonehouse, D.Y. Sumner, C.A. Suttle, A. Trembanis, C. Turse, M. Wilhelm, N. Wilkinson, D. Williams, D.M. Winget and C. Winter, A historical overview of the Pavilion Lake Research Project—Analog science and exploration in an underwater environment, Geol. Soc. America Spec. Papers 483 (2011) 85-115.

[9] R.W. Fricke, Jr., STS-122 Space Shuttle Mission Report, NSTS-37446, National Aeronautics and Space Administration, Houston, 2008.

[10] B.G. Drake, ed., Human exploration of Mars: Design reference architecture 5.0, NASA SP-2009-566, National Aeronautics and Space Administration, Washington, D. C., 2009.

[11] S. G. Love and M. L. Reagan, Delayed voice communication, Acta Astronautica 91 (2013) 89-95.

[12] D.S. McKay, E.K. Gibson, K.L. Thomas-Keprta, H. Vali, C.S. Romanek, S.J. Clemett, X.D.F. Chillier, C.R. Maechling, R.N. Zare, Search for past life on Mars: Possible relic biogenic activity in martian meteorite ALH84001, Science 273, 924-930 (1996).

[13] F. Nansen, Farthest North, Modern Library, New York, 1999.

[14] E. Shackleton, The Heart of the Antarctic: The Farthest South Expedition 1907-1909, Penguin, New York, 2000.

[15] Aviation Week and Space Technology vol. 148 no. 21 (1998 May 25).

[16] C. Pearson, NOLS Cookery, Stackpole Books, Mechanicsburg, PA, 1997.

[17] B. Cohen, The ANSMET Cookbook for Hungry Hunters, self-published, 2012.

[18] C. Allen, J. Allton, G. Lofgren, K. Righter, R. Zeigler, M. Zolensky, Curating NASA's extraterrestrial samples, Eos 94 (2013) 253-254.

[19] A.H. Mishkin, D. Limonadi, S.L. Laubach, D.S. Bass, Working the Martian night shift - the MER surface operations process, IEEE Robotics and Automation 13 (2006) 46-53.

[20] S.K. Krikalev, A.Yu. Kalery, I.V. Sorokin, Crew on the ISS: Creativity or determinism? Acta Astronautica 66 (2010) 70-73.

[21] N. Kanas, S. Saylor, M. Harris, T. Neylan, J. Boyd, D. Weiss, P. Baskin, C. Cook, C. Marmar, High vs. low crewmember autonomy in space simulation environments, Acta Astronautica 67 (2010) 731-738.

[22] N. Kanas, M. Harris, T. Neylan, J. Boyd, D. Weiss, C. Cook, S. Saylor, High vs. low crewmember autonomy during a 105-day Mars simulation mission. Acta Astronautica 69 (2011) 240-244.

[23] J. Frank, L. Spirkovska, R. McCann, L. Wang, K. Pohlkamp, L. Morin, Autonomous Mission Operations, Proceedings of the IEEE Aerospace Conference, March 2-9, 2013.

[24] S.G. Love and R.P. Harvey, Crew autonomy for deep space exploration: Lessons from the Antarctic Search for Meteorites, Acta Astronautica (2013) in press.

[25] M. Mader, D. Eppler, G.R. Osinski, J. Brown, N. Ghafoor, Unifying science-driven and resource exploitation strategies for lunar missions: applying lessons learned from terrestrial geological exploration and Canadian planetary analogue missions, IAC-12-A3-2C.5, 63rd International Astronautical Congress, Naples, Italy.

[26] Y.H Lee, D.E. Eagles, F. Moreno, M. Rodriggs, S. Beisert, and D. Stapleton, The International Space Station: Unique in-space testbed as exploration analog, Paper ID # 1274874, 12th International Conference on Space Operations, Stockholm, Sweden (2012).

Author vita

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