

The design and serviceability  
of Antarctic stations

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*David Rootes*

# ABSTRACT

Stations in Antarctica must fulfil the basic aims of providing protection from the harsh climate and a safe and comfortable environment for staff.

Four stations have been selected, from the 39 operating during the winter of 1986, and analysed for the way they match the various constraints to construction in Antarctica. In the harsh Antarctic climate, stations and facilities require regular servicing and maintenance and the effect of this on design is considered.

The analysis demonstrates that there has been a general improvement in design since the the first permanent stations were established but the standard of accommodation lags a long way behind. Regulation of Antarctic activities is limited to recommendations from the Scientific Committee on Antarctic Research (SCAR) and the Antarctic Treaty, and these organisations should attend to the siting of stations and the standard of facilities. The SCAR should stimulate further international cooperation between designers and promote studies of designs suitable for construction on ice. Designers should ensure that they remain up-to-date with technological developments applicable to polar construction.



#### ACKNOWLEDGEMENTS

A number of people have given freely of their time to help this work come to completion. The brunt has been taken by the Library staff at the Scott Polar Research Institute who have accepted every request with equanimity. Bernard Stonehouse provided a valuable insight into station life based on recent visits, Peter Keage in Tasmania, responded in full to a late request for Australian material and Bob Headland provided encouragement and Stroh regularly.

It would be invidious to mention one Polar Institute in Cambridge without naming the other. The experience on which this thesis is founded came from many happy years with the British Antarctic Survey and several people there, including Al Smith and Ron Lewis Smith rapidly answered cries for help. Dr Drewry supervised and guided the thesis into its final shape.

If dedications are needed then this work goes to the comfort of all who venture south. But pride of place goes to Mo, my wife, for every sort of support and for the inspiration to finish the work.

## CONTENTS

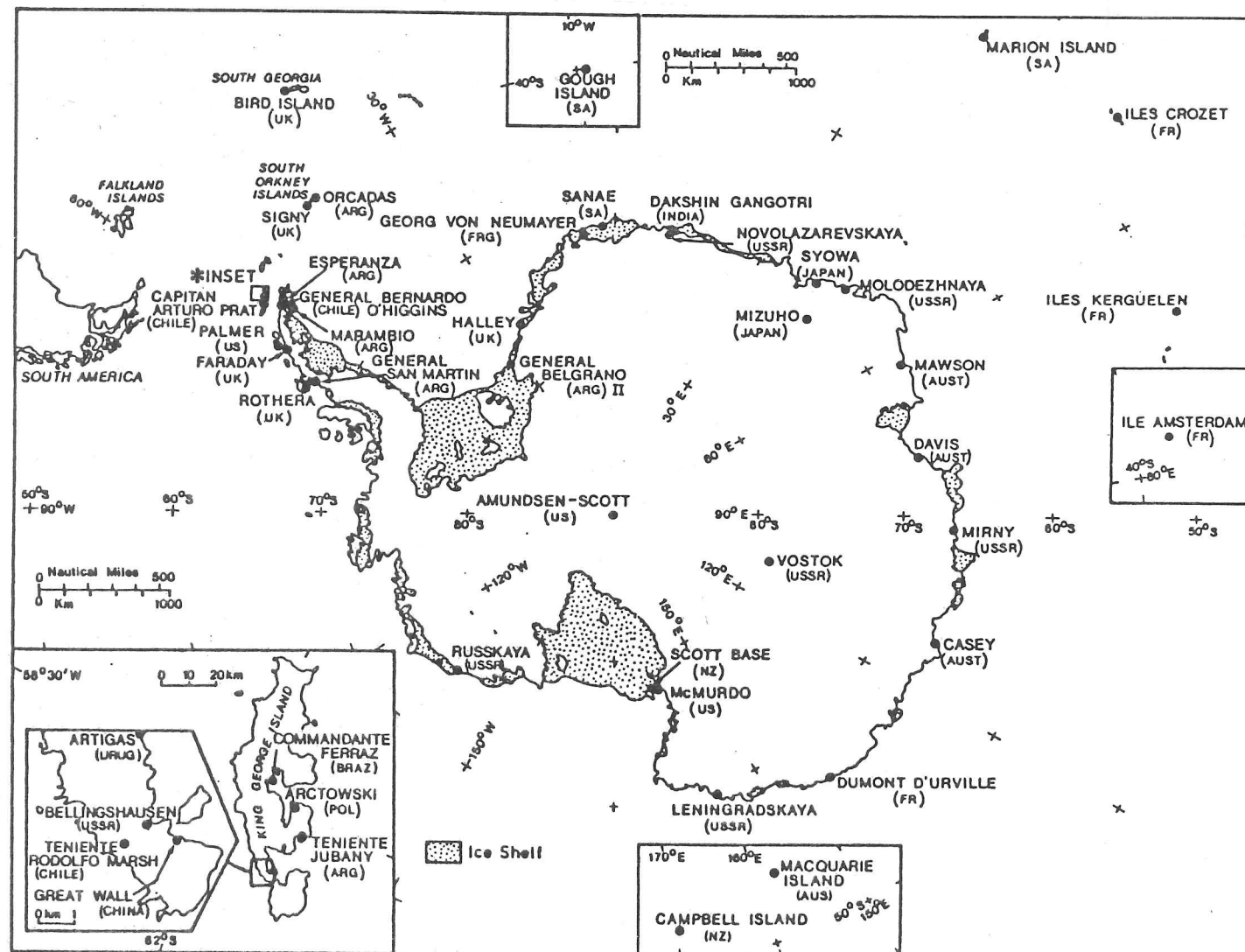
Abstract	(i)
Acknowledgements	(ii)
Frontispiece	(v)
 Chapter 1	 
Introduction	1
1. The Antarctic Environment	1
2. The Polar Station	3
3. Science and Politics in Antarctica	5
4. Station Function	7
5. Designs for Polar Stations	9
 Chapter 2	 
Station Descriptions	12
1. Amundsen-Scott Station	12
2. Casey Station	17
3. Georg-von-Neumayer Station	21
4. Signy Station	25
 Chapter 3	 
Suitability of Designs	30
1. Constraints to Construction in Antarctica	30
1.1 Placement on Rock	30
1.2 Placement on Snow and Ice	31
1.3 Coastal Sites	33
1.4 Inland Sites	34
1.5 Relation of Station to Ground	37
1.6 Logistic Constraints	39
2. Construction Methods in Antarctica	42
2.1 Thermal Constraints	42
2.2 Vapour and Moisture	44
2.3 Materials	45
3. Planning and Layouts	47
3.1 Planning	47
3.2 Layout	50

Chapter 4	Serviceability of Design	52
1.	Snowdrift	53
2.	Sea Spray and Wind Scour	55
3.	Maintenance of Fabric of Station	55
	3.1 Foundations	55
	3.2 Floors, Walls and openings	57
4.	Serviceability of Utilities	58
	4.1 Storage of fuel	59
	4.2 Water Cycle	62
	4.3 Waste Water and Sewage	64
	4.4 Solid Waste	64
5.	Emergency Systems	66
Chapter 5	Living and Working Environment	68
1.	Living Environment	68
2.	Working Environment	72
	2.1 Scientific Requirements	72
	2.2 Technical Requirements	73
Chapter 6	Conclusion	76
1.	Selected Stations	77
	1.1 Amundsen-Scott Station	77
	1.2 Casey Station	80
	1.3 Georg-von-Neumayer	82
	1.4 Signy Station	84
2.	SCAR and the Antarctic Treaty	86
3.	The Need for Overwintering Stations	89
4.	New Technologies	90
5.	Summary	95
References		96
Annexes		102

# Frontispiece

Stations operating in the Antarctic  
Winter 1986

(SCAR Bulletin No. 84 1986)



My own bolt is shot; I do not suppose I shall ever go south again before I go west; but if I do it will be under proper and reasonable conditions. I may not come back a hero; but I shall come back none the worse; for I repeat, the Antarctic, in moderation as to length of stay, and with such accommodation as is now easily within the means of modern civilised Powers, is not half as bad a place for public service as the worst military stations on the equator.

--Apsley Cherry-Garrard, 1929

## CHAPTER 1

## Introduction

For the austral winter of 1986 the Scientific Committee on Antarctic Research (SCAR) reported 39 stations operating in the Antarctic and 8 stations operating in the Sub-Antarctic region (*Frontispiece*) (SCAR Bulletin No.84 1986). These stations are the centres of Antarctic science for 16 nations and accommodate a population of about 800 scientists and support staff during winter. For the austral summer the population increases to 2000-2500 people and about 40 ships are required to service the logistic and scientific needs of these stations (Beddington and Bonner 1986). By any account, Antarctic science is expensive and to maintain an over-wintering station requires a major input of funding.

It is in the best interests of governments and polar institutes supporting stations in Antarctica to minimise logistic expenditure and a properly designed and efficiently run station will go a long way to achieving this aim, as well as providing a comfortable and enjoyable place for personnel to live and work. Many Antarctic stations do not succeed in this aim and the object of this thesis is to analyse selected Antarctic research stations in terms of their suitability and serviceability in the Antarctic environment.

### 1. The Antarctic Environment.

The Antarctic continent (fig.1.2), centred on the South Pole, covers a land area of approximately 14 million km<sup>2</sup>, greater than the size of USA and Mexico together. The continent is described in two

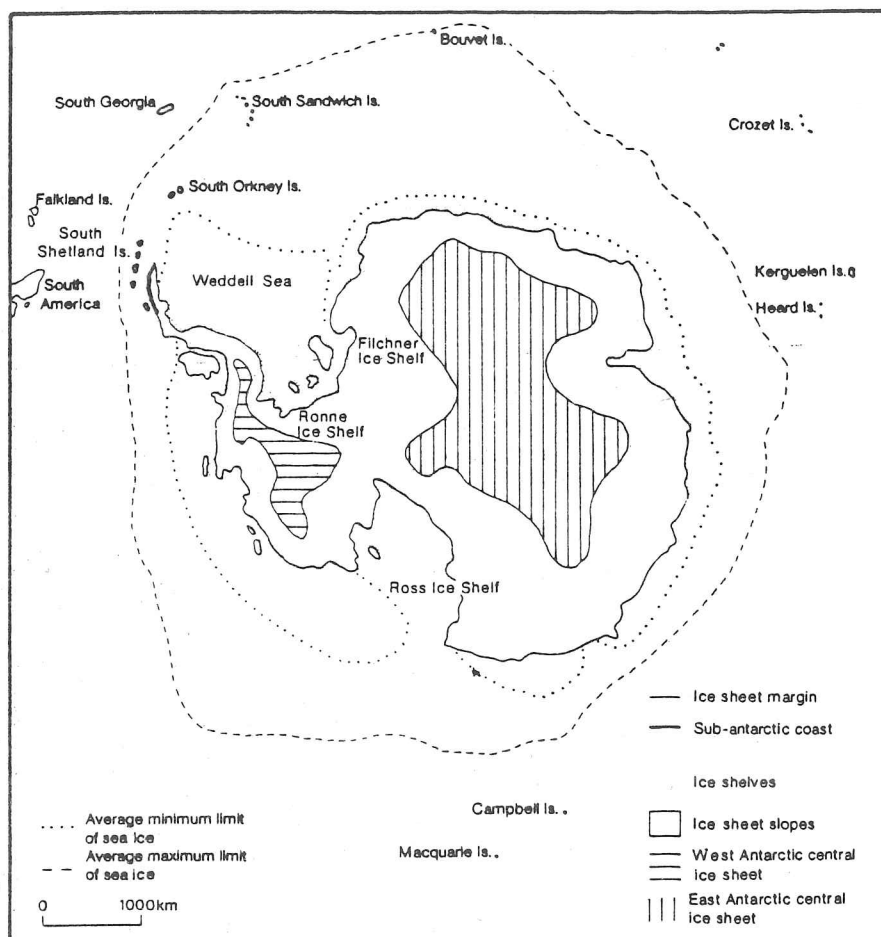


Fig.1.1 The main natural regions and constraints on human activity in Antarctica.

(Sugden 1982 p.390)

parts; East Antarctica is an ancient and stable shield area whilst West Antarctica consists of sediments and volcanic intrusions (Sugden 1982). For the most part, the continent is set within the Antarctic circle and only the Antarctic Peninsula and one or two areas of East Antarctica extend north of this latitude.

Overlying East and West Antarctica is an extensive ice sheet with an average elevation of 2,300m. The ice cap reaches an altitude of 4,100m in East Antarctica and covers 98% of the continent, leaving exposed only the tops of mountain chains inland and discontinuous areas of rock along the coastline. The Antarctic Peninsula has a milder climate than continental Antarctica, a result of its northern extension and, as a consequence, there is a relatively greater extent of exposed rock at sea level than for other regions. Antarctica is remote from the other southern hemisphere continents, separated from them by a cold ocean, the limit of which is marked by the Antarctic Convergence. The Convergence, which circles the continent between 50°S and 60°S, approximately marks the northern extent of sea ice cover during the austral winter when the ice expands to a maximum of about 21 million sq km from a summer minimum of approximately 4 million sq km (Sugden 1982).

Climatic conditions in Antarctica are severe and average annual temperatures range from 0°C in the Sub-Antarctic islands to below -50°C in the interior (Schwerdtfeger 1970). As a result of the atmospheric systems over Antarctica, accumulation of snow is greatest around the periphery of the continent, whereas on the polar plateau accumulation is low, for example 150 mm per annum at Amundsen-Scott station (Brier and Paige, 1972).

## 2. The Polar Station.

The main constraints on human activity in Antarctica are the combination of climate, sea ice cover, altitude and isolation. Climatic conditions and the vast expanse of winter sea ice effectively



sever all means of support, whether by air or ship, for continental stations during the polar winter. Over-flights and air-drops are made at only a few stations during the winter period and stations must be self-sufficient in every way until the pack ice extent and weather conditions ameliorate in spring. The seasonal pack ice fluctuation sets a limit to the operational length of the austral summer and air support is similarly restricted to the milder conditions experienced during summer.

Humankind could not exist in Antarctica without considerable support: Man cannot tolerate continuous exposure to extreme cold air or be in permanent contact with ice and snow; he must maintain his core temperature within sharply defined limits and, in the Antarctic environment, requires a daily input of about 17000 kJ per day (Shurley 1971). In the Statement of Evidence to the Parliamentary Standing Committee on Public Works, the Australian Antarctic Division notes,

*The primary function of the Antarctic stations is to provide accommodation and the necessary support facilities to enable a group of people to live and work in remote polar regions for long periods without physical communication with other areas during this time.*

(Anon 1981 p.8)

The polar station must be able to resist freezing salt spray, if sited on the coast; wind scour, if sited inland; alternate drifting and exposure where built on rock or gradual burial by snow for stations constructed on ice shelf or plateau. On the polar plateau, personnel must acclimatise to an altitude in excess of 3000m, almost at the limit of habitation anywhere else in the world. At any station, solar radiation will be sufficient to cause freeze-thaw cycles that will shatter any porous materials and the temperature gradient between interior and exterior surfaces will create serious condensation problems.

### 3. Science and Politics in Antarctica.

Stations are established on Antarctica for scientific or political reasons and there is the prospect that economic and commercial activities may promote future construction. Within recent years, the number of States with an interest in Antarctica has increased and further stations have been opened. There is a growing focus on Antarctica as a result of political, economic and scientific interests in the continent but in political terms, Antarctica is one of the most stable regions of the world. This is due entirely to the Antarctic Treaty which came into force in 1961 and the number of States that have acceded to the Treaty has grown from the original 12, in 1961, to 35, in 1987 (cf Annex A). Of these 18 are actively engaged in Antarctic research and have achieved the status of Consultative Parties, giving them full voting rights at the Antarctic Treaty meetings.

The Treaty arose from the scientific and political accord that developed during the International Geophysical Year (IGY) of 1957-58 and has effectively terminated political conflict over Antarctica to the present day. The geographical limits to the Treaty are clearly set out,

#### *Article VI*

*The provisions of the present Treaty shall apply to the area south of 60° South Latitude, including all ice shelves, but nothing in the present Treaty shall prejudice or in any way affect the rights, or the exercise of the rights, of any State under international law with regard to the high seas within the area.*

(Heap 1987 p.xi)

Some States laid claims to sections of Antarctica before the Treaty came into force although these are held in abeyance for its duration. Establishing a station in a claimed sector has been seen as a means of reinforcing sovereignty but other States do not recognise claims and have sited their stations accordingly. The Antarctic

Treaty does not regulate where States may establish a station accept in as much as Treaty Recommendations comment about environmental conduct (Recommendations VI-4, VIII-11, XII-4, and XIII-4) and to advise consultation between governments which intend to establish stations in the same vicinity (Recommendation XIII-6) (Heap 1987).

Pre-dating the Antarctic Treaty by a few years but with similar origins, the Scientific (originally Special) Committee on Antarctic Research (SCAR) advises the Antarctic Treaty on matters of scientific and environmental concern. All the Consultative Parties except Uruguay are full members of the Committee (cf Annex B) and have acted together to propose designated conservation areas in Antarctica, to make recommendations to the Treaty, and to produce handbooks such as *Man's impact on the Antarctic environment* (Benninghoff and Bonner 1985). SCAR has also set up Working Groups to monitor Antarctic activities and make recommendations to the Antarctic Treaty. The exchange of information enshrined in Article III of the Antarctic Treaty has been carried forward by the Working Groups and the Group of Antarctic Logistic Experts meets regularly but only three symposia have been organised, in 1962, 1968, and 1982, and one proposed for 1988.

In contrast to the international collaboration between scientists, which has been one of the great achievements of the Treaty, many States have developed their own approach to the design and construction of polar stations. Comparative studies of Antarctic stations are rare and the last attempt even to list general arrangements and station utilities dates from the 1960s (Dubrovin and Petrov 1971).

The stations considered in this thesis are permanent, overwintering scientific research stations. In order to illustrate certain points, some seasonally occupied stations will be cited and the future development of commercial activities and its effect on building design considered. The discussion is limited to stations in the Antarctic Treaty area, those established south of 60°S latitude,

notwithstanding the significant developments occurring in the Sub-Antarctic regions.

Commercial ventures such as sealing and whaling promoted the first permanent buildings to be constructed in the Antarctic although various expeditions constructed huts for use over one or two year visits and some of these buildings have lasted to the present day. During the first part of the Twentieth Century a number of expeditions visited Antarctica and Orcadas station, in the South Orkney Islands, has been continuously occupied since the station was established by W.S. Bruce in 1904. Significant remains at some of the early expedition bases has led to the Treaty adopting Recommendations to protect these sites (Recommendation I-X, V-4, VI-14), and to propose a list of historic monuments.

The type of stations considered in this thesis were not established in the Antarctic until the Second World War when military and political purposes supported the concept of permanently manned stations. Following the war many of these stations took up a scientific role and the IGY led to further observatories being opened in Antarctica, including stations at the Geographic South Pole (USA) and the Pole of Inaccessibility (USSR). In recent years, a growing concern among some States about the future development of the continent has resulted in a further pulse of station construction.

#### 4. Station Function.

Stations in Antarctica fulfil different roles according to their position, accessibility, and scientific discipline. Stations are most easily established at coastal sites where there is an early retreat of pack ice and reasonably level terrain, free of permanent snow and ice fields. Unfortunately, there is a shortage of such sites resulting in overcrowding in some areas, such as King George Island, South Shetland Islands (Headland and Keage 1985). However, as the development of Antarctica continues, further stations will be opened and the greater

accessibility of coastal stations will increase the conflict with biological communities that favour the same features.

Support of inland stations requires a coastal port where cargo can be transferred to aircraft or tractor for onward transport and at particularly favourable sites, where summer sea ice conditions allow good access, 'stepping off' points have been established. Stations have therefore assumed a form of specialisation, depending on their logistic function as much as their scientific role. There are three dominant logistic functions.

1. *Transfer Stations*
2. *Field Stations*
3. *Independent Stations*

*Transfer Stations* are those whose main role is to provide a stepping off point for activities elsewhere. Only four nations, Argentina, Chile, USA and USSR, operate intercontinental flights to Antarctica although some other nations are developing facilities. These routes are generally served by wheeled aircraft which require well prepared runways and the link is mostly used for the quick transfer of personnel to and from Antarctica. The receiving stations in Antarctica are accessible to ice-strengthened ships which bring the bulk of the cargo for transport to research activities or sites further inland by ski-aircraft or tractor train. Examples of *Transfer Stations* are: Casey (Australia), Marambio (Argentina), McMurdo (USA), Molodezhnaya (USSR), Rothera (UK), Scott Base (NZ), Rodolfo Marsh (Chile),

• Stations that are difficult to reach because of continuous presence of sea ice, preventing regular visits by shipping, or are remote from the coast and require to be re-stored by other means, fall into the second category. These sites rely on a *Transfer Station* for support and the costs of maintaining personnel on the station are some of the most expensive in Antarctica; in 1969, USA estimates for supporting one man at an inland station was calculated at \$102,000 per

man year (Bleasel 1987). Often *Field Stations* are constructed on a snow or ice foundation, providing exciting challenges to station designers, and Amundsen-Scott (USA), Mizuho (Japan), and Vostok (USSR) fall in this group. A number of seasonally occupied stations, sited on rock or ice, are also in this category, eg. Edgeworth-David (Australia), Fossil Bluff (UK), Siple (USA), Vanda (NZ).

