

# Proposed Construction and Operation of Halley VI Research Station, Brunt Ice Shelf, Antarctica



## DRAFT COMPREHENSIVE ENVIRONMENTAL EVALUATION (CEE)

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**British  
Antarctic Survey**

NATURAL ENVIRONMENT RESEARCH COUNCIL



**COVER:**

Artist's impressions of concept designs for Halley VI Research Station. From top:

Hopkins/Expedition/atelier ten – 'walking' buildings using hydraulic legs;

FaberMaunsell and Hugh Broughton – modular buildings and service pods on skis; and

Buro Happold and Lifschutz Davidson – 'icecraft' buildings on telescopic legs.

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**PROPOSED CONSTRUCTION AND OPERATION OF HALLEY VI  
RESEARCH STATION, BRUNT ICE SHELF, ANTARCTICA**

**DRAFT COMPREHENSIVE ENVIRONMENTAL EVALUATION**

**NON-TECHNICAL SUMMARY**

**1. INTRODUCTION**

A draft Comprehensive Environmental Evaluation (CEE) has been carried out by the British Antarctic Survey (BAS) for the proposed construction and operation of the UK's Halley VI Research Station, Brunt Ice Shelf, Antarctica. The draft CEE has been prepared in accordance with Annex I of the Protocol on Environmental Protection to the Antarctic Treaty (1998). The Guidelines for Environmental Impact Assessment in Antarctica (Resolution 1, XXIII ATCM, 1999) were also consulted. The draft CEE describes the proposed activity, alternatives, the local environment and the likely environmental impact. It recommends preventative and mitigation measures and outlines gaps and uncertainties regarding the Halley VI project.

At this stage of the CEE process (February 2005), the final design of Halley VI is still in preparation. Therefore, the draft CEE provides the overall design objectives for Halley VI, and explains the three design concepts being developed to identify the best solution. A key design criterion is that Halley VI must minimise impact on the Antarctic environment and comply with the Environmental Protocol. The predicted impact of Halley VI will not depend, therefore, on the final design chosen. The environmental effects of Halley VI will be substantially reduced compared to the existing station at Halley V by having fewer people working at the new facility, decreasing fossil fuel consumption, using new sustainable technologies and implementing new management procedures.

**2. DESCRIPTION OF THE PROPOSED ACTIVITY**

The UK has operated Halley Research Station on the Brunt Ice Shelf since 1956. The proposed activity assessed in this draft CEE is the construction and operation of Halley VI Research Station, which will replace the current Halley V station. The new facility will be located on the Brunt Ice Shelf, Caird Coast, Dronning Maud Land (75°37'S, 26°06'W; February 2005).

The UK plans to decommission, demolish and remove Halley V from Antarctica once Halley VI is built and fully operational. The clean-up of Halley V is not considered in this draft CEE, and instead will be the subject of a separate EIA.

The Brunt Ice Shelf is a floating ice sheet and is 200m thick. It is currently flowing at a rate of 550m per annum (February 2005) towards the Weddell Sea, but is slowing down. At irregular intervals, the ice shelf breaks off as icebergs. BAS has assessed that there is a growing risk that the ice on which the existing research station sits could be lost in a major calving event in the next decade. The UK has therefore decided to design and build a replacement station in a safe location on the Brunt Ice Shelf for initial operation in 2008/09. To cope with any future, major calving events the new station will be designed so that it can be relocated.

Halley is one of the most important research locations in Antarctica for atmospheric sciences and snow chemistry. The first Halley was established as part of the International Geophysical Year (IGY) in 1957/58 and many scientific studies have continued uninterrupted since then producing globally important long-term monitoring datasets. It is the site where BAS

scientists discovered the ozone hole in 1985. Since 1992 when Halley V opened, well in excess of 400 internationally peer-reviewed scientific papers have been published using data collected at the station. At present, Halley supports world-class research into atmospheric physics, geospace, atmospheric and snow chemistry, meteorology and ozone monitoring, and glaciology.

The overall objectives for Halley VI are to design, build and operate an Antarctic research station that:

- minimises environmental impact and complies with the Environmental Protocol;
- can withstand the extreme environmental conditions found on the Brunt Ice Shelf;
- provides a safe, comfortable and stimulating place to live and work for 16 people in the austral winter and 52 people in the austral summer;
- must be completed, commissioned and handed over to BAS for occupancy by the end of December 2008;
- has a design life of 20 years;
- allows the main buildings to be relocated by several kilometres, if necessary, during the life of the station;
- is functionally efficient, fit for purpose and best value for money;
- minimises the requirement for snow management in all aspects of the station's operations;
- has a lifetime maintenance strategy that takes into account the remoteness of the station and the limitations of logistics supply;
- uses technology to reduce running costs;
- reduces the use of fossil fuels through increased energy efficiency and maximises the use of renewable energy where practical and affordable; and
- minimises risks to Health and Safety, and complies with all relevant UK Health and Safety legislation where reasonably practicable.

BAS aim is to reduce the number of technical staff working at Halley VI, both in winter and summer, compared to Halley V. Compared to staffing levels at Halley V in 2004/05, planned total winter numbers at Halley VI will reduce by 11% (from 18 to 16 staff) and in summer numbers will reduce by 26% (from 70 to 52 people).

### **3. DESIGN COMPETITION FOR HALLEY VI**

In June 2004, BAS, in association with the UK Royal Institute of British Architects, launched an international design competition to provide new and innovative ideas for the future development of Halley. There were 86 entries submitted from around the world of which six were asked to put forward concept designs. Of these six, three have been chosen by BAS to develop their ideas further and form an integrated team with a building contractor to bid for the Halley VI construction contract. The three design teams, and their concepts, are:

- Buro Happold and Lifschutz Davidson
  - 'icecraft' buildings on telescopic legs;
- FaberMaunsell and Hugh Broughton Architects
  - modular buildings and service pods on skis;
- Hopkins/Expedition/atelier ten

- 'walking' buildings using hydraulic legs.

All three chosen concepts meet the requirements of the Environmental Protocol. The three design teams are currently undertaking a site visit to Halley V (February 2005). The announcement of the winning design will be made by BAS in September 2005. Planning assumes that construction of Halley VI will take place on the Brunt Ice Shelf during the austral summers of 2006/07 and 2007/08, with the construction team possibly wintering over in austral winter 2008. The completed station is due to be handed over to BAS in December 2008.

#### **4. ALTERNATIVES**

Five options for the future of Halley Research Station have been examined:

- discontinue scientific research at Halley;
- attempt to extend the life of the existing facilities at Halley V;
- move Halley V to a safer location on the Brunt Ice Shelf;
- relocate and build Halley VI on the Lyddan Ice Rise (74°25'S, 20°45'W) to the north-east of the Brunt Ice Shelf; and
- commission a wide range of different designs for Halley VI and build a new, replacement station on a safe location on the Brunt Ice Shelf.

The first four options are not viable for a variety of logistical, engineering, scientific, environmental and safety reasons. Therefore, the UK has decided that the best practical option is to build and operate Halley VI at a safe site on the Brunt Ice Shelf beyond the furthest upstream limit of where the ice shelf is predicted to break off.

#### **5. DESCRIPTION OF THE ENVIRONMENT**

Halley VI will be located on the Brunt Ice Shelf approximately 30km from its northwest coast. Average temperatures are  $-5^{\circ}\text{C}$  in midsummer, falling to  $-30^{\circ}\text{C}$  in winter, with an extreme maximum of  $+4.5^{\circ}\text{C}$  and an extreme minimum  $-55.3^{\circ}\text{C}$ . There is snowdrift on about 180 days per year. Annual snow accumulation is about 1m. The winds are predominately from the east-north-east. Mean annual wind speed is  $7\text{ms}^{-1}$ . Gales occur on average for 40 days each year. The average annual total sunshine is 1445 hours, and in winter the sun does not rise above the horizon for 100 days. There is total darkness for 55 days.

The Brunt Ice Shelf does not support any flora, and there are no breeding birds or mammals at the proposed location of Halley VI. The station may very occasionally be visited by small numbers of moulting Adélie penguins and emperor penguins. There is an emperor penguin colony of about 15,000 breeding pairs on the fast ice at 'Windy Creek', about 30km from Halley VI. Weddell seals are common on the sea ice adjacent to the ice shelf.

#### **6. IMPACT ASSESSMENT AND MITIGATION MEASURES**

The environmental impacts predicted at Halley VI have been identified on the basis of those recorded at Halley V, and using the 50 years of BAS experience of working on the Brunt Ice Shelf.

On the Brunt Ice Shelf, the area most heavily disturbed by the construction and operation of Halley VI will be around the station itself and cover approximately  $20\text{km}^2$ . In addition, there

will be disturbance along the traverse routes used by tracked vehicles operating to and from the supply ship moored at the edge of the ice shelf.

The impacts related to the construction and operation of Halley VI are summarised in the draft CEE using impact matrices. They show that the environmental impacts are predicted to be:

- air pollution and particulate deposition from atmospheric emissions produced by the combustion of fossil fuels;
- disposal of grey water and human wastes and abandoned materials buried under the snow; and
- contamination of snow and ice by minor fuel spills and leaks.

Of these impacts the most significant are air pollution and particulate deposition. The major source of additional atmospheric emissions, compared with operations today, will be from the extra ship visits to Halley during the construction phase. The matrices indicate that the environmental impacts identified as medium to high significance, such as major a fuel spill (>1000 litres), will be of very low to low probability.

Impacts of medium significance to scientific research at Halley VI are predicted, in the same way as today. Impacts predicted are the potential loss of atmospheric observations due to light pollution from station buildings and disturbance to electromagnetic observations from station electrical equipment and vehicles. There will also be some air pollution from station fossil fuel generators and vehicles that can affect air chemistry measurements, and disturbance to the snow surface could affect meteorological boundary layer experiments.

Prevention and mitigation measures have been identified to avoid or minimise all the impacts predicted.

All construction works and operational activities at Halley VI will be in compliance with, and where practical exceed, the requirements of the Environmental Protocol. Stringent environmental conditions will be included in the building contract for Halley VI, and will be enforced through careful contract supervision by BAS. Appropriate environmental education, training and guidance will be provided for all staff and contractors working at Halley VI. All activities at Halley VI will be subject to a permit issued by the UK Foreign & Commonwealth Office under the Antarctic Act (1994).

BAS expects that the operation of Halley VI will have substantially reduced environmental impact compared to Halley V because of the reduced station population, improved environmental management procedures, and the introduction of new technology to reduce fossil fuel consumption, minimise waste disposal, and recycle and reuse waste water. In addition, Halley VI is being designed with a much longer design life (>25% longer) than its predecessors, and to be capable of being easily decommissioned and removed when it eventually closes, and this will contribute to reducing the impact.

## **7. ENVIRONMENTAL MONITORING AND MANAGEMENT**

Once the detailed design and technical specifications for Halley VI are complete, BAS will establish a station environmental monitoring programme to measure the actual impacts of the project in Antarctica. As a minimum, BAS will monitor atmospheric emissions (calculated on the basis of fuel used), wastes produced, and fuel spills. Long-term glaciological monitoring of the Brunt Ice Shelf will continue to provide early warning of a major calving event. Also, continuous measurements of black carbon aerosol will be made to identify pollution from station generators and vehicles.

BAS plans to undertake an environmental audit of Halley VI during construction in 2006/07 or 2007/08 and in the first season of operations in 2008/09 to assess and verify the environmental impacts predicted in the CEE.

## 8. GAPS IN KNOWLEDGE AND UNCERTAINTIES

Gaps in knowledge and uncertainties have been identified in the draft CEE. The main uncertainties are the:

- natural variability of the hostile environment at Halley VI, such as weather, sea ice or ice shelf conditions;
- final design and detailed technical specification for the construction and operation of Halley VI will not be fully known until September 2005;
- inability to be precise about the actual environmental impacts of Halley VI and the extent to which these impacts will be less than those observed at Halley V; and
- changes in future activities at Halley VI over its design life of 20 years, especially the progressive introduction of renewable energy and water recycling technology and developments in BAS global science programmes beyond 2010.

## 9. CONCLUSION

The UK considers that the construction and operation of Halley VI Research Station on the Brunt Ice Shelf will have more than a minor or transitory impact on the Antarctic environment. The implementation of the preventative and mitigation measures outlined in this draft CEE will reduce environmental impacts, and BAS considers the overall impact of Halley VI will be substantially less than Halley V.

The UK concludes that the global scientific importance and value to be gained by the construction and operation of Halley VI and the continued operation of the research facility by BAS on the Brunt Ice Shelf outweighs the more than minor and transitory impact the station will have on the Antarctic environment and fully justifies the activity proceeding.

## 10. FURTHER INFORMATION

This draft CEE has been prepared by the British Antarctic Survey and has been approved and endorsed by the UK Government. It was released on 4 February 2005 and is available for download via the BAS website ([www.antarctica.ac.uk/halleyvi/cee.html](http://www.antarctica.ac.uk/halleyvi/cee.html)).

The UK welcomes comments and feedback on the draft CEE.

If you would like further information on the CEE of Halley VI or would like to respond with comments then please contact:

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## 1. INTRODUCTION

### 1.1 THE ROLE OF HALLEY RESEARCH STATION

Halley Research Station is the UK's most isolated research facility in Antarctica, and is located on the floating Brunt Ice Shelf, Coats Land (Figure 1). The British Antarctic Survey (BAS) has operated five successive stations at Halley for nearly 50 years.

BAS, part of the UK Natural Environment Research Council (NERC), is a world leader in research into global science in the Antarctic context and is the UK's national Antarctic operator. The majority of the BAS science programme is undertaken in Antarctica and the Southern Ocean, and Halley is one of the five research stations run by the Survey in the Antarctic and South Atlantic regions.

**Figure 1. Location of Halley Research Station on the Brunt Ice Shelf, Antarctica.**



Halley provides a vital research location for achieving a global perspective on climate change, ozone depletion and atmospheric pollution, and for long-term monitoring studies of weather, glaciers and ice shelves, solar storms and the upper atmosphere.

The current Halley is the fifth station to have been built by the UK on the Brunt Ice Shelf (Figure 2). It is located about 12km inland of the seaward edge of the Brunt Ice Shelf

(75°35'S, 26°39'W; February 2005). The ice shelf is 200m thick, and flows northwest from Coats Land towards the sea where, at irregular intervals, it calves off as icebergs. BAS scientists assess that there is a growing risk that the ice on which the station sits could be lost in a major calving event in the next decade (Hayes, 2003).

**Figure 2. Halley V Research Station, Brunt Ice Shelf.**



## 1.2 HISTORY OF HALLEY RESEARCH STATION

The first Halley Research Station was established in January 1956 by the UK Royal Society for the International Geophysical Year (IGY) 1957/58, and was named after the British astronomer Edmond Halley. Work carried out at this station included meteorology, glaciology, seismology, radio astronomy, ionospheric physics, aurora and airglow, and geomagnetism. The station was transferred from the Royal Society to what is now BAS in 1959.

The extreme environment of the Brunt Ice Shelf poses significant building and technical problems with blizzards and snowdrift eventually burying everything on the surface. Buildings disappear beneath the snow, requiring vertical access shafts to be lengthened every year. Because of burial by snow and movement of the ice shelf, it was necessary to close Halley I in 1968, when it was 14m below the snow surface. Four further Halley stations were constructed on the Brunt Ice Shelf (see Table 1) in 1967, 1973, 1983 and 1992 (BAS, 2004a). All but the most recent, Halley V, have been buried under the snow until they were no longer safe to inhabit. Abandoned sub-surface buildings have been lost to sea in icebergs, which have calved off the ice shelf. Hazardous wastes were removed from Halley III in 1991 before it became impossible to access safely. Halley IV was decommissioned in 1991/92 and 1992/93 when all removable items and fittings were taken from the buildings before they were abandoned (Whittamore, 1992).

Halley V began operations in February 1992 (Blake, 2003). There are usually 18 people working at the station during the Antarctic winter, increasing to a maximum of 70 science and support staff in the summer. The station contains a mix of building technologies. Four buildings are built on platforms, which sit 4m above the surface on legs that are jacked up annually to keep them clear of the accumulated snowfall. A further two buildings are mounted on skis and winched by tracked vehicles each year to a new position on the snow surface and then winched back to their original position the following year.

**Table 1. History of the Halley Research stations built on the Brunt Ice Shelf.**

Station	Dates of Use	Construction Type	
Halley I	1957–1968	Large wooden hut built on snow surface	
Halley II	1967–1973	Seven wooden huts built on snow surface	
Halley III	1973–1984	Series of prefabricated wooden huts housed inside corrugated steel tubes	
Halley IV	1983–1992	Two storey wooden huts inside tubes constructed from interlocking plywood-faced panels	
Halley V	1991–present	Four buildings on platforms on steel legs, jacked up annually. Two buildings on skis are towed to a new position each year	

### 1.3 SCIENTIFIC RESEARCH AT HALLEY

Halley is one of the most important research locations for atmospheric sciences and snow chemistry in Antarctica. BAS scientists discovered the spring-time ‘ozone hole’ over Antarctica using Halley data in 1985. Since 1992 when Halley V opened, well in excess of 400 research papers have been published in internationally peer-reviewed science journals using data collected at the station. At present, Halley supports world-class research into atmospheric physics, geospace, atmospheric and snow chemistry, meteorology and ozone monitoring, and glaciology. Many of the scientific studies have continued uninterrupted since 1956, when the station opened, producing globally important long-term monitoring datasets.

Work carried out at Halley is an integral part of BAS’ new five year science programme (2005–10) – Global Science in the Antarctic Context (GSAC) (see [www.antarctica.ac.uk](http://www.antarctica.ac.uk) for further details). This programme has been constructed to deliver integrated, inter-disciplinary Earth System research, monitoring and survey, primarily in the Antarctic and the surrounding Southern Ocean. The programme was internationally peer-reviewed, and then approved by the UK NERC in 2004.

Halley will continue to be a globally important research location as the UK and the international science community focuses on Earth System science. BAS scientists working at Halley already participate in a large number of international scientific programmes and international data-gathering activities, such as the World Meteorological Network. This is set to increase with the onset of the International Polar Year 2007/08.

#### 1.3.1 Climate, ice and ozone studies

Meteorological data has been collected at Halley since 1956, and in combination with data from other Antarctic research stations, provides a climatic database for an area larger than Europe. The data is sent by satellite to weather forecasting centres around the world, and is vital for immediate use and for all aspects of climate change research. The data are also used to improve the representation of high latitude processes in General Circulation Models used for climate modelling.

Halley is situated in one of the best natural laboratories in the world for studying the dynamics of the atmosphere close to the ground, due to its remoteness and the flatness of the ice shelf. A sophisticated Clean Air Sector Laboratory (CASLab) at Halley is providing new insights into the chemistry of the air/ice interface, levels of pollution and a range of processes critical for interpreting ice core data. Glaciologists study past climate using ice cores.

New and existing datasets are being used to understand the relationship between Antarctic and global climate over millennial timescales. The drivers and amplifiers controlling climate over the last million years are being investigated. This should allow the correct processes to be incorporated into the predictive models, so that policy makers can make informed choices about how to manage the Earth in the future.

