Appendix C

OTHER REMOTE RESEARCH FACILITIES

This appendix studies remote research facilities currently under operation. Specifically, research in the Antarctica and sub-sea/ocean exploration facilities are reviewed. In both of these cases it is common for the investigations to occur by a limited set of scientists; the full research team is not always present where the research is being conducted. Further, the operators in charge of the facilities are not always the researchers. While sometimes the full research team can be present for Antarctic/Ocean research missions, these facilities present the best models for remote operations of shared facilities.

C.1 Antarctic Research

While human exploration of the Antarctic region dates as far back as the travels of Magellan in 1520, there are two important periods in Antarctic scientific history highly relevant to the ideas of cooperative research and the establishment of remote scientific bases: the years around the 1957-58 International Geographical Year (IGY) and today. The years around IGY are of special importance since they resulted in the creation of the Antarctic Treaty System and the Special Committee for Antarctic Research (SCAR). Before the treaty and SCAR, Antarctica exploration, while significant, had no overall plan, and was mostly driven by commercial interests. A realistic potential of conflict existed by several nations making claim to the land, while other nations simply went through it without making claims, but expecting to be able to cross again. The Antarctic Treaty is a political agreement created between 12 nations to guarantee the non-military use of the Antarctic continent; over 30 nations now adhere to the treaty (Figure C.1 - from [BAS2] [BAS1] - shows a map of current stations and a picture of research being conducted in a British station). SCAR is a scientific tool for research in the region; it works in parallel and as an advisor to its political counterparts in the Antarctic Treaty to promote science and guide the politics of the region.

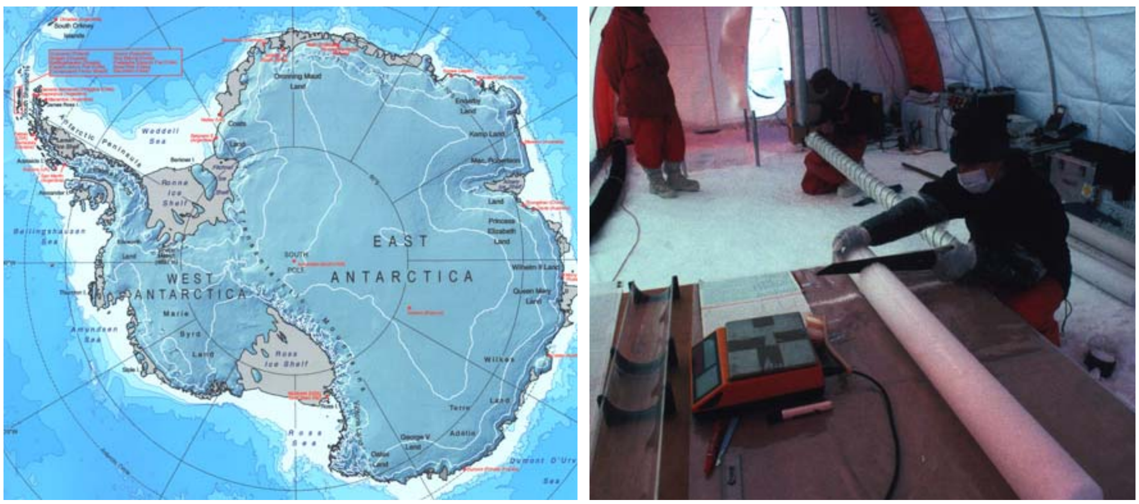

Figure C.1 Antarctic research stations

When discussing the Antarctic Treaty System as a mechanism for scientific research, William F. Budd starts with the following thesis:

> "The main thesis of this chapter is that humankind's quest for knowledge needs to be recognized as the primary motivation for the high level of continued interest and activity in the Antarctic. The treaty nations, through the Antarctic Treaty System, have supported this objective." [NRC PRB]

Like the ISS today, the Antarctic Treaty System and SCAR were formed with science as their primary goal. At a Conference in honor of the 30th Anniversary of the Antarctic Treaty System six primary motives were identified:

1. Basic Research
2. Political - national presence and prestige

3. Economic - natural resources and technology development
4. Military - although against the treaty, recognized as an important military arena
5. Jurisdictional
6. Environmental

All of these motives continue to spur developments and research programs in the Antarctic Region. At the same conference, though, "Finn Sollie [who] was intimately involved in the drafting of the Antarctic Treaty... [expressed that] His major point was that science in fact was the crucial element that made the treaty possible. Without science there wouldn't have been an Antarctic Treaty." [Elzinga, 1993]

The requirements of science ultimately set the guiding principles of the Antarctic Treaty System:

- free access to Antarctic territory
- free use
- free exchange of information
- allowance of inspections of any base by any member country's scientist
- joint planning and execution of activities
- peaceful uses only
- no territorial claims

"Antarctic politics is unique, and truly in a world of its own. While on a national level local issues may determine how a country runs its Antarctic programme and funds its science, on an international level Antarctic politics and science are about co-operation." [Burton, 2004] Nations fund Antarctic science either individually or in collaboration, therefore funding processes differ greatly from nation to nation. But the lack of national boundaries allows collaborations to occur easily. It is not uncommon for scientists to work in bases of countries other than their own; as long as the science is in-line with the standards of the host country (and its scientists agree), bases welcome investigators from across the world.

While the scientific community has achieved an environment which reduces the politics in the Antarctic substantially, they still must endure the physical conditions of the southern continent. To this purpose each country that has a base has established vast logistical support for scientific research. In the case of the United States, for example, there are three different bases (McMurdo Station at 77°53’S, Amundsen-Scott South Pole Station at 90°S, and Palmer Station at 64°46’S). Temporary camps can be setup during the summer months out from McMurdo Station. Automated unmanned data collection can be established; the University of Wisconsin has placed automatic weather stations and supports ice coring and drilling. Several research ships are available (the *Laurence M Gould* and the *Nathaniel B. Palmer* are the primary ones). Several support instruments are also available, such as differential GPS and radars. A vast database of maps, aerial photographs, and bibliographic documents exist to help prepare research missions.

In these large organizations there are multiple challenges. "Logistics has a hardware side and a software side. The latter is the more important, covering the know-how and competence of the people operating vessels, the ship and crew that are there to support the scientists, the helicopter pilots, technicians, consultants, etc. It was pointed out that a ship should always be under the command of the captain, and not of the scientist." [Elzinga, 1993] Scientists conducting research in Antarctica must face social and cultural factors, understanding that issues such as safety may override the scientific needs. The same holds true for the ISS, where even though the astronaut conducts the science *and* manages the spacecraft, they must balance their priorities, and science may not always be the highest. The conclusion in Antarctic research is that the ship’s captain must always be in charge; in the ISS there is always going to be someone in charge over the scientist.

It is also of use to understand the challenges posed by the Antarctic environment, as some of these closely resemble some of the features that define the uniqueness of the ISS. When developing an experiment for operations in the Antarctica, the following factors will play an important role in the design [Ashley, 2004]:

- Transporting large structures is a cumbersome and slow process

- High altitude environment reduces the effects of convection and fans
- Large temperature fluctuations throughout the day and night cause multiple problems
  - Need to insulate for temperatures as low as -80°C
  - Must account for changes of up to 30°C
  - Batteries loose capacity
  - O-ring become brittle
  - Thermal compression and expansion of materials
  - Metals become brittle
- High relative humidity approaching 100%
- Electrostatic damage at room temperature (humidity quickly drops)
- Difficult to maintain exposed equipment

An example of a manner to overcome the difficulties of Antarctic research comes from the development of a robotic autonomous telescope for use in the Antarctica by the University of New South Wales, Australia. The approach has been to minimize the number of computers, addressing many of the issues. Both hardware and software watchdogs watch over the computers. A priority of the computer systems is to prevent reaching ambient temperature (as low as -80°C). They have taken a modular approach to the software environment, allowing scientists to create their own programs for telescope control. Still, even for the design of an autonomous telescope, they conclude that "for the foreseeable future humans will be an essential component in building, operating and maintaining telescopes in Antarctica." [Ashley, 2004]