*Independent stations* are those that are directly supported by ship and do not, themselves, support long distance field work. These sites do not require the back-up of another station to operate and are accessible to shipping for the annual relief visit. Examples are: Georg-von-Neumayer (FRG), Halley and Signy (UK), Palmer (USA), Dakshin Gangotri (India), Sanae (South Africa), and many of the Peninsula stations.

#### 5. Designs for Polar Stations.

Whatever their function, stations in Antarctica have a number of common objectives,

1. Provision of secure dwelling in the Antarctic environment.
2. A standard of accommodation that will maintain proficiency and morale of personnel.
3. Furnish a safe working environment.

The paucity of studies of Antarctic polar designs was noted above but Arctic studies have demonstrated that a minimum standard of accommodation is required to maintain the level and quality of activity. Smith (1972) noted that health and well-being is intimately related to habitat but,

*In the rare instances where attempts have been made to design for these [Arctic] regions, emphasis has been on engineering considerations rather than habitability.*

(Smith 1972 p.55)



Smith also studied the tendency of people in northern communities to become less active with time after approximately three months in the region, a feature he also recorded in the Antarctic, which was a result of poor design and insufficient space allocation (Smith 1972). Among his recommendations for Arctic community planning are suggestions for; specific designs for the region; study of the use of space; a greater allowance of space for activities; better sound-proofing of buildings. A similar call was sounded at the SCAR Symposium of Logistic Experts held in Japan in 1968,

*Modern comfortable camps are essential to good morale and high productivity for personnel living in polar regions. This is particularly true ...where the occupants are isolated for long periods, recreational facilities are limited, and scientific exploration has replaced high adventure.*

(Brier and Moser 1968 p.305)

Station design should be more than finesse in engineering although reliability of utilities is of the utmost importance. Is there a requirement for buildings to be specifically designed for Antarctica? Environmental, psychological and economic reasons affirm this need and a considerable body of work on Arctic community planning confirms the same conclusion,

*Competent planners, community designers, and architects have to take a look at this [Arctic] area of the world and try to design specifically for it.*

(Smith 1972 p.61)

In this thesis the design and serviceability of selected Antarctic stations will be analysed and stations will be evaluated under the headings,

1. Suitability of the design for Antarctica.
2. Serviceability in the Antarctic environment.
3. Living and working conditions.

The analysis will demonstrate the lack of international contact between Antarctic polar designers and how, in the isolation of Antarctica, standards of heating, light and working conditions are often lower than those applied in the expeditioner's home country. Construction in Antarctica, necessarily, has to be conservative as only well tested and reliable technology should be deployed but this is not an excuse to ignore developments elsewhere in the world. Undoubtedly, further stations will be established in the region and accessibility will force greater conflict with coastal biological communities, however, a vast expanse of ice-shelf remains available and economical designs for use in this environment are needed.



## CHAPTER 2

### Station Descriptions

#### 1. Amundsen-Scott South Pole Station.

The International Geophysical Year of 1957-58 stimulated the construction of many stations in Antarctica as part of a world-wide chain of observatories. A crucial gap lay across the centre of the Antarctic continent with the result that the USSR built a station at the Geomagnetic Pole and the US went to the South Pole. The first geographic pole station, built by the US in 1957 as part of Operation Deepfreeze II, was constructed from *Jamesway* huts and prefabricated wooden buildings placed on the snow surface. By 1967, the buildings had been buried to a depth of about 6 m of snow and had required strengthening to take the load. The USA desired to maintain a facility at the South Pole and design studies for a replacement station were initiated (Guthridge 1975).

The pole facility is supported from McMurdo, Ross Island, which is 1 300 km distant, about 2½ hours flight, and this has a strong influence on the design and construction of the station. Unlike Vostok, which is supplied by tractor train (Shirshov and Gindin 1985), Amundsen-Scott (Fig.2.1) is entirely supported by air. During construction of the new station, ski-equipped LC-130 Hercules aircraft were used to transport materials and personnel to the Pole and components were constrained to a maximum weight of 9 tonnes and size of 2.5 x 2.5 x 11 m. The flying and construction season lasts only about 75 days and the new facility took from 1970 to 1975 to complete.

A 14 m steel arch houses part of the facilities but one of the interesting developments at Amundsen-Scott station is the use of a

geodesic dome, 50 m diameter by 15.8 m high, to house the main accommodation. In addition, a five-storey auroral tower, the 'Sky Lab', was constructed to one side of the dome and a balloon inflation and launching tower is connected to the steel arch (Fig.2.2). Underlying the steel arch is a 2 m high corrugated steel utilidor which carries the station services. Use of steel protective shelters, the dome and the archway, has enabled the buildings inside to be a lightweight modular design, of a size that fit the cargo hold of a LC-130 (Brier and Paige 1972; Guthridge, 1975).

The dome and archway provide protection for the buildings from wind and accumulation of drift. This has two advantages: the buildings do not have to be as strongly constructed as they would if unprotected; shelter from wind and reduced temperature fluctuations will reduce fuel consumption. Both points are important for an air supported station and were a considerable advantage to the logistics of air-lifting the structure to the pole site (Brier and Paige 1972).

Ice formation inside the steel arches and dome is prevented by maintaining the void space at ambient temperature. Excess heat from the station is vented to the atmosphere and, in case of heat loss from the buildings inside, the dome is also vented. As far as possible, a total energy concept has been applied to the services at Amundsen-Scott station and waste energy from the generator coolant circuits and exhaust is used to heat the station and to melt snow for domestic water (Ibid).

The main accommodation space, communications offices, and laboratory space are housed in three two-storey buildings, constructed from the pre-fitted modular units referred to earlier. There is also a small annex in the dome with further sleeping accommodation and an archway leading to the 'skylab'. This five storey building houses scientific laboratories, the auroral camera, and, on the fourth floor, a 'sky lounge' with large picture windows. Contained in the arch ways are power house and fuel stores, medical centre, gymnasium, carpenters shop, and garage (Currie 1985). Leading off one archway is a cargo

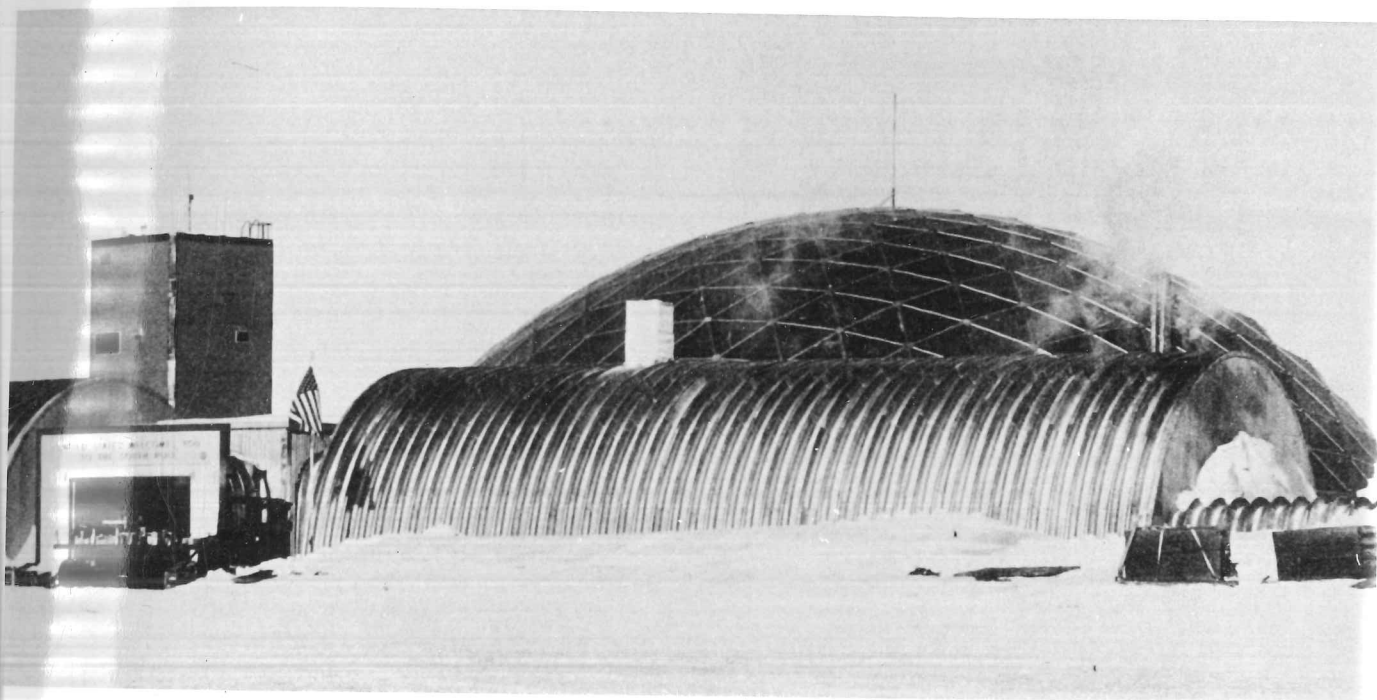


Fig.2.1 Amundsen-Scott South Pole Station.

The main entrance and steel arches lie in front of the dome, which houses the accommodation, and the 'Sky Lab'.  
(after Guthridge 1975)

handling area and a balloon inflation and launch building. Since 1983, all balloons have been filled with hydrogen, generated on site. During the last few years, a major refurbishing of the station has been undertaken. Buildings have been levelled, the station re-wired and re-plumbed, and the exterior buildings, such as the clean air facility, raised (Anon 1986a; Becker 1984). All this activity is an indication of the continuing requirement for a scientific facility at the South Pole and the station provides the opportunity for visiting scientists to work at this spot.

The station was constructed on the snow surface but with the knowledge that accumulation, about 15 cm a<sup>-1</sup> of snow (Brier and Paige 1972), will eventually bury the facility. The station was designed with a projected life of 15 years before accumulation would overwhelm the dome. Although the archways are able to withstand a maximum of 1.5 m of snow cover, the dome was not designed to withstand any overburden (Ibid; Guthridge 1975).

Amundsen-Scott is one of the few stations where costs for construction have been supplied. The total cost of building the station amounted to about US\$6 millions (in 1975), broken down into materials, at about US\$3.5 millions and labour and related services, about US\$2.5 millions. In 1986, 19 personnel overwintered, including 6 scientists, and for the 1986-87 summer season a total of 83 people worked at the site, including 43 scientists. The main studies are: upper atmosphere; geomagnetism; seismology; meteorology; and glaciology.

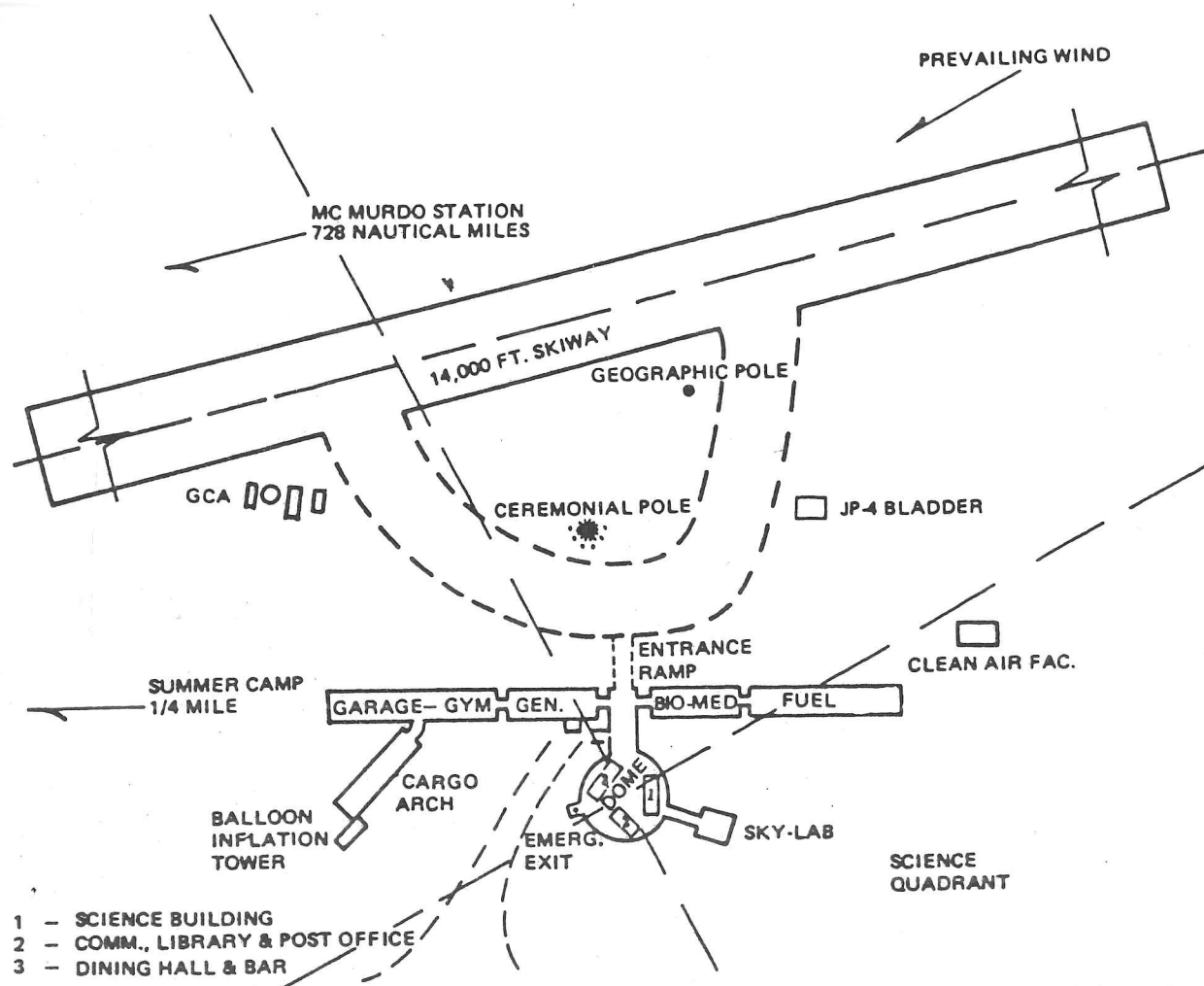


Fig.2.2 Amundsen-Scott South Pole Station.  
 Site layout showing arrangement of skiway, steel arches  
 and dome.  
 (Antarctic Services 1985 p.10)

## 2. Casey Station.

Casey station (66°17'S 110°32'E) lies on the Bailey Peninsula, Wilkes Land (Fig.2.3). The region was discovered by Charles Wilkes during the United States Exploring Expedition of 1838-42. British whaling vessels operated off Wilkes Land during 1947 but the first detailed investigation of the coast was made by the 1955-56 United States expedition which reconnoitred possible sites for stations (Headland [n.d.]).

Casey was officially opened in 1969 (a 4 man team had overwintered the previous year), construction having started in 1965. The station was built to replace Wilkes Base which was established by the USA in 1957 for the IGY and later handed over to the Australian Government. Although Wilkes had deteriorated to a point where replacement had become necessary, the permanent inundation of the station by snow and attendant fire risk indicated that a new design was required.

The station is situated on a area of exposed rock which appears as low islands and peninsulas extending a short distance from the polar plateau. Casey was built and is serviced by the Australian Government through the Antarctic Division and the Department of Transport and Construction. The station provides a base for Upper Atmosphere Physics, Geomagnetism, Glaciology and Meteorology. Autumn and spring traverses depart most years into the interior of the region whereas during summer biologists and geologists work from the station (Betts, [n.d.]). Relief is generally by charter ship which calls once or twice in a season. An airlink has been established via McMurdo using US ski-equipped LC-130 aircraft which land on a snow strip some 18 km inland, on Law Dome (Ibid).

Considerable effort was expended to overcome the drift problems experienced at Wilkes. Approval was given in 1964 to replace Wilkes and an aerodynamically designed station was developed by the Repstat Design Group (Styles and Melbourne 1968). The existing station is





Fig.2.3 Casey Station. Old site (above) constructed 1969, and new site (below) under construction in 1986. (photographs by Lewis Smith)



raised 1.5-3 m off the ground and is aligned at right angles to the prevailing easterly wind. The station consists of thirteen structures connected by an elevated corridor, some 200 m long, on the windward side. The individual structures are separated as a fire precaution but are linked by a corridor which provides convenient all-weather access and a sheltered passage for utilities.

This main block houses accommodation, laboratories and administration. The existing capacity for Casey is 33 winterers with an additional 5 places in the summer, the extra accommodation being provided by sharing of bunkrooms (Anon 1981). The power Houses are sited a short way from the southern end of the main structure near the vehicle and tradesmen workshops which need to be at ground level for access. Fuel tanks are sited downwind of the station (Betts [n.d.]).

The solution to the problem of drift at Casey has been effective, however, the elevated structure has proven to have undesirable vibrations in certain wind speeds and unexpected corrosion from salt spray (Incoll 1980; Gosbell and Holmes 1982). The noise and vibrations apparently gave the impression that the weather was worse than in reality and the linking of structures appeared to be a disincentive for people to venture outside. All these factors seemed to have an adverse effect on station morale. In 1978 surveying was undertaken for a site of a new station at Casey and a proposal to redevelop the three Antarctic stations, Casey, Davis and Mawson, was initiated in 1980 as part of a ten year plan (Anon 1981).

The new site is approximately 1 km southwest of the existing station on a low rocky hill, clear of the effects of sea spray (Fig.2.4). The station will not be elevated and will consist of several large multi-purpose buildings constructed on concrete ring beams. The new site will cover an extensive area, partly because the present station fuel facilities will continue to be used. The station is being designed for 40 personnel and for reasons of fire safety and to minimise snow accumulation the buildings are widely separated. Accommodation block, power houses, meteorological complex



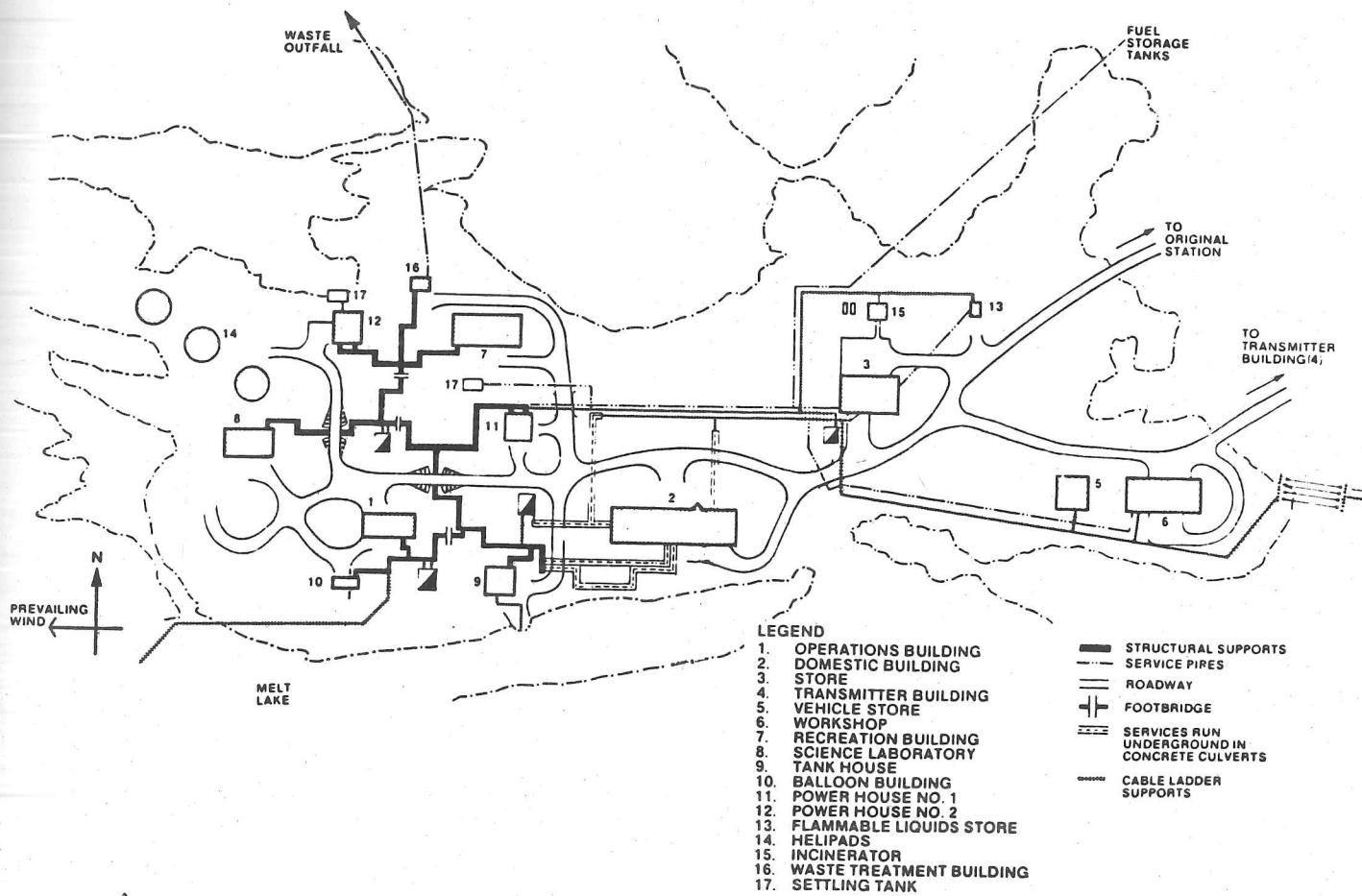


Fig.2.4 Site plan for replacement station at Casey. The existing facility is about 1 km to the northeast. The new station will continue to use the fuel tanks sited near the existing station.  
(Department of Transport and Construction 1982 p.1.4)

and station office complex have been constructed. A science and recreation block are planned to be completed by 1993 (Lewis Smith pers comm).