The ozone layer has been measured at Halley since 1956. The spring-time depletion in stratospheric ozone was discovered by BAS scientists using Halley data in 1985 (Farman et al., 1985). The scientists observed that during each spring, ozone was almost completely destroyed over Antarctica, producing what is now known as the ‘ozone hole’. These measurements attracted world-wide interest from scientists, the public and senior government policy makers. The discovery led very quickly to the agreement of the Montreal Protocol to protect the ozone layer and the global response to curtail production of chlorofluorocarbons (CFCs) and other ozone depleting substances (DEFRA, 2000).

**Figure 3. Left: Scientist releasing meteorological balloon. Right: High Frequency Southern Hemisphere Auroral Radar Experiment (SHARE) at Halley V station.**



### 1.3.2 Geospace research

The near-Earth region of interplanetary space, known as geospace, is dominated by the interaction of the Sun's atmosphere with the magnetic field of the Earth. Understanding the physics of geospace is of increasing importance as periodic increases in solar activity create magnetic storms that affect a wide range of technical systems on satellites and impact radio communications and power-line transmissions.

Halley is ideally situated for geospace research as it lies on the edge of the southern auroral zone. A high frequency (HF) Southern Hemisphere Auroral Radar Experiment (SHARE) radar is a key part of the Super Dual Auroral Radar Network (SuperDARN), which is a network of high frequency radars in the polar regions being used to observe the impact of the Sun's activity on space weather. There is also a comprehensive suite of other powerful radio and optical instruments and together they provide an unparalleled spatial picture of the consequences of geospace interactions in the upper atmosphere (above 100km) (see Figure 3). Instruments monitor an area of around three million square kilometres above the South Pole. Halley is also the focus of the BAS Low Power Magnetometer (LPM) network, a suite of ten unmanned monitoring stations distributed between Halley and the Amundsen-Scott South Pole Research Station (USA), which also contribute to geospace research.

At around 85km above sea level, the mesosphere is the coldest part of the Earth's atmosphere and is at the boundary between geospace and the stratosphere. This region has long been inaccessible to instrumentation, but Halley now has a suite of state-of-the-art radio and optical instruments for observing the mesosphere's structure and dynamics. This instrument suite completes the ensemble at Halley and allows the Earth's atmosphere to be studied from ground level to its very outer limits.

## 1.4 THE FUTURE DEVELOPMENT OF HALLEY

In 2004, the UK decided that Halley V Research Station needed to be replaced because of the growing risk that the part of the ice shelf on which it sits could break off in the next decade. An innovative multi-disciplinary design competition was launched to provide new and

exciting concepts for the future development of Halley. A key design criterion is that Halley VI must minimise impact on the Antarctic environment and comply with the Environmental Protocol.

#### 1.4.1 Halley VI Research Station design competition

The Halley VI Research Station design competition is being run in association with the UK Royal Institute of British Architects (RIBA) (BAS, 2004b). The requirement is to design, manufacture, and construct a new British research station on the Brunt Ice Shelf. BAS and RIBA hope the competition will encourage a fusion of science, architecture, technology and engineering that will produce a world-class science facility, which minimises environmental impact. The competition comprises four stages (Table 2). Further details about the competition can be found on the BAS website ([www.antarctica.ac.uk](http://www.antarctica.ac.uk)).

**Table 2. Halley VI design competition programme.**

Stage	Activity	Timescale
Stage 1	Expression of Interest	June – August 2004
Stage 2	Concept Proposal	September – December 2004
Stage 3	Concept Development	January – September 2005
Stage 4	Procurement and Construction	October 2005 – December 2008

#### 1.4.2 Expressions of Interest

The design competition was launched by RIBA and BAS in late June 2004, with a call for Expressions of Interest (EOI) from design teams around the world. Competition entrants were asked to put forward a design concept for Halley that:

- minimises environmental impact and complies with the Environmental Protocol;
- is functionally efficient;
- is able to be relocated by several kilometres;
- is aesthetically stimulating;
- can withstand the extreme environmental conditions found on the Brunt Ice Shelf;
- must be completed within its construction phase timetable of two austral summers and two austral winters;
- represents best value for money over its full expected design life of 20 years;
- has a lifetime maintenance strategy that takes into account the remoteness of the station and the limitations of logistic supply; and
- uses technology to reduce running costs and increases energy efficiency.

#### 1.4.3 Concept proposals

In August 2004, a total of 86 EOIs from different design teams based in seven nations were evaluated by a Jury Panel, chaired by the Director of BAS. Six design teams were selected to take forward their ideas and develop concept proposals. The proposals had to cover the following four themes:

- architecture and sustainability;

- structure and materials;
- environment and energy; and
- construction and logistics.

All of the six produced innovative and creative designs, displaying ingenious new ways of building and operating the station. A major design requirement is for the station to have minimal environmental impact, so the teams developed strategies for energy saving and for solar and wind power, water recycling, and reducing wastes. Concepts for Halley VI included pyramid-shaped hovercraft, a linear terminal on skis, transportable modules on skis, 'walking' buildings, and 'icecraft' with telescopic legs. Images of the six concept designs can be found on the competitions section of the RIBA website ([www.riba.org](http://www.riba.org)).

#### **1.4.4 Concept development**

A BAS technical panel, followed by the Jury Panel, assessed the six concept proposals in November 2004. Three design teams were selected to develop detailed concept designs. The winning design teams were Buro Happold and Lifschutz Davidson, FaberMaunsell and Hugh Broughton Architects and Hopkins/Expedition/atelier ten. Structural engineers from each of the design teams, along with the BAS Halley VI Project Manager, are undertaking a site visit to Halley during January and February 2005.

As part of the concept development, each of the three design teams was asked to take part in and contribute to the draft CEE of Halley VI. To assist in this process, BAS organised a Halley VI EIA workshop on 15 December 2004, which was attended by senior representatives from all three design teams, the UK Foreign & Commonwealth Office, environmental consultants (Poles Apart) and BAS. Section 3 of this draft CEE contains a summary of the three concept proposals, which have been provided by each design team.

The selected teams are now undertaking detailed work on their concepts. The deadline for the concept development design is August 2005, with an announcement of the winner to be made by BAS in September 2005. As part of the final evaluation, the Jury Panel will be provided with any comments made on the draft CEE for Halley VI.

BAS are currently in the process of selecting the building contractor who will construct Halley VI. The chosen contractor will work together with the winning design team to design and build Halley VI.

### **1.5 PREPARATION AND PRODUCTION OF THE CEE FOR HALLEY VI**

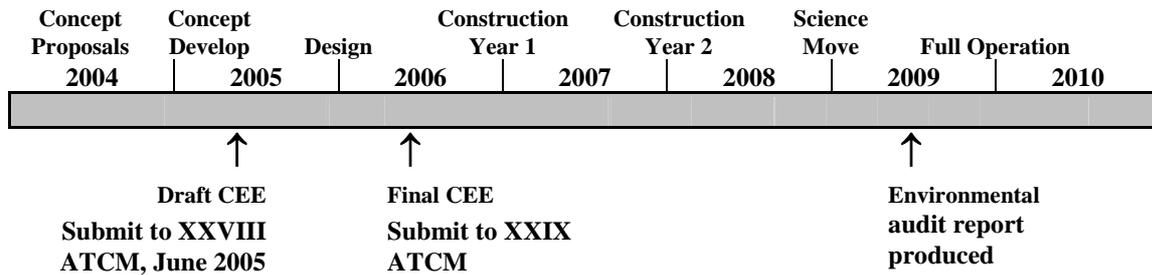
The preparation and production of the draft and final CEE for Halley VI is being led and managed by BAS through its Environmental Office, with support from the polar environmental consultancy – Poles Apart. The lead author of the draft CEE is the BAS Environmental Officer. Input to the CEE has been provided from across BAS, including the Halley VI Project Manager, the Halley VI Project Board, Technical Services, Operations Group and scientists from Physical Sciences Division and Biological Sciences Division.

The draft CEE has been released and made available to the public for comment via the BAS web site ([www.antarctica.ac.uk/halleyvi/cee.html](http://www.antarctica.ac.uk/halleyvi/cee.html)). The draft CEE will also be circulated by the UK Government to the Governments of the other Antarctic Treaty Consultative Parties (ATCPs) not less than 120 days before the XXVIII Antarctic Treaty Consultative Meeting (ATCM) to be held in Stockholm, Sweden in June 2005. The draft CEE will be considered by

the Committee for Environmental Protection (CEP) established under the Environmental Protocol at the ATCM.

Following the XXVIII ATCM and the announcement of the winning design for Halley VI, BAS will prepare a final CEE. This will be made available for comment in the same way as the draft CEE. The UK Government will submit the final CEE to the XXIX ATCM in June 2006. Figure 4 shows a timeline diagram showing the stages for the design competition and for the draft and final CEE for Halley VI.

**Figure 4. Timeline diagram showing the stages for the design competition and for the draft and final CEE for Halley VI.**



## **2. DESCRIPTION OF THE PROPOSED ACTIVITY**

### **2.1 SCOPE**

This draft Comprehensive Environmental Evaluation (CEE) has been carried out by BAS for the proposed construction and operation of the UK's Halley VI Research Station, including the transport of station personnel and cargo in the Antarctic Treaty Area. It has been prepared in accordance with Annex I of the Protocol on Environmental Protection to the Antarctic Treaty (1998). The Guidelines for Environmental Impact Assessment in Antarctica (Resolution 1, XXIII ATCM, 1999) were also consulted.

The UK plans to decommission, demolish and remove Halley V from Antarctica, once Halley VI is operational in 2008/09. The clean-up of Halley V is not considered in this draft CEE, and instead will be the subject of a separate EIA.

### **2.2 LOCATION**

The location of the proposed Halley VI Research Station (75°37'S, 26°06'W; February 2005) is approximately 30km inland from the northwest seaward edge of the Brunt Ice Shelf. The ice shelf at this point is floating and is approximately 200m thick, and currently moving at a rate of 550m per annum (February 2005) towards the Weddell Sea.

As the ice shelf advances towards the coast, the proposed station will periodically be moved back to the same geographic location on the ice and therefore will not move westwards as the current and previous stations have. It is expected that any relocation of the station will coincide with either a major future calving event on the ice shelf, or with the BAS five year science research programme cycle. In this context, relocation is defined as the movement of the facilities over several kilometres (5–10km), a maximum of once every five years with at least one year's notice to prepare.

The map shown in Figure 5 shows the location of the Brunt Ice Shelf, the current location (February 2005) of Halley V and the proposed site of Halley VI (February 2005).

#### **2.2.1 Geographical boundaries of the draft CEE**

The geographical boundaries of this draft CEE include the proposed location of Halley VI Research Station on the Brunt Ice Shelf, and the transport routes for associated activities, such as shipping, aircraft and tracked vehicles within the Antarctic Treaty Area. Any activities associated with the existing operation and resupply of Halley V are not included.

### **2.3 PRINCIPAL CHARACTERISTICS OF THE PROPOSED ACTIVITY**

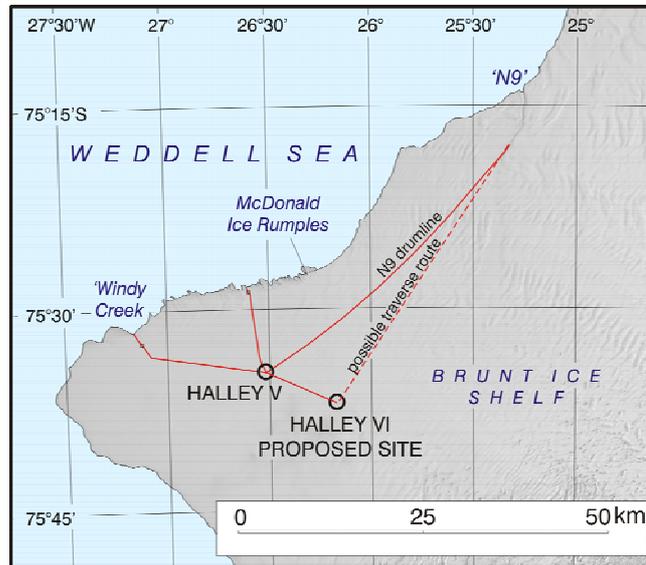
In summary, the principal activities covered by the draft CEE are the:

- construction and operation of Halley VI Research Station;
- building and operation of the temporary construction camp required for the Halley VI project; and
- transport and movement of personnel and cargo to Halley VI within the Antarctic Treaty Area.

At the time of writing of this draft CEE, the final design and technical specifications for Halley VI are still in preparation. The draft CEE, therefore, provides the overall design objectives for Halley VI, and uses data from the construction and operation of Halley V to

help determine impacts. One of BAS' major planning objectives is that the environmental effects of Halley VI will be substantially reduced compared to Halley V, and this will be taken into account during all stages of the design, construction and operation of the new station.

**Figure 5. Brunt Ice Shelf showing Halley V and the proposed location of Halley VI.**



#### 2.4 GENERAL SPECIFICATION FOR HALLEY VI

The principal general characteristics of Halley VI will be as follows:

- new accommodation and laboratory facilities for 16 people in the austral winter, and 52 people in the austral summer, which will be safe, comfortable and stimulating to live and work in;
- the design life of all the new facilities will be 20 years;
- methods of construction, operation and decommissioning will comply with, and where practical exceed, the requirements of the Environmental Protocol;
- the environmental impact of the whole station throughout all phases of its life will be kept to a minimum;
- the facilities will minimise the use of fossil fuels, and maximise the use of renewable energy where practical;
- a comprehensive waste management regime, including the treatment of human waste, will be devised and designed into the station;
- the nature of the design will allow for the replacement of individual facilities without significant interference to, or requiring the replacement of, the whole station;
- the station will be built above the snow surface, and the main buildings will be capable of being relocated by several kilometres if required;
- the facilities will be completed, commissioned and handed over to BAS by the end of 2008;

- the facilities will minimise the requirement for snow management in all aspects of the station's operation in order to reduce maintenance and minimise environmental impact from vehicle use;
- the manual handling and multiple handling of all stores and equipment will be minimised across all operations, including annual relief, normal operation and eventual decommissioning of the facilities;
- the requirement for maintenance of the facilities will be reduced and simplified (less labour/specialist trade intensive); and
- risks to Health and Safety will be minimised, and the design, planning, training and provision of equipment at the station will be carried out to ensure there are no major health or safety accidents.

Appendix 1 shows a schedule of the accommodation for the domestic, technical and science facilities planned for Halley VI Research Station.

#### **2.4.1 Halley VI staff complement**

BAS has decided to reduce the numbers of technical staff at Halley VI, both in winter and summer, compared to Halley V. This is because Halley VI is being designed to minimise building maintenance and snow management, and will therefore require less technical support. Also, BAS will make more use of automated data collection and satellite communications to reduce staff numbers.

Compared to staffing levels at Halley V in 2004/05, planned total winter numbers at Halley VI will reduce by 11% (from 18 to 16 staff) and in summer numbers will reduce by 26% (from 70 to 52 people).

### **2.5 CONSTRUCTION OF HALLEY VI**

#### **2.5.1 Construction camp**

Planning assumes that construction of Halley VI will take place during the austral summer seasons (December – February) of 2006/07 and 2007/08, with handover to BAS at the end of December 2008. At the beginning of the first season, a small team of contractors will be sent to the Halley VI site to set up a temporary construction camp, which will be required throughout the building programme. It has not been decided yet whether the contractor will winter over the construction team in 2007 and/or 2008. Dismantling and removal of the camp is planned to take place in the 2008/09 season.

The construction camp will be designed so that it can be easily erected, dismantled and removed from the site, and may comprise tented or caboose accommodation. It will operate independently of Halley V and will have its own power generation, water production system, toilet facilities, cooking and messing areas and sleeping accommodation as well as workshops and offices.

#### **2.5.2 Shipping and logistics**

The majority of the personnel and cargo needed to build Halley VI will be brought to the Brunt Ice Shelf by an ice-strengthened vessel during 2006/07 and 2007/08 seasons. Currently, Halley V is re-supplied by the BAS logistics vessel RRS *Ernest Shackleton* and BAS hopes to utilise this vessel as much as practical for the Halley VI project.

At this stage in the project, it is impossible to calculate how much spare shipping capacity there may be on RRS *Ernest Shackleton*. Only when the final design for Halley VI has been chosen in September 2005 will it be feasible to calculate accurate cargo volumes and weights, and the final numbers of people needed for the building team. BAS plans to use the most appropriate and efficient combination of the RRS *Ernest Shackleton* and a specially chartered ice-strengthened cargo/passenger vessel to build Halley VI.

BAS uses ski-equipped DHC-6 Twin Otter aircraft at Halley V to support scientific field parties and to transport personnel and light-weight cargo. The aircraft operate from a 1000x50m snow skiway. Whilst aircraft access to Halley VI will be limited, consideration will be given to moving some contractor staff by air, including making use of the Dronning Maud land Air Network (DROMLAN), where practicable and operationally sensible.

### **2.5.1 Movement of cargo and people from the supply ship to Halley VI**

Offloading of cargo and people will take place from the supply ship onto sea ice formed within a small creek or bay along the north-west coastline of the Brunt Ice Shelf, as near as practical to Halley VI. Cargo will be off-loaded onto sledges on the sea ice, and towed by tracked vehicles across the sea ice, up a prepared ramp of bulldozed snow, and onto the ice shelf. The vehicles will then follow a marked traverse route across the ice shelf to Halley VI, about 30km from the ice edge. The route to Halley VI will be via Halley V, which will provide a stopping-off point for meals and rest-periods for vehicle drivers and crew, or a refuge in bad weather or emergencies.

If a suitable creek cannot be found or a ramp cannot be bulldozed safely near to Halley VI or if the sea ice conditions are poor, then a longer resupply route from N9 (see Figure 5) will have to be used. Here cargo and people can be offloaded from the ship directly onto the ice shelf.