> "Without pre-existing infrastructure and support capability, conducting frontier science is impossible... for the explorer, engaged in comprehending their surroundings this [be an adventurer] is no longer possible. Nations conducting Antarctic science go to great lengths to provide facilities that are safe and practical for their inhabitants. For every scientist present, four or five people are there to support them... Nations that don't put this effort into their stations... are not in Antarctica to do science." [Burton, 2004]

Researchers in Antarctica do have the opportunity to be present where they plan to conduct research, although the conditions are not ideal. During the summer months the bases are overcrowded; the winter months have very limited daylight. Schedules are an important part of the scientists routines. To start, every instrument must be tested at home before deployment to Antarctica. The base stations do have supplies to repair equipment, although it may take time to schedule the available support personnel or the facilities needed to conduct the repairs. Antarctic researchers have the benefit that obtaining parts from their home laboratories is only a week away during the summer months. The schedule plays an important part for many scientists that must leave before winter, since it is essential to finish their research before then.

For those that reside in the bases during the winter, they will face inter-personal challenges, where it is impossible to avoid those living in the base. Communications have highly improved the conditions of conducting research in the Antarctic. All staff in the base can communicate with the rest of the world and be informed. When scientific teams get split those residing in the base can contact the rest of the team via video conference. Through extended communications research occurs at Antarctica year-round.

Antarctic research that does not require the scientist to conduct fieldwork also occurs. Locations such as the Antarctic Research Facility (ARF) in Florida State University have been setup to provide access to Antarctic research. The ARF services include vast literature through journals and books, photography and map collections. The facility also provides access to specialized equipment such as x-ray sensors, diffractors, and imagers, digital and analog photography, and sediment processing facilities. The ARF collects samples from the Antarctica through the US vessels and makes them available to scientists; the ARF even supports special requests for samples.

Even if some facilities exist to permit off-site research, the vast investment in supporting fieldwork in the Antarctica clearly points to the fact that the presence of humans in the research environment remains critical. Every nation that has a scientific presence in the Antarctica provides a large number of support personnel and equipment. In many cases thousands of support staff help hundreds of scientists.

There are several lessons to be learned from Antarctic research. Possibly the most important lesson lies in the development of the Antarctic Treaty, where science played the driving force, rather than politics. The vast success in cooperation between nations that conduct science in the Antarctic is overwhelming. There are also lessons regarding remote operations. The practices to develop experiments which operate in a harsh environment, where simple repairs and operations are not possible, provide valuable lessons for the design of ISS experiments. Technological improvements in communications have helped both the operations and science in the Antarctic. But, at the same time, the environments have been set up to ensure that at least a portion of the scientists involved in the research are present. Therefore, Antarctic Research history says that when possible it is best to have the researcher conduct the experiments. This means that the ISS must provide enhanced capabilities such that astronauts conducting research remotely can communicate effectively with the scientists on Earth.

C.2 Ocean Research and Exploration

The challenges incurred in ocean research closely resemble those of space research. The design and operation of ocean facilities must allow for humans to conduct research in a harsh environment: life support is essential; the presence of humans is limited; mechanical tools must enhance the human ability to manipulate the environment; in many cases the facility operates separate from its home station - it must ensure safe return to its base; communications play an essential role in the ability to conduct science; and the vessel must support all of these functions on its own power.

Ocean engineering manned vehicle systems can be grouped into four primary areas, just like microgravity facilities. These areas are [Penzias, 1973]:

- Conventional diving systems - these range from sponge divers and SCUBA gear to hard-hat body suits which allow humans to explore in shallow depths. Humans are usually exposed to the environment, and as such the human performs most of the actuation directly. The gear’s primary task is for life support.