### 3. Georg-von-Neumayer station.

There are very few stations constructed on ice in the coastal zone of Antarctica. The problems to be faced in this environment are unlike virtually any other region; annual accumulation can be high, persistent easterly winds bring snow drift and any objects placed on the snow surface are soon buried. Further inland, where accumulation rates are lower, surface built stations can expect a reasonable life-time, however, to provide a useful life in the coastal zone stations must either be raised to stay clear of the snow surface or be constructed of strong enough materials to withstand the crushing weight of snow overburden.

Georg-von-Neumayer (Fig.2.5) is one of the most recent stations to be established in this environment. The high rate of accumulation, about  $75 \text{ cm a}^{-1}$  of snow (Dörr and Jessberger 1983), indicated that the station should be able to withstand an overburden of about 7 m if a reasonable life-time is to be expected and the design called for an outer skin of corrugated steel, similar to that used for Halley (1974) and Sanae (1979) stations (Jacobs 1982; Smith 1982).

Two interconnected steel tubes were deployed during the 1980-81 season and prefabricated units, fully fitted out in Germany before shipment, were installed inside (Fig.2.6). The building units conformed to ISO standards for 20 foot containers, mainly to meet shipping requirements (Mannhardt 1982), which leads to rather a low ceiling in the finished, fully insulated unit. The advantage of fitting out units before transport is a reduction to the number of items, requiring listing, packing, and installation, to be carried to the site. Many services can be pre-fitted and construction on site becomes a simple matter of linking up units on a steel sub-frame. The



Fig.2.5 Georg-von-Neumayer Station.

The two steel tubes are buried and only the tops of the access shafts and the large doorways on the end are visible.  
(Alfred-Wegener-Institute)

disadvantage of modular systems is cargo volume - although the units can be filled with lightweight stores during transportation - and unloading, for which special cranes may be required.

By combinations of two and four units, comfortable accommodation and communal areas have been constructed. Single bunkrooms are provided with excess summer personnel being placed in a surface building. The living areas on the main station are comfortable and furnished with curtains and carpets to give a more 'homely' feel (Stonehouse pers comm) and a generally high standard has been maintained throughout (Ibid).

Particular care has been paid to minimising fuel consumption at the station and heat exchangers are fitted to the generators to scavenge waste energy (Mannhardt 1982). All the heating of the station is supplied from this source and Mannhardt (1982) estimates some 90 tonnes of fuel are saved over conventional central heating systems. Ventilation of the accommodation and working areas is carefully controlled so that there is no build up of heat in the power house and sufficient fresh air is supplied. Control of temperature of the air space between the tube and the buildings is critical to the integrity of the structure and is discussed in detail later in the thesis.

Water is produced by using generator exhaust heat to melt snow which is shovelled in through a chute. Waste is pumped out along a 75 m heated pipe to a snow pit. Other waste is collected and removed from the station at annual relief (Ibid).

To reduce the possibility of fire spreading through the station strict limits were imposed on the fire resistance and non-toxic construction of station components. Fire walls are sited at various points through the buildings and the ventilation system is fitted with automatic dampers that shut off the air supply in order to starve fires of oxygen. A fire alarm system and smoke detectors are installed throughout the station and a halon flooding device is fitted

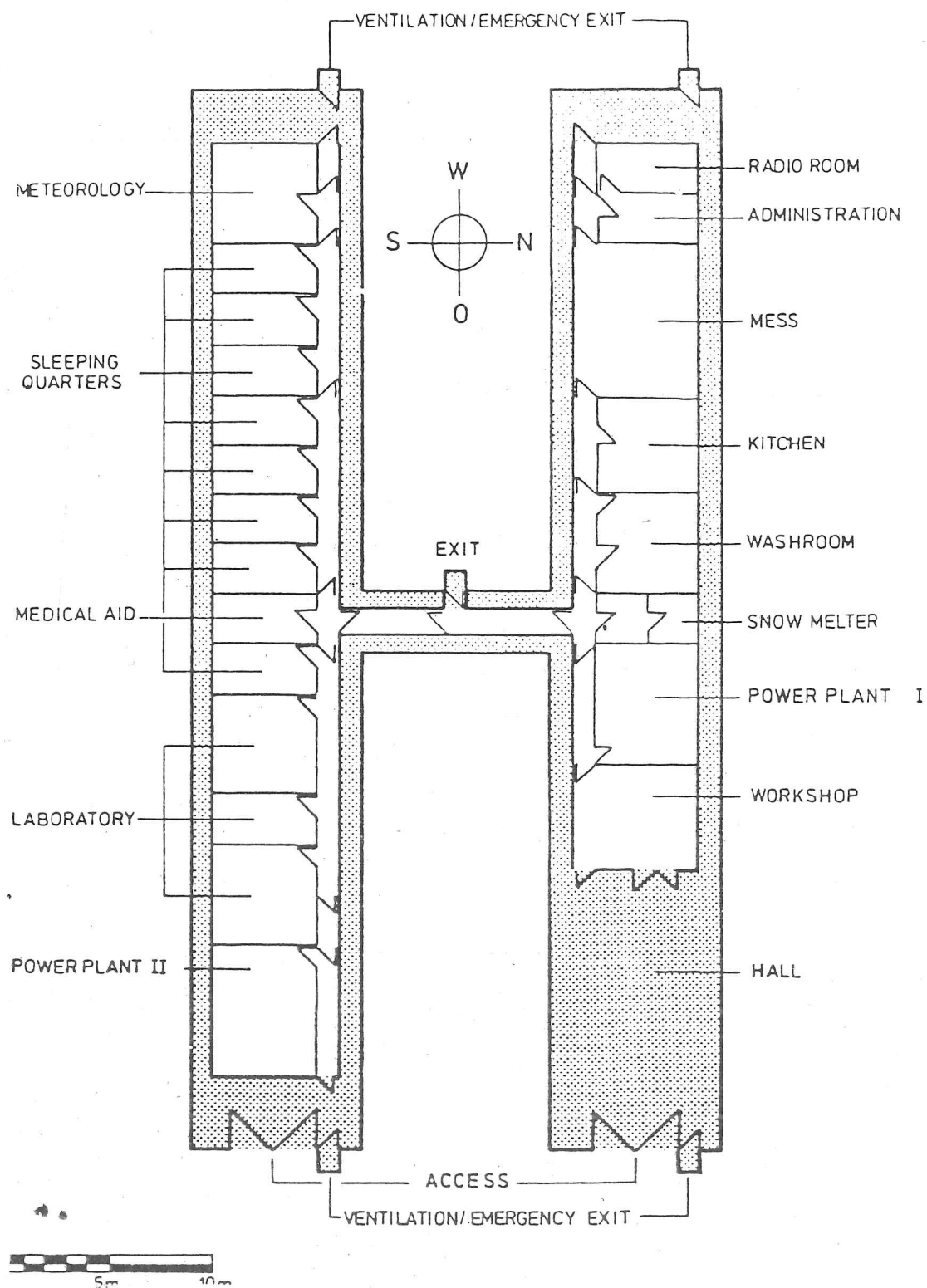


Fig.2.6 Georg-von-Neumayer Station.

Arrangement of facilities within steel protective tubes.  
Note main and emergency exits via access shafts.

(Mannhardt 1982 p.339)

to the power units (Ibid). The emergency access is clearly labelled and the station plan is simple and easy to grasp and, therefore, should be easy to negotiate in a emergency (Stonehouse pers comm). As back-up to the main station, a building, equipped with generator, stove, food, and clothing is sited some way off.

The station accommodates 9 people over winter and up to 30 during summer, using the surface building. The station is active in the fields of geophysics, atmospheric, meteorology, glaciology, air chemistry and pollution. In addition, monitoring of the behaviour of the structure as the overburden of snow increases has been maintained (Dörr and Jessberger 1983).

#### 4. Signy Station.

Signy station (Fig.2.7) was established in 1947 on Signy Island, (60°45'S 45°36'W), in the South Orkney Islands. The group lies at the northern edge of the Weddell Sea and comprises 4 main islands, of which Signy Island is the smallest, and a number of islets amounting to a total area of about 1 000 km<sup>2</sup>. The islands lie in the Maritime Antarctic Zone but the influence of the cold waters of the Weddell Sea and the proximity (c.500 km) of the Antarctic Peninsula cause the islands to have cooler conditions than their latitude alone would indicate. During winter the group is usually surrounded by pack ice and shipping is restricted to the summer months (November to April).

The islands were discovered by sealers in 1821 but were of little interest to them because of the small fur seal population. Buildings were first constructed on the island by the steam-whaling industry in 1920-21 when a small shore station was established in Borge Bay. A wooden plan was constructed, vertical pressure cookers and steam generators installed and a dormitory block built nearby. Operations ceased after four seasons and processing reverted to floating factory ships. The present research station is situated on the same site which is one of the most sheltered on the island. A number of whaling



Fig.2.7 Signy Station.

The buildings are placed close together and in winter snow drifts form around them. The jetty is just visible in front of the station.  
(photograph by P. Tearle)



relics are still to be seen and one building, the whalers' gunpowder hut, is used as an emergency store for the present station.

All the islands of the South Orkney group are heavily glaciated, however, Signy Island has the greatest extent of ice-free ground. The island is small, measuring about 8 km north to south and 5 km east to west and rises to an elevation of 279 m at Tioga Hill. The present station is situated close to the shoreline on the south side of Factory Cove having moved there, in 1955, from a position on the top of Berntsen Point.

The present station layout (Fig.2.8) consists of 5 main buildings and several smaller outhouses. The oldest existing building dates from 1955 and is a single-storey wooden construction providing laboratory, work spaces and technical support for the station. A two-storey GRP-foam-sandwich construction was erected in 1964 and houses laboratories and administration on the ground floor with living accommodation above. In 1974 a Power House and Boathouse were constructed replacing earlier arrangements. Both are timber frame construction, metal-clad on the outside but only secondarily insulated. Finally, a large building was constructed in 1981 of metal-clad plywood-styrafoam panels which houses scientific support facilities (Dive store; Constant Temperature rooms; clean room), food and freezer store and other general storage areas.

The station has developed over a long period and shows examples of various different techniques of construction. The site is small and buildings are positioned closer together than is ideal from a safety point of view. The area of reasonably level ground to develop the station further is limited and a major reconstruction will require the removal of some of the existing structures. Clearly, there has been no long term development plan for the site and this is best demonstrated by problems of access - part of the Intersection had to be removed to replace the generators - and the effect of winter accumulation of snow causing considerable impediment to movement between the buildings.



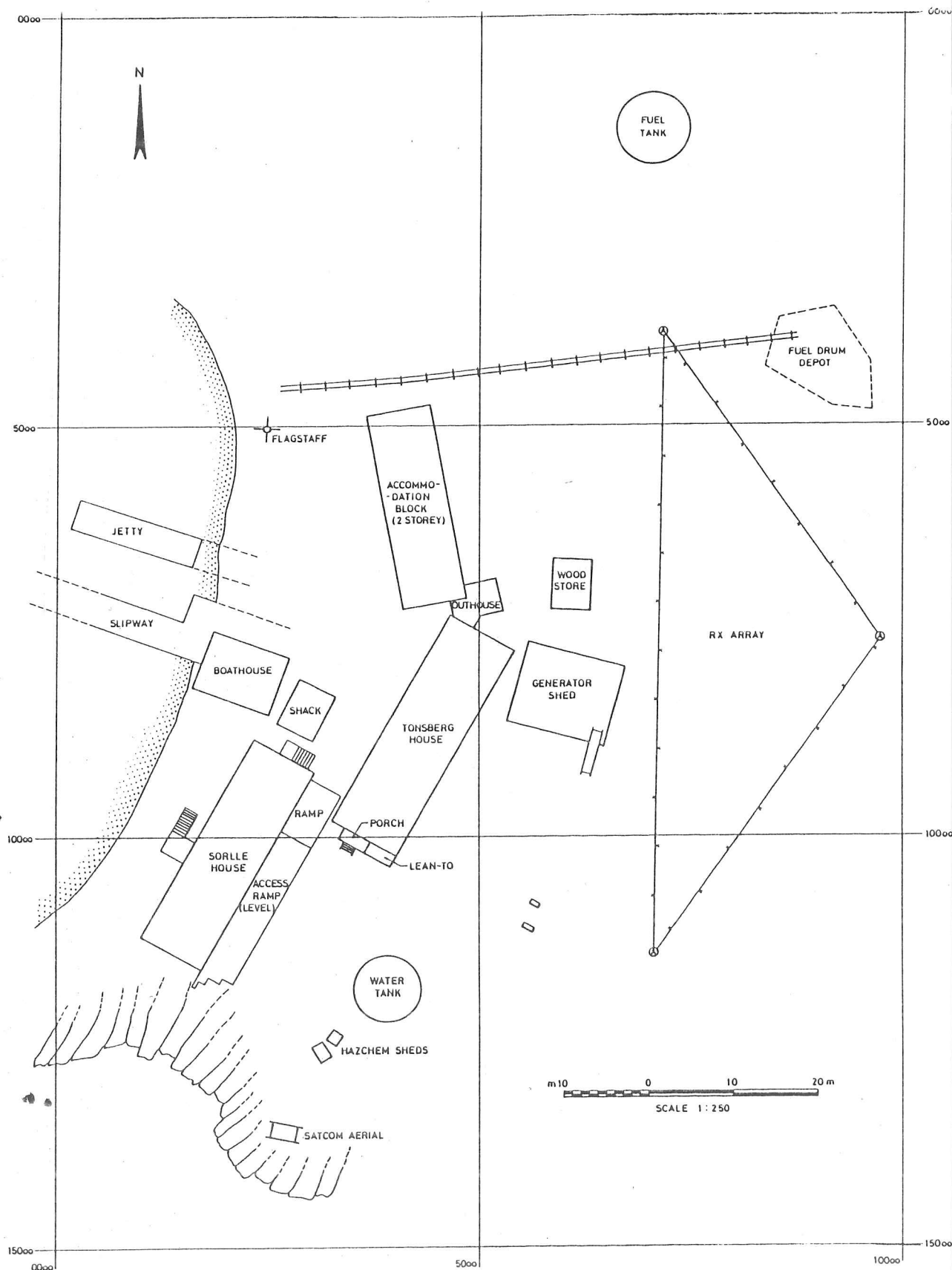


Fig.2.8 Signy Station.  
 Rocky bluffs and steep ground confine the buildings to  
 land adjacent to the shore line.  
 (British Antarctic Survey)

Signy Island offers an unique biological community for study. Programmes are supported by a comprehensive suite of laboratories including, balance room, analytical laboratory, and wetlab, and a number of general laboratories that double as workstations. Constant temperature rooms and a computer facility are provided and a small launch, slipped into the Boathouse in winter, supports the marine projects. During the summer, up to 27 people can be accommodated; in winter, the number reduces to 12-16 people.

## CHAPTER 3

### Suitability of Designs

A number of ways have been found to resolve the problems associated with construction on rock and of siting a station on an ice shelf or the polar plateau in Antarctica. Over the period of exploration and scientific development of Antarctica various solutions have been tried and the advent of new materials and techniques has opened up a range of different possibilities. Constraints upon station design that are specific to the polar regions include drifting snow, permafrost, snow and ice foundations and freeze/thaw cycles, and these will be considered in this section as well as the means by which some of these problems have been overcome.

#### 1. Constraints to construction in Antarctica

##### 1.1 Placement on Rock.

Of the 39 stations reported to SCAR as operating in the winter of 1986, 31 are sited on rock (SCAR Bulletin No.84 1986) and, clearly, this is the preferred foundation. An advantage of rock as a foundation is the greater experience of engineers with this type of material but there is a limit to the number of suitable sites. Rarely is bed rock level and buildings either have to be designed to accommodate irregularities in the ground or the surface has to be levelled. Raised beaches, moraine and other deposits may provide suitable ground on which to site a station but these areas are often underlain by permafrost which is highly susceptible to thermal disruption.

Areas of ground disturbed by frost heaving and instability have been avoided as far as possible and areas of deep soil, equivalent to the tundra zone of the Arctic, are not common in Antarctica. Few of the techniques employed in the north, such as berms, insulation between building and foundations, and protection of permafrost are used in Antarctic station design although Scott Base, Ross Island, is sited on frozen volcanic scoria and, during reconstruction of the station, buildings were raised off the ground in order to minimise heat transfer to the permafrost (Easton 1983). There is extensive experience of permafrost in the Arctic and some simple principles have been elucidated,

- foundations should be brought down to a safe depth below the active layer;
- heat transfer to the ground must be prevented to maintain the permafrost below the foundations.

(United Nations 1980 p.83)

The 'active layer' is the surface zone that is affected by seasonal thawing. Heat transfer from buildings will locally increase the depth of this layer, causing slumping or other soil movements which would be disastrous for the structure (United Nations 1980).

#### 1.2 Placement on Snow and Ice.

In terms of soil mechanics, snow and ice are by no means the worst foundation material (Mellor 1965) but the, apparently, unlimited choice of sites on snow or ice is offset by considerably less experience of this medium. Summaries of the mechanical and engineering properties of snow, firn and ice are to be found in Mellor (1965) and Gray and Male (1981).

• The first criterion for snow and ice sites is to determine a safe site for the station. Several abandoned stations have drifted off as parts of icebergs, for example, Belgrano I (Argentina), Druzhnaya I (USSR), and Camp Michigan (USA) (Anon 1986b; Sharma 1986), and an understanding of ice movement, crevassing, and horizontal stress at the intended site is required (Fig.3.1).

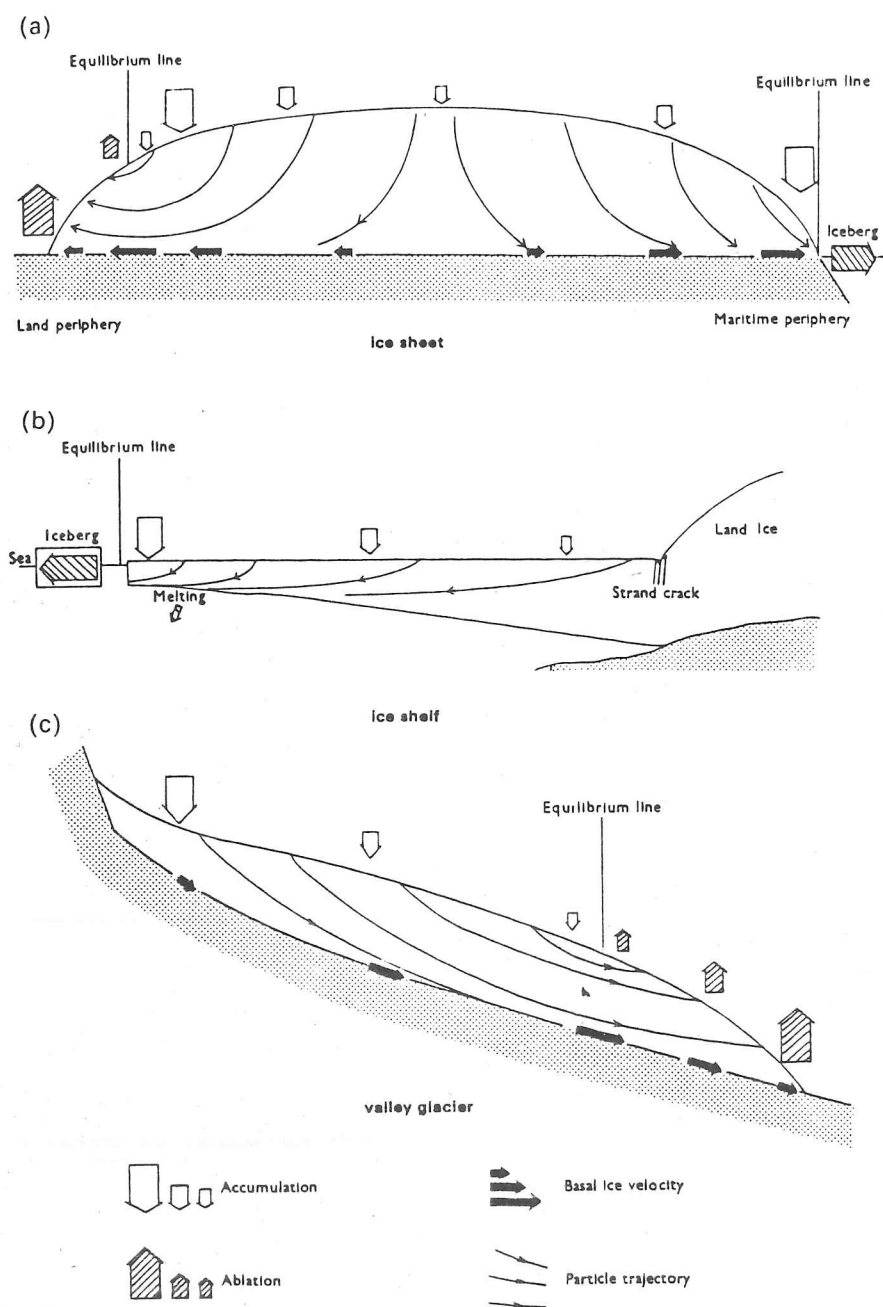


Fig. 3.1 Models of (a) ice sheet (b) ice shelf and (c) valley glacier, showing the distribution of accumulation and ablation and related characteristics. (Sugden 1985 p. 70)