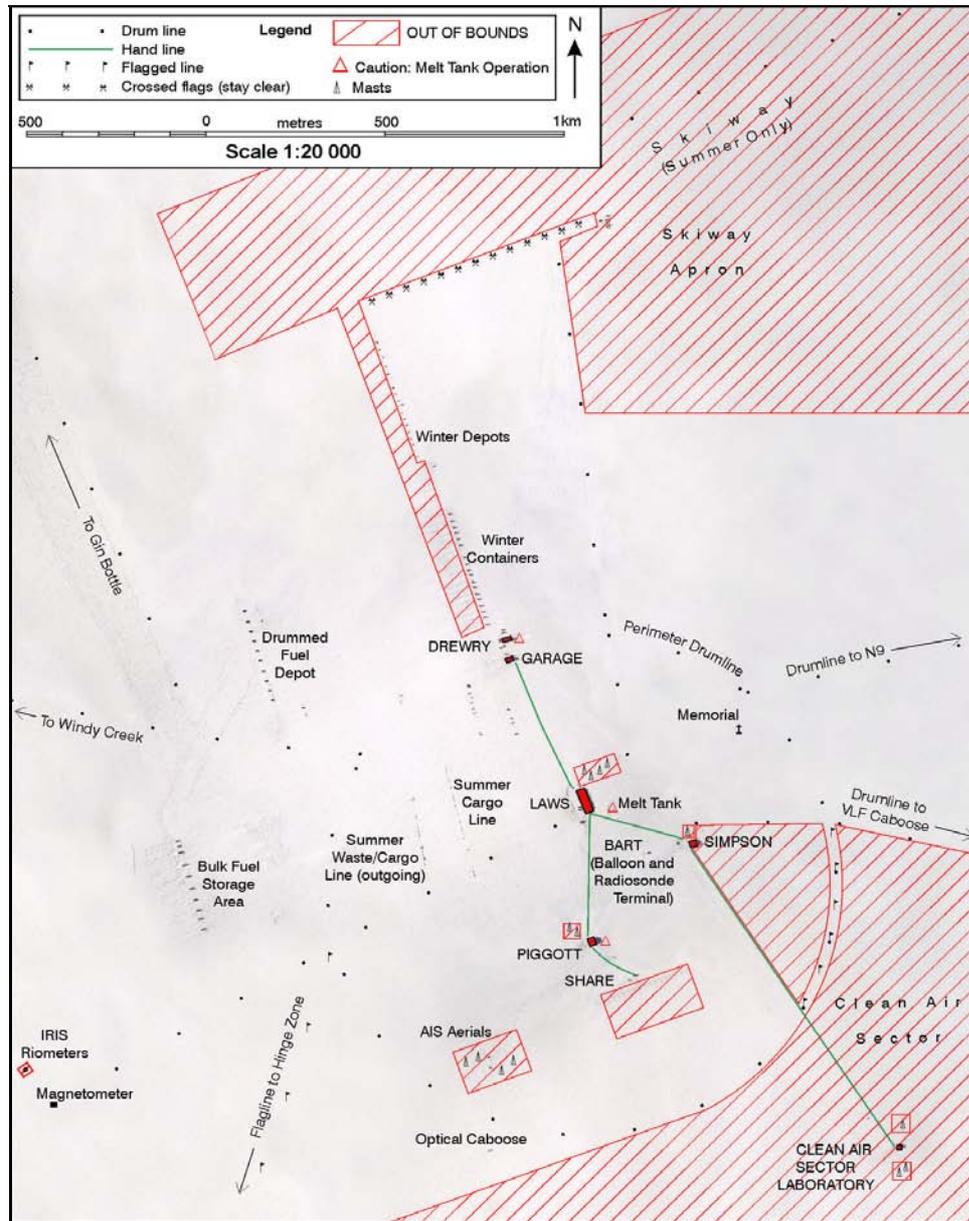
Full advantage will be taken of the 24 hour daylight available during the austral summer, which will allow cargo operations to take place around the clock.

## **2.6 AREA OF DISTURBANCE**

The area of disturbance around Halley VI will include the buildings and facilities within the station perimeter, and all outlying facilities, such as the CASLab, magnetometer tunnels, ski-way and cargo depots. Based on the experience at Halley V, this area will be about 20km<sup>2</sup>. In addition, there will be disturbance caused by the annual resupply of the station using tracked vehicles driving from the resupply ship to and from Halley VI, and the movement of limited numbers of people and small amounts of cargo to the station using the BAS DHC-6 Twin Otter aircraft.

The final layout of Halley VI has not yet been decided but it is likely to be similar to Halley V (see Figure 6).

Figure 6. Layout of Halley V Research Station.



**2.7 TIMESCALE, DURATION AND INTENSITY**

The timescale of the construction of Halley VI has been determined by the need for replacement of the existing facilities at Halley V. Research into the movement of the Brunt Ice Shelf suggests that after 2010, the portion of the ice shelf on which the current station is situated may be at an increased risk of break-off (see Section 5.3). The timetable for the construction of Halley VI is shown in Table 3. It is important to make sure the new station is built on this timescale to allow the timely removal of Halley V before any possible break-off.

**Table 3. Project timescale for construction of Halley VI research station**

<b>Stage</b>	<b>Timeframe</b>
Concept Proposals	June 2004 – December 2004
Site Visit	January 2005 – March 2005
Concept Development	January 2005 – Sept 2005
Design and Build Contract	October 2005 – December 2008
Construction Year 1	December 2006 – February 2007
Construction Year 2	December 2007 – February 2008
Transfer science equipment	December 2008 – February 2009
Site Handover	December 2008
Construction Camp Removal	By February 2009
Full operation of Halley VI	December 2009 – February 2010

The construction of Halley VI is likely to take 10–16 months, depending on whether the construction crew winters over in both 2007 and 2008. By the beginning of December 2008 all construction works should be complete at Halley VI, with all services commissioned and all fixtures, fittings and equipment installed. The new station will then be handed over to BAS, who will supply, install and commission all scientific equipment during the 2008/09 season. BAS plans to start scientific research and logistics operations at Halley VI during the 2009/10 season. BAS expects Halley VI to remain operational until 2028.

BAS plans to reduce significantly the time taken to build Halley VI compared to Halley V. Four summer seasons and one winter were required to build Halley V, whilst Halley VI is estimated to take two summers and one or two winters. This is because much of Halley VI will be pre-fabricated outside of Antarctica and will be designed for easy assembly on the ice shelf. The construction team required for Halley VI is likely to be similar in size to that used for Halley V and will be around 40–60 people.

## **2.8 DECOMMISSIONING OF HALLEY VI**

Halley VI is being designed with a 20 year intended life span, which is much longer than its predecessors. For example, Halley III and Halley IV were only operational for a decade. Near the end of its design life, Halley VI will be assessed to determine whether a refit and life extension is feasible. The station is also being designed so that it can be easily decommissioned, demolished and removed when it eventually closes. The eventual clean-up of Halley VI will be subject to an EIA.

### 3. DESIGN CONCEPTS FOR HALLEY VI

Three design concepts are currently being considered for Halley VI Research Station. They all meet the principles and requirements of the Environmental Protocol and whichever design is selected will result in substantially reduced environmental impacts compared to Halley V. Summaries of each of the three concepts provided by the design teams are given below. However, the final design chosen by BAS is likely to include ideas and characteristics from all three concepts, particularly where environmental benefits can be demonstrated.

#### 3.1 BURO HAPPOLD AND LIFSCHUTZ DAVIDSON

The Buro Happold and Lifschutz Davidson proposal for Halley VI features a series of three, two tier, independently serviced linear “icecraft” (Buro Happold and Lifschutz Davidson, 2004). The craft will be built above the surface on steel legs to limit snow drifting and wind scour (see Figure 7). Each craft is linked by bridges, which minimise travel distances and the need to go outside. The buildings can be moved around the site, and their layout can also be easily re-arranged during project planning or later after installation.

**Figure 7. Artist’s impression of Buro Happold and Lifschutz Davidson design for Halley VI.**



The craft stand above the ground on stainless steel legs with circular convex shoes that rest on the snow surface. When a craft needs to be raised, a shoe inflates itself using air bags, lifting it up out of the snow and then sets back down on a new bed of compacted snow to keep the structure at ground level. The station is mobile, temporary and light-weight. In winter, the windows in the inner layer will light up the outer fabric skin of the craft. At the ends of the craft large double-glazed apertures in the communal rooms cantilever forward.

##### 3.1.1 Architecture and sustainability

The underlying design philosophy is that the occupants can control Halley VI - a place that can be easily updated, adapted, and altered. The three craft will comprise:

- the winter accommodation and science laboratories;
- the social craft in the centre, including messing, recreation and medical facilities; and

- summer accommodation.

The summer craft can be “mothballed” during the winter period, but will be easily accessible via a bridge in case of fire or emergency.

The upper deck of each craft will be uninterrupted by structure or services, permitting flexibility in layout before and after installation. The ends of the upper deck accommodate open-plan or social spaces while the central zones contain cellular space. The lower deck provides services to the upper deck including fresh air, heating and cooling, water, power and drainage and the floor is fully accessible to facilitate changes in layout (see Figure 8).

This approach provides occupants with a choice of social and work spaces, particularly in the winter. The arrangement of cabins is predicated on the need to provide control of noise – a key requirement for privacy.

### 3.1.2 Structure and materials

#### Structural form

Each craft will have a similar structure, consisting of a rib cage of curved beams that enclose the upper deck supported on a rigid chassis. The upper deck will have a clear floor plate approximately 12m wide internally and up to 24m long depending on the configuration of modules. The ribs above the deck have a curved outer and rectangular inner profile. The lower deck is a rigid trussed box, set out in a 2.7m wide structural grid, forming the base of the craft, and its height is sufficient to accommodate service and store rooms. The structure is supported on the telescopic, adjusting steel legs.

**Figure 8.** Cross-section of icecraft



#### Building envelope

It is envisaged that the craft will be clad in an outer skin of soft translucent fabric, acting as a weather shield to keep wind and snow off the interior skin, and the two elements of cladding will provide a high level of insulation. The fabric will be a stretched white material made of

Teflon-coated glass fibre. Occasional glass or Ethylene Tetrafluoroethylene (ETFE) foil windows will puncture the outer skin, and at the ends of each craft will be larger double-glazed windows giving panoramic views in and out of the open communal areas they enclose.

The interior of the upper deck will be lined with an insulated aluminium sandwich panel erected from inside, and will have double-glazed windows that coordinate with those on the exterior. Coloured fabric bellows connect the windows in the two layers to create 'cones' of vision. In case of damage to the outer layer, the internal layer is designed to perform satisfactorily on its own.

Materials required for Halley VI will be selected for minimum environmental impact with the following objectives:

- maximum durability and use of renewable materials or materials suitable for recycling; and
- minimum use of energy in manufacture.

The craft are conceived to allow all components to be easily and separately replaced at the end of their useful lives, thus minimising unnecessary built-in obsolescence. Eventually when station components break down, they will be designed so that they can be refurbished and reused or dismantled to facilitate recycling. This will extend the useful life of the craft indefinitely.

#### Drifting of snow and ice build-up

The smooth, curved form of the craft supported above ground level on legs will reduce the wind drag and also the drifting of snow and build-up of ice. The modules will be aligned at a slight angle to the prevailing wind to further minimise snow build up.

#### Multi-functional efficiency

Each of the craft has been designed to have a number of technical, environmental and aesthetic benefits. The outer fabric cladding to the main craft, for example, provides a highly-efficient skin that:

- is quick to erect, providing a safe and sheltered construction workplace;
- reduces air leakage and heat loss from the interior skin;
- is a second-line of defence in case the inner skin is breached;
- allows solar heat/energy to be collected; and
- permits the inner skin to be altered or replaced independently, and can itself be altered and replaced.

Limiting substantial areas of glazing to the ends of the craft minimises heat losses, building costs are concentrated where they have the most benefit and the visual impact is maximised.

#### Raising and moving

The craft are set on telescopic steel legs above the ground to limit snow drifting and scour. Each leg can be lifted individually. To enable the craft to be relocated the legs will be broken free from the snow using air bags, have their elephant feet removed, and motorised, tracked wheel assemblies will be fitted for the duration of the move.

### 3.1.3 Environment and energy

#### Waste management

All requirements of Annex III of the Environmental Protocol will be followed.

The approach to managing waste at Halley VI will be to follow a four stage process of: first, reducing production of waste, then if possible reusing wastes, otherwise recover energy (preferably on-site via high temperature incineration), and finally removing minimal waste materials for final disposal outside of the Antarctic. Wastes will be segregated at source on the station to facilitate reuse and recycling.

All hazardous wastes will be separated by type, stored in approved UN dangerous goods containers or drums, and removed from the station for appropriate treatment or disposal in the UK.

Spillages will be minimised both by the use of bulk storage tanks and the storage of some oil and fuel drums in the lower storey of the craft. This will reduce the need for the annual digging-out and raising of drums from fuel depots, thus reducing the potential for spillages. The use of bulk storage will reduce the numbers of steel fuel drums needed, and any empty drums will continue to be used as waste containers or shipped out for reuse elsewhere, as they are now at Halley V.

#### Environmental impact during construction

This design has been conceived to reduce environmental impact during on site assembly by:

- minimal need for temporary construction site accommodation;
- designed for re-location with minimum use of vehicles, fuel and other consumables;
- maximise life of structure and interior equipment and furnishings;
- modular components for easy maintenance and changing the size of the station; and
- ease of transportation and installation.

An Environmental Management Plan will be developed with the building contractor(s) during the design stage to minimise environmental impact during construction works, with suitable procedures in place to ensure compliance with the Environmental Protocol (especially pollution prevention and waste management).

#### Atmospheric emissions abatement

The station has been designed to minimise energy consumption, and hence emissions to atmosphere, whilst meeting the requirements for a good level of occupant comfort and control. The design uses a three-step process to reduce dependence on fossil fuel:

##### i) Reducing energy usage

- reduction of heat loss due to the thermal skin;
- low energy-use equipment;
- use of spray water taps and grey-water recycling to reduce water consumption and thus the energy needed for snow melting;
- energy-efficient lighting, with presence detection fitted for when rooms are unoccupied; and
- effective energy usage control package via the Building Management System.

## ii) Passive environmental technologies

- good natural daylight design;
- pre-heating of air by solar radiation using the thermal skin;
- high thermal insulation using two-skin technology; and
- efficient heat recovery from ventilation systems.

## iii) Efficiency of energy generation

- maximising usage of waste heat from diesel-powered Combined Heat and Power (CHP) plant.

Electrical generation

Each craft will have its own energy generation units installed below the main inhabited space. The output from each energy generator unit will be sized electrically at a third of the total site's requirement. With two units in each craft, there is provision for run and standby within each of the craft.

During the summer months, air will be warmed by solar energy by being drawn through the thermal skin. The ventilation plant will be able to optimize between this and external air according to the environmental conditions.

Water provision, recycling and drainage

The water recycling system will substantially reduce the need for snow melting, and the drainage design will ensure effective separation of the different types of liquid wastes. Also the drainage design will:

- ensure correct gradients of fall and sizes of pipework to reflect the waste being carried;
- use trace heating of drainage pipework to allow for building to be closed down over the winter months;
- deal with contamination and spillages in a safe manner; and
- ensure separation of potential contaminants, as required.

**3.1.4 Construction and logistics**

The choice of construction methodology is guided by the constraints on transporting components and the extremely short time period available for on site assembly. The design has been developed to ensure:

- rapid enclosure to permit fit-out to commence quickly; and
- the pre-fabrication of components to minimise on-site activities.

Transportation from ship to the final site is also governed by how close the ship can get to the edge of the Brunt Ice Shelf. The choice between possible methods of delivery and assembly will depend on the capacity of the supply ship. All components will be packaged in 6-8 tonne units for safe movement across the sea ice.

Pre-fabricated components/furniture systems

Office, science and social areas are all planned on the same basis; fitted out with pre-fabricated furniture components that can easily be moved into new positions or shipped to the UK for upgrading and repair.

The scientific cabooses will be container-sized, as at present, with a purpose-designed container-handling vehicle for moving these around the base away from accumulating snow drifts. The same lifting device will handle cargo containers and bulk-storage fuel tanks.

#### Annual site activity and relief operations

The handling of stores and fuel by BAS staff in the craft will be minimised by using hoists and specially designed packaging that can fit into the lower deck.

Detailed consideration will be given to the efficient packaging of all fuel and cargo to be shipped on RRS *Ernest Shackleton* and off-loaded at the edge of the ice shelf, a constraint that varies from year to year, so the size and weight of the containers would be sized for the worst-case conditions. On the ice shelf, containers would be moved to Halley VI site in a similar manner to existing operations, or using a specially designed track-driven container handling vehicle (see Figure 9).

**Figure 9.** Artist's impression of container-handling vehicle.



#### Decommissioning the craft

Halley VI will be designed with decommissioning and deconstruction in mind to ensure that materials and components can be reused or recycled at the end of their life. The modular buildings will facilitate replacement of damaged or worn-out parts on a rolling basis.

The end of the life of the buildings will not be determined by them getting buried under the snow as they will be capable of moving. However, when they are eventually closed down and decommissioned they will be designed so that they can be towed back to the edge of the ice shelf, dismantled and loaded onto the supply ship.

### 3.2 FABERMAUNSELL AND HUGH BROUGHTON

The FaberMaunsell and Hugh Broughton design concept (see Figure 10) is based on a series of separate building modules built on skis (FaberMaunsell and Hugh Broughton, 2004). This design enables the various modules to be linked together in a variety of ways to form a station that can accommodate changing user requirements and be easily relocated. Grouped around a central living module, the accommodation, workspace and energy generation modules will form an integrated research facility designed to deal with the extreme conditions on the Brunt Ice Shelf and future science needs.

**Figure 10. Artist's impression of the FaberMaunsell and Hugh Broughton design for Halley VI.**



The station facilities have been designed around survival, maintainability and sustainability principles that will allow the station to function reliably and economically, taking full account of the requirements of the Environmental Protocol.

#### 3.2.1 Architecture and sustainability

The design has been developed in direct response to the logistic demands of the construction, operation, and annual resupply of Halley VI. To meet these demands, the design maximises flexibility and minimises the environmental impact through the adoption of a modular concept, which can suit a multitude of tasks.

The architectural solution for the station proposes a number of light-weight, semi-autonomous modular buildings, which can be plugged together in a variety of ways. The design learns from existing buildings at Halley and extracts the best aspects of each to create elevated, modular, ski-based structures, which utilise standardised structural components and a tried and tested highly sealed and insulated enclosure. Each module will be highly insulated to incorporate low energy and sustainable principles to help reduce the station's environmental impact.

The plan form of the basic module derives from a balance of structural and load criteria, the requirements for living and working space and a need for compact space planning. The resultant building plan creates a well-proportioned module with a central zone for bedrooms, offices and laboratories with smaller service zones at each end (see Figure 11). The reduction in width at each end of the modules facilitates simple, flexible and robust links between modules. Sleeping and working areas are designed to be as space efficient as possible to minimise the overall footprint on the ice, use and volume of materials, environmental impacts

of transportation and local handling. A minimised station ‘footprint’ reduces resource demands and environmental impacts of snow management.

The building modules will be raised on steel legs clear of the ground and are designed to be relocated to deal with snow accumulation and the movement of the ice shelf. The base of the legs will be supported by specially developed skis, which will enable the modules to be towed by tracked vehicles. The skis will be designed to be man-handleable and interchangeable to allow for future flexibility and mobility.

**Figure 11. Artist’s cut-away view of the inside of the main living module**



Each of the main modules will provide plug in points for other services and facilities. Services enter and leave the station through smaller core modules. These smaller modules will house power generators and waste management equipment (e.g. sewage biodigester, rubbish compactors) reducing fire risk and acoustic and vibration nuisance. Using these basic component modules it is possible to assemble them in different ways to create all of the key parts of the station whether science facilities, summer accommodation or an emergency refuge.

Some activities, such as operations and communications, eating and recreation, are central to the life of Halley VI. These will be housed in the larger, main living module. This will incorporate moveable partitions to suit the change in needs between winter and summer. At its centre will be a double height space with a hydroponics facility to introduce light, humidity and greenery to the station. The design concept promotes the use of large communal spaces as a means of improving the living space.