- Saturation diving systems - these systems are composed of large pressurized chambers which allow humans to live and work at pressure continuously for weeks or months at a time. They are mostly used for observation and study of human physiology in pressurized environments.
- Fixed bottom stations - fixed stations create an under-water shirt-sleeve environment for long-term human presence in the bottom of the ocean. As with saturation systems, these stations provide spaces for observation and exposure. The larger size of the stations allows more instruments which can interact with the ocean environment, but the location of the station is fixed, so the exploration capabilities are limited.
- Submersible vehicles - while these systems include large submarines, this research concentrates on submersible work-boats for research. These vessels usually carry: a crew of two to seven in a shirt-sleeve environment. Each time the vessel is deployed it is intended to carry a specific experiment. To accomplish this mission the vessels can carry special actuators and sensors to conduct the necessary investigations of the ocean environment. It is also possible for the vehicles to have a lock to allow human to exit and re-enter.

A closer look at the functional requirements of submersible research vehicles further points out the similarities between Ocean research vessels and spacecraft. Ocean research vessels must have the ability to traverse across the oceans. They need to pick up and reposition objects and samples. Scientists require the ability to see, via both visual and electronic methods. The vehicles must endure their missions over extended periods of time. For all missions there is a need to have special instruments. In some cases vehicles must be able to mate/dock with each other and/or with their bases. Researchers may require that humans be able to leave the vehicle, requiring a lock. [Penzias, 1973]

A review of the major sub-systems of a manned submersible [Penzias, 1973], presented in Table C.1, shows the close relationships between ocean and space research facilities. Both types of vehicles must have a pressurized cabin with their respective life support systems. The propulsion of the vehicle must provide both coarse control and fine maneuvering control; this control must be supported by navigation systems. In both cases a ground/surface station is necessary. The principal difference is that, while Ocean vehicles require flotation control systems, space vehicles require a launch system to place them into orbit.

Overall, though, the similarities between the two predict that the challenges are answered in similar ways.

TABLE C.1 Major sub-systems of space and ocean research vehicles

Ocean Vehicle	Space Vehicle
Pressure Hull or Cabin	Pressurized Cabin
Structure (beyond pressure hull)	Truss elements
Flotation	Launch Vehicle
Power	Power
Propulsion	Propulsion
Maneuvering	Maneuvering
Life Support	Life Support
Navigation	Navigation
Work Space	Research Space
Surface Support	Ground Station

[Cunninghman, 1970] studied the design of an ocean engineering vessel in the 1970's. The study included a survey of researchers to identify the most important tasks that needed to be performed in such a vessel. This survey identified the functional requirements of the vessel. There were some interesting results relevant to the design of microgravity laboratories:

- Four features were considered luxuries, that is, they are not high priority for implementation; of these features one is relevant to microgravity laboratories: real-time data analysis. The survey concluded that many scientists preferred to collect the highest amount of data possible for post-analysis, rather than invest in real-time data analysis.
- Large laboratory areas were of low priority. Instead, the scientists preferred to have large deck areas. Deck areas are large common spaces for the deployment of experiments. Rather than limit the capabilities of their equipment due to size limitations, scientists preferred to have smaller analysis areas in the vessel, and perform more in depth analysis off the vessel. This is not to say that laboratory areas were not needed. Five specific laboratory areas (structures and materials, instrumentation, chemical and biological,

electrical and electronic, and human engineering) and two general purpose laboratory areas (machine shop and computer center) were identified.

- It appeared from the analysis that scientists would like to conduct more than one experiment at a time; the results called for multiple hoists to deploy experiments.

Current ocean research vehicles at the Woods-Hole Oceanographic Institute [WHOI, URL] show that the results of the early survey still apply in general. New technology allows integration of more tools for data analysis (both for real-time and post-processing) into new vessels, but the primary goal of the vessels remains to provide human support and the deployment of equipment for exploration and research. The most important functions of these vessels are to:

- support missions of days to months
- provide navigation and communication systems
- support for multiple projects
  - availability of multiple winches for experiment deployment
- carry submersibles
  - provide space for scientists: manned submersibles require only one pilot and have space for one or two scientists.
  - allow unmanned observation and sample recovery

Figure C.2 WHOI research vessels Knorr (left) and Alvin

The design of submersible research vessels closely matches the design needed for a space-based research laboratory, such as the ISS. The challenges and results of the design of sea vessels can be applied to some aspects of the designs for microgravity facilities. Yet, the review of both past and current ocean engineering systems shows a trend similar to that of Antarctic research: take the scientists to the place of research.