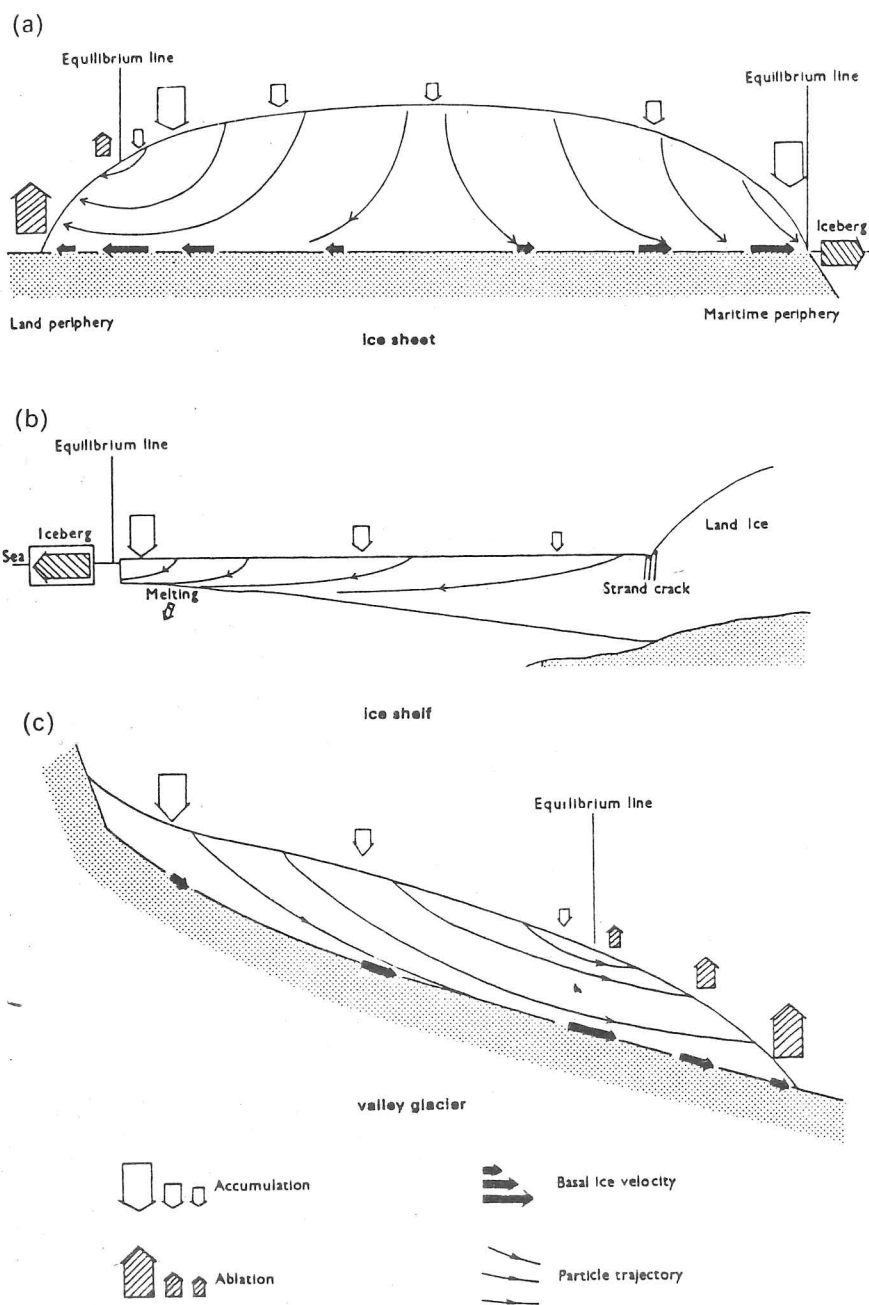


Fig.3.1 Models of (a) ice sheet (b) ice shelf and (c) valley glacier, showing the distribution of accumulation and ablation and related characteristics.  
(Sugden 1985 p. 70)

Measurements of accumulation rates, prevailing wind direction, variability of wind direction and maximum gusts for the intended site are also needed to develop a suitable design.

Snow and firn provide adequate foundation material provided heat transfer is minimised. Pile or spread foundations may be used but in both cases protection from radiation or heat transfer is vital if integrity of the snow is to be maintained. Piles require to be sleeved above ground level so that no melt back of overburden can occur because it has been shown that friction along the length of the pile, rather than point loading, is the supporting mechanism (Clark 1965). Similarly, spread footings must be protected from solar radiation and heat transfer from buildings to prevent slumping or slippage due to differential melting of snow (Ibid; Mellor 1965).

### 1.3 Coastal Sites.

Reference to the station map of Antarctica (*Frontispiece*) shows that the majority of stations are sited on or near the coast or on islands, particularly those at the Antarctic Peninsula. Good sites with convenient anchorages for shipping have been located on many of the islands along the Antarctic Peninsula and as a result only 3 of the 15 wintering stations in this region are sited on the Peninsula itself. The logistic benefit gained is offset against poor accessibility to the mainland and several nations have developed rock or snow runways to compensate.

The coastal stations generally have a milder climate than those inland due to the ameliorating effect of the ocean and lower altitude (Table 3.1). Warmer minimum temperatures require less insulation to the buildings but the active layer may be deeper, in turn affecting the foundation design.

Table 3.1 Comparison of mean annual temperatures for Mizuho (inland), and Novolazarevskaya (coastal) stations.

Station & Coordinates	Altitude m	Jan	mean temps °C	
			July	Annual
Mizuho 70°42'S 44°20'E	2230	-18.6	-39.1	-32.3
Novolazarevskaya 70°46'S 11°50'E	99	-0.7	-17.7	-10.6

(after Schwerdtfeger 1984)

In the salt laden atmosphere of the coast, stations are exposed to the corrosive effect of sea spray. Exterior surfaces and equipment require frequent maintenance and have a short life-time. Signy and Casey stations have both suffered from this problem and at Casey,

*It was soon found that the black iron tube [of the sub-structure] and the panels [of the building] were being affected by unexpected salt spray from the upwind bay of the sea.*

(Incoll 1980 p.23)

All exterior equipment and surfaces must be protected from the effect of salt spray and, in addition, ventilation systems will require a filter or louvre device to remove salt spray and water droplets before the air enters the circulating and heating elements.

#### 1.4 Inland sites.

Inland stations require a greater commitment to logistic support than coastal sites. The latter, if well situated, are able to take advantage of direct fueling, relatively easy transfer of cargo and the general convenience of access to shipping. Inland stations require the support of a coastal station where cargo can be discharged and transferred to tractor or aircraft for transport inland. Amundsen-Scott, for example, is dependent on air support from McMurdo; Vostok



is supported by tractor from Mirny (Guthridge 1975; Shirshov and Gindin 1985).

The climate at inland stations is often colder than at coastal ones, as indicated in Table 3.1, but, generally, lower wind speeds are experienced than in the coastal zone; the strongest winds occur where the Antarctic Plateau slopes steeply down to the coast (Schwerdtfeger 1970). Mawson suffered the effects of katabatic winds at Commonwealth Bay, during the Australasian Antarctic Expedition of 1911-13 (Mawson 1915) and Russkaya station, Burks Cape, Marie Byrd Land, currently holds the world wind velocity record at  $77 \text{ m s}^{-1}$  experienced in February, 1984 (Anon 1984b).

The advantage of low wind velocity is a slower rate of accumulation. Snow deposition is often due more to drift rather than precipitation (Schwerdtfeger 1970) and inland stations do not become overwhelmed at the same rate as those on the coast (Ibid).

The further south a station, the longer the dark period and this may become a psychological problem for some personnel. At Amundsen-Scott station the sun sinks below the horizon about 24 March. The relationship between latitude and the period of sun above the horizon is given in Fig 3.2. Stations such as Neumayer and Halley, which have been designed to be buried and therefore have no windows, are at the extreme end of the scale in terms of natural light and appear to present a mild form of sensory deprivation to personnel. Taylor notes,

*It appeared that an optimum level of stimulation was required, below and above which functional efficiency deteriorated.*

(Taylor 1978 p.31)

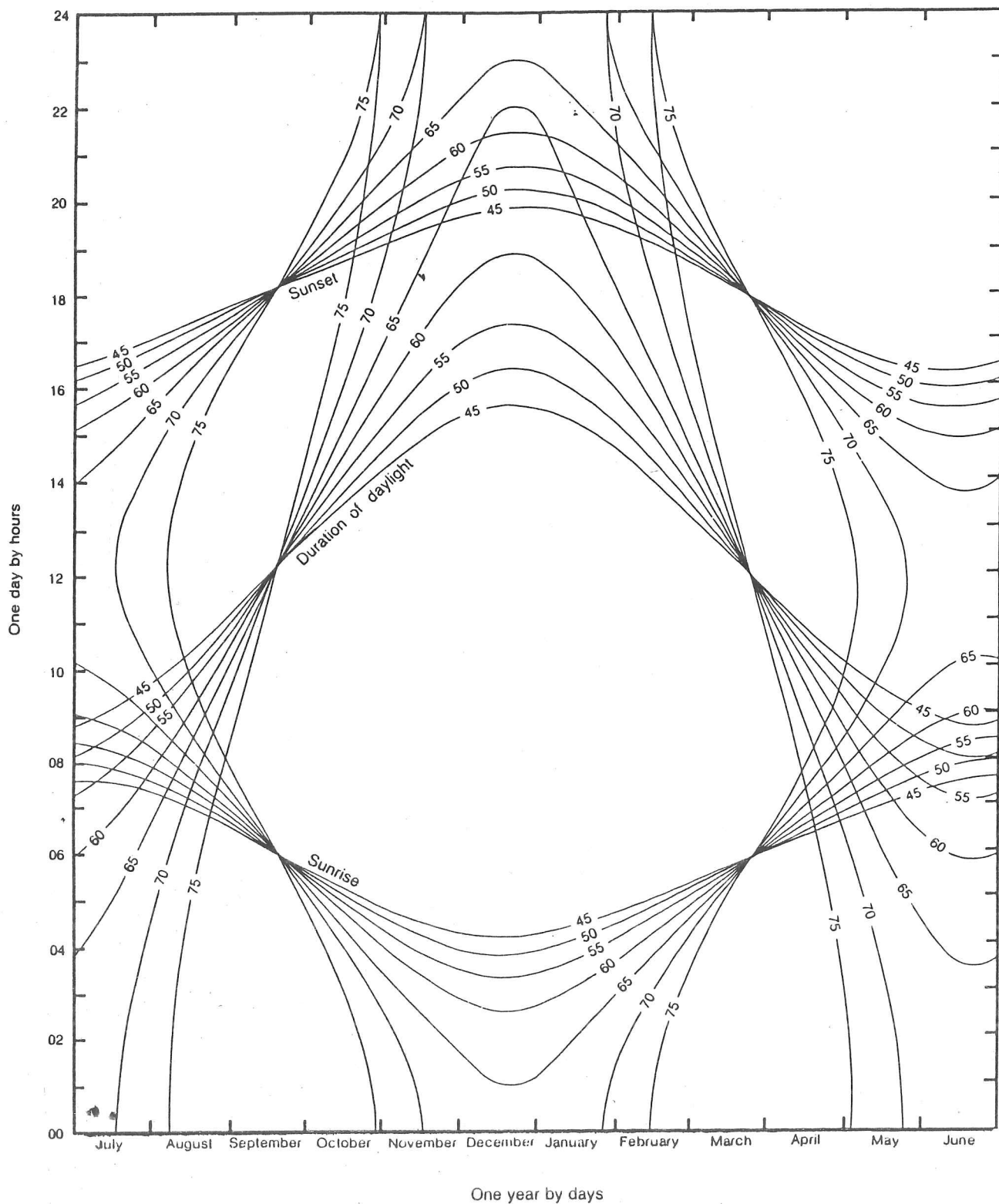


Fig.3.2 Sunrise, sunset, and duration of daylight at various latitudes. Amundsen-Scott 90°S; Casey 66°S; Neumayer 70°S; Signy 60°S.  
(after Smith 1986 p.E-11)

Inland stations, especially those situated on the polar plateau, may well have an unrelieved vista of snowfields. Stimulation for some people in this environment can only be found on the station and the design must reflect this fact. A different aspect may be obtained by raising the structure on a jackable platform and there are several small experimental examples of jackable structures, Filchner and Drescher summer stations and, in the Arctic, the major stations, Dye II and III (Brier and Moser 1982; Mannhardt 1982).

#### 1.5 Relationship of station to the ground.

Stations may be constructed:

*At Ground Level;*

*Above Ground Level;*

*Below Ground Level;*

All three options have been used in Antarctica except *Below Ground Level*, in rock, which has only commercial application (De Wit 1985).

The most common method is construction *At Ground Level* which has been employed at rock and snow sites. To protect the permafrost layer and to maintain the station clear of snow drifts, buildings are raised off the ground and studies of wind blown snow indicate that heights in the range of 2-5 m give the best results (Mellor 1965; Styles and Melbourne 1968). For certain facilities, such as vehicle garages, this is impractical and some sites, eg. Casey station, have a mixture of raised and ground level buildings, dictated by their function (Incoll 1980).

Stations constructed on the ice surface will, inevitably, become overwhelmed. On the polar plateau accumulation rates are lower than for the coastal zone and the projected design life for surface placed buildings may be acceptable. Amundsen-Scott South Pole station has *At Ground Level* buildings and a projected life of 15 years (Guthridge 1975). The Indian station, Dakshin Gangotri (70°05'S 12°00'E), sited on the edge of the coastal zone, is a simple, low cost design which was built *At Ground Level* in 1984. Accumulation reached roof level by

1986 but the station has not yet materially suffered although in time it will be crushed (Sharma 1986).

At greater cost, stations can be designed to resist the crushing force of snow overburden. Initially, at Byrd station and others, this was achieved by cutting a trench and roofing with a steel arch (Mellor and Hendrickson 1965). Relatively lightweight buildings may be installed inside the trench where they are protected from the overburden. It was found that creep of the trench walls and floor occurred and later designs were modified by siting the huts inside an entire ring of steel. Halley, Sanae and Neumayer are constructed in this manner and have achieved design life projections (Jacobs 1982; Mannhardt 1982; Smith 1982).

The psychological disadvantage to personnel of this style of accommodation and the limited life-time in return for investment has encouraged consideration of *Above Ground Level* stations for ice sites. The knowledge and experience required to design permanent stations on a jackable platform exists and it is likely that this technique will be employed in the future to replace some of the stations that are currently buried. Mellor (1965) describes Arctic applications but the scale and cost of the operation are far in excess of conventional Antarctic stations. Dye II and Dye III, part of the US Distant Early Warning system, were constructed on the Greenland Ice Cap in 1959-60 at a design elevation of 6m in an accumulation zone of about  $1 \text{ m a}^{-1}$  of snow, however, these stations are of the order of 3000 tons weight each (Mellor 1965). Even at this height, the structures caused the deposition of snow, inundating various poorly placed stores depots. Mellor comments,

*It seems clear that all but the most elaborately streamlined structure must create drifts; perhaps the most that can be done for the present is to cause drifts to occur where they can best be tolerated.*

(Mellor 1965 p.64)

*Above Ground Level* stations are exposed to the full force of wind and climate and, perhaps, require a more highly developed design. The only raised buildings on snow in Antarctica are Filchner and Drescher summer stations and several small research units at Halley and elsewhere (BAS 1980; Mannhardt 1982). An alternative to raising buildings on a jackable platform is to mount individual units on skids that can be hauled back onto the surface following drifting during a blizzard. Vostok has been built up from a number of units in this way but it is difficult to retain mobility without creating problems with services and loss of community atmosphere. Further, experience at Dye sites has shown the difficulty of breaking buildings out of age-hardened snow (Mellor 1965).

The choice of *At Ground Level* and *Above Ground Level* buildings at rock sites varies between different nations. Australian designers have decided to return to *At Ground Level* for the replacement structures at Casey (Incoll 1980) choosing to manage snow accumulation by orientation of buildings parallel to the prevailing wind direction, limited to a 30° arc at Casey (Ibid). The re-constructed New Zealand station, Scott Base, Ross Island, has been raised to allow wind scour to reduce drifting as well as protecting the permafrost from heat transfer from the station (Easton 1983).

#### 1.6 Logistic Constraints.

All logistic operations in Antarctica are a combination of transport modes. Early explorers reached the continent by ship and this remains the predominant method of transport for personnel and materials so that Antarctic Institutes therefore require the use of ice-breaking or ice-strengthened vessels. Refinement of logistic effort has allowed scientists greater freedom to pursue research and less time spent on staying alive: this is the primary aim of all logistic operations.

It is becoming common for scientists to shorten their summer season in Antarctica and air networks are being extended to give quicker and more extensive access to the continent (Smith and Dana

1973). Elaborate installations are needed in Antarctica to receive intercontinental flights and to provide search and rescue services and McMurdo (USA), Molodezhnaya (USSR), and Rothera (UK) are stations that have developed into flight control centres. Only a small complement overwinter to run the station but during the summer numbers are increased substantially by field workers, flight controllers, and station support staff.

Three aspects of the design of stations are of logistic interest,

- a. the volume and weight of cargo required to establish the station;
- b. the logistic effort required to service and maintain the facility;
- c. the fuel demand of the station.

Part of any design brief for an Antarctic station must be the capacity, in terms of volume and weight, of the transport medium. Coastal stations have the advantage in requiring little more than ship-to-shore transport and by the use of barges or direct docking most cargo can be easily handled. Few stations have permanent wharves although several have jetties or slipways to accommodate small craft. Stations in the vicinity of ice shelves can use the natural ice front as a wharf but this is a risky and uncertain procedure and various nations have artificially strengthened the ice to assist docking, for example at McMurdo and Molodezhnaya stations (Dubrovin and Preobrazhenskaya 1985). This is not always practical and at Halley station unloading has been undertaken, on occasion, with the vessel moored alongside first-year sea ice in an area where a snow ramp has formed allowing access onto the ice shelf. The limit to vehicle size and cargo weight then becomes critical, affecting the running of the station, and because ice shelf stations are, at the least, several kilometres inland from the ice edge, a tractor shuttle or air-lift is required to relieve the station. Stations further inland rely on air or tractor transport for resupply and the cost per kilogramme for cargo increases dramatically, the further inland the station (Bleasel 1987).



To support Vostok on the East Antarctica Plateau, cargo is transferred at Mirny from ship to tractor and a caravan of several large vehicles makes the journey to relieve the inland station. In 1979-80 season 14 vehicles transferred about 400 tonnes of freight to Vostok, including 294 tonnes of fuel (Shirshov and Gindin 1985). Tractor train transport of this type is slow and laborious but compared to flight, relatively inexpensive and less weight-critical. By contrast, Amundsen-Scott station relies entirely on air supply from McMurdo at considerable logistic and economic cost.

Delivery of cargo to the station is only the first step in the logistic chain and proper provision is required on site to organise the cargo for short and long term storage. The annual relief requirements of stations usually arrive in one or two large consignments and suitable arrangements are needed; first, to protect the cargo pending unpacking and distribution; second, to store items correctly until required. Sufficient storage space appears as an afterthought in many designs, items being consigned to lofts and other remote or awkward corners, whereas extensive, ground floor space where packing and unpacking can be completed, is needed. The allocation at Casey is magnificent and a large building is dedicated to the various types of storage needs for frozen, cool, and general stores (Lewis Smith 1986). At stations on snow, it is common practice to make stores dumps of the less frequently required items, however, this only serves to generate a further maintenance problem, raising the dumps after storms. Adequate storage space should be included in the design of any station, irrespective of locality.

Refuelling Antarctic stations occupies a major part of the logistic effort and good design will help to minimise the power demand of the station. Consumption figures are not available for all of the selected stations and although some figures for storage capacities are, these represent the total held for usage and back-up. Table 3.2 gives a selection of available fuel capacities. Fuel is either supplied in bulk or drummed, the latter occupying considerable cargo space.



Table 3.2 Fuel storage capacity and use at selected stations.

Station	Site	Elevation (m)	Fuel	
			Storage (tonnes)	Consumption (tonnes)
Mirny	Coastal	42	8 600	500
Vostok	Inland	3488	300	300
Signy	Coastal	7	400	150
Syowa	Coastal	15	400	300
Mizuho	Inland	2230		420
Amundsen-Scott	Inland	2835	855	

(after various sources)

## 2. Construction Methods in Antarctica.

The extremes of temperature and wind experienced in Antarctica significantly affect the construction of stations and various concepts, such as heat loss from structures, thermal transfer to foundations, vapour barriers and fire proofing, will be incorporated into successful station designs. Two of these, *Thermal Constraints* and *Vapour and Moisture*, are fundamental to the design and merit further consideration.

### 2.1 Thermal Constraints.

As a temperate animal, the human species is unable to withstand long exposure to cold air temperatures, snow or ice without some protective clothing and shelter (Shurley 1971). Many polar buildings are well insulated against cold and it is sound economic sense to limit the amount of heat loss from structures.

Hoch (1986) discusses the problems associated with measuring thermal efficiency on site and illustrates the various pitfalls of improper placement of insulation with respect to the interior or exterior surfaces of the structure. Air is still the best practical thermal insulator but only if stationary, moving air will quickly dissipate thermal energy (Hoch 1986; United Nations 1980). There

appears to be far greater attention paid to this important detail by Arctic designers than their Antarctic counterparts.