### 3.2.2 Structure and materials

The principle for the structural concept is to use modular units raised above the snow that can be moved on skis. Common themes for the structural design are replaceability, reliability and

robustness, whilst providing alternative solutions to overcome the re-occurring challenges of relocation and snow accumulation.

Structural support to each module can be provided by a steel spaceframe on a relatively simple layout - a regular plan grid for both top and bottom chords, with 45° diagonals between the node points. The spaceframe is therefore made of two standard components (a horizontal chord member and a diagonal) that are put together to form a very rigid, robust, but lightweight structure.

Lightweight environmentally preferable materials will be used both internally and externally (e.g. timber from sustainable sources). Materials prohibited by the Environmental Protocol will not be used. The aim would be to go beyond the Protocol by avoiding other potential contaminants, such as hazardous timber preservatives. Internal air quality will be enhanced by avoiding building materials which produce hazardous emissions, such as volatile organic compounds (VOCs).

Special attention will be given to the use of new window technology to provide a standard unit that is able to provide daylight to the spaces when available but can be easily blacked out. These windows will have high thermal performance using warm edge technology (insulated spacer bars), super low emissivity coatings and inert gas within interpane cavities to minimise heat losses.

### **3.2.3 Environment and Energy**

#### Heat and power

The overall energy balance between the heating requirement and electrical generation for the station will be the basis for the selection of the Combined Heat and Power (CHP) plant. The heating sources within the accommodation will provide the correct mix of convective and radiative heating to optimise comfort. Heat recovery on all ventilation air, with demand side control based on air quality monitoring, will keep airflows at the most energy advantageous rates.

Electric lighting is a major consumer of energy in any design, and low energy, good quality and long life lamps and luminaries will be used. Long life lamps also mean low maintenance and less waste. The use of standardised lighting components means less storage of spares and movement of parts around the site.

White goods such as washing machines, dishwashers, fridges and cookers with low energy AAA ratings will use less energy and water in use (i.e. often over 50% lower compared to machines manufactured 10 years ago). Newer computer technology using Liquid Electronic Display (LED) screens and with low energy consumption will reduce power demand within the building.

#### Water

The design will minimise the use of water providing spray and aerated taps, dual low flush toilets and low-flow showers. Grey water from washing will be used to flush toilets to further reduce water demand (see Figure 12). The use of new laundry and dishwasher machinery will also reduce water demand. Reduced water consumption means less energy needed to melt snow, less pump power to circulate the water and lower volumes of wastewater to process and dispose of. By careful design and planning it should be possible to reduce water consumption by 50% over the existing demand at Halley V.

### Waste

The design will improve on the existing management of sewage and wastewater by using biodigestion to create clean wastewater and dry solids that can be taken away from Antarctica. The supply chain will be examined to make sure that the most appropriate materials are used by the station, and that these materials can be reused or recycled at the end of their useful life. Solid wastes will be sorted for recycling and compacted to make it easy to handle and store ready for removal.

### Fuel spills

The transfer and movements of fuel at Halley VI will be reduced. The underground ‘flubber’ fuel tanks in use at Halley V will be eliminated, and instead tanks will be on the surface and will be connected to the service modules with ‘Plug and Play’ technology that will mean a reduced risk of fuel spills and therefore contamination of the ice.

### Emissions to air

The main environmental impact of Halley V is the use of fossil fuels for generating electricity and operating machinery. The design aims to minimise CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>x</sub>, and particulates emitted from plant using as clean CHP generation as possible. The aim will be to reduce the requirement for power to a minimum and then create that power with the cleanest viable technology. This will involve the use of appropriate renewable energy sources, such as photovoltaic (PV) panels on remote monitoring equipment.

### Operations manuals, staff training and energy metering

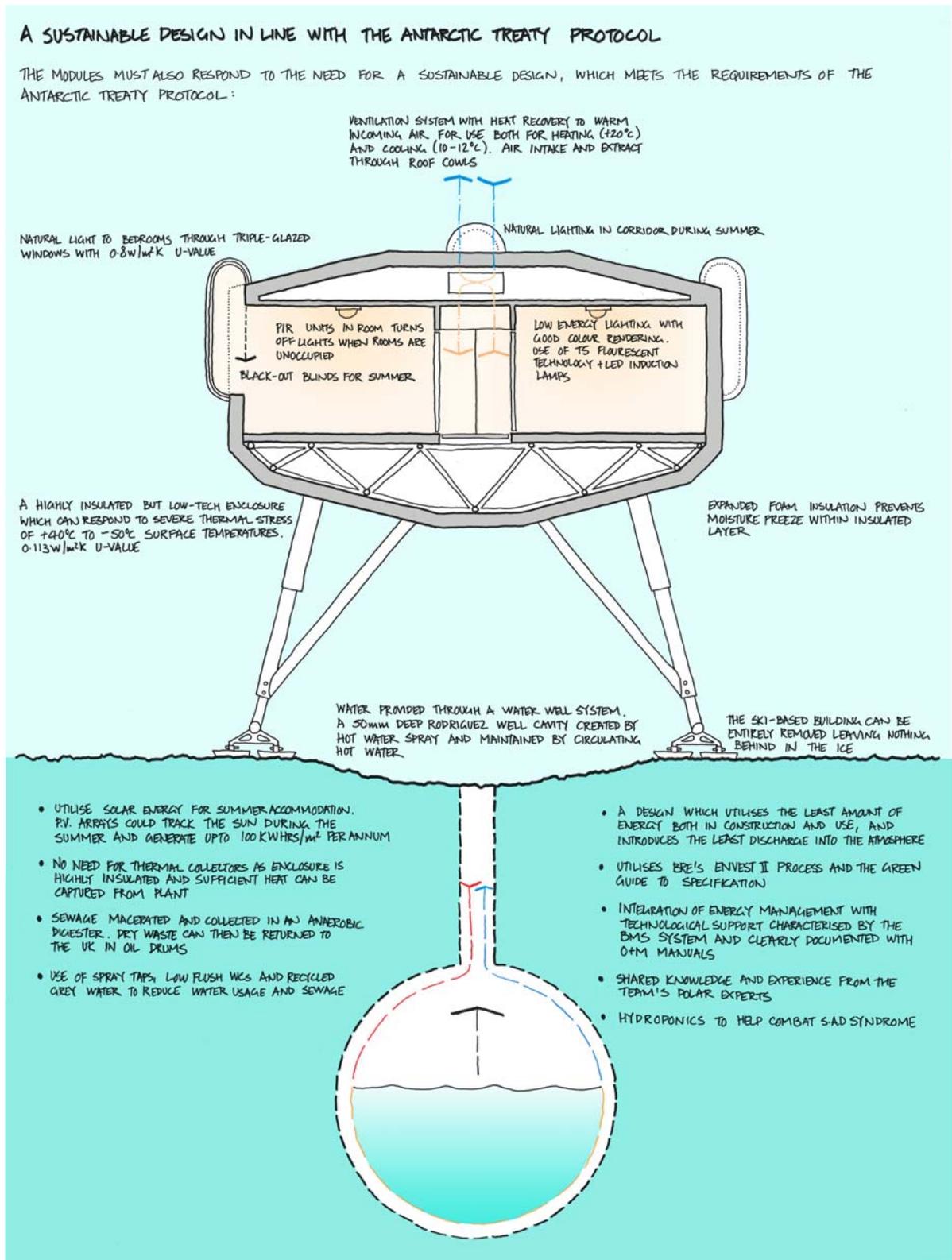
Best practice management techniques will be included in the operations and maintenance manuals provided for Halley VI. The manuals will provide staff with clear instructions on the best way to operate the facilities. The documentation will be based on previous work undertaken by FaberMaunsell and Hugh Broughton in producing handover manuals on how to operate and maintain buildings in a sustainable manner.

## **3.2.4 Construction and logistics**

Off-site prefabrication of the sub-frames for the core modules is the key to a shortened construction period in Antarctica. The small modular platforms, with space frames, legs and skis attached would be prefabricated with some flooring cladding and interstitial services installed. These platforms would then be offloaded from the resupply ship to the sea ice and then towed to the construction site. Prefabricated steel skeletal building frames would then be slotted into position and cladding panels clipped into place. Cladding will be installed with mechanical fixings to enable easy removal when the station is decommissioned. Once the outer shell has been constructed, the fit out can begin and could extend over the winter period within the protective enclosures.

The design team and contractor will work to develop a construction Environmental Management Plan to ensure that the likely environmental impacts are tightly controlled and minimised. In particular, emergency response plans, re-fuelling protocols and waste disposal procedures will be carefully drawn up with assistance from BAS, and implemented.

Figure 12. Sustainability features of station design.



The off-site prefabrication of the modules outside of Antarctica avoids construction waste, reduces the amount of construction activity on site and reduces the risk of contamination through the use of fuel, sealants and other chemicals during construction works. It is proposed that the modules are designed for deconstruction at the end of their useful life. For example, the use of mechanical fixings in preference to adhesives, the use of fixings that allow disassembly in an appropriate sequence and the generation of a decommissioning manual are all proposed. This will help to ensure that the station can be quickly and successfully decommissioned and eventually removed. This avoids the impacts of leaving whole or parts of the building in the ice.

With the building design using less energy and water than the existing Halley V there will be inherently lower amounts of solid and liquid wastes produced, as well as much lower atmospheric emissions. The situation is further improved through the use of more energy efficient equipment using reliable techniques, such as variable speed inverter drives on all fans and pumps. The whole process is further enhanced with good documentation and user manuals, and staff training that will go with the handover. The station from the outset is being designed to require the minimum of maintenance and a smaller set of spares to keep it operational.

In developing this concept the aim has been to create a highly flexible yet integrated station design which provides an ergonomic and stimulating home and workplace, an exemplar for sustainability, and a model for living in extreme environments.

### **3.3 HOPKINS/EXPEDITION/ATELIER TEN**

The concept design suggested by Hopkins/Expedition/atelier ten for Halley VI is for two walking buildings (Hopkins/Expedition/atelier ten, 2004). This is a very innovative approach to relocating the structure and has never been tried in Antarctica before. See Figure 13.

The main buildings will be constructed from transportable, purpose-designed container pods, with hydraulic legs that will allow them to step up and “walk” across the ice shelf on a regular basis. Ancillary facilities and cabooses would be located around the main buildings according to function, producing a site plan that takes into account the environmental conditions and impact, such as wind, ice movement, snow drift, atmospheric emissions, radio interference and views out of the buildings.

#### **3.3.1 Architecture and sustainability**

The structure is conceived as a pair of prefabricated modular buildings with a movement system that solves the twin problems of snow build up and the moving ice shelf by means of hydraulic legs that allow the building to walk on the ice.

The buildings form is derived from an analysis of the snow deposition characteristics on the Brunt Ice Shelf. The two-storey structure, side profile, and the curved end bays limit the disturbance effects to the wind driven snow to a minimum for the volume.

The living accommodation floor comprises communal facilities flanked at either end by two semi circles of winter bedrooms. Lobbies and the separation of the stairways ensure these areas are not disturbed by other activities. The lower floor contains the technical rooms and the additional summer accommodation. On the uppermost level at one end is the control room for the base, with a commanding view over the whole site; at the other is an upper lounge.

While potentially complex, it is thought that the hydraulic leg concept will lead to very significant operational and energy savings in practice because of the way it solves the problem of snow build up, annual levelling and routine relocation as the ice surface moves.

**Figure 13. Artist's impression of Hopkins/Expedition/atelier ten design.**



The building concept is a simple structure with a flexible interior. Recognising the harsh climate, the building components are robust, and made from easy to ship and assemble ISO standard containers, custom-designed, fitted out and prefabricated for Halley VI. Each of the walking buildings is surrounded with a “puffer jacket” of structural fabric pillows, which streamline the building aerodynamically, provide additional insulation from the external environment, but also allow views of the sky and the station. The softer form of the buildings and their ground clearance has been deliberately engineered to manage snow drifting.

The priority is to concentrate on a quality design that absolutely minimises the demand on fuel for heating, ventilation, lighting and water supply. We then consider how those resources can be most effectively delivered.

The two-storey arrangement of the structure is more energy efficient per unit area than a single storey arrangement. The reduction in surface area per unit volume gives rise to lower conduction surface and less exposure of the roof and floor. The curvature of the ends of the structure and the curved outer skin are intended to reduce structural wind effects with the associated materials demands and heat losses with the associated energy savings as well as helping snow management.

A major element of the concept design for Halley VI is that the main buildings will be able to move. Each building has steel legs, driven by hydraulic jacks, allowing them to step up over accumulating snow and walk forward. The jacks would be operated from within the building to avoid external manual operations.

### 3.3.2 Structure and materials

The structure is designed to use the minimum material and resources in the most efficient way and to be very straightforward to build. The buildings will be an assembly of ISO containers (6.1m long, 2.44m wide, and 2.9m tall). These containers will be pre-fabricated and fully fitted out before shipment to Antarctica, including bedrooms, offices, as well as service plant rooms, and the hydraulic lift systems for the legs. The buildings will have a semi-monocoque structure, similar to an egg box, to get the maximum strength with the minimum weight. The walls, ceilings and floors of the containers will double up as stiff structural plates. When bolted together the containers will become a single structure, stiffened internally using bulkheads and floor plates. The structure will be further strengthened using a lightweight steel stiffening chassis, with front and rear torsion arms to carry the hydraulic leg jacking system.

The inflated external “puffa-jacket” to the buildings is a key environmental element of the proposal. The jacket material is envisaged to incorporate a three-layer ETFE foil, and has the following benefits:

- The membrane acts as an effective barrier to eliminate infiltration through any gaps that may occur in the container structure over time. The panels provide a simple and uncomplicated way of sealing the containers together to achieve and maintain a high degree of airtightness;
- It is lightweight and easy to transport and rapid to assemble, even in the harsh conditions of Antarctica. The combination of sailboat and construction technology is robust and well tried. The membrane ‘cells’ are fixed into luff grooves (similar to sails) in lightweight extrusions on the container, which can be manufactured to be very airtight;
- It improves the overall heat transfer coefficient of the wall system (the membrane has a U-value of 1.2 W/m<sup>2</sup>K);
- Surface coatings on the ETFE system allow more sophisticated manipulation of the thermal properties of the assembly. The assembly can function as an active solar radiation absorber in the summer since ETFE has similar transmission properties to glass and will form mini ‘greenhouses’ in each cell; and
- The membrane elements are very light and easy to transport and will be designed to repetitive modular dimensions so that replacement is straightforward.

All rooms on the exterior will have small triple glazed windows with low E coatings and argon gas filled cavities that look out through membrane cells. Internally, the windows will have shutters so that in winter the summer bedrooms can be ‘closed down’ to minimise heat loss.

All entrances and exits will be designed with air locks to minimise the heat lost to the outside air. All rooms will receive a supply of fresh air from a mechanical ventilation system.

### 3.3.3 Environment and energy

#### Power generation

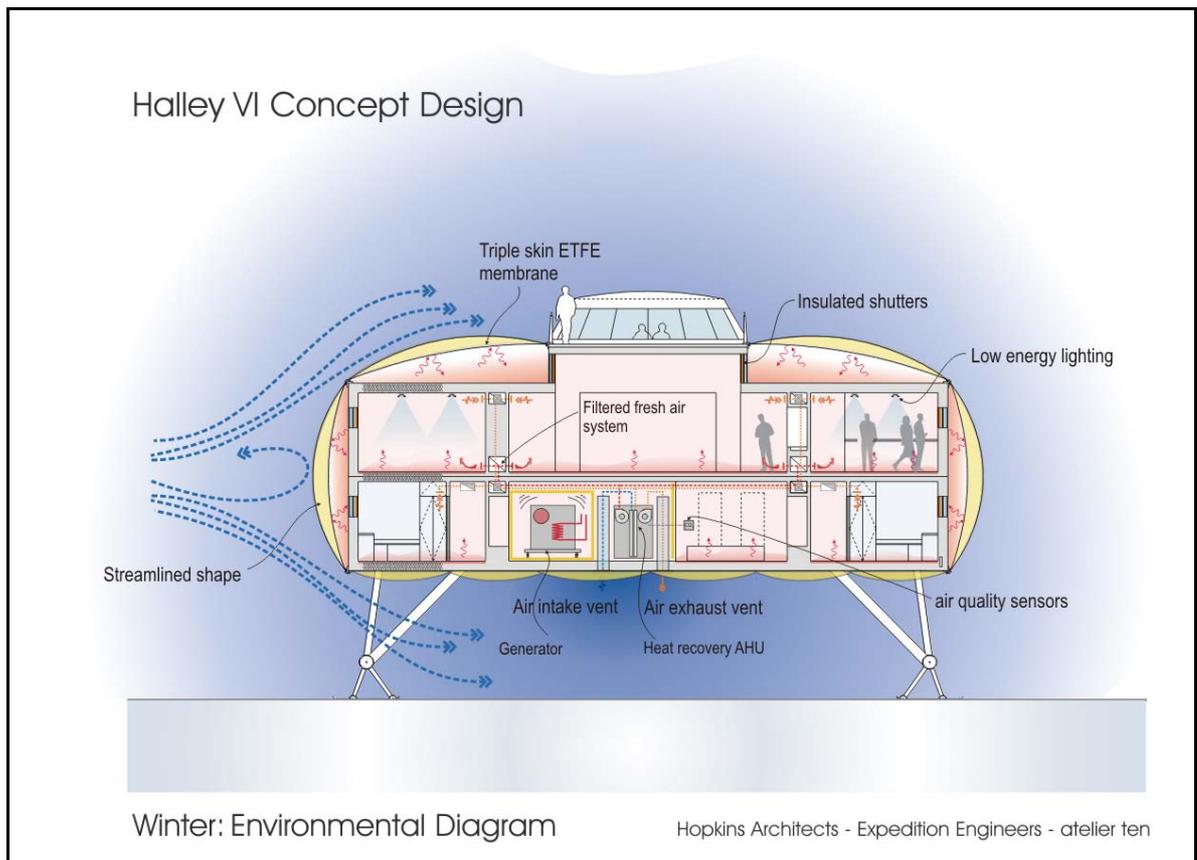
In the short term, the use of fossil fuels to power Halley VI remains inevitable but the passive measures incorporated into the design will minimise overall energy requirements to a logical minimum (see Figure 14). So the high performance design will minimise emissions from the transport of fuel to the site and from the use of the fuel itself.

The long term goal for Halley VI is a “zero CO<sub>2</sub>” facility using wind power, hydrogen generation and fuel cells to eliminate the need for fossil fuels in power generation. It is

important to realise that such renewable energy technology is in its infancy in terms of robustness. “Zero CO<sub>2</sub>” does not currently form a part of the initial proposal for Halley VI, but is a long-term aspiration of the design concept.

The aim is to produce a quality design that minimises the fuel required for heating, ventilation, lighting and water supply. Consideration can then be given to how these resources can be most effectively delivered. The two storey arrangement of the proposed structure is more energy efficient per unit area than a single storey arrangement.

**Figure 14. Artist’s cutaway drawing of station showing environmental features of design**



### Water recycling

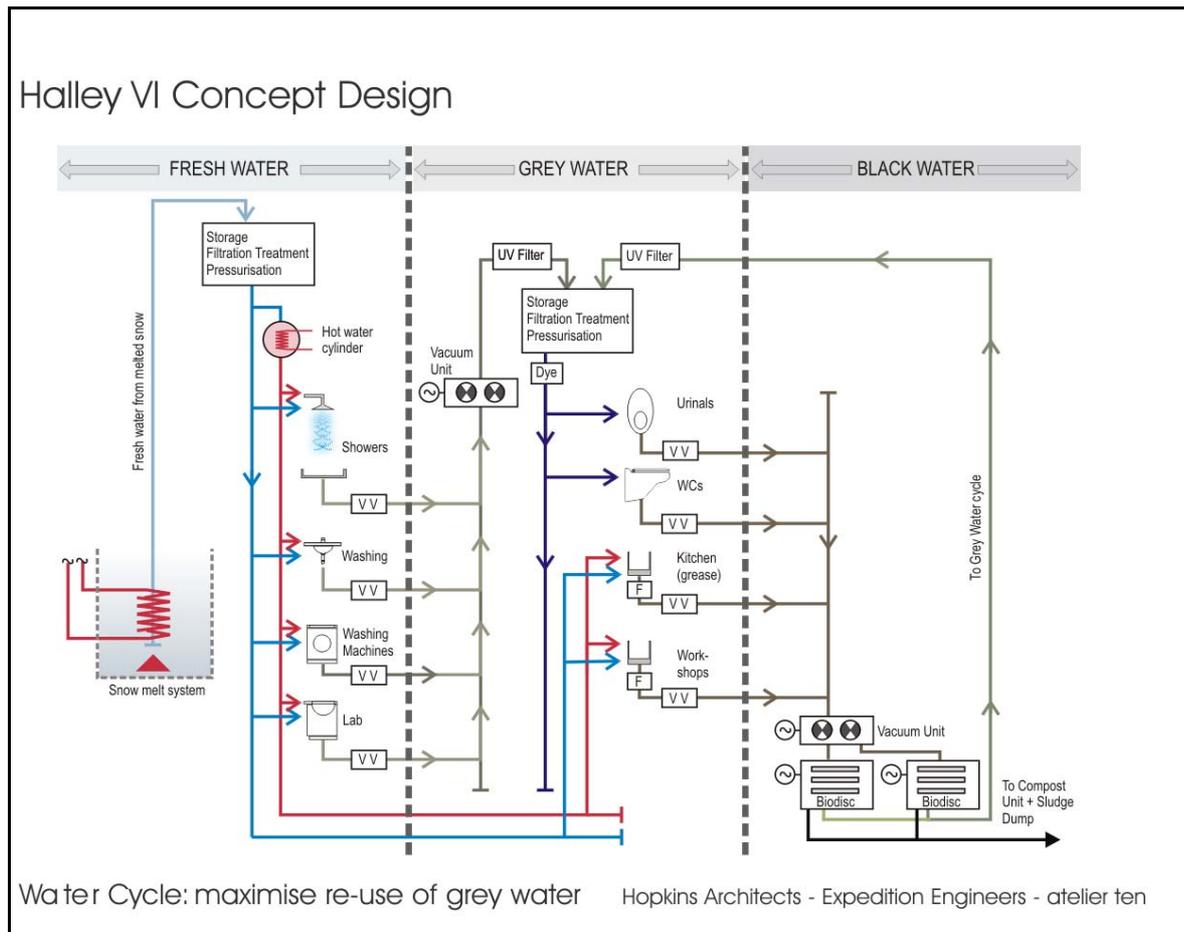
The proposed design minimises water demand, and incorporates an extensive water recycling system (see Figure 15). This is because the conversion of snow into potable water takes considerable energy and physical effort. A three-stage conservation cycle is proposed which will optimise the water use. The three stages are:

- melt water/potable water;
- grey water; and
- black water.

In most domestic environments the predominant water use is for toilet (and urinal) flushing. The proposal is to use a combination of vacuum drainage technology (familiar on planes,

boats and trains where water consumption is of similar concern) and waterless urinals to minimise the amount of black water that is produced. The vacuum drainage system has the further advantage of not requiring large diameter gravity pipework at a level beneath the lowest appliance. This greatly simplifies installation and maintenance. A vacuum toilet requires just 2 litres to flush compared to 6 litres for a conventional unit, and a vacuum toilet can be flushed with grey water.

Figure 15. Proposed water treatment and recycling system



Melt water would be used for all potable functions including showers, washing and cooking. Grey water from all uses except the kitchen and workshops are drawn through a vacuum unit via a filtration set to grey water storage tanks. Pressurised grey water will be supplied for toilet flushing and for other non potable uses. Kitchen waste will pass through a grease eliminator before passing into the black water system.

Black water from toilets and sinks will pass through Biodisc water treatment units. This treatment system produces a grey water discharge and a small amount of sludge which will require intermittent disposal by freezing and then annual removal from Antarctica. The grey water from the Biodisc will be returned to the used water storage and distribution system and will be re-cycled several times for toilet flushing and low grade wash-down operations. All grey water will be dyed to ensure that it cannot be confused with potable water. The whole process requires a limited amount of energy input to the vacuum units, the pressurisation

pumps and the Biodisc units, but estimates suggest that this is considerably less energy that that required to melt the amount of water that is saved. A 60% reduction in water usage compared to the present water cycle system at Halley V is envisaged.

#### Solid waste management

The design concept minimises the production of waste during construction and operation by reducing packaging and maximising reuse and recycling opportunities. The management of solid waste is based on a simple system of dual use metal storage containers. The containers will first be used to take supplies into the station, and then be reused to take solid waste materials (e.g. cans, card, glass) away.

#### Decommissioning

The particular ability of the buildings to step forwards and up inclines means that it can be relocated as often as necessary to ensure a long life without the need for major reconstruction. The proposal is modular in nature and can be completely removed from the Antarctic at the end of its life.

### **3.3.4 Construction and logistics**

The design concept sets out to minimise the time required for on-site construction of the station by extensive use of prefabrication and modularisation.

It is envisaged that it is possible to construct the station in one austral summer season, possibly with some commissioning during the following winter or the next austral summer. To do this it is proposed that a chartered ice-breaker be used to access the Brunt Ice Shelf very early in the summer season, and for cargo and equipment to be offloaded directly to the ice shelf at N9. New, more powerful and faster tractors, with suitable cargo sledges, would then be used to haul the containers across the ice shelf to Halley VI. The container modules will be designed to be fitted together from the inside, and will have simple “plug and play” connections. This will substantially reduce the need for outdoor construction activity.

Once Halley VI is operational, the design concept proposes a radical change in the resupply strategy for the station with all cargo being shipped in ISO containers. A “hover-barge” or similar would then be used to transport the containers across the sea ice to the ice shelf.

## **4. ALTERNATIVES TO THE PROPOSED ACTIVITY**

Five options for the future of Halley Research Station have been examined by BAS in light of environmental, logistical, engineering, and health and safety requirements.

### **4.1 DISCONTINUE SCIENTIFIC RESEARCH AT HALLEY**

This option examined whether the UK should discontinue scientific research at Halley and close down the research station. This would mean the loss of one of the most important research and long-term monitoring locations in Antarctica. It was decided that this was not an acceptable option. A variant to this option, replacing Halley V with a smaller and fully-automated station, was also considered. This was judged to be not feasible. Although BAS envisages greater automation at Halley VI, complete automation is not practical.

### **4.2 ATTEMPT TO EXTEND THE LIFE OF THE EXISTING FACILITIES AT HALLEY V**

This option examined whether the existing facilities at Halley V could be updated and the design life of the station extended. However, there is a growing risk that Halley V could be lost due to a calving event on the Brunt Ice Shelf within the next decade (see Section 5.3). Risk assessment indicates that Halley V needs to be replaced by 2010 and the facility decommissioned, demolished and removed from Antarctica before being there is a significant risk of it being lost on an iceberg.

The existing facilities at Halley V are approaching the end of their design life. The station has been operating since 1992, and was originally designed in 1986. The buildings, especially the steel platform legs, require significant maintenance. Also, the steel sub-surface tunnels, which carry services such as electrical power and sewage, are being buried deeper and deeper under the snow surface and becoming difficult to access and service. Some of the tunnels are now more than 20m beneath the snow surface. A specialist building team is required each season to replace platform legs, raise the platforms and clear snow. In addition, the main buildings at Halley V were designed and built before the Environmental Protocol.

Given these circumstances, it was decided that extending life of the facility was not a feasible option and the existing facilities cannot be used beyond 2010.

### **4.3 MOVE EXISTING FACILITIES AT HALLEY V EASTWARDS ON THE BRUNT ICE SHELF**

The third option examined was to move the existing facilities at Halley V eastwards to a safer location on the Brunt Ice Shelf, towards Coats Land.

The main buildings at Halley V are permanent structures, which are mounted on platforms kept above the snow surface by jackable legs, and were not designed to be moved. Also, the steel sub-surface tunnels are now permanently buried. It would be more cost-effective to design and build new structures than relocate the old ones.

The summer accommodation building and the garage are mounted on skis. Each building weighs about 60 tonnes and is moved several tens of metres over prepared ground each season to prevent burial by snow. They are winched forward using two tracked bulldozers. However, the buildings were not designed to be moved over any great distance (>100m), and cannot be moved to the proposed location of Halley VI. Winching, even small distances, by the

bulldozers results in considerable shaking and jarring of the buildings, and they would be very unlikely to survive the journey to Halley VI.

It was decided that this option was not feasible. However, a number of small science facilities and cabooses will be hauled by tractor or Snocat from Halley V to Halley VI.

#### 4.4 RELOCATE AND BUILD HALLEY VI AWAY FROM THE BRUNT ICE SHELF ON GROUNDED ICE AT THE LYDDAN ICE RISE

The fourth option examined was to build Halley VI away from the Brunt Ice Shelf on grounded ice at the Lyddan Ice Rise (74°25'S, 20°45'W). The Lyddan Ice Rise is located on the coast, about 200km north-east of Halley V (see Figure 16). Here the ice is grounded on rock and movement of the ice is minimal. This would make building and maintaining Halley VI much simpler. Also, because the Lyddan Ice Rise is further north, it would be easier to reach by resupply ship. It was also considered to be an acceptable alternative location for the atmospheric research and snow chemistry currently undertaken at Halley.

**Figure 16.** Satellite image showing location of Lyddan Ice Rise.



BAS carried out a major reconnaissance of the Lyddan Ice Rise during the 2002/03 and 2003/04 seasons. The site was visited by an air-supported BAS field survey party in 2003/04. The party carried out glaciological monitoring and installed an automatic weather station. In 2003/04 season, the RRS *Ernest Shackleton* also visited the Lyddan Ice Rise to investigate further the area and determine whether it was safe and practical to offload personnel and cargo.

After careful analysis of the field survey reports, BAS decided that constructing and operating Halley VI on the Lyddan Ice Rise was not practical. The RRS *Ernest Shackleton* was unable to find a safe access route from the sea ice up onto the grounded ice rise because of a series of major crevasses. Also, the safe area on top of the ice rise was small and would not have enabled the full range of scientific research to be continued. In addition, cloud cover was considered to be greater on the Lyddan Ice Rise compared to Halley and this would have also affected air operations. A further complication for air operations would be that an extra refuelling stop would have to be made by aircraft flying across from the BAS Rothera Research Station to Halley, because of the additional distance between the two.

#### **4.5 COMMISSION ALTERNATIVE DESIGNS FOR HALLEY VI AND BUILD A NEW STATION AT A SAFE LOCATION ON THE BRUNT ICE SHELF**

After looking at the above alternatives, the UK decided that the best practical option was to build Halley VI at a safe location on the Brunt Ice Shelf. This would provide world-class laboratory facilities to pursue science topics of global relevance and assure the continuation of vital long-term environmental datasets. BAS decided that the best way to design the station was to launch an international design competition together with the UK Royal Institute of British Architects (RIBA) (see Section 1.4.1).

## 5. INITIAL ENVIRONMENTAL REFERENCE STATE OF THE BRUNT ICE SHELF

### 5.1 THE BRUNT ICE SHELF

Halley VI will be located approximately 20km from the northwest coast of the Brunt Ice Shelf (75°37'S, 26°06'W; February 2005) (see Figure 17). BAS has successfully and safely operated a research station on the ice shelf for almost 50 years. The Brunt Ice Shelf is a floating ice shelf situated on the Caird Coast on the eastern edge of the Weddell Sea. It borders the coast between the Stancomb–Wills glacier tongue and the north-east end of the Dawson–Lambton glacier. The topography around the station is very flat up to the grounding line, which is around 40km southeast of the station, where the ice rises steeply to the Coats Land plateau (Wolff et al., 1998).

**Figure 17.** The seaward edge of the Brunt Ice Shelf, Caird Coast.



### 5.2 SEA ICE

The sea-ice extent in the Weddell Sea has a pronounced annual cycle and is at its minimum in February – March and maximum in September – October. Sea ice variation in the Weddell Sea is associated with the Weddell Gyre, a strong coastal current flowing from the east southward along the coast. During winter, sea ice almost completely covers the Weddell Sea, although a number of polynyas (areas of open sea surrounded by ice) form where the ice front has a north-south orientation. These polynyas may close up during periods of westerly winds. South-west of the Brunt Ice Shelf is Precious Bay, which is an area of perennial open water (Anderson, 2002). During summer, a lead, which may be several tens of kilometres wide, extends along the front of the ice shelf, and allows ice-strengthened vessels to gain access to Halley.

### 5.3 GLACIOLOGY

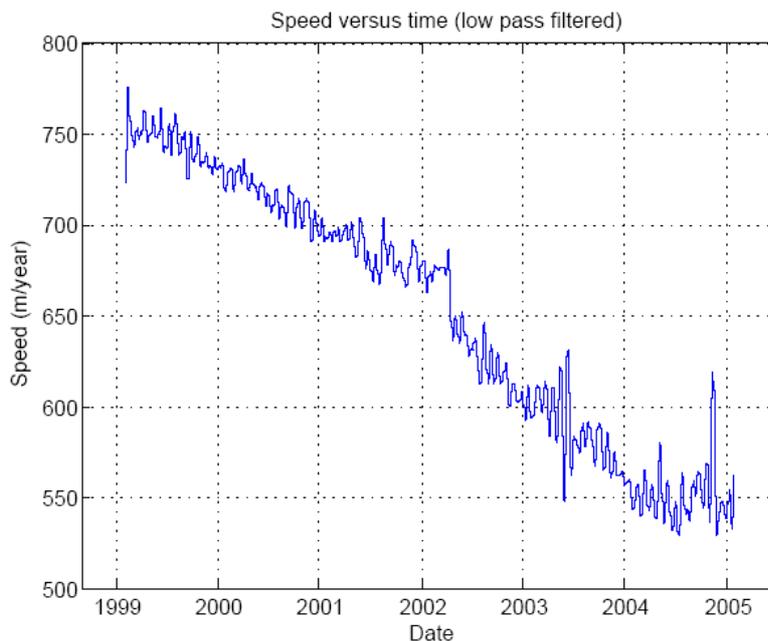
An ice shelf is the floating extension of a grounded ice sheet, composed of freshwater ice that originally fell as snow. The Brunt Ice Shelf is approximately 200m thick, and the surface of the ice shelf at Halley V is approximately 30m above sea level. The ice shelf has a flat surface and small gradient of less than 5% towards the west. There are slight undulations that increase in frequency towards the hinge zone at the Caird Coast. The ice shelf is fed by ice discharging from the Stancomb–Wills Glacier in the east and from a smaller glacier and ice sheet to the west (Hulbe et al., 2003). Most of the shelf is severely rifted, with marine ice filling the space between rift walls and around ice rafts. Approximately 20 to 30% of the Brunt Ice Shelf area is marine ice. The nearest rock exposure is 320km to the south in the Theron Mountains.

The Brunt Ice Shelf is currently moving at a rate of 550m per annum (February 2005) in a westerly direction from Coats Land towards the Weddell Sea, but is slowing down. Historically the ice shelf has displayed two velocity phases.

- 1956–70 velocity averaged approximately 380m per annum; and
- 1970–99 velocity almost doubled to 750m per annum.

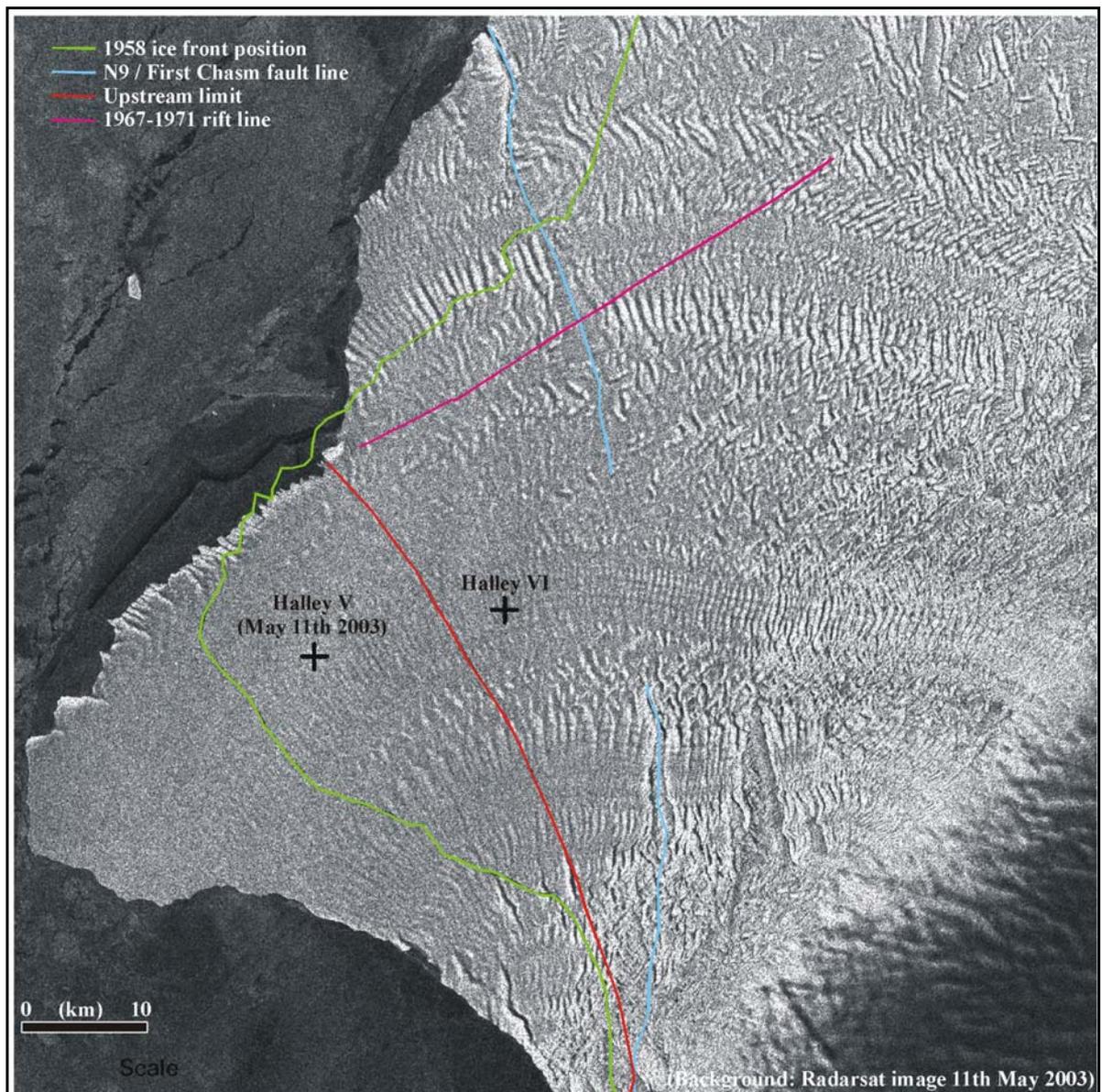
Since 1999, velocity has been decelerating at a rate of about 40m per annum as the ice shelf wraps itself around the grounded area of the McDonald Ice Rumples (Hayes, 2004). Figure 18 shows a plot of the speed of the ice shelf between 1999 and 2005. The McDonald Ice Rumples are a small zone of grounded ice at the ice front approximately 20km from Halley V. The effect of this dramatic deceleration on the stability and dynamics of the ice shelf is unknown. The ice shelf also moves vertically due to tidal displacement, and some variation in its horizontal velocity may also be attributable to tidal changes (Doake et al., 2002).