The Swedish report to *Human Settlements in the Arctic* (United Nations 1980) outlined the effect of wind on non-rigid external insulated walls,

*If the external board covering is not rigid, it will operate like the diaphragm of a pump, so that even relatively small elastic movements set up by pulsating wind pressure can cause cold outdoor air to be pumped into the heat insulation, thus impairing the insulation capacity.*

(United Nations 1980 p.85).

A common panel design used by several nations in Antarctica is the stressed plywood skin insulated panel. Under the conditions present in Antarctica and in the light of Hoch's discussion, it is not at all clear whether these panels are acting according to their design properties. The panels in Sörlle House, Signy, are interlocked but the joint is not sealed by gasket or compound and in strong winds there will be a certain amount of air movement. This is termed *air leakage* and is responsible for a considerable amount of heat loss from buildings (United Nations 1980).

The sealing of all building joints, use of triple glazed windows and other means of minimising *air leakage* has increased the dependence of the inhabitants on forced ventilation systems (Ibid). This raises questions of health and safety, for example, that the air exchange rate is sufficient to prevent build up of noxious gases and the consequences in the event of fire (Ibid). Regardless of the thickness of insulation, a completely sealed structure may still experience moisture problems and the hidden effects of condensation are considered in the following section.

## 2.2 Vapour and Moisture.

The effects of condensation and subsequent freezing have been described in the Antarctic but not, it seems, always recognised as such;

*- panel faces were losing their adhesion to the core and in some cases to the frame as well, and were rusting out from the inside.*

(Incoll 1980 p.13)

This may be explained by vapour penetrating through the insulation onto the inner face of the exterior wall where, by a process of freeze and thaw, the panel was being delaminated and the metal skin rusting (Fig 3.3)

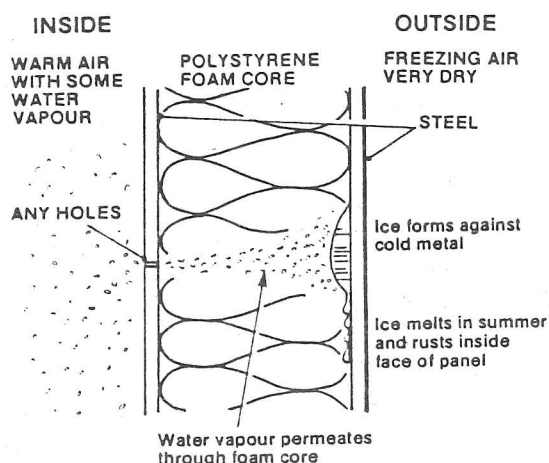


Fig.3.3 Effect of puncture in vapour barrier correctly sited on warm side of insulation. Moisture will permeate the insulation to condensate and freeze on the cold exterior wall.

(Department of Transport and Construction 1982 p.2.3)

Ventilation, heat transfer and humidity control are interrelated but have received insufficient attention in Antarctic station design. The temperature gradient from interior to exterior across panels is sufficient to support the type of process outlined above (Hoch 1986) and research into this topic has indicated it is not diffusion that is the major cause of vapour movement, as previously suspected, but *air leakage* (Ibid; United Nations 1980). It appears that sealing of the structure, as far as is reasonably possible, will improve insulation, reduce heat loss and minimise vapour flow. *Air leakage* is driven by pressure differences set up across buildings by the action of wind and recognition of this phenomenon has caused the function of the vapour barrier to be re-examined (Hoch 1986).

*In order to control these processes, vapour barriers must satisfy two criteria: they must be made of a waterproof material (to prevent moisture flow by diffusion), and they must be installed in such a way as to create an airtight envelope around the building's interior (to prevent moisture flow by air leakage).*

(Hoch 1986 p.48)

This principle has been applied to the new buildings being constructed by the Australian Antarctic Division at Casey, Mawson and Davis and the point is stressed that the vapour barrier, to be effective, must be on the *inside* of the panel insulation, ie. on the warm side, to prevent condensation on its surface (Department of Transport and Construction 1982). To install a totally airtight vapour barrier is difficult and, on the assumption that some moisture will enter the wall, Hoch suggests that the exterior face be pierced in a few places to allow moisture to escape (Hoch 1986).

### 2.3 Materials.

Porous materials such as brick have long been held as inadequate for polar use because of freeze and thaw damage. The last section indicates that exterior conditions may not have been the cause of deterioration so much as moisture originating from inside (Hoch 1986). Nevertheless, timber has, since the early exploring days, been the prime building material but from time to time other materials have

been used, such as metal, glass reinforced plastics (GRP) and mineral compositions (Easton 1983; Incoll 1982; Shirshov and Gindin 1985).

Timber, however, is not impermeable to water and may suffer by impregnation of water or, conversely, in the dry atmosphere of Antarctic stations, dry out and twist and deform. Varcoe (1982a) commented that timber at Scott Base, Ross Island, became impregnated with water causing major maintenance difficulties. Similar problems were reported at Wilkes station, Wilkes Land, because the buildings had become buried by drift which periodically melted due to heat loss from the structure (Styles and Melbourne 1968). Warping of timber, doors, and window frames is often reported (Easton 1983; United Nations 1980) as has occurred to the external doors of Sörlle House at Signy, causing air leaks around the rebates.

GRP materials have also been used at a number of stations with some degree of success. The accommodation block at Signy is constructed from panels of GRP insulated sandwich but the individual panels are heavy and require a substantial steel supporting frame. GRP panels are expensive to manufacture because of the cost of moulds and labour to lay-up and this was found to be prohibitive by the Australian Antarctic Division (Incoll 1980). The Signy panels were off an existing mould thus saving cost, although the structure was originally designed for temperate, not polar, use.

Metal cladding to exterior surfaces has been employed at a number of sites because of the low maintenance requirement. Generally, the metal is faced with a coloured plastic skin on the exterior to seal and add durability to the metal. At British stations, plastic-coated profiled-metal sheets are attached to the completed structure on site, a dangerous and difficult procedure requiring good weather conditions whereas both Australia and New Zealand are now using a metal-foam sandwich which are lighter weight than equivalent ply panels (Easton 1983). Steel has been employed as a facing material in preference to aluminium because the latter melts at temperatures generated in major fires (Department of Transport and Construction 1982).

### 3. Planning and Layouts.

#### 3.1 Planning.

Styles and methods of construction have changed dramatically over the short period that Antarctic stations have been established. The early pioneering bases were simple and quick to erect because the expedition had only a brief stay in Antarctica. An attitude of 'Man challenging the elements' developed during these expeditions and spilled over into the first permanent stations.

The majority of Antarctic stations still retain a 'temporary' atmosphere. For stations built on ice, this is because they will eventually become overwhelmed; for coastal ones, because development of the station has typically progressed by virtue of fire, bursts of capital injection or deterioration of buildings, but rarely by planned steps. A feeling of impermanence is inevitable with the current staffing regime of the stations. It is unusual for personnel to remain more than one winter south, although the British Antarctic Survey still pursues a policy of two-winter contracts. Many scientists only visit Antarctica during the short summer season and, with good transport arrangements, some could reduce their stay to a matter of weeks. A very different form of planning is required to deal with this situation from that used in more temperate latitude communities, and,

*In the north, one test of success may be whether, in the long-term, planning helps to create a feeling of temporal and spatial linkage and continuity.*

(United Nations 1980 p.37)

Clearly, the problem of impermanence appertains to the Arctic as well. Australia has approached this problem during the re-design of their continental Antarctic stations, Casey, Davis and Mawson,

*Australia is indicating its long term interest in this continent by providing modern, functional and permanent facilities by means of the current building program.*

(Gosbell, Incoll and Hoffman 1982 p.6)

Much of the design effort has gone into providing suitable accommodation and support facilities but without allowing for any extension of activities beyond their present level (Ibid).

Flexibility in design, however, is important because activities change with time and stations should be able to accommodate new scientific programmes without the necessity of a complete rebuild. Signy has, for example, moved from survey and geological studies to become a prime biological station over a period of forty years. Some old buildings still remain on site and these have been extensively altered in order to accommodate new facilities.

Stations constructed on ice shelf or the plateau have, at present, a built-in obsolescence. Accumulation will eventually cause them to become uninhabitable, providing the opportunity for re-design and construction of a new station. Life-times for stations in this environment is in the order of 10-15 years. Neumayer was designed to operate for an initial period of 8 years (Mannhardt 1982), Halley II, built in 1974, achieved its design life of 10 years (Smith 1982) and Amundsen-Scott has a projected life of 15 years from completion (Guthridge 1975). This process gives the opportunity for a complete re-design of the facility every 8-12 years, a degree of flexibility not possible for stations built on rock. If the development of ice stations constructed on jackable platforms is achieved and their life-time is therefore extended to perhaps 20 years, this flexibility will be lost and more careful planning will be required in the first instance.

There are three basic methods of construction of which only two are applicable to Antarctica. The three methods are,

- a. Construction on site;
- b. Prefabrication;
- c. Modular units.

Use of ice or snow as a construction material has received limited attention although 'icecrete', a mixture of ice and wood



chippings, has been known for many years (Perutz 1948) and has recently been used to build a jetty for a Hovercraft terminal at Oslo (Anon 1985). Sea ice and ice wharves are strengthened for cargo work, as noted earlier, but otherwise construction on site is not practised in Antarctica.

Prefabrication is a more commonly used technique. Early expedition buildings were completely broken down into their separate parts for shipment, for ease of stowage. Reconstruction is slow, requiring skilled staff, and it is complicated to seal and effectively to insulate the building. The modern prefabricated building is constructed from insulated panels, pre-formed before shipment to Antarctica, based on wood, glass reinforced plastic (GRP) or metal, and which stows reasonably well.

Careful planning will ensure that the panel size is convenient to manhandle and the building easy to erect. The number of skilled personnel required can be reduced to a minimum because once the foundation grid is laid out and surveyed, in theory, the panels should slot together in a pre-numbered sequence. On the whole, panels have produced excellent results, and have only failed where poor standards of fabrication have resulted in insufficient quality to the edges and joints of the panels or to the insulation infill. This was experienced at Signy during the construction of Sörlle House where some panels required reshaping to fit.

Damage to panels during transport and on site has also resulted in poorly fitting panels and some designs have been rejected because of the greater likelihood of transit damage (Incoll 1980). Few structures allow easy removal of panels for replacement although this design feature is included in recent Australian designs (Ibid). The sealing of joints is critical to maintaining a complete vapour seal around the inside of the building and requires that any punctures are resealed to retain the integrity of the barrier (Department of Transport and Construction 1982).

Modular construction offers further advantages over prefabricated panels. For the construction of Halley III (1984) some 4000 panels were shipped to Antarctica and erected on site but by manufacturing modules, site erection reduces to interconnection and linking of services and can be very speedy. The Brazilian station, Comandante Ferraz, King George Island, was established in less than a month by linking together hydraulically equipped GRP modules on site (Anon 1984c; Simoes 1984). Container modules are used at Neumayer station, installed inside a protective steel culvert. Two, three or four containers were combined to form reasonable sized units (Mannhardt 1982). The entire project, from unloading to completion was accomplished in 30 days (Ibid), a remarkably short time for a major station.

The precept of all cold region engineering is prefabricate as far as possible. The major advantage of modular construction is complete fitting out of the module or container before shipment. The cost of transporting personnel to Antarctica, of supporting them there, of the shipment of many small items needed for construction and services and the problems generated when items are incorrectly supplied, all point to the benefit of modular prefabrication. The drawback is cargo volume; assembled units will inevitably occupy a much larger space than a knock-down version.

### 3.2 Layouts.

Sater (1963) has described the three basic layouts that may be used in polar regions:

*Train - One or more buildings on a common centre line, with each adjacent building butted together.*

*Dispersed - A complex of separate individual buildings which may or may not be completely or partially interconnected.*

*Composite - A single building, usually multistorey, with space provided for most station functions.*

(Sater 1963 p.269)

The most widely used layout in Antarctica is *Dispersed*. Layouts of this type form a range with 'compact' and 'open' as the extremes. Compact layouts are those where the individual buildings are constrained by terrain or design to close proximity, open layouts have the buildings spread over a wide area. Signy station falls at the compact end of the scale and several buildings are separated from one another by less than 5 metres. Design plans for the new Casey installation represents the other end; a few large buildings well spaced apart relative to the prevailing wind direction.

The existing Casey station, however, is an example of the *Train* style of layout, where all the buildings except the power house are in a long line. The buildings are connected by a corridor on the windward side allowing access at all times and in all weather conditions but the power house is separated from the train for reasons of access and fire safety (Betts [n.d.]). The benefit of this construction is obvious from the point of view of personnel moving around the station, however, it was found to have an unexpected effect on station morale and generated a reluctance to venture outside (Incoll 1980). The *Train* arrangement has been used at a number of sites in the Arctic, Polaris Mine, Little Cornwallis Island, and the initial Distant Early Warning Line stations, where the buildings were fabricated inside a large hanger and then shunted out along a track to the final position (Sater 1963).

*Composite* buildings, of the Dye II and III type, are uncommon in Antarctica and this may be due to safety concerns. Buried stations such as Halley and Neumayer reflect this concern and fire precautions are particularly stringent (Mannhardt 1982; Smith 1982). The use of jackable platforms in Antarctica, effectively creating a *Composite* structure will require careful consideration with regard to safety of personnel.

## CHAPTER 4

### Serviceability of Design

The quality of design of buildings will have a significant effect on the ease and expense of the operation and maintenance of the station. In the last Chapter various constraints were discussed and their effect on station design considered. These same constraints, directly or indirectly, will affect the serviceability of the station. Poor design of foundations and sub-structure will mean that drains, for example, will be difficult to service; planning and layout faults will result in doorways drifting up every time there is a blizzard.

In Chapter 2, four stations were described in detail and these will be used to illustrate various points. Other stations may be cited and the good and bad points, advantages and disadvantages of different designs will be highlighted. No one station is likely to represent the best of all aspects of design; polar construction is still a young practice and each new station provides the opportunity to develop further ideas. Polar institutes and government agencies may argue that they are not the place for building design and research but, whatever their origin, they generally have a strong scientific involvement. Perforce, polar design is still developing and many buildings will represent some stage in a trial and error sequence. It is to the benefit of all polar designers that monitoring of structures is undertaken and the reports published.

In the polar regions wind is a constant companion, bringing with it snow, salt spray or grit. In this environment there is a requirement for the proper upkeep of the station fabric and design of the facilities will have a critical effect upon the ease by which this

can be undertaken. Before discussing station maintenance, snow drift, sea spray and wind scour will be briefly reviewed.

#### 1. Snow Drift.

Snow drift can affect the structure in several ways. Obstruction of windows, doorways and ventilators is both an inconvenience and a safety hazard but the deposition of drift against buildings will also prevent inspection and maintenance. Stations built on the ice surface create drift patterns which will eventually bury the structure, in as short a time as one year at some regions (Brier and Moser 1968; Roots and Swithinbank 1955).

Drift management is a major concern to northern communities because of the economic effects of damage to buildings, interruption of transport systems and general inconvenience (Kind 1981). A large literature has built up concerning the management and removal of drift, especially from roads and runways, and,

*The three major factors governing the formation of drifts are the amount and type of snow, the speed and direction of the wind, and the terrain (including obstacles) over which the windblown snow is carried.*

(Verge and Williams 1981 p.631)

The exact dynamics of snow drifting have not been fully elucidated even for movement across a level, smooth plane and the complexity increases when structures and obstacles are present (Kind 1981). As a result engineers have to rely upon empirical evidence to gauge the likely effect of snow drift formation despite modelling of drift by wind tunnel testing (Ibid; Mellor 1965). Most designs are now tested in wind tunnels before construction to gauge the effect of wind loading and drift formation and a variety of materials are being used to simulate snow, from borax to clay particles (Sherwood 1967; Tomabechi and Endo 1985).

Signy station provides an example of the problems resulting from a poor drift management regime. The effects of drifting snow are most pronounced during the winter but their inconvenience is, perhaps, greatest during the spring. The layout of the station is such that extensive drifts build up in between the buildings, reaching down to the shoreline, and as a result part of the area in front of the station has to be cleared in order to allow the station relief to take place, usually during the last week of November. The drifts also act as dams to melt water running off the slopes behind the station during the spring melt and unless drainage channels are dug water may flood the floors of some of the huts.

Wilkes station, Wilkes Land, suffered a similar problem. Drift had totally buried the structure and, during periods of melt, water would rise into the structure carrying with it spilt oil which soaked into the timber, significantly increasing the chances of fire (Styles and Melbourne 1968). These experiences led the Australians to a design concept of a raised station to allow drift to be cleared from around the station by wind scour (Ibid).

Casey station, built to replace Wilkes, was both raised on a tubular sub-frame 1.5-2.5 m high and sited on the top of a ridge to give the highest wind velocity possible (Styles and Melbourne 1968). Sörle House at Signy demonstrates the result of insufficient scouring under buildings where for part of the summer the foundations are encased in a large ice block resulting from early melt soaking the snow and re-freezing.

Buried stations do not escape all drift problems. Although the main body of the structure is below ground, station activities, access shafts, service lines and aerials will stall the wind flow sufficiently to cause deposition of snow. There is a continuing demand at such stations to pursue good station management in order to maintain access and the parking of vehicles or placing of stores depots is critically important. Similarly, stations raised on platforms on ice fields will require regular jacking to maintain a



clear space underneath. Nevertheless, raised structures will still cause deposition of snow as experienced at Dye II, Greenland (Mellor 1965).

## 2. Sea Spray and Wind Scour.

Strong winds and storms are sufficiently common at most coastal sites that buildings and equipment quickly become coated with salt from wind borne sea spray. The corrosive effect is considerable and maintenance is continually required. At Signy, the older wooden huts and more recent structures with wooden window frames or doors, require annual preservative treatment. Annual or biennial treatment of the bulk fuel tank and pipelines at Signy is a further maintenance chore, requiring the surfaces to be cleaned of salt before repainting. At Casey, salt corrosion has been a significant factor in the deterioration of the sub-structure and metal panel skin (Incoll 1980).

Wind scour of the finished surfaces of modern buildings can also be a problem. The surface of the GRP building at Signy has now lost much of the thickness of the original gel coat through the abrasive action of wind borne grit or ice. More recent buildings are faced with coated metal sheet described in Chapter 3, Section 2.3. Davis station is particularly susceptible to wind scour and a special hypalon-based coating has been applied to the outer skin of the buildings to provide a longer lasting surface (Ibid). All these treatments of the exterior surface, which provide a good means of reducing station maintenance, are easily damaged during transit and erection. Extra care is needed because once the coating is pierced, if not repaired, corrosion will soon spread. Raised stations constructed on ice fields also suffer a certain amount of wind scour and considerable damage can be caused by ice abrasion.



### 3. Maintenance of fabric of station.

#### 3.1 Foundations.

If loss of integrity of the permafrost is to be avoided, the design of foundations should minimise thermal transfer between the structure and the ground. Part of the station management plan should be annual inspection of foundations but, if well designed, there should be little requirement to undertake maintenance. Buildings constructed on spread foundations clearly run a far greater risk of disturbing frozen ground than those raised on piles and it is this consideration that has resulted in the design of raised stations (Easton 1983; Smith pers comm).

Spread and pile foundations on rock may suffer erosion of the foundation or surrounding material by the action of melt streams. As spring and summer progress at Signy, a small melt stream runs continuously under Sörlle House and will, in time, erode the base of the concrete piles.

Corrosion of metal piles or steel sub-frames used to support internal structure is a further area requiring maintenance. The original Casey building unexpectedly suffered from this problem and, because of the method of attachment of the sub-structure to the rock, replacement was impractical (Holmes 1982).

Where heavy loads are expected, such as power houses and garages, ring beam foundations provide an alternative to supporting buildings on piles. With careful design, heat transfer to the ground and cold bridges can be avoided and ring beams have the advantage of better protection of the ground floor. At Signy, the power house and boat shed have ring beams and the Australian Division has decided to construct all their buildings on this type of foundation (Incoll 1980)

Snow and ice are far more susceptible to thermal interference than is permafrost and must be well protected if the foundation is to remain stable. Protection of pile foundations was mentioned earlier

and experience in Greenland has shown that solar radiation is sufficient to cause melting around the piles unless they are screened (Mellor 1965). Spread footings are less likely to be affected by radiation incident on the column above the surface, however, heat transfer from the station must be limited.

Dark objects placed on the ground will cause ablation and the area around foundations of stations on snow or ice must be kept scrupulously clean and clear of stores and rubbish. Petrol and oil transfer must not be undertaken near the foundations to avoid spillage in their vicinity and maintenance of services should ensure that water or waste outflow do not seep into the foundation area.

### 3.2 Floors, walls and openings.

Maintenance of the exterior fabric of the structure is often a problem of access and suitable weather conditions. Finishing materials are now sufficiently durable that exterior maintenance should be no more than regular inspection to check for damage or deterioration. The type of problems experienced at Casey where salt spray corroded the surface skin of the structure (Incoll 1980) should, with proper design, be a thing of the past.

The exterior surface of buried stations cannot be inspected and work can only be undertaken from the inside. Design-life of buried stations is only 10-12 years and materials or surface finishes that can outlast this period should be used. At Halley station, on the Brunt Ice Shelf, the glue used in the stressed skin panels was specified for a service life of 30 years in the conditions at the site (Smith pers comm).

Of critical importance to buried stations is the temperature of the void space, the free air space between the buildings and the protective shell. If the shell is allowed to transfer heat to the surrounding snow, local melting will occur causing snow arches and caverns and generating unequal stress on the structure. This effect was the cause of deterioration of earlier Halley designs (Smith 1982)

and regular maintenance of the internal buildings is therefore important to reduce heat loss to the void space.

On all stations, the integrity of the vapour barrier is critical to prevent condensation within the walls. Early designs at Scott Base and Casey suffered delamination due to insufficient vapour barrier or puncturing of the seal by fixtures and fittings (Easton 1983; Incoll 1982). 'Styrofoam' (Dow Chemical Co.Ltd.) insulation material which is moisture resistant and does not, in theory, require a vapour barrier, is used in the panels of several stations (Smith pers comm). It is interesting to note, however, that the technical specifications still suggest the use of vapour barriers with this material (Provisional Data Sheet 1975). The use of such materials does not overcome the problems of *air leakage* of the structure as panels are not sealed by gaskets at their edges (see Chapter 3).

Doors, windows and other apertures often require attention. Rebates can collect snow and are susceptible to icing and, for exterior doors at least, a butt facing is preferable. Heat tracing to door rebates will assist but should also be fitted to butt facings. In either case, some form of cam or wedge closure, preferably two, is required properly to seal the unit. Maintenance of door and window apertures is a problem which would benefit from further design work on different closures. Hoch (1986) advises that designers would prefer all windows to be sealed, but he does acknowledge the undesirability of this from the inhabitant's point of view.

#### 4. Serviceability of utilities.

At the United Nations Economic Commission for Europe, the US delegation asserted that,

*Problems of water supply and sanitation (together with energy requirements) are the most critical factors of Arctic housing and community design, construction and maintenance.*

(United Nations 1980 p.51)

In the polar environment, energy must come first on the utilities list because none of the other services are possible without a reliable energy supply. In the provision of utilities, the first question that should be asked is: what level of services are to be provided? Environmental, economical and logistic requirements affect the level of services provided and their serviceability on Antarctic stations.

Present technological development means that the most reliable energy converter is the diesel engine. A nuclear reactor has been run in Antarctica at McMurdo station, however, the experiment was made at an early stage of nuclear development and was not a success. The reactor and huge quantities of the site were later removed (Anon 1980). It is unlikely that nuclear reactors will be used in Antarctica for the immediate future because of the resistance of the environmental lobby. Various options to the diesel generator are considered in Chapter 6.

Diesel fuel is therefore the major energy source in Antarctica and, in the absence of local sources, has to be shipped in to each station, requiring a considerable logistic effort. Clearly, well designed stations that minimise heat loss will help to reduce the amount of fuel required, providing savings at every stage along the logistic chain.

#### 4.1 Storage of fuel.

There are three methods used to store fuel in Antarctica: bulk tank; fuel bladder and drum. The choice of method used is dictated by logistical and site arrangements. Bulk tanks require direct pumping from a supply vessel lying close to the fuelling point and this method is employed at Signy and Casey where refuelling is a critical part of relief because reasonable weather conditions are required.

Fuel tanks and fuel bladders may be connected permanently to the station or, as at Rothera, the fuel pipe is changed from one bladder to another. The advantage of the Rothera arrangement is duplication

of storage units, should a tank or bladder rupture. At Signy, there is only one bulk tank but a small quantity of drummed diesel is kept well away from the station as back-up. The amount stored is negligible compared to monthly consumption and a better arrangement would be to have several small storage tanks or bladders.

The alternative to bulk storage is (200 l) fuel drums. These are disliked by ships officers because they occupy a large stowage, are difficult to handle, and take a long time to unload. Halley is fuelled entirely by drums requiring several thousand a year to support the station and to provide an emergency supply.

At Halley station, the drums are ranged out in marked depots and allowed to drift over; from time to time the remaining stocks are lifted so as not to become too deeply buried. This does not seem a satisfactory system but the alternative of constructing a raised storage platform would appear to be uneconomical.

For stations further inland, refuelling is either by aircraft or by tractor train and at considerable cost (Guthridge 1975; Shirshov and Gindin 1985). At Amundsen-Scott, and formerly at Byrd station, the fuel bladders are stored inside the steel arch and are filled directly from the supply aircraft although fuel for the aircraft itself is stored on the snow surface.

Drums also provide the means of storing waste fuels and oils pending shipment out of Antarctica, however, there is generally an excess of drums which require disposal. In accord with Antarctic Treaty Recommendations (Recommendation VIII-11), waste oil should be incinerated if it is not returned to the home country for treatment. Dispensation is given for inland or remote stations to dump waste in deep pits (Heap 1987) and several stations follow this course.

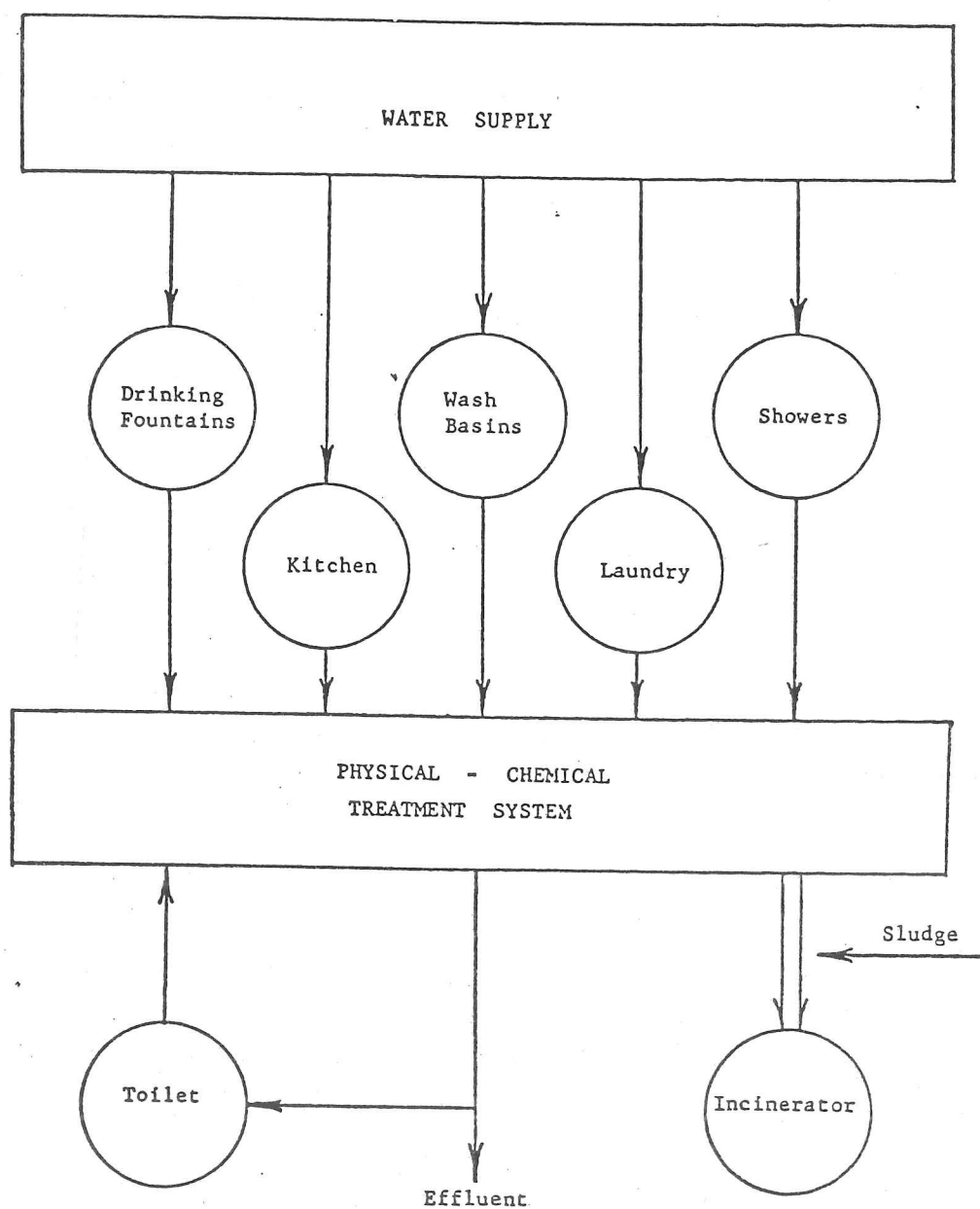


Fig.4.1 A simple flow diagram for limited water system. *Water supply* originates from snow melt, lake or run-off and consumption is reduced by recycling low quality water through the toilets. At Australian stations, rotating biological filters form the *treatment system*. (Kreissl et al 1971 p.674)

#### 4.2 Water cycle.

Fig. 4.1 gives the basic water cycle for sites with limited water supply. The design of the station, once again, will dictate the water demand of the facility and careful planning can reduce the daily requirement to a minimum.

Water presents three problems to the station designer: procurement; storage; and disposal. Average water usage figures are provided in several publications (Kreissl 1971; Smith 1986) but show considerable variability. Approximate percentages of water use distribution are at Fig. 4.2

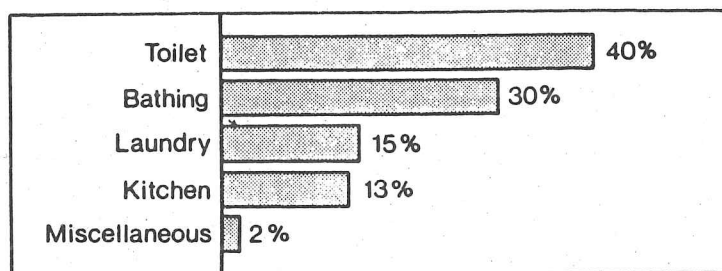


Fig.4.2 Approximate percentages for water use in the home.  
(Armstrong et al 1981 p.69)

Present methods of water procurement rely upon the existence of a natural lake or pond, snow and ice melting, or desalination. The process of snow melt warrants far greater attention than it has received even though regular use is made of waste heat from the generator sets to melt snow (Awano and Takeuchi 1985; Smith 1982). The feeding of snow melters and the maintenance of water supply lines is a time consuming and, in winter, uncomfortable occupation. Use of snow management techniques to augment fresh water supply and methods of water storage, such as artificial lakes, have received too little



attention in the Antarctic. Summaries of the main techniques are found at Slaughter et al (1975) and Steppuhn (1981).

An alternative to transporting snow to melt tanks was developed by Schmitt and Rodriguez (1963) in the Arctic and called the *Rodriguez Well*. A shaft is steam melted into the snow layers until an impermeable region is reached and further melting results in the formation of a melt cavity where, surprisingly, refreezing is slow (Schmitt and Rodriguez 1963; Williams 1974). The system has been used at Camp Century, Greenland Ice Cap, and tested at the first South Pole station, however, it was not installed at the new site of Amundsen-Scott station. It seems that the extra fuel cost to run the well is prohibiting further use, especially as more efficient waste heat scavenging systems are used to melt water; the South Pole test used about 50 gallons of fuel a day (Williams 1974).

Neumayer and Amundsen-Scott both rely on snow melt to produce water and at Amundsen-Scott a front end loader is used to feed the snow shute (Antarctic Services 1985). At Casey a tracked vehicle is similarly used to collect water from a frozen lake where a hole is maintained by heat traces.

*The water run required two people to drive the water cart by bulldozer at barely 2 mph a distance of 1 km to a frozen lake with heat traces round the pump hole. At 4000 gallons per run, two to three runs were required per day, each taking at least 1½ hours.*

(Lewis Smith 1986 p.5)

The use of large vehicles at Casey and Amundsen-Scott illustrate the lack of thought about the provision of water. In terms of the logistic effort to bring fuel to the stations, the use of a caterpillar tractor to fill a snow shute appears uneconomical. At Signy, desalination is used as a water supply during winter but there is a small reservoir, about 50 000 l, that holds meltwater collected off the surrounding slopes during summer.

It is difficult to determine whether water purity tests are undertaken at any of the stations but at Signy, the water supply has been contaminated from time to time. A simple filtration system and water monitoring arrangement should be fitted to all stations.

#### 4.3 Waste water and sewage.

Flush toilets produce the greatest amount of waste water on stations but the total amount of water required can be reduced by recycling as only low quality water is needed for toilets. By contrast, water of the highest quality is required for kitchen use and drinking. Treatment of waste water in polar regions is a problem of maintaining a warm enough temperature in the treatment plant to allow proper biological activity to take place. In Arctic utilities, a temperature of 8°C is considered to be the minimum (United Nations 1980).

The collection, treatment and disposal of waste water is important to the health and well being of station personnel. In the USA and Canada, legislation requires that field camps for exploration and survey must provide secondary sewage treatment (Smith 1986) but the Antarctic Treaty, however, does not recommend treatment except maceration (Recommendation VIII-11) and many stations dump raw waste water and sewage into the sea, as at Signy, or into snow pits, as at Amundsen-Scott. Other systems include the use of no-water humus toilets at Halley and, at Casey, rotating biological filters. These filters produce an innocuous effluent and a residue which is shipped back to Australia for disposal and appear to provide a good solution for large stations and those removed from the coast. However, the extra energy used to run the system must be balanced against the aesthetic environmental impact of non-treatment (Benninghoff and Bonner 1985).

#### 4.4 Solid waste.

Incineration is clearly the route for the safe destruction of all combustible solid waste on stations. The dumping of waste in pits, such as at Amundsen-Scott really is untenable in the light of modern

environmental standards. Small, safe and effective incinerators, of the type used successfully onboard ships, would be quite adequate for station use and these or similar are now being supplied to Australian and British stations, for instance Casey and Signy (Keage pers comm; Smith pers comm)

At Neumayer, solid waste is collected and returned to Germany for disposal and the Australians pursue a similar policy. However, at British stations, only specified items, batteries for example, are removed from the Treaty Area, the remainder is dumped locally at sea (Ibid; Mannhardt 1982).

Examples of the amount of solid waste produced by a station are given by Monteath (1977) for Scott Base, Table 4.1

Table 4.1 Solid waste returned annually from Scott Base, in kg.

Year	scrap Metal	glass	plastic	batteries & acid
1972-73	300	60		
1973-74	500	60		
1974-75	850	320	190	250
1975-76	2800	700	160	350
1976-77	3280	600	460	

(after Monteath 1977)

Although this shows an annually increasing amount of material being returned to the home country, the weight is small compared to incoming cargo and could be easily accommodated on a returning vessel. The Antarctic Treaty Code of Conduct for Antarctic Expeditions and Station Activities (Recommendation VIII-11) (cf Annex C) lists which materials should be removed from the Treaty Area and this recommendation is more or less followed. Overwinter storage of waste presents a problem of space and containment because of corrosion and freezing of liquid waste. At Signy, empty fuel drums are used to be

later dumped at sea by the Survey's vessels north of 60°S latitude. This is not altogether satisfactory and the material should be returned to UK for processing.

#### 5. Emergency systems.

Back-up facilities must be provided at all stations for emergency use and, in addition, many stations carry extra food and fuel against delay of the relief vessel. All stations should have a building, well removed from the main facility, in which to store emergency supplies of food, clothing, shelter and fuel. This is basic common sense and adequate provision is usually made.

Duplication of station facilities against fire or mechanical failure is an important design factor in Antarctica. For this reason Casey station has two Power Houses either of which is capable of maintaining a supply to the entire station should a major fault or disaster overtake the other, as happened during construction (Incoll 1980; Lewis Smith 1986). For buried stations, such as Neumayer, separate energy units are sited in different parts of the station and stringent fire precautions are imposed (Mannhardt 1982). Escape from a buried station in an emergency must be a harrowing experience and escape routes must be carefully considered in the design of the station.

Fire is recognised as the major hazard on polar stations (Varcoe 1982b), exacerbated by limited water supply, unskilled fire fighting force and the need to keep fire prevention to the front of people's minds. In addition, the humidity levels on stations are generally low so that timber and furnishings are very susceptible to fire. The use of fireproof materials was stressed by Stonehouse after a series of disasters during the period 1946-1952 (Stonehouse 1953) and although most buildings are now constructed with fire resistant materials, many interior fittings are not and give off poisonous fumes when ignited.

Modern fire systems have been installed in a number of stations (Mannhardt 1982; Smith 1982; Varcoe 1982b) and the basic requirements are: *smoke* or *rate of change* sensors in the kitchen, power house, lounge and other hazardous zones; *halon* or *carbon dioxide* flooding system in the power house; and a comprehensive *fire alarm* circuit. In addition, good emergency access routes should be maintained and the station management plan should detail evacuation and muster procedures. The station design should limit the spread of fire yet provide simple escape routes for personnel. Clearly, the juxtaposition of rooms is a significant feature in the likelihood and spread of fire.

## CHAPTER 5

## Provision of Living and Working Environment

No standards are set, either by the Antarctic Treaty or SCAR, for the living and working environment of personnel working in Antarctica and the choice for these matters is left entirely to each nation. This has resulted in a great range of standards at the different stations and in many instances these fall below the minimum set in the expeditioners' home country. British stations are not designed to any specific standards of space per person, light levels, or air purity (Smith pers comm). It is possibly the 'exploratory' attitude generated during the years following the Second World War, when there was a long period of exploration and survey undertaken at many places in Antarctica, that has led to the present approach to design of station accommodation. In the few studies that have been made, the allocation and designation of space is stressed (Brier and Moser 1968; Kondo et al 1985) and in the right environment personnel will pass the winter comfortably and tasks will be completed with reasonable efficiency; if personnel are not content, proficiency and morale will deteriorate.

## 1. Living Environment.

The primary aim of accommodation is to provide staff with a comfortable and healthy environment. Sater (1969) has identified four aspects that will lead to unhealthy conditions;

- a. Overheated living space.
- b. Overeating.
- c. Lack of exposure to fresh air.

- d. Lack of vigorous exercise.

A well designed heating and ventilation system will solve problems a. and c. by providing the right combination of humidity, ventilation, and temperature. Hoch (1986) considers the various options for heating rooms, concluding that a heated plenum beneath the floor provides the most even room temperatures (Hoch 1986 p.22).

The quality of catering on the stations depends on the produce provided. At British stations, a significant proportion of the food is tinned or dried and whilst there is a need for an emergency supply of such items, produce should be frozen or fresh wherever possible and should be maintained in proper storage conditions. The importance of good food to the Australians at Casey is reflected upon by Lewis Smith,

*The food was magnificent... On station virtually no tinned food is used and dried food (other than fruit) is unheard of. Fresh frozen meat is served twice or three times per day together with fresh potatoes, vegetables and fruit. Large consignments of the latter arrive on every ship and special meat and vegetable/fruit stores are provided.... The provision of many high quality meals is apparently a critical incentive to get people to work in the Antarctic.*

(Lewis Smith 1986 p.5)

Lack of exercise is a further important criterion to the well being of staff. Because conditions are not always suitable for outdoor activities, some space should be allocated to exercise. Neumayer, for example, has a gymnasium and Amundsen-Scott has a basketball court and sauna (Currie 1985; Mannhardt 1982). The differing functions of stations result in different requirements to go outdoors and it is possible for some staff not to venture outside at all for long periods of time. At Casey, it was felt that this led to lowering of efficiency and morale on the station (Incoll 1980) and the Australian policy now is to encourage some contact with exterior conditions by placing living and working facilities in separate buildings.



*Lack of incentive to venture regularly outdoors had an adverse effect on expedition members and contributes to unwillingness to participate in tasks both indoors and out... Consequently work areas have been separated in the proposed station plans and a concept of a few large structures, rather than one very large single complex has been adopted.*

(Anon 1981 p.11)

Similar results have been recorded in the Arctic where some 'contact with nature' is considered important to small communities (United Nations 1980). In Antarctica, the New Zealand attitude is to maintain a weatherproof link between buildings for safe transfer of personnel and the redevelopment of Scott Base uses this principle (Easton 1983).

Living and working areas should be separated for reasons of safety and Signy is an example where the type of science undertaken requires hazardous chemicals and gases to be used yet the design of the station has led to the bunkrooms being sited above the main laboratories. This arrangement puts personnel at considerable risk should an accident occur and ought to be re-designed.

The development of multi-glazed units has enabled a far wider use of windows than was traditional and there is no reason why modern stations, except those designed to be buried, should not use natural light. The Australians see this as a further way of encouraging contact with the environment,

*Windows were generally larger than had previously been the practice... Two windows were stacked vertically to increase the effect in some places. This was a deliberate effort to cut down the isolation of indoor life from the environment as well as to fill the normal window functions of providing a view and natural light.*

(Incoll 1980 p.37)

Bay windows were also fitted at a number of points and these have proved to be very popular as a rest area. Currie (1985) notes that the fourth floor of the five storey 'Sky Lab' at Amundsen-Scott,

provided with all-round windows, is a "good place to get away from it all, to relax.." (Currie 1985 p.26) and at Signy one of the most popular spots is by the 'Television Window' that overlooks the bay. Windows, natural views, and light are, clearly, popular and should be a major consideration during design of living accommodation.

Soundproofing of community space is important, a fact highlighted by Kondo et al (1985) in their study of Syowa station and a recurring complaint at Signy is the juxtaposition of the bunkrooms next to the lounge. Station policy necessitates an overnight firewatch system and so there is often somebody asleep in the bunkrooms during the day requiring that occupants of the lounge have to remain reasonably quiet.

In addition to the adequate provision of communal space, Kondo et al (1985) noted that private space was high on the preference list of wintering staff. In traditional stations, such as Mawson's hut at Commonwealth Bay, the community lived in one room, bunks spaced around the walls. This was the occupants' private space and was sacrosanct (Mawson 1915). With the advent of permanent stations, bunkrooms were provided where two or more people would share a room, intended for little more than sleeping; such is the present situation at Signy. But now, the trend is to provide single bedrooms for each of the wintering staff, containing a wardrobe and desk (Incoll 1980; Smith pers comm). These rooms should not revert to multiple occupancy during the summer but should remain the personal space of the winterer. Summer visitors should be provided with alternative accommodation, which may be more basic in design. Provision for staff of either sex should be incorporated and at Casey, the new accommodation block has a variety of private rooms, including married quarters (Lewis Smith 1986).

Comfort, interior design and quality of the communal living areas will greatly benefit the station personnel. In concert should be the provision of the working environment on the station.

## 2. Working Environment.

Provision of laboratories will be dependent upon the scientific investigations undertaken; what form of special analysis is required? How will data be stored? Is material to be analysed on site? In the same way, the station policy regarding servicing and overhaul of equipment will effect the service areas, workshops and storage space. Minimum standards for science or support facilities should form the basis of design criteria, whatever the final decision regarding the working environment layout.

### 2.1 Scientific Requirements

It is not proposed to consider all the various options for the different scientific studies that may be undertaken in Antarctica, rather, there are certain basic questions that must be answered both by the scientist, who wishes to work at a polar station, and by the designer who is attempting to provide a suitable environment.

Is Antarctica the place for elaborate scientific facilities? Stations have tended to specialise in one or two areas of science, which is often the reason for the choice of site in the first place, for example, Signy concentrates on biological activities, Amundsen-Scott on upper-atmosphere and glaciological work. But despite the cost of installing complex equipment in Antarctica, scientific facilities are becoming more and more complex.

Antarctica is, primarily, the collection point for data and it is the level of further analysis that will determine the complexity of the facilities provided. At the very least scientists will require space for the collation of samples and storage pending shipment to their home country. In some specialised fields, such as upper-atmosphere studies at Halley, analysis has been taken to an advanced stage and a high speed data link, via satellite, enables real-time analysis and control of the data from the UK.

At a biological station, such as Signy, a different style of facility is required, one that allows detailed and changing analyses of biological and chemical samples. Specialised facilities have been built, for example a Wetlab, which is supplied with a continuous flow of fresh sea water, and an analytical laboratory has been established. Other rooms are less specialised and need to be flexible enough to accommodate changing roles. One way to achieve flexibility is by containerisation of facilities, such as the advanced ionospheric sounder (AIS) at Halley which is mounted on jackable legs. Such structures are easily replaced when programmes change or when updating of equipment is required.

The position of the scientific facilities in the layout of the station is important not only from the point of view of separating science and accommodation but also because of the interference of electromagnetic emissions from generators, radio equipment and electrical motors. At Signy, the worst offender was the VHF radio but poor control of the generator output voltage and switching of heavy electrical loads was also a nuisance. For particularly sensitive items of equipment, isolation from the main power supply may be necessary and in the dry atmosphere on the station, computer terminals will require static protection.

## 2.2 Technical Requirements.

There are two options for the provision of workshops and stores facilities on stations. The choice depends on the decision to adopt a maintenance or replacement policy.

- a. Maintenance policy: This policy requires that maintenance and repair work will be accomplished at the station site.

This policy has three consequences; first, fully competent engineers and mechanics must be available all year to maintain and service the equipment and to deal with any breakdowns. Although they will have had an apprenticeship to gain their qualifications they may

still require further training on specialised items before leaving for Antarctica; second, a large quantity of spares, tools, and materials, both specific and general, will be held on the station, requiring considerable storage area; third, extensive and well equipped work shops will be needed to service and overhaul station equipment.

- b. Replacement policy: Equipment will be maintained only, sufficient replacements being held to maintain facilities overwinter.

Less general stores will be required and equipment will be removed from Antarctica on a regular basis for major servicing. Fully competent staff will still be required, at least for part of the year, in order to service large items, such as generators, which cannot easily be transported. Under this policy workshop space could be reduced and far fewer spares need be stored on the station.

Most stations operate on a mix of the two systems; large equipment will be maintained on site and smaller items will be subject to routine servicing and replacement. The cost of maintaining a large number of spares and of storing them will favour the second option, however, all items should have a designated life-time after which replacement occurs as a matter of course; the Antarctic is not the environment for ageing equipment.

Although provision of storage space may be adequate it is often the last area to be designated during design. It is remarkable how many items, especially food, end up in loft spaces whereas consumables and large items of equipment should be stored at ground floor level. It is important that these areas are kept at the correct conditions of temperature and ventilation for the items to be stored. In the interests of safety, inflammable items and gases must be stored separately from the living and working areas and not be allowed to accumulate in the main part of the station.

Within the relatively constrained space of an Antarctic station, scientists and support staff are unlikely to have offices separate from their workstations. A station office, for the Leader, preferably with a good view of the main approach to the station, is necessary and if space allows a general support staff office and a separate room for the scientific leader are desirable. Clear designation of these areas, as noted earlier, is needed.

## CHAPTER 6

## Conclusion

The design, support, and maintenance of stations in Antarctica has been considered in detail. Antarctica is a harsh environment in which to establish a research facility and the impermanence of many stations is almost an admission of weakness by designers in facing up to the isolation and climate of the region. Early visits to Antarctica were brief and used simple huts to house the expedition but following the Second World War nations desired a continuous presence in Antarctica requiring camps with more elaborate facilities. The initial response of designers to up-grade temperate buildings by adding further insulation led to surprisingly rapid deterioration of the fabric of the station as a result of moisture penetration of the insulation (Chapter 3). Disregard of the effects of blowing snow resulted in the situation that developed at Wilkes station - burial of the station by drift - and to the inconveniences experienced at Signy each winter by the obstruction of passage ways.

By a process of trial and error, such empirical evidence has been incorporated into more recent designs resulting in improved buildings and layouts. A major impetus to design in cold regions was the increase in the price of fuel oil in the early 1970s, forcing more efficient use of energy systems and improving building design to reduce heat loss. As all materials, including fuel, must be shipped to Antarctica, more efficient use of energy has a logistic advantage.

Good design, like the rest of life, does not come for free and many organisations balk at the initial costs of design and testing of structures prior to manufacture. It seems, rather, that more weight is given to reducing the initial costs of projects than to the long



term running expenditure. The result of this policy is insufficient funds allocated to design and development and even less to the monitoring of the resulting structure.

In an environment where the polar institutes are the main contractors then building design will only progress if there is support of building research. The involvement of building research establishments in studies of the structures built in Antarctica is minimal and it is fortunate that there are many studies on building for northern communities even though only part of the work is relevant.

## 1. Selected Stations.

Four stations, selected in Chapter 2, have been considered in detail. The stations, Amundsen-Scott, Casey, Neumayer and Signy, represent a range of differed ages, designs, methods of construction, and functions and are the product of differing approaches to Antarctic design. These stations have been used to demonstrate what attempts have been made to solve the problems of construction and maintenance in Antarctica.

Not all the solutions will be found at any one station and any organisation intending to construct a permanent station in Antarctica is well advised to look at the range of existing facilities in order to obtain an overall picture of the demands of the environment and the ways in which these have been resolved. A brief summary of the four selected stations is given here, highlighting their strengths and weaknesses.

### 1.1 Amundsen-Scott South Pole Station.

Amundsen-Scott is set on the polar plateau and benefits from a low rate of accumulation, approximately  $15 \text{ cm a}^{-1}$  of snow (Brier and Paige 1972). This has enabled a station to be built partly on, and partly below, ground level but which will have a design life of about

15 years (Guthridge 1975). Considerable work was undertaken on the design concept, including wind tunnel testing and, more appropriately in the view of the investigators, testing of one-tenth size models at the intended site (Brier and Paige 1972).

The dome and archways have been built directly on to compacted snow and the foundations have been protected by raising buildings on 0.6 m high trusses, thus preventing heat transfer to the snow. Further protection is afforded by venting of the dome and archways to dissipate any heat loss from buildings, preventing the build-up of ice on the structures through condensation. Inside the shell the modular buildings are sheltered from the effects of wind and drift. Only minor levelling of buildings has been required, attesting to the success of this design concept, however, a drawback to housing buildings inside the dome is loss of exterior view. Psychologically, this is important and reparation is made in part by the provision of a lounge on the fourth floor of the 'Sky Lab' with panoramic windows (Currie 1985).

The general finish of the interior of the buildings has been described as high, with panelled walls, carpeted throughout, and a well appointed dining room (Anon 1974). However, accommodation for the summer influx of staff is limited to an annex in the dome and to temporary *Jamesway* buildings sited about a quarter mile away from the station complex.

The danger of fire is great in this type of structure, which is the nearest approach in Antarctica to a *Composite* structure, as described by Brier and Moser (1968), because all the relevant units are interlinked. The alternative is to construct separate buildings requiring outside passage which is more likely to be the cause of an accident, especially in the depth of winter, than is fire.

Treatment of solid waste at Amundsen-Scott is poor. Refuse is dumped on the snow, usually in the snow pits excavated for the melt tank, despite the number of aircraft that must return relatively empty

to McMurdo following refuelling or cargo relief flights. Compaction, storage, and removal of refuse generated by the overwinter team (17 in 1986) should present few problems and there is good reason for suggesting this,

*Although this may seem no more than moving unwanted material from one part of the world to another, the process can be justified on the grounds that the Antarctic's near-pristine condition demands special treatment and that what is waste in the Antarctic may be recyclable elsewhere.*

(Benninghoff and Bonner 1985 p.49-50)

Sewage is pumped along a utilidor running 60 m beyond the station to the outfall, apparently, without any prior treatment. Benninghoff and Bonner (1985), perhaps, would consider this the lesser of two evils as the installation of sewage treatment equipment would demand a greater energy supply.

Such is the strategic and political importance of a station at the South Geographic Pole that, sooner or later, some nation would establish a facility there, regardless of the logistic cost. The United States were able to achieve this in time for the IGY, leaving the Soviets to establish a station at the Geomagnetic Pole. Guthridge (1975) reports that the costs of the materials for the present station were of the order of \$US 3.5 millions, logistics and labour adding a further \$US 2.5 millions. Weather and mechanical problems slowed down construction, nevertheless the station was 85% completed in 4 summer seasons (Ibid), a remarkable feat. The reason for constructing the present structure at the South Pole, rather than a jackable station, was one of expense (Guthridge 1975). Few nations could have afforded these costs (at 1975 figures) unaided and perhaps the international development of Antarctica could have been better served if an internationally sponsored station had been established.

In terms of visibility for United States' activities in Antarctica and for scientific output, Amundsen-Scott South Pole

Station must be considered a success, although at considerable logistic support cost.

### 1.2 Casey Station.

Casey station is situated on a group of rock outcrops on the coast of Wilkes Land. Casey is in the process of being rebuilt, the 1969 facilities no longer providing the quality demanded by the Australian Antarctic Division and the original linear building is being replaced by a very different type of structure.

Linear construction provides the design features of all year covered access to the station facilities. The experience at Casey has shown how this may, in the long term, have been counter productive and that the ideal situation, noted by community planners in the Arctic (United Nations 1980), is an emphasis on *"living with nature, not despite nature"* (United Nations 1980 p.70). As a result, the replacement station has been opened out and the facilities are being segregated into separate buildings without protected passages between them.

The Australians have used the effects of wind scour in attempting to manage snow accumulation at their stations. The linear structure, orientated perpendicularly to the prevailing wind, was raised on a tubular sub-frame in order to minimise accumulation. The resulting structure was about 200 m long and did cause drifting of the access road. In contrast, the new designs have not been raised but are constructed on a concrete ring beam, and are aligned parallel to the wind. The first buildings indicate success in maintaining a structure relatively clear of drift by this arrangement (Incoll 1980).

The buildings give an impression of permanence that is unusual at polar stations and has allowed detailed attention to the accommodation. By all accounts the new buildings are well appointed and,

*When completed (around 1993) this, ...will surely be the most luxurious, comfortable and permanent of all Antarctic stations.*

(Lewis Smith 1986 p.8-9)

A popular design feature, according to Incoll (1980) is the installation of large bay and clerestory windows allowing better use of natural light and more contact for the staff with the environment. The bunkrooms, however, are only 2.4 x 4.2 m, an area, according to Incoll that is just less than *Other Ranks* accommodation in the Australian Services. Despite the demands of Antarctic service, it seems that lower standards are accepted by polar designers than would be allowed elsewhere.

The Australians have taken pains to attend to the treatment and disposal of waste in accordance with Antarctic Treaty and SCAR Recommendations. The use of rotating biological filters to treat human and domestic waste is the first noted use of this method in continental Antarctica and provides a useful lead for other nations to follow. However, the warning from Benninghoff and Bonner (1985) not to let technology run up a high energy demand solely for aesthetic reasons should be borne in mind. Australian policy also dictates the removal of solid waste from Antarctica and compactors are provided with ample space in which to store rubbish pending shipment.

The original station is a good example of the *Linear* type of layout and demonstrated the benefits and weaknesses of that style whereas the new station is very much in the *Dispersed* style. The success of this layout, when completed, will be most interesting to future designers.

The investment by the Australian Government in their Antarctic stations is considerable and is an indication of their opinion of the political and strategic importance of the region. At Casey, a great deal of effort (and cost) has been spent on design and, as a result, the station better suits the environment. The desire to move away

from the 'temporary' attitude noted earlier is to be commended, however, thus far it appears that scientific work at the station has taken second place (Lewis Smith 1986). The stations are expensive to construct, of the order of £20 millions each (Lewis Smith 1986) and many countries could not afford such investment. However, the expenditure on design will have obvious benefits for Australia and other nations, especially if completion is followed by careful monitoring of the facilities.

### 1.3 Georg-von-Neumayer Station.

The opening of Neumayer station, situated on the Ekströmsen in February 1981, marked the first West German (FRG) permanent station to be constructed in Antarctica. The buildings were intended for the Filchner Ice Shelf but pack ice conditions at the southern end of the Weddell Sea indicated the present site to be more accessible to shipping.

Buried stations are a design style that will be replaced as the technical difficulties of jackable platforms are surmounted. The main benefits of a buried station are protection from the effects of wind and an even temperature regime but the stress on the shell increases as the weight of overburden and horizontal forces within the ice field bear upon the structure.

Rapid escape from such structures in emergency, as access shafts and garage ramps are progressively lengthened, becomes impossible and great strain is put on station services, such as ventilation and waste disposal, as the depth increases. Nobody voluntarily lives underground and the lack of exterior view and incentive to venture outdoors cannot be a good psychological influence. Despite these drawbacks, the concept of a protective tube containing insulated buildings has been used several times in the last decade, at Halley (1974), Sanae (1979), and Neumayer (1981).

The FRG design was based on previous stations but introduced a modular layout inside the tubes using standard 20 foot ISO containers,



fully fitted out before shipment. This allowed a quick construction time, minimising the amount of on-site work, and is only limited by the capacity and unloading capabilities of the supply vessels.

Personnel living in *Below Ground Level* stations are, probably, at the greatest risk from fire because of the difficulty of evacuation. At Neumayer, active and passive fire systems have been incorporated into the design and the careful choice made of flame resistant materials that emit non-toxic gases when ignited. The benefit of fire systems is lost, however, if good practice is not followed on the station. During a winter visit by the German research ship RV *Polarstern*, it was noted that rubbish and materials had been allowed to accumulate in the corridors and passages, hindering emergency access (Stonehouse, pers comm). A similar fault was also noted at Halley station during the same voyage indicating a failure in design; people, like electricity, will follow the course of least resistance and disposal of rubbish on stations must be made easy.

Neumayer provides a reasonable standard of accommodation and personnel are housed in individual bunkrooms with wardrobe and desk. Extra summer staff are temporarily housed in accommodation on the surface. By the use of drapes, carpets and furnishings, the living and communal areas have been made comfortable and the station has an "air of culture" (Stonehouse, pers comm). At Neumayer many of the communal areas are carpeted and it is common practice to remove one's shoes before entering such areas (Ibid); it is by such means that station morale is maintained.

Neumayer may be one of the last stations established in the high accumulation coastal zone that is designed to be buried, in this case to a depth of 7 m. Shortly after opening Neumayer station, the FRG decided to experiment with a jackable structure for summer use on the Filchner Ice Shelf and subsequently another site, Drescher station, has been established at 72°53'S 19°10'W, between Neumayer and Halley. These are the first major facilities employing jackable platforms to be built on ice in Antarctica and indicate the probable direction of



future permanent station designs for ice sites. Nevertheless, within the constraints of the site and the design used, Neumayer has demonstrated the benefit of modular design and pre-fitting of units before shipment to Antarctica.

#### 1.4 Signy Station.

Signy station is one of the longest running stations in Antarctica and the oldest of the selected stations. On the present site buildings of various ages and styles are represented, many of which have been much altered inside, and because the initial planners could not have foreseen the present requirements, a somewhat haphazard layout has resulted.

Some of the station buildings are undoubtedly showing their age and a major reconstruction is needed. Bunkroom space is very limited and not all the wintering personnel have a separate room and, in any case, there is no provision for any use other than sleeping. During the summer, when the station population may double, up to four staff are accommodated in some rooms, eroding any privacy the winterers may have had and making the rooms very crowded.

The dining room and lounge are also small, and therefore cramped in summer, but despite this apparent lack of comfort for the staff, the station has a reputation of good morale and a pleasant atmosphere which is due to two factors: first, it is still BAS policy only to offer two-winter contracts for many of the posts giving continuity to the activities and resulting in a young average age on the stations of about 25 years; second, fully designed interior finishes usually look institutionalised but at Signy wintering staff have been allowed to develop communal areas, reconstructing the bar on several occasions and making alterations to the panelling of the lounge, resulting in a more 'homely' feel to the station.

A major fault in the present layout is the siting of accommodation above laboratories. The type of science undertaken at this station requires the use of strong acids, inflammable gases and

toxic chemicals and it would be sensible to separate these from the living space. On the present station this is impractical and only by tight control of laboratory practice is the hazard reduced. Radio- and mains-borne interference to scientific equipment has also been a considerable problem due to the compact layout.

Cargo handling at Signy relies on manhandling of cargo, which is reliable but slow. A small amount of mechanisation would speed up the process of relief without significantly affecting the impact of the station. Similarly, a small handling shed for incoming and outgoing cargo would save packing and opening of stores in the open.

Many of the problems of running high grade laboratories in Antarctica have been overcome at Signy. Projects have demanded the use of various chemicals and equipment that have required special storage and handling. In 1981, for example, a fume cupboard was installed to the chemistry laboratory requiring extra ventilation to the room for the fans to operate. Storage of hazardous materials at Signy is poor but the arrangements for removal of toxic chemicals are simple yet effective; the material is stored in empty 200 litre drums pending removal by ship. Lamentably, the drums are later dumped at sea, supposedly north of the Antarctic Treaty Area whereas, of course, they should be returned to the UK for treatment.

Signy station requires a major reconstruction and this will provide an opportunity for a re-evaluation of the type and standard of scientific facilities that can be constructed at an Antarctic station. Very few recently established stations have attempted to accomplish a similar range and standard of scientific investigation as is currently pursued at Signy and an exciting challenge awaits the design team. With good planning, foresight, and adequate funding a leading example of a scientific station will be established, which will last many years and incorporate the flexibility to adjust to new fields of research.

## 2. SCAR and the Antarctic Treaty.

It is generally agreed that most of the environmental impact in Antarctica is a result of logistic activity; caused by shipping, aircraft and the establishment of research stations (Beddington and Bonner 1986). SCAR and the Antarctic Treaty nations have turned their attention to various aspects of logistics and summaries of the relevant recommendations are provided in Heap (1987) and Beddington and Bonner (1986). The main areas of interest, in terms of this thesis, are those relating to the Siting of Stations (Recommendation XIII-6), Co-operation in Transport (Recommendations VII-8, VIII-7, IX-4), the Code of Conduct for Antarctic Expeditions and Station Activities (Recommendations VIII-11, XII-4, XIII-4,) (cf Annex C), and the Meetings on Logistics (Recommendation II-V, III-III, IV-25) (Heap 1987).

International cooperation on Antarctic logistics is limited and certainly, has not developed to the same degree as scientific cooperation or collaboration. SCAR has only initiated three logistic symposia, although the Working Group meets regularly. By contrast, in the Arctic there are now regular annual and biennial symposia relating to cold regions technology, clearly spurred by the development of the oil industries. Antarctic logistics would undoubtedly benefit by a more frequent forum for international discussion and exchange between experts. An annual or biennial symposium on Logistics, concentrating on two or three aspects at each meeting, and organised through the SCAR Working Group, would provide this opportunity.

There are a number of aspects of Antarctic logistics which have been discussed in this thesis to which SCAR and the Antarctic Treaty nations should attend. The first of these is selection of sites. The Antarctic Treaty has little to say about this matter,

### *Recommendation XIII-6.*

*The Representatives,  
Recommend to their Governments that where stations have been  
established in the same vicinity the concerned national  
Antarctic operating agencies should consult together, by*

*whatever means found appropriate, so as to safeguard existing scientific activities, avoid operational logistic difficulties and avoid undue adverse environmental effects arising from cumulative impacts.*

(Heap 1987 p.4601)

Despite, or perhaps because of, this Recommendation there are several sites in Antarctica where a cluster of stations is developing. King George Island, South Shetland Islands, off the north western tip of the Antarctic Peninsula is an obvious example where,

*Each of the stations is virtually independent in its provisioning, accommodation, power generation, fuel storage, water supply, medical facilities, etc.*

(Headland and Keage 1985 p.482)

However, since the opening of a compacted earth runway at Marsh station (Chile) capable of accepting wheeled aircraft, several nations, including Britain, Brazil, and Uruguay, have used the facility. This is in accord with Antarctic Treaty Recommendations urging nations to use common air and sea transport facilities (Recommendations VII-8, VIII-7, IX-4) but over population of the island has resulted in infringements to the Specially Protected Areas (SPA) on Fildes Peninsula and encroachment on bird and seal colonies (Ibid).

The Antarctic Peninsula generally, has a greater number of stations than any other region of Antarctica, largely due to ease of access and longer summer season of its more northerly position. Adelaide Island, Marguerite Bay now accommodates stations from two nationalities (British and Chilean) and Brazil is contemplating establishing a site (Simoes, pers comm). Shirmacheroasen (70°45'S 11°40'E), Dronning Maud Land, is another site, occupied by a Soviet station, Novolazarevskaya; one Indian station, Dakshin Gangotri plus a projected site near the Wohlthat-massiv (71°35'S 12°20'E); and an East German (GDR) site about 1.5 km from the Soviet station. One of the better examples of logistic cooperation in Antarctica is demonstrated

by the USSR and GDR, as the East German station is reliant on Soviet fuel and power but initiates separate scientific programmes.

The King George Island experience demonstrates the need for tighter control over the placement of stations. The suggestion by Beddington and Bonner (1986) that each station should have a definite boundary should be enacted, although it is difficult to develop a system of review which does not act against the spirit of Article II of the Antarctic Treaty. It is only with further international cooperation, especially through the sharing of logistic effort, that significant advance can be made in the control of choice of sites. The SCAR should also arrange regular visits to stations by observers, publishing their reports in the public domain, and use the strength of public opinion to bring improvements. This would provide a useful adjunct to the somewhat under used system of Antarctic Treaty Observers

The provision of adequate and acceptable standards of accommodation is the second logistic topic that requires action. Many nations have their own national regulations for living environments, health and safety and other factors but, as has been shown in Chapter 5, Antarctic stations often fall *below* these standards. The Antarctic is no place for lengthy and detailed building standards and little would result from such an arrangement, however, there is a good case for the SCAR Working Group on Logistics to formulate a set of guidelines for designers of polar stations to follow, to be passed on to the Antarctic Treaty Consultative Parties for agreement in the same way that a Code of Conduct for Antarctic Expeditions and Station Activities (Recommendation VIII-11). Armed with SCAR Design Criteria for Antarctic Stations, a designer may be able to induce increased funding for accommodation.

These criteria would be presented as a guide in order to inculcate a more responsible attitude to building in Antarctica, necessary because of the advent of facilities established by private or commercial non-governmental organisations. Greenpeace, at the

second attempt, opened a station on Ross Island during the 1986-87 season and an hotel has been opened at the Chilean station (Rodolfo Marsh) on King George Island to accommodate flight passengers. Beddington and Bonner (1986) recognised the likely development of tourism in Antarctica and the construction of more tourist accommodation. SCAR and the Antarctic Treaty must be prepared to act to ensure that such private ventures apply reasonable standards of design and construction as well as following existing Recommendations regarding environmental impact. But first of all, this process must act upon existing Antarctic stations, some of which do not provide a guiding example for commercial operators to follow.

### 3. The need for overwintering stations.

How necessary are overwinter stations? In addition to permanently occupied sites, many nations run seasonal stations which achieve excellent scientific results without the cost and environmental impact of overwintering stations. Part of the drive behind establishing overwinter stations is political although scientific reasons may dictate the actual site of the station. Various nations have claimed sectors of the Antarctic continent and one way to substantiate that claim is by occupation but there are also very good scientific purposes to be served by an overwinter station. Biological activity may attenuate during cold periods but there is much to be learned from winter research and at Signy, for example, programmes continue all year. With 'real time' communication via satellite, close links can be maintained with wintering atmospheric scientists in the Antarctic. However, institutes should not be profligate with manpower,

*Unmanned stations on the polar ice cap are far cheaper to establish and maintain than permanently manned stations. Manned stations and human sensors should be reserved for those research objectives that need the presence of a human mind to be really successful, such as biological studies, fossil search, and a number of geological investigations.*

(Stuhlinger 1973 p.377)



Where sampling season is not critical, such as ice coring, summer only stations provide an economical alternative: for many years the US have used *Jamesway* huts as base camps for field activities; the FRG jackable stations, Filchner and Drescher, are only occupied on a seasonal basis; an extensive base camp, Edgeworth-David, has been constructed at Bunger Hills by the Australian Antarctic Division using a new form of re-useable shelter (Ledingham 1986a 1986b). From a scientific standpoint, many more stations could probably operate seasonally and the discussion of summer versus winter stations devolves to a question of aims of the station.

#### 4. New Technologies.

The greatest bulk to be carried to Antarctica each season is fuel. Various grades of fuel are required to power the stations, operate tractors, boats, ships and aircraft and only rough estimates have been made for the total amount transported to the continent each year. Brewster (1982) guesses 20 million litres (about 20 000 tonnes), however, the annual consumption at Molodezhnaya station is 1000 tonnes - with a capacity of about 6000 tonnes as reserve and for ships bunkering - (Shirshov and Gindin 1985) suggesting that Brewster's estimate may be low. The logistic and economic considerations of handling this much fuel, especially for inland stations, are such that designers should investigate alternative means of powering stations. Bleasel (1987) has commented,

*Technological innovation alone offers the greatest potential for improving operational efficiency and reducing overall costs. ....advances in alternative and new technology (e.g. solar and wind power, fuel cells, improved weather forecasting etc.) must be closely monitored and their potential contribution gauged.*

(Bleasel 1987 p.xiv)

The reliability of diesel generators, relative ease of storage of energy in the form of fuel oil, and the economics of diesel as a fuel, all point to a continued reliance on this system. Efficiency of



energy conversion of diesel-electric generators is relatively low, in the order of 30% (Awano and Takeuchi 1985), but heat scavenging systems enable the utilisation of much of the waste energy for hot water supply, snow melting and central heating. Tharpe and May (1972) have summarised the basic requirements for power systems and discussed alternatives for Arctic use. They conclude,

*...three advanced types of energy systems emerge as primary candidates for near-term arctic use. These include isotope thermoelectric, isotope heat engines, and chemically powered heat engines. The elimination of resupply makes the isotope systems attractive. The waste heat of the latter two provide for water and waste management, which further reduce logistics and waste burdens.*

(Tharpe and May 1972 p.251)

Various power regimes are given in Table 6.1

	DAYS	MONTHS	YEARS
MEGAWATTS	<ul style="list-style-type: none"> <li>• CHEMICAL HEAT ENGINES</li> </ul>	<ul style="list-style-type: none"> <li>• CHEMICAL HEAT ENGINES</li> <li>• NUCLEAR REACTORS</li> </ul>	<ul style="list-style-type: none"> <li>• CHEMICAL HEAT ENGINES</li> <li>• NUCLEAR REACTORS</li> </ul>
KILOWATTS	<ul style="list-style-type: none"> <li>• BATTERIES</li> <li>• FUEL CELLS</li> <li>• CHEMICAL HEAT ENGINES</li> </ul>	<ul style="list-style-type: none"> <li>• FUEL CELLS</li> <li>• ISOTOPE HEAT ENGINES</li> <li>• CHEMICAL HEAT ENGINES</li> <li>• NUCLEAR REACTORS</li> </ul>	<ul style="list-style-type: none"> <li>• FUEL CELLS</li> <li>• ISOTOPE HEAT ENGINES</li> <li>• CHEMICAL HEAT ENGINES</li> <li>• NUCLEAR REACTORS</li> </ul>
WATTS	<ul style="list-style-type: none"> <li>• BATTERIES</li> <li>• FUEL CELLS</li> <li>• CHEMICAL HEAT ENGINES</li> <li>• CHEMICAL THERMOELECTRICS</li> </ul>	<ul style="list-style-type: none"> <li>• BATTERIES</li> <li>• FUEL CELLS</li> <li>• CHEMICAL HEAT ENGINES</li> <li>• CHEMICAL THERMOELECTRICS</li> <li>• ISOTOPE THERMOELECTRICS</li> </ul>	<ul style="list-style-type: none"> <li>• FUEL CELLS</li> <li>• CHEMICAL HEAT ENGINES</li> <li>• CHEMICAL THERMOELECTRICS</li> <li>• ISOTOPE THERMOELECTRICS</li> </ul>

Table 6.1 Classification of power systems according to power level and operating time.

(Tharpe and May 1972 p.250)

Isotope heat engines have been used in Antarctica and for the period 1962 to 1972 McMurdo was powered by a small nuclear reactor (cf Chapter 4 Section 4). However, the plant was never able to replace the diesel generators which were used during periods of service and unscheduled shut-down (Anon 1980). Economic considerations eventually caused the decommissioning of the reactor and a massive amount of contaminated rock was removed from Antarctica (Ibid). Nevertheless, the use of nuclear power remains a viable option and advances in nuclear technology may eventually result in future stations powered by reactors, provided controls can be established that satisfy the environmental organisations.

A number of small scale uses of wind and solar energy have been made in Antarctica, generally, to run remote data platforms such as Automatic Weather Stations (AWS). MacGregor (1986) summarises the evidence which appears to indicate that use of solar energy may be more viable in higher latitudes, where the longer heating season allows better utilisation of solar energy than previously suspected. Often considered an 'alternative technology', use of solar energy is common enough worldwide to be a serious contender for the Antarctic and may provide a means of reducing the fuel requirement of stations, at least during the summer months.

Similarly, experiments have been made with wind generation as a power source and the Japanese have tested small wind generators at Syowa station (Awano and Takeuchi 1985). Use of natural sources of energy remains a supplementary, and not always predictable, source of power and the development of safe storage systems that require minimum maintenance will greatly increase the effectiveness of natural energy for Antarctic use.

The introduction of new building techniques and materials to Antarctica has been a continual process culminating in the jackable station for use on snow and ice fields. Future advances are likely in two main areas: materials and components. Zetlin (1972) suggests that

failures in Arctic construction have occurred because designers have worked from the wrong end of the problem,

*This process of concept first and production techniques second, however, is in most cases wrong. ... considerable success with great economic advantage has come out of a slightly different process in which we start without any preconceived concepts, ... The only starting place should be overall function and the vast knowledge of available technology in materials, fabrication, labor, etc.*

(Zetlin 1972 p.274)

Antarctic stations are box-like in construction, isolating the occupants from the environment and, in many cases, lending an air of impermanence to the whole operation. Exciting designs are being proposed for cold climate use, such as a study to enclose a small township in a covered environment by use of a pneumatic or tent structure (Fig. 6.1). Design criteria included minimum temperature of  $-41^{\circ}\text{C}$  and a maximum wind speed of  $20 \text{ m s}^{-1}$ , at a latitude equivalent to  $60^{\circ}\text{N}$  (Croome 1986). Stimulated by Gerard K O'Neil's book 'The High Frontier' (1978), a current project in Arizona, *Biosphere II*, is attempting to discover whether a self-contained closed environment, containing various species of animals and plants, can support humans (Armstrong 1987). These ideas may appear to be far removed from polar stations but the technological problems faced by space travel and polar activities have a similar starting point: support of humans in hostile environments, and polar designers should keep abreast of activities in other fields that have relevance to polar design.

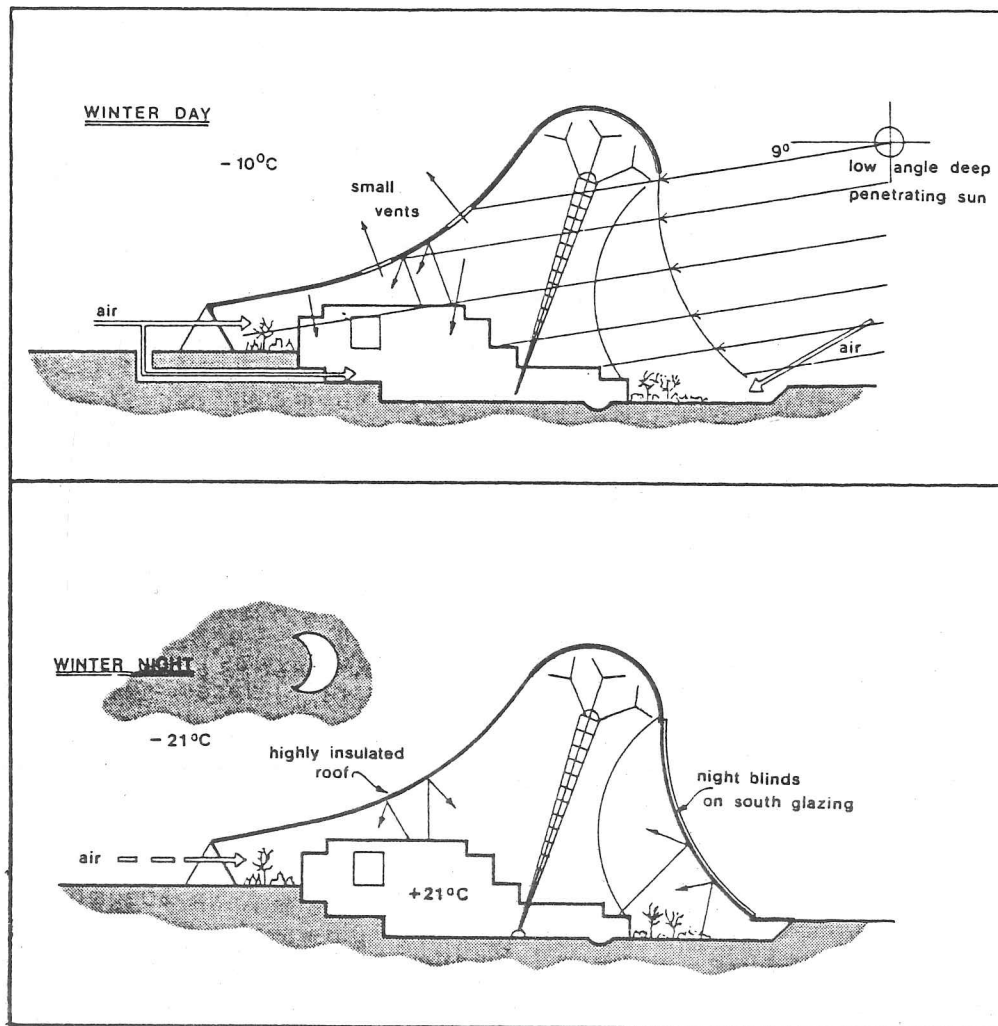


Fig.6.1 Design study to create a covered township in north Canada using a flexible membrane tent. Environmental response of tent structure in winter. (Croome 1985 p.181)

## 5. Summary

The central theme of this thesis is the design, service and maintenance of stations in Antarctica. The main part of the work is concerned with four permanent overwintering stations that have been established to undertake scientific research. Other stations have been introduced where they illustrate particular points.

Design and construction of stations in Antarctica is an exciting and dynamic field. Commensurate with increased interest in the region, more design groups, perhaps than ever before, are studying the problems and devising solutions. This process is set to continue; Antarctica is becoming a continent for the traveller, who will expect luxury and leisure; and for the exploiter, who will develop the natural resources of the region at minimum expenditure.

A gap in the literature has been partially filled by this thesis and an opportunity provided for polar designers to review the present status of selected Antarctic stations. Improvements to several aspects of station design, the regulation of Antarctic station activities, and other factors have been identified. These are:

- Design criteria for Antarctic stations recommended by SCAR
- Tighter control of the siting of Antarctic stations.
- The provision of basic standards of accommodation for those who work in Antarctica.
- The need for a review of designs for stations on ice fields.
- The continual review of new technologies for their relevance to Antarctic activities.
- Insufficient communication between station designers from different nations.

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Made 1 December 1959; came into force 23 June 1961.

(The Treaty has no limit on its duration; it may be reviewed, at the request of a Consultative Party, 30 years after coming into force [that is in 1991].)

Membership; in chronological order.

§ <i>United Kingdom</i>	31 May 1960	1
§ <i>South Africa</i>	21 June 1960	2
§ <i>Belgium</i>	26 July 1960	3
§ <i>Japan</i>	4 August 1960	4
§ <i>United States of America</i>	18 August 1960	5
§ <i>Norway</i>	24 August 1960	6
§ <i>France</i>	16 September 1960	7
§ <i>New Zealand</i>	1 November 1960	8
§ <i>Soviet Union</i>	2 November 1960	9
§ Poland *	8 June 1961	10
§ <i>Argentina</i>	23 June 1961	11
§ <i>Australia</i>	23 June 1961	12
§ <i>Chile</i>	23 June 1961	13
Czechoslovakia	14 June 1962	14
Denmark	20 May 1965	15
Netherlands	30 March 1967	16
Romania	15 September 1971	17
Germany, DDR	19 November 1974	18
§ Brasil *	16 May 1975	19
Bulgaria	11 September 1978	20
§ Germany, BRD *	5 February 1979	21
§ Uruguay *	11 January 1980	22
Papua New Guinea +	16 March 1981	23
Italy	18 March 1981	24
Peru	10 April 1981	25
Spain	31 March 1982	26
§ China, Peoples' Republic *	8 June 1983	27
§ India *	19 August 1983	28
Hungary	27 January 1984	29
Sweden	24 April 1984	30
Finland	15 May 1984	31
Cuba	16 August 1984	32
Korea (Seoul)	28 November 1986	33
Greece	8 January 1987	34
Korea (Pyongyang)	21 January 1987	35

*Original signatories* (12), which initialled the Treaty on 1 December 1959, are *italicised*; the dates given are those of the deposition of the ratifications of the Treaty.

§ Consultative Parties (18; 12 original signatories and 6 others which achieved this status after becoming actively involved in Antarctic Research).

\* These acceding states became Consultative Parties on 29 July 1977 (Poland), 3 March 1981 (Germany, BRD), 12 September 1983 (Brasil and India), and 7 October 1985 (China [Peoples' Republic] and Uruguay).

+ Papua New Guinea succeeded to the Treaty after becoming independent of Australia.

(after Headland 1987)

INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS  
SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH

National membership, with dates of accession:

*Full members:*

Argentina	3 February 1958
Australia	3 February 1958
Belgium	3 February 1958
Chile	3 February 1958
France	3 February 1958
Japan	3 February 1958
New Zealand	3 February 1958
Norway	3 February 1958
South Africa	3 February 1958
Union of Soviet Socialist Republics	3 February 1958
United Kingdom	3 February 1958
United States of America	3 February 1958
Germany, Federal Republic of	22 May 1978
Poland	22 May 1978
German Democratic Republic	9 September 1981
India	1 October 1984
Brazil	1 October 1984
China (Peoples' Republic)	23 June 1986

*Associate members:*

Spain	15 January 1987
Sweden	24 March 1987
Peru	14 April 1987
Italy	19 May 1987
Netherlands	20 May 1987

(after Headland 1987)



## CODE OF CONDUCT FOR ANTARCTIC EXPEDITIONS AND STATION ACTIVITIES

### 1. *Waste disposal*

The following are recommended procedures:

#### (a) *Solid Waste*

- (i) *Non-combustible, including chemicals (except batteries).* These materials may be disposed of at sea either in deep water or, if this is not possible, at specified sites in shallow water.
- (ii) *Batteries* should be removed from the Antarctic Treaty Area.
- (iii) *Combustibles.*
  - Wood, wood products and paper should be incinerated, the ash being disposed of at sea.
  - Lubricating oils may be burnt except those containing harmful additives which should be removed from the Antarctic Treaty Area.
  - Carcasses and materials associated with imported experimental animals should be incinerated.
  - All plastics and rubber products should be removed from the Antarctic Treaty Area.

#### (b) *Liquid Waste*

- (i) Human waste, garbage and laundry effluents should, where possible, be macerated and be flushed into the sea.
- (ii) Large quantities of photographic liquids should be treated for the recovery of silver and the residue should be flushed into the sea.
- (c) The above procedures are recommended for coastal stations. Field sites supported from coastal stations should, where feasible, use the facilities of their supporting station. Inland stations should concentrate all waste in deep pits. Except as stated for inland stations, waste should not be buried.
- (d) Waste containing radio-isotopes should be removed from the Antarctic Treaty Area.
- (e) Every effort should be made to reduce the plastic packaging of products imported into the Antarctic Treaty Area.
- (f) If possible the use of leaded fuels or fuels containing ethylene bromide and ethylene chloride should be avoided.
- (g) When incinerators are used it is desirable to monitor the effluents.

### 2. *Introduction of alien species*

Procedures to safeguard against the introduction of alien species are covered by Article IX of the Agreed Measures for the Conservation of Antarctic Fauna and Flora.

### 3. *Disturbance of breeding colonies and concentration of birds and mammals*

Procedures to minimize such disturbances are covered by Article VII of the Agreed Measures for the Conservation of Antarctic Fauna and Flora.

### 4. *Guidelines for Antarctic operating organizations planning major Antarctic Projects*

- (a) In the planning of major operations in the Antarctic Treaty Area an evaluation of the environmental impact of the proposed activity should be carried out by the Antarctic operating organizations concerned. Such an evaluation should include:
  - (i) A description of the proposed action and an assessment of its potential benefits and its possible impact on the relevant ecosystems.
  - (ii) A consideration of alternative actions which might alter the pattern of benefits versus adverse environmental effects expected to result from the action.
- (b) These evaluations may be circulated for information through SCAR channels to all the states engaged in Antarctic activities.