**Figure 18. Movement of Brunt Ice Shelf as measured at Halley V between 1999 and 2005.**



Periodically sections of the ice shelf calve off into the sea to form icebergs. A possible position of the calving front has been estimated using ice fronts surveyed in 1915, 1958, 1968, 1978, 1986, 1992, 1997 and 2001. The last major calving event is believed to have occurred between 1949 and 1955. The closest and most reliable ice front position to this time period is from 1958 (see Figure 19), thus providing a record of the last calving front. Once Halley reaches and passes the 1958 ice front position the risk of losing the station to calving increases significantly. Halley V is presently 8km from the 1958 ice front and at its current velocity will reach it in 14–16 years (Hayes, 2004).

**Figure 19. RADARSAT satellite image of Brunt Ice Shelf.**



The risk of losing Halley V in a major calving event results from a combination of crevasse crack extension on the ice shelf, or iceberg collision from the advancing Stancomb–Wills ice stream.

The information about the threat of calving of the Brunt Ice Shelf comes from studying three main sources of measurements and observations. Firstly, the Brunt Ice Shelf is currently at its most advanced state known implying that a calving event is imminent. Secondly, between 1967–70 a section of the ice shelf near the McDonald Ice Rumples calved and resulted in the observed increase in ice shelf velocity between 1970–99. Comparison of aerial photography from 1967 (prior to calving) and 2003 in conjunction with the decelerating velocity has revealed that conditions today are beginning to resemble those seen in 1967. This suggests that a similar calving event could be developing. Finally, upstream of Halley is ‘First Chasm’. This is a large weakness in the ice shelf that formed in response to the 1967–70 calving event. Directly opposite is a second feature called the N9 fault line. This is a faulted flow line believed to have formed in response to activity further north at the Stancomb–Wills Ice Stream.

The Stancomb–Wills glacier has been extending for the last 50 years and is currently at its most advanced state since 1915. If the front of the glacier tongue were to break off, the massive icebergs produced could collide with the front of the Brunt Ice Shelf causing a major collapse.

If a similar calving event to 1967–70 occurs and/or the Stancomb–Wills glacier breaks off, a similar amount of displacement of ‘First Chasm’ and the N9 fault line is possible. These weaknesses could potentially join across the ice shelf and result in a major calving event of the Brunt Ice Shelf.

In summary, the risk of the Brunt Ice Shelf calving is clearly increasing with time. The ice shelf is at its most advanced state since 1915 and Halley V is only 8km from the predicted position of the last calving front. There is also the risk of iceberg collision because of the advanced state of the Stancomb–Wills glacier and possible movement and growth of the N9 fault line and ‘First Chasm’. How the observed decelerating velocity and conditions near the McDonald Ice Rumples are affecting the stability and dynamics of the ice shelf are unknown. However, availability of historical survey data of the ice front position, combined with velocity measurements, satellite image analysis, and extensive Global Positioning System (GPS) monitoring will help provide the basis for both understanding the dynamics of the ice shelf and monitoring crack propagation.

#### **5.4 CLIMATE**

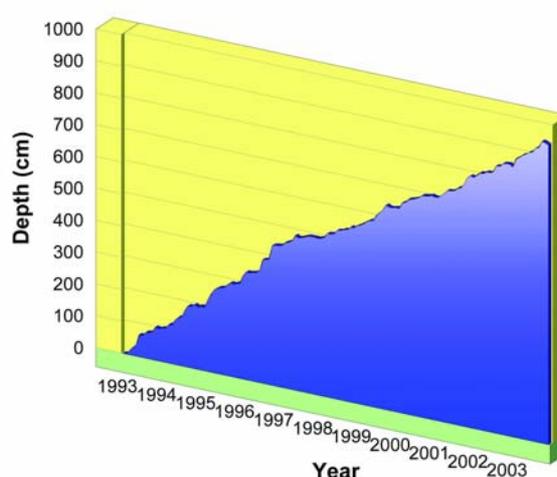
The weather in the region of the Brunt Ice Shelf is characterised by below freezing temperatures, moderate to strong winds and drifting and blowing snow. Precipitation events occur throughout the year. The sun stays permanently above the horizon from 2 November to 9 February and permanently below the horizon from 30 April to 13 August (König-Langlo et al., 1998). The average annual total sunshine is 1445 hours (34% of the maximum possible). There is total darkness for 55 days.

In mid-summer, average temperatures are around  $-5^{\circ}\text{C}$ , but in winter the monthly mean temperatures are in the region of  $-30^{\circ}\text{C}$ . Monthly mean temperatures always stay below zero, as seen in Table 4, but slightly positive temperatures may occur at times from December to February.

**Table 4. Mean monthly temperature data for Halley, based on data from 1956 to present.**

Month	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Temp (°C)	-4.6	-9.8	-16.2	-20.8	-24.7	-26.5	-28.5	-28.3	-26.3	-19.5	-11.6	-5.1

The annual snow accumulation at Halley is approximately 1m. Figure 20 shows the progressive snow accumulation at Halley between 1993 and 2003.

**Figure 20. Snow accumulation at Halley V (courtesy of RWDI Consultants)**

The prevailing wind direction is 075° (true). The secondary wind direction is 270° (true). Easterly winds occur 68.8% of the time and winds with a strong northerly or southerly component are rare (König-Langlo et al., 1998). It is calm for only 2.4% of the time. Mean annual wind speed is 7ms<sup>-1</sup>, and extreme gusts of up to 40ms<sup>-1</sup> may occur. The majority of strong and moderate winds are from the east-north-east. Moderately strong winds from the south-west also occur.

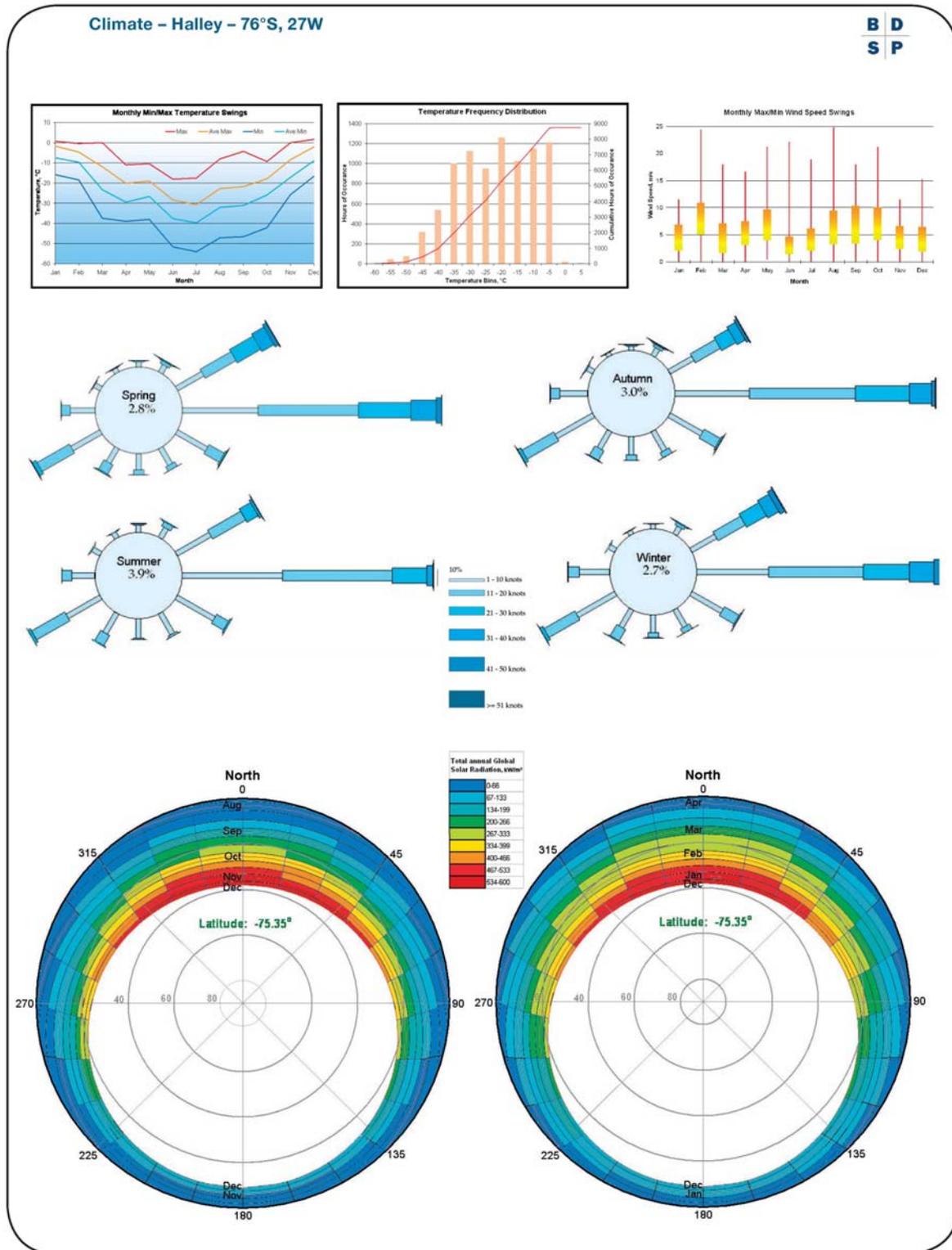
A study of data from Automatic Weather stations (AWS) on the slopes of Coats Land and the Brunt Ice Shelf indicate that there are well-defined katabatic wind flows in Coats Land. However, strong katabatic winds are rare at Halley (Renfrew and Anderson, 2002).

Weather systems move rapidly within the Brunt Ice Shelf area. The wind causes drifting or blowing snow on about 180 days each year. Rain has never been reported, but freezing drizzle may occur.

Polynyas are a significant local water vapour source and can cause super-cooled water fogs on the Brunt Ice Shelf (König-Langlo et al., 1998). Surface inversions, created by radiative cooling typical during anti-cyclonic conditions, are common at Halley.

Climate data for Halley is summarised in Figure 21 and Table 5.

Figure 21. Summary of Halley climate data (courtesy of BDSP Partnership)



**Table 5. Summary of climatic conditions at Halley.**

Annual snow accumulation	~1m
Snowfall frequency	175 days per year
Drifting/blowing snow	180 days per year
Relative humidity	30–100%
Water vapour pressure	0.05–3.0mb (mixing ratio 0.02–1.5g kg <sup>-1</sup> )
Mean annual wind speed	6.5ms <sup>-1</sup>
Extreme mean hourly wind speed	31.4ms <sup>-1</sup>
Gales	40 days per year
Maximum solar incidence angle	37.8°
Mean annual temperature	–18.5°C
Extreme maximum temperature	+4.5°C
Extreme minimum temperature	–55.3°C.
Average annual total sunshine	1445 hours (34% of maximum possible)

## 5.5 FLORA AND FAUNA

The Brunt Ice Shelf does not support any flora. There are no breeding birds or mammals at the proposed location of Halley VI, although emperor penguins (*Aptenodytes forsteri*) breed nearby at the coast. Seabirds fly over the site on their way to breeding grounds to the south, and penguins and other seabirds have been known to visit the Halley V area occasionally.

### 5.5.1 The pelagic food web

The southern area of the Weddell Sea forms a conspicuous biogeographical province known as the permanent pack-ice or coastal fast-ice zone (Knox 1994). This zone encompasses the continental shelf of the Antarctic continent and is covered for almost the entire year with pack ice or fast ice anchored to the coast and ice shelves, but also includes polynyas (Eicken 1992).

Primary production in the permanent pack-ice zone is highly variable, both spatially and temporally. Although algae can grow under sea ice, significant production is possible here only during the brief open water period. Ice conditions in the south-east Weddell Sea are highly variable from year to year, and the presence of polynyas and open leads, crucial for primary production and predator foraging, is unpredictable. This unpredictability is perhaps why most of the photosynthetically-fixed carbon sinks out of the system to the benthos rather than entering the pelagic food web.

In the coastal fast ice zone of the Weddell Sea food webs involve krill (*Euphausia superba*) and krill-dependent higher predators, but smaller grazers, including the ice krill *Euphausia crystallophias*, are probably more important. The ecosystem is also unique in the Southern Ocean because pelagic, planktivorous fish such as Antarctic silverfish (*Peuragramma*

*antarcticum*) and *Euphausia crystallorophias*, replace Antarctic krill as the staple food of some of the vertebrate higher predator species.

Squid from four different families (Onychoteuthidae, Psychroteuthidae, Neoteuthidae and Gonatidae) have been identified in the eastern Weddell Sea. The most common species is *Psychroteuthis glacialis* (Piatkowski and Pütz, 1994). Squid are a major prey species of penguins and seals.

During the break up of the sea ice in early summer, large numbers of marine mammals and sea birds migrate into the region to take advantage of these food sources.

### 5.5.2 Penguins

Emperor penguins (*Aptenodytes forsteri*) breed on the fast ice at the foot of the Brunt Ice Shelf at a location known as ‘Windy Creek’, approximately 12–15km from Halley V (see Figure 22). Even during winter, when the Weddell Sea is largely frozen, the penguins have easy access to the open sea as a polynya forms along the coastline.

**Figure 22. Emperor penguin colony at ‘Windy Creek’, Brunt Ice Shelf.**



In 1993, the colony was estimated to contain around 15,000 breeding pairs (approximately 7.5% of the global population) (Woehler, 1993), and similar numbers were recorded during counts made in the mid-1980s (14,300 and 15,700 breeding pairs; Aslin, 1986; Aslin, 1987). Emperor penguins have occasionally been sighted at Halley V.

There are around 40 emperor penguin colonies scattered around the Antarctic continent totalling c.200,000 breeding pairs (Marchant and Higgings, 1990). Colony size ranges from a few hundred to more than 20,000 pairs. Emperor penguins breed during the Antarctic winter. The male penguins incubate a single egg on their feet from May–July, while the females return to sea. The parents brood the youngsters on their feet. Chicks moult before departing in late November to early December.

Adélie penguins (*Pygoscelis adeliae*) feed in open water adjacent to the Brunt Ice Shelf during the summer months. There are no breeding colonies in the eastern Weddell Sea. Occasionally, Adélie penguins are seen at Halley V. They walk to the station and shelter in the lee of buildings to moult, before returning to the coast.

Gentoo (*Pygoscelis papua*) and chinstrap penguins (*Pygoscelis antarctica*) have also been recorded at the coast feeding in creeks close to the Brunt Ice Shelf.

### 5.5.3 Other seabirds

Other seabird species recorded in the coastal region around the Brunt Ice Shelf and at Halley V include, Antarctic petrels (*Thalassoica antarctica*), snow petrels (*Pagodroma nivea*), Wilson's storm petrels (*Oceanites oceanicus*) and South polar and Subantarctic skuas (*Catharacta maccormicki*; *Catharacta lonnbergi*) (Allan, 1983). The ice shelf offers no nesting sites for such birds as there are no nearby rock exposures, suggesting that they are feeding or flying to their breeding colonies.

### 5.5.4 Seals and whales

Weddell seals (*Leptonychotes weddellii*) are common along the sea ice, adjacent to the Brunt Ice Shelf. They come up onto the fast ice at the foot of the ice shelf in the spring to give birth to their pups in August. Pupping is complete by November (Bonner, 1989). Crabeater seals (*Lobodon carcinophagus*) and leopard seals (*Hydrurga leptonyx*) have been sighted in the water off the Brunt Ice Shelf during the summer months.

Several cetacean species have been recorded close to the Brunt Ice Shelf, including minke whales (*Balaenoptera acutorostrata*) and killer whales (*Orcinus orca*) (see Figure 23). The rare Couvier's beaked whale (*Ziphius cavirostris*) has also been sighted.

**Figure 23. Killer whales (*Orcinus orca*) in sea ice near the Brunt Ice Shelf.**



## 5.6 TOURISM

The Brunt Ice Shelf has seen little tourist activity. In 1996/97 season, one tourist visited Halley V in a Cessna aircraft operated by Adventure Network International. In December 2004, the icebreaker *Kapitan Klebnikov* visited 'Windy Creek' and 100 tourists were flown to Halley V by helicopter and were given a tour of the facilities and scientific activities.

Tourist groups also sometimes visit the emperor penguin colony at the Dawson–Lambton Glacier (76°15'S, 27°30'W) and colonies further south in the Weddell Sea.

**5.7 PROTECTED AREAS**

There are no Antarctic Specially Protected Areas or Historic Sites and Monuments in the vicinity of the proposed Halley VI station.

**5.8 HUMAN ACTIVITIES**

The nearest buildings to Halley VI are at Halley V, located approximately 20km northwest towards the coast (75°35'S, 26°39'W; February 2005). A British research station has been located on the Brunt Ice Shelf since 1956 (see Section 1.2).

There are a number of items of scientific equipment located on the Brunt Ice Shelf, remote from Halley V station. An Automatic Weather Station (AWS) has been deployed at the proposed location of Halley VI. Also, there is a network of stakes on the Brunt Ice Shelf used to mark out a GPS survey area, which is being used to assess ice shelf movement.

Two Simpson's micro barographs are located around 10km from Halley V, one on the main traverse route from the supply ship on the ice edge to Halley V and the other on the traverse route from N9 to Halley V.

**5.9 PREDICTION OF THE FUTURE ENVIRONMENTAL REFERENCE STATE IN THE ABSENCE OF HALLEY VI**

The location of the proposed Halley VI Research Station is on an ice shelf and over a period of decades the ice shelf will advance towards the Weddell Sea and eventually calve off as an iceberg and melt into the ocean. It is unlikely that any other human activity will take place at this location in the absence of the proposed activity.

## **6. IDENTIFICATION OR PREDICTION OF IMPACTS, INCLUDING PREVENTATIVE OR MITIGATING MEASURES**

### **6.1 METHODS AND DATA USED TO PREDICT IMPACTS AND MITIGATION MEASURES**

The environmental impacts of Halley VI are predicted on the basis of expert judgement, using the results of scientific research and environmental monitoring undertaken at Halley V and extensive local knowledge of the Brunt Ice Shelf. Distinction is drawn between the impact caused by the construction of the station, and the impact of operating it. Direct, indirect, cumulative and unavoidable impacts are examined. Impact matrices have been prepared (Section 6.5) to assess the predicted impacts of the construction and operation of Halley VI. Impacts are ranked according to their extent, probability, duration, intensity and significance. Reversibility and lag time of impacts are noted where applicable.

Where impacts are predicted, measures to mitigate or prevent those impacts are identified and discussed. All construction works and operational activities at Halley VI will be undertaken in compliance with the Environmental Protocol. Stringent environmental conditions will be included in the building contract for Halley VI, and will be enforced through contract supervision by BAS. Appropriate environmental education, training and guidance will be provided for all staff and contractors working at Halley VI. All activities at Halley VI will be subject to a permit issued by the UK Foreign & Commonwealth Office under the Antarctic Act (1994).

### **6.2 IMPACT OF CONSTRUCTION ACTIVITIES**

#### **6.2.1 Impact to air from construction activities**

##### Atmospheric emissions

The combustion of fossil fuels from the resupply vessel, construction camp generators, and tracked vehicles will produce carbon dioxide, carbon monoxide, hydrocarbons, nitrogen oxides, sulphur dioxide and particulates.

An unavoidable and cumulative impact of construction is predicted to arise from the operation of an ice-strengthened vessel to transport cargo, equipment and construction staff to Halley. BAS aims to use its own logistics vessel RRS *Ernest Shackleton* to support the construction work, but the volume of cargo and number of people needed to build the station will probably require an ice-strengthened cargo vessel to be chartered as well.

It is estimated that 100 days of ship time over two austral summer seasons will be needed to support the construction works at Halley VI. Data for the RRS *Ernest Shackleton* are used to estimate the likely atmospheric emissions. The average daily fuel consumption of the RRS *Ernest Shackleton* on passage to Halley since 1999 has varied significantly depending on weather and sea-ice conditions, ranging from 12.6m<sup>3</sup> per day to 18.14m<sup>3</sup> per day, although it may drop to 5.1m<sup>3</sup> per day when the vessel is stopped in ice. When tied up alongside at Halley during cargo operations, daily fuel consumption is approximately 4m<sup>3</sup>.

Assuming a total of 100 days ship time during 2006/07 and 2007/08 (60 days passage and 40 days alongside at Halley) it is estimated that 857 tonnes of CO<sub>2</sub> as carbon, 57 tonnes of NO<sub>x</sub> as NO<sub>2</sub>, and 19 tonnes of SO<sub>2</sub> will be emitted to the atmosphere (see Table 6). These gases will

quickly disperse and will not add significantly to local background levels after mixing. Approximately 1 tonne of Particulate Matter (PM) will also be emitted.

**Table 6. Predicted atmospheric emissions (CO<sub>2</sub> as carbon, NO<sub>x</sub>, SO<sub>2</sub>, PM<sub>10</sub>) generated by the RRS *Ernest Shackleton* during the construction of Halley VI.**

Estimated fuel consumption - marine gas oil (tonnes)	Type of emission	Conversion factor	Total emissions (tonnes)
1000 tonnes	CO <sub>2</sub> as carbon	0.857	857
	NO <sub>x</sub>	0.057	57
	SO <sub>2</sub>	0.019	19
	<sup>1</sup> PM <sub>10</sub>	0.00107	1.07
Conversion factors provided by the UK National Atmospheric Emissions Inventory (2002) ( <a href="http://www.naei.org.uk">www.naei.org.uk</a> ) <sup>1</sup> PM <sub>10</sub> particulate matter refers to particles produced by fuel combustion with a diameter less than or equal to 10 micrometres.			

Transporting materials, equipment and people from the resupply ship to the construction site, and the use of vehicles for construction works, will result in air pollution of very low to low significance. BAS will provide the contractor with a vehicle fleet dedicated to construction activities. This is likely to include 2 x Nodwell cranes, 6 x Snocat tractor/groomers, 3 x D5 N Caterpillar bulldozers, 1 x digger/forklift truck and 12 x snowmobiles. This plant will be for the sole use of the contractor for the duration of the construction phase, and will be handed back to BAS when Halley VI is commissioned.

Fossil fuel generators will also be used to provide power at the construction camp. The overall emissions generated by the construction works will quickly disperse, and will not effect ambient air quality. There will be some fallout of pollutants (e.g. lead and carbon) from generator and vehicle emissions which will be detectable in the local snow. As the size and type of construction camp, and the numbers of people needed to undertake the works, has not yet been decided, the amount of fuel that will be used by the generators and vehicles is not yet known. Therefore, emissions from these activities cannot be accurately predicted.

#### *Mitigating measures for impacts to air*

Whilst acknowledging that the charter market for ice-strengthened or ice-breaker cargo/passenger vessels is limited, BAS will seek to minimise the distance required to re-position the supply vessel to the Antarctic. Any vessel chartered by BAS will, where practicable, use low-sulphur Marine Gas Oil or similar. BAS will not charter vessels using heavy fuel oil. If feasible, the charter vessel will also comply with the requirements of MARPOL Annex VI (air emissions).

Vehicles and temporary generators used during construction will be maintained to high standards in order to minimise atmospheric emissions. Vehicles will not be left idling when not required. BAS may reduce emissions from its vehicle fleet at Halley by fitting catalytic converters or scrubbers to reduce engine exhausts. Solar panels have been fitted to some vehicles to trickle-charge starter batteries.

## 6.2.2 Impact to ice from construction activities

### Fuel spills

Only light refined fuels such as Marine Gas Oil, AVTUR, AVCAT and petrol will be used during the construction of Halley VI and aboard the BAS or chartered vessel. Small quantities of lubricating oils and hydraulic oils will also be used. Fuel may be transported in bulk by the supply vessel, or in UN-approved 205 litre drums. If bulk fuel is used, then it will likely be transferred from the supply vessel into specially designed 5,000 litre ski-mounted transit tanks. These will be towed to the construction site where the contents will be pumped into 20,000 litre ski-mounted bulk fuel tanks (see Figure 24).

**Figure 24.** Refuelling bulk fuel tanks at Halley V.



Fuel spills and leaks may occur during construction activities. The most likely risks include punctured fuel drums, leaks from faulty engines and splashes or overflows during the refuelling of vehicles. Such spills will likely be of less than 5 litres. The maximum spill size at the construction camp would be 20,000 litres, due to the catastrophic loss of a bulk fuel tank.

Unless recovered immediately, larger spills will be partially absorbed by surface snow, although most fuel will pass quickly through the surface layer to considerable depth (20–30m) until hard ice is reached. At this depth, fuel will remain locked within the ice for decades, until that part of the ice shelf breaks off. Once this happens, the fuel will eventually be released into the sea as the ice melts, and would rapidly disperse and evaporate.

There would be no immediate biological effect of a fuel spill or leak at the construction site. However, fuel spilled at Halley could have a serious effect on the water supply for the construction camp and station. Spills during construction could also have a delayed impact on scientific studies undertaken at Halley VI through contamination of ice cores taken for snow chemistry.

*Mitigating measures*

All reasonable steps will be taken to prevent fuel spills from occurring. If bulk fuel is used at the construction site, then fuel transfer operations will be carried out in line with the Halley Bulk Fuel Storage and Transfer Procedures (BAS, 2004c). Bulk fuel tanks used at the construction camp will be sited and designed to minimise deleterious effects of the environment, such as ice and snow build up on valves and fittings, and from accidental damage caused by operational activities such as vehicles. All fuel tanks will have secondary containment with the capacity to contain the full contents of the tank, as well as high level cut off valves to prevent overfilling. Fuel drum depots will be clearly marked and carefully managed. Drums will be handled with care to prevent ruptures.

An Oil Spill Contingency Plan will be prepared for the construction camp at Halley VI. Absorbents and fuel recovery equipment will be kept on site for immediate response to minor fuel spills, and contractors will receive training in oil spill response. Any spills will be reported immediately to the on-site Project Manager.

Waste disposal

The proposed construction activities will generate increased quantities of non-hazardous solid wastes, such as packaging materials, metal, plastic and wood. Some hazardous waste, including batteries, paints, and adhesives will also be produced. If not properly managed, waste may be scattered by the strong winds, or be buried due to snow accumulation. The construction camp will also discharge sewage and grey water.

No records are available of the quantity of waste produced during the construction of Halley V, as much of the waste was burnt on site in 1990 and early 1991. Clean plastic waste and hazardous waste, including fuels, were removed from Antarctica (Lovegrove, 1991).

Although it is not possible at this stage to accurately predict the volume of waste that will be produced at Halley VI as a direct result of construction activities, the data available indicates that it will not exceed 500m<sup>3</sup>. The majority of this waste will most likely comprise packaging materials.

*Mitigating measures*

Prefabrication of the station buildings outside Antarctica will considerably limit the volume of waste produced on site. The requirement to further reduce the quantity of waste produced to the maximum extent practicable will be included within contract specifications, enforced through project supervision by BAS, and included in Antarctic Act (1994) permit conditions

All waste, other than sewage and grey water, will be carefully packaged, labelled, secured to prevent its dispersal, and removed from Antarctica, in line with the comprehensive BAS waste management policy and procedures (BAS, 2004d). It will be reused, recycled or disposed of safely by licensed contractors.

If practicable, the construction camp will include temporary sewage treatment facilities and/or incinerating toilets. Treated dry sludge or ash will be removed from Antarctica for safe disposal.

**6.2.3 Impact to flora and fauna from construction activities**

Minor disturbance to seals and penguins may occur due to ship and cargo operations at the ice edge. Disturbance may include transitory stress to animals, resulting in a temporary increase in heart rate, metabolism and energy expenditure.

There is a small risk of the accidental introduction of non-native biota, in particular micro-organisms, because of the importation of materials and food supplies. However, it is highly unlikely that any introduced species could survive outdoors at Halley. Upton et al. (1997) examined the presence of bacteria of human origin around Halley V. The results of this study showed that although human commensals can be detected inside station buildings, contamination levels in the environment surrounding Halley were extremely low. Bacteria deposited with waste food outdoors at Halley V were shown to quickly perish.

Construction activities will result in noise pollution at the building site. However, this will be transitory and will not cause any disturbance to fauna.

#### *Mitigating measures*

All staff and contractors will be given guidance on minimising disturbance to seals, penguins and other sea-birds. To prevent the introduction of non-native species, the contractor will ensure that all equipment is cleaned, preferably by steam cleaning, before dispatch to Antarctica.

### **6.2.4 Impact to the marine environment from construction activities**

#### Waste

Operating the resupply vessel will result in the production of solid and liquid wastes, including sewage and food waste. Treated sewage and macerated food waste may be discharged overboard, as permitted under MARPOL 73/78 (Annex IV). This could result in nutrient enrichment and contamination of seawater by bacteria, heavy metals and organic pollutants.

#### *Mitigating measures*

All waste, except for treated sewage and food waste, will be stored onboard, and incinerated or discharged to appropriate port reception facilities. The RRS *Ernest Shackleton* operates an aerobic sewage treatment plant. The treated effluent is discharged overboard. During fresh water production, sewage is retained in a 40m<sup>3</sup> holding tank. In the unlikely event of a failure of the treatment plant, sewage will be discharged beyond 12 nautical miles of land or ice shelf and while the ship is proceeding at a speed of no less than 4 knots.

#### Anti-fouling paints

The loss of anti-fouling paint from the ships hull due to scraping by sea ice is an unavoidable impact. BAS vessels use antifouling paints which do not contain toxic organotin compounds.

#### Ballast water exchange

The exchange of ballast water could result in the transfer of aquatic organisms, including plankton, algae, and invertebrates, as well as pathogens. This is particularly the case in shallow coastal water, where there is generally higher species diversity. Introducing invasive marine species could have a serious and irreversible impact on marine eco-systems.

#### *Mitigating measures*

Ballast water will only be exchanged when at deep sea. Ballast water taken from South American or South Atlantic waters will be exchanged in the Scotia Sea and before arrival in Antarctic coastal waters. Ballast water taken from Antarctic coastal waters will be exchanged in the Scotia Sea before the next port of call.

### 6.2.5 Impact to aesthetic and wilderness values from construction activities

The construction site will be located on a flat and relatively featureless ice shelf, which is nevertheless of outstanding natural beauty. The construction camp and the building of Halley VI station will result in a minor and local (within line of sight) visual impact and loss of wilderness value.

#### *Mitigating measures*

The construction camp will be temporary and will be removed once Halley VI has been built.

## 6.3 IMPACT OF OPERATION

### 6.3.1 Impact to air from the operation of Halley VI

Atmospheric emissions, including carbon dioxide, carbon monoxide, nitrogen oxides, sulphur dioxide, heavy metals and particulates are identified as the main cumulative and unavoidable impact of the operation of Halley VI. Emissions will result from the use of the resupply vessels, fossil-fuel generators, tracked vehicles and DHC-6 twin Otter aircraft.

#### Resupply vessel

The BAS resupply vessel RRS *Ernest Shackleton* (see Figure 25) will visit Halley VI twice a season to bring cargo and passengers to the station, to remove waste, and pick-up returning cargo and passengers.

**Figure 25. RRS *Ernest Shackleton* unloading alongside the Brunt Ice Shelf.**



The number of day's passage to Halley, and time spent at Halley for relief, is highly variable. Allowance is made for 50 days passage and time alongside at Halley. It is estimated that the vessel will use approximately 500 tonnes of Marine Gas Oil per season supporting scientific research and logistical operations at Halley VI, as it does now at Halley V.

#### Fossil-fuel generators

Initially at Halley VI, electric power generation for domestic and scientific purposes will be provided by fossil fuel generators, running on AVTUR. This fuel type is 10% less efficient than diesel, but is a cleaner burning fuel and better suited to low temperatures.

The design specification for Halley VI aims to minimise the use of fossil fuels and maximise the use of renewable energy. However, at this stage in the design development (February 2005), the number and size of generators has yet to be determined. The current maximum power supplied at Halley V, including science equipment, is 255KVa. A total of 201,290 litres of fuel was used to power the generators at Halley in 2003/04, but BAS expects to reduce this at Halley VI.

#### Tracked vehicles

At Halley VI, vehicles will be used for general station support, including relief operations twice a year, and the possible relocation of the station by 5 to 10km every 5 years. The vehicle fleet will largely comprise the vehicles listed in Section 6.2.1. Currently, approximately 41,000 litres of fuel is used at Halley V by the vehicle fleet per annum. It is predicted that this will increase by approximately 30% to 53,000 litres per annum at Halley VI because of the increased distance between the ice edge and the new station.

#### BAS ski-equipped DHC-6 Twin Otter aircraft

The Twin Otters will be used to fly passengers and some cargo between Rothera and Halley during December – February (Figure 26). Annually, the number of flights varies considerably, with an average of seven flights to Rothera plus additional flights to support scientific field parties. Approximately 92,250 litres of AVTUR is supplied per annum for refuelling BAS Twin Otters at Halley.

**Figure 26. BAS DHC-6 Twin Otter aircraft supporting a Global Positioning System (GPS) survey**



### 6.3.2 Predicted atmospheric emissions

Based on conversion factors provided by the UK national Atmospheric Emissions Inventory, the total estimated annual emissions of CO<sub>2</sub> as carbon, NO<sub>x</sub> as NO<sub>2</sub>, SO<sub>2</sub> and Particulate Matter (PM) for Halley VI have been calculated. Total estimated emissions are shown in Table 7.

**Table 7. Predicted atmospheric emissions (CO<sub>2</sub> as carbon, NO<sub>x</sub>, SO<sub>2</sub>, PM<sub>10</sub>) from the operation of Halley VI.**

Source	Estimated fuel consumption (tonnes)	Type of emission	Conversion factor	Total emissions (tonnes)
<b>Resupply vessel (Marine Gas Oil)</b>	500	CO <sub>2</sub> as carbon	0.857	428.5
		NO <sub>x</sub>	0.057	28.5
		SO <sub>2</sub>	0.019	9.5
		PM <sub>10</sub>	0.00107	0.535
<b>Fossil fuel generators (AVTUR)</b>	170	CO <sub>2</sub> as carbon	0.859	146.03
		NO <sub>x</sub>	0.00837	1.4229
		SO <sub>2</sub>	0.00000001	0.0000017
		PM <sub>10</sub>	0.0002	0.034
<b>Twin Otter Aircraft (AVTUR)</b>	80	CO <sub>2</sub> as carbon	0.859	68.72
		NO <sub>x</sub>	0.00837	0.6696
		SO <sub>2</sub>	0.00000001	0.0000008
		PM <sub>10</sub>	0.0002	0.016
<b>Tracked vehicles (Principally AVTUR)</b>	50	CO <sub>2</sub> as carbon	0.859	42.95
		NO <sub>x</sub>	0.00837	0.4185
		SO <sub>2</sub>	0.00000001	0.0000005
		PM <sub>10</sub>	0.0002	0.01
Conversion factors provided by the UK National Atmospheric Emissions Inventory (2002) ( <a href="http://www.naei.org.uk">www.naei.org.uk</a> )				
<b>Estimated total annual emissions from Halley VI (tonnes)</b>				
CO <sub>2</sub> as carbon				686
NO <sub>x</sub> as NO <sub>2</sub>				31
SO <sub>2</sub>				10
PM <sub>10</sub>				< 1

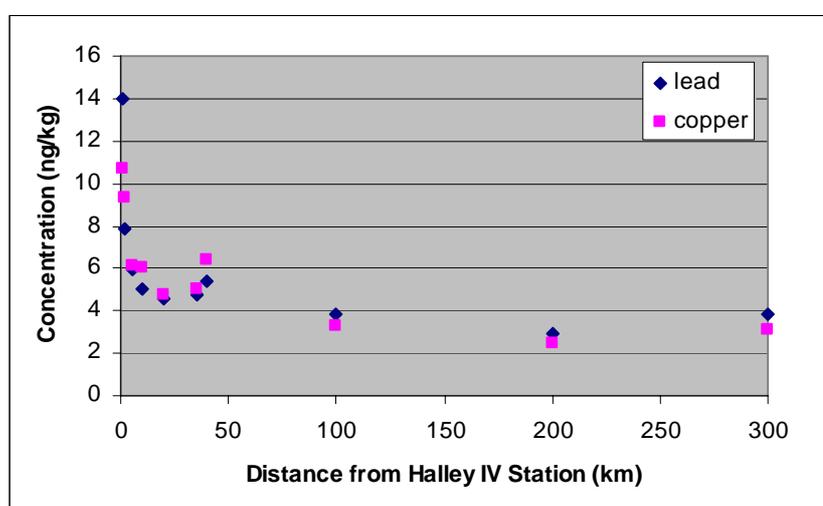
It is predicted that there will be no significant effects on ambient air quality from the combustion of fossil fuels at Halley. Levels of all pollutant gasses will remain at least three orders of magnitude below thresholds set in the Air Quality (England) Regulations 2000 and Air Quality (England) (Amendment) Regulations 2002. Emissions will generally be rapidly dispersed by the strong and regular winds.

Sampling undertaken at Halley V in 2001 showed that concentrations of sodium, chloride and sulphates in shallow ice cores collected 10m from the station generator were three times greater than background levels. By 100m, mean concentrations had reduced to near background levels, and by 1km, there was no measurable effect from the station generators (Rankin, 2004).

Larger and heavier particles, such as soot, will also have a relatively short maximum transport distance. Soot plumes are well defined and detectable in snow downwind of station generators in the Antarctic (Warren and Clarke, 1990). Background levels are expected to be reached within 2km downwind of Halley VI.

Heavy metals have been measured in surface snow samples around Halley IV and Halley V, and show contamination by lead, copper, cadmium and zinc (Suttie and Wolff, 1993). Snow samples were taken on a traverse directly inland from Halley IV over a distance of 300km. The data showed a significant decline in heavy metal concentrations with distance from the station (see Figure 27).

**Figure 27.** Surface concentrations of lead and copper ( $\text{ng kg}^{-1}$ ) from snow samples taken on Halley IV inland traverse.



Background levels of the metals in deep field samples arise from a combination of long-range natural and anthropogenic sources. Closer to the station, local emissions were detectable. Based on these results, it is possible that background levels of lead in snow surface samples would be exceeded up to a maximum of 10km downwind of Halley VI, but remain, even within the station boundary, three orders of magnitude below statutory limits in, for example, European tap water.

#### *Mitigating measures*

Maintenance standards for engines and fuel systems on board the RRS *Ernest Shackleton* are high. Careful attention is paid to fuel filtration and fuel injection systems to reduce the emission of  $\text{CO}_2$ ,  $\text{NO}_x$  and  $\text{SO}_2$ . The BAS vessel fleet also use low sulphur fuel. Whenever possible, fuel procurement specifies 0.2% sulphur content, far exceeding the requirements under MARPOL 73/78 of 4.5%. BAS vessels may run on one engine when practicable to do so, achieving between 10 to 20% reduction in fuel consumption and in atmospheric emissions.

Much of the science undertaken at Halley VI will depend on the integrity of the local air quality, and therefore minimising atmospheric pollutants will be accorded a high priority. A clean air sector will be established at Halley VI, up-wind of the station generators.

Power consumption will be monitored. All buildings and services will be designed to achieve maximum energy efficiency and minimum heat loss by the use of passive design features and

efficient generation methods for heating and power. Interior design will maximise the use of daylight. Energy saving controls will be used in the buildings and will be incorporated into the building management system. Kitchen and laundry facilities will incorporate energy saving and water efficiency measures. The water system will be designed to conserve water, recycle grey water and reduce the need for snow melting. Internal drainage systems will use gravity flow where possible.

All of the stations buildings will be sited within 2km of each other. The main science laboratory will be located within 500m of the domestic accommodation. This will minimise the dependence on vehicles, and allow staff to walk or ski to work.

The long-term aim for power generation at Halley VI is to reduce fossil fuel consumption and to maximise the use of renewable and sustainable energy sources. It is envisaged that renewable and sustainable energy will be phased in over the lifetime of the building rather than at the initial construction stage.

BAS maintains its fleet of vehicles and generators to the highest standard. Catalytic converters or scrubbers may be fitted to vehicles to reduce exhaust emissions.

Snow management and clearance at Halley V is one of the major uses of the larger tracked vehicles. It is an energy and staff intensive task. Minimising snow management is a key design requirement for Halley VI. Structures and buildings at Halley VI will, therefore, be aerodynamic in terms of shape, size, orientation and finish to reduce snow drift and wind scour. This will result in a major reduction in snow management and thus in atmospheric emissions. The requirement to prepare and groom a 1000x50m snow runway for use by the BAS DHC-6 Twin Otter aircraft will however remain unchanged.

The clean air sector at Halley will be located at least 1km upwind of the station generators and designated as vehicle-free.

### **6.3.3 Impact to ice from the operation of Halley VI**

#### Fuel spills

BAS makes every effort to prevent accidental fuel spills in Antarctica. Nevertheless, fuel spills may occur during the transfer or storage of fuel, or during the operational use of vehicles and machinery.

Less than 255,000 litres of bulk fuel (the current maximum held at Halley V) will be stored at Halley VI. Fuel will be stored in 20,000 litre steel fuel tanks. Between 100,000 and 200,000 litres of drummed fuel will also be stored on the station for use by vehicles and aircraft. Table 8 contains a risk assessment for a range of possible spill sizes at Halley VI.

Since 1999, 23 minor fuel spills have been reported at Halley, resulting in a total of 600 litres of spilled fuel and lubes. It is estimated that at least 150 litres, or 25%, was recovered. The largest quantity of fuel spilled was 205 litres (on two occasions from pinhole leaks in fuel drums). 16 spills were less than 10 litres, and 5 spills were between 10–100 litres. Most spills were of AVTUR, but antifreeze/AVTUR mix, oil and petrol have also been spilled.

#### *Mitigating measures*

The fuel system used at Halley VI will be designed to minimise the multiple handling of fuel and reduce the risk of potential leaks and spills. Bulk fuel tanks will be sited and designed to minimise deleterious effects of the environment, such as ice build up on valves and fittings, and from accidental damage by operational activities. All fuel tanks will have secondary

containment with the capacity to hold the full contents of the tank, as well as high level cut off valves to prevent overfilling.

**Table 8. Risk assessment for fuel spill scenarios at Halley VI**

Type of Spill	Probability	Maximum Spill Size (litres)	Fuel Type
Collision or grounding of BAS vessel at ice shelf	Very low	1,000,000	MGO, AVTUR and other petroleum products
Catastrophic failure of a bulk fuel tank	Low	20,000	AVTUR
Loss of transit tank through sea ice	Medium	5000	AVTUR
Rupture/overflow of day tank	Medium	< 4000	AVTUR
Rupture /overflow of boiler tank	Medium	< 2000	AVTUR
Rupture/overflow of waste oil tank	Medium	< 2000	Waste oil and lubes
Pipeline break or leak during refuelling (ship to transit tank)	Medium	1000	AVTUR
Damaged drum during drum raising	High	205	AVTUR
Oil/fuel leak from generator	High	40	AVTUR/ Lubricating Oil
During refuelling (vehicles or aircraft) minor spills may occur from drums or bowser	High	5	AVTUR Petrol Lubricating Oil

Equipment will be of the highest standard to prevent spills. All fuel hoses will as a minimum be double wall  $-42^{\circ}\text{C}$  aviation hose. Fuel pumps will incorporate nitrile rubber seals, and will be located within heated buildings. Only dry-break fuel hose fittings, made of brass or copper, will be used for bulk fuel transfer. Fuel valves will incorporate soft metal seats suitable for cold temperatures to  $-40^{\circ}\text{C}$ . All fuel transfer and storage equipment will be rigorously tested before acceptance by BAS.

All staff involved in refuelling operations will be provided with appropriate training and documented procedures. An Oil Spill Contingency Plan will be prepared for Halley VI similar to that for Halley V (Downie and Shears, 2003). Absorbents and oil spill clean up equipment will be provided. Staff at Halley will carry out regular oil spill response exercises during summer and winter. BAS will also undertake regular audits of its fuel handling and spill response procedures.

Waste

Hazardous and non-hazardous solid and liquid waste will be produced during the operation of Halley VI. If not properly stored and managed, waste may be scattered by the strong winds or become buried under snow.

Table 9 shows the total quantity of waste removed from Halley V since 1998/99. Figure 28 shows waste being taken by a Snocat and sledge from Halley V to the resupply ship.

During the 2002/03 season at Halley V, a total of 811m<sup>3</sup> of waste was removed, of which 648m<sup>3</sup> (79.9%) was reused or recycled. A total of 3000 uncrushed drums (more than 600m<sup>3</sup>) were shipped out for reuse. Also, several redundant cabooses were removed. Together, they comprised the majority of the wastes. A further 850m<sup>3</sup> of grey water/sewage was discharged to a deep ice pit and 20m<sup>3</sup> of food waste was discharged to a shallow snow hole.

BAS will continue to release some scientific equipment to the environment from Halley VI, which will not be retrieved. This includes approximately 400 meteorological balloons per annum, which are flown according to standard World Meteorological Organisation (WMO) procedures. Attached to the balloons are small cardboard packages, containing an electronic circuit board and wet cell battery. These may land up to 150km from Halley, in the sea or on the ice shelf. When the balloons burst, small quantities of helium are released to the atmosphere.

**Table 9. Total wastes (m<sup>3</sup>) removed from Halley V (1998/99 to 2002/03).**

	1998/99	1999/2000	2000/01	2001/02 <sup>1</sup>	2002/03 <sup>2</sup>
<b>Hazardous waste (m<sup>3</sup>)</b>	6.40	4.42	1.29	0.00	6.39
<b>Fuels and lubes</b>	3.28	1.85	4.10	0.00	3.47
<b>Non-hazardous waste</b>	227.18	263.77	258.91	61.30	801.15
<b>Total (m<sup>3</sup>)</b>	236.86	270.04	264.30	61.30	811.01

Source: Foreign & Commonwealth Office. Antarctic Treaty Exchange of Information under Article VII (5) – United Kingdom. Reports 1998/99–2002/03.

<sup>1</sup>In 2001/02, BAS discontinued crushing drums for disposal. They are now sent out intact from Halley for reuse.

<sup>2</sup>This figure includes the waste from 2001/02 season, which was not removed because the ship did not reach Halley due to exceptionally heavy ice conditions. In 2003/04, poor ice conditions again hampered the removal of waste, which has been depoted at Halley for safe removal in 2004/05.

Magnetometer and riometer tunnels will be required at Halley VI for scientific research. The wood and steel used to support the access shafts and tunnels will be left in place when the station is relocated, as they will be buried deep in the snow and therefore unsafe to remove. Other material which will be left buried in the snow will include the foundations and lower sections of aerial arrays and electric cables.

*Mitigating Measures*

A comprehensive waste management system will be included as part of the design of Halley VI. The system will comply with the Environmental Protocol, be as energy and manpower efficient as possible, whilst having the minimum practical impact on the environment. Wastes will be managed according to the BAS Waste Management Handbook (BAS, 2004d). Staff will be provided with appropriate training and guidance on waste management. All waste, other than sewage and grey water, will be separated at source, compacted where possible to reduce its volume, and removed from Halley VI for reuse, recycling or safe disposal. Sewage

and grey water will be treated. Solid treated sludge will be removed from Antarctica for safe disposal. Treated grey water will be sterilised and discharged to the ice.

**Figure 28. Waste removal from Halley V to the resupply ship using Snocat and sledge.**



Given the predicted decrease in station population (Section 2.4.1) and a reduction in the quantity of drummed fuel by several thousand drums per annum, it is envisaged that the total volume of waste removed from Halley VI each year will be significantly less than that removed from Halley V. BAS has also already introduced a number of measures to decrease the volume of waste produced at Halley, including reusable packing crates and packaging materials, and purchasing food supplies in larger catering-sized packs.

#### **6.3.4 Impact to marine environment from the operation of Halley VI**

The impact to the marine environment from the operation of Halley VI is predicted to be no different to the impact from construction activities. See Section 6.2.4.

#### **6.3.5 Impact to science from the operation of Halley VI**

##### Light pollution

Local light pollution at Halley may disrupt the observation of the aurora, airglow and other upper atmospheric phenomena. It can also impede cloud observations at night. Light pollution generally reduces the quality of such observations, and is particularly noticeable in marginal conditions, when observation without local light pollution would be difficult but possible. Marginal conditions for airglow observations include broken cloud or drifting snow, which act to scatter light.

##### *Mitigating Measures*

External lighting will be designed to minimise light pollution, without compromising the safety of the staff working at Halley VI. Low-pressure sodium lighting will be used where

possible, as it can be filtered out from astronomic observations of the night sky. Light casings will prevent the emission of light above the horizontal.

#### Disturbance to electromagnetic observations

Science instruments at Halley make observations in the following regions of the electromagnetic wave spectrum:

VLF:	1 Hz to 30 kHz
HF:	100 kHz to 30 MHz
VHF:	38 MHz
Microwave:	~ 225 GHz

All of these wavebands require the quietest possible site conditions. Indeed, some of these observations (e.g. VLF) can only be made in remote parts of the world. At Halley, measurements are also made of the Earth's magnetic field, where the highest frequency component measured is likely to be 10Hz.

Sources affecting the science equipment may include the mains power generation (and long power supply lines running across the base site) and plant control equipment (e.g. electrical motor speed controllers, particularly those involving thyristors).

Any of the science instruments, and particularly those with sensors mounted outside, could also be vulnerable to strong radio signals. Sources of such signals include science radars and HF communication systems.

#### *Mitigation measures*

Careful site planning and zoning of activities at Halley VI will minimise the impact of the station on electromagnetic science observations. As a minimum, all electrical equipment installed at Halley VI will meet the European EMC (Electromagnetic Compatibility) standards.

The most sensitive electromagnetic measurements (e.g. VLF and Riometers at 38MHz) can only be made by moving the sensors 1–2km away from the station infrastructure, and in the case of VLF (which is very susceptible to harmonics from mains power) by not running any mains power to the antenna site. Magnetic field measurements are also made at between 1–2km away from the station, and vehicles banned from the area except for essential maintenance activities. This is to prevent large pieces of metal from disturbing the magnetic measurements.

#### Disturbance to meteorological measurements of the boundary layer

At Halley meteorological measurements are made of the boundary layer between the atmosphere and snow interface.

#### *Mitigation measures*

No structures or vehicles will be allowed upwind or within the measurement area. This will prevent disturbance to the snow surface and stop snow drifts.

### **6.3.6 Disturbance to flora and fauna from the operation of Halley VI**

The site of Halley VI supports no flora or breeding fauna, and therefore has no biological significance.

Emperor penguin colony

Occasional recreational visits are made by small groups of BAS staff (usually a minimum of 4 people) to the breeding colony of emperor penguins at ‘Windy Creek’, approximately 15km from Halley V. Such visits will continue for staff working at Halley VI.

*Mitigating measures*

All BAS staff and visitors are issued with the BAS Handbook (BAS, 2004e). This contains guidance on preventing disturbance to wildlife, which is based on ‘Guidance for Visitors to the Antarctic’, Recommendation XVIII-1, adopted at the XVIII ATCM (1994). BAS will prepare site specific guidelines for the occasional visit made by Halley VI staff to the emperor penguin colony at ‘Windy Creek’. The guidelines will include advice on avoiding disturbance to the breeding birds.

**6.3.7 Impact to aesthetic and wilderness values from the operation of Halley VI**

The station will be located on a flat and relatively featureless ice shelf, which is nevertheless of outstanding natural beauty. This will result in a minor and local loss (within line of sight) of wilderness value on that part of the Brunt Ice Shelf.

*Mitigating measures*

The design of the station is to be aesthetically stimulating and sympathetic to its surroundings on the Brunt Ice Shelf.

**6.4 CUMULATIVE IMPACTS**

The only significant cumulative impacts associated with the construction and operation of Halley VI are predicted to be atmospheric emissions, which are detailed in Section 6.2.1 and Section 6.3.1.

**6.5 IMPACT MATRICES**

Table 10 and Table 11 summarise the environmental impacts of the construction and operation activities. The output and resulting environmental impact of each activity is identified. The probability, extent, duration and significance of these impacts are then ranked according to the criteria below, and finally measures that BAS will put in place to mitigate or prevent those impacts from occurring are shown.

Criteria for ranking impacts are as follows:

<b>Probability</b>	Unlikely	
	Low	
	Medium	
	High	
	Certain	
<b>Extent</b>	Area -specific	Small area within construction camp, at location of Halley VI , ice edge, or on traverse route between ice edge and Halley VI
	Local	Construction camp, location of Halley VI , ice edge or traverse route between ice edge and Halley VI
	Regional	Brunt Ice Shelf, including coastal area

	Continental	Antarctica and Southern Ocean south of 60°S
	Global	Earth and atmosphere
<b>Duration</b>	Very short	Minutes to days
	Short	Weeks to months
	Medium	Years
	Long	Decades
	Very Long	Centuries to millennia
<b>Significance</b>	Very low	Ecosystems or natural processes or scientific research not affected
	Low	Changes to ecosystems or natural processes or scientific research are less than minor or transitory
	Medium	Changes to ecosystems or natural processes or scientific research are minor or transitory
	High	Changes to ecosystems or natural processes or scientific research are greater than minor or transitory
	Very high	Major changes to ecosystem or natural processes or scientific research are significant and irreversible

**Table 10. Impact Matrix – Construction activities at Halley VI.**

Activity	Output	Predicted Impact	Probability	Extent	Duration	Significance/ Severity	Mitigating or Preventative Measure
Shipping and cargo handling at ice edge	Atmospheric emissions	Minor but cumulative contribution to local and global atmospheric pollution including greenhouse gas emissions.  Local fallout of particulates and heavy metals.	Certain	Local to global	Long	Very Low to Low	Minimise distance required to re-position supply vessel to Antarctica.  Light refined fuel (e.g. MGO) with low-sulphur content to be used if practicable. Ships engines maintained to highest standards with fuel filtration and fuel injection systems to reduce emissions if practicable.  When practicable, resupply vessel to operate on one engine only to reduce emissions.
	Minor and transitory disturbance to non-nesting penguins and seals at ice edge	Increased energy expenditure.	High	Area-specific	Very Short	Very Low	All staff and contractors to be briefed on minimising disturbance to fauna.
	Release of anti-fouling paint from ships hull to marine environment.	Toxic to marine organisms.	Certain	Area-specific (ship route in Weddell Sea)	Short	Very low	Use of antifouling paints on ships hull which do not contain organotin compounds.
	Solid and liquid waste, including sewage, grey water and food waste.	Introduction of faecal bacteria.  Nutrient –enrichment and contamination of sea water by heavy metals and organic pollutants.	Certain	Area-specific (ship route in Weddell Sea)	Short	Very Low	All wastes to be managed in accordance with BAS Waste Management Handbook. Most waste stored on-board for discharge at Port Reception Facilities.  Food waste is macerated before discharge to sea.  Sewage treated aboard supply vessel and effluent discharged at sea.

Activity	Output	Predicted Impact	Probability	Extent	Duration	Significance/Severity	Mitigating or Preventative Measure
	Ballast water discharge	Transfer of non-native species. Invasive species may alter local ecosystem.	Low	Local	Long (if non-native species survives and breeds)	Very Low (if no survivors)  High (if breeds, but low probability)	Exchange of ballast water to be undertaken at deep sea locations only.  BAS Ballast Water Management Plan to be followed.
Use of vehicles and generators	Atmospheric emissions	Minor but cumulative contribution to atmospheric pollution including greenhouse gas emissions.  Local fallout of particulates.	Certain	Local to global	Very Long	Very Low to Low	Maintain vehicles and generators to highest standards.  Catalytic converters or exhaust scrubbers may be fitted to vehicle engines.  Vehicles not be left idling unnecessarily.
	Minor fuel spills during refuelling and vehicle/generator operation	Contamination of snow. Possible indirect impact on science.  Possible indirect impact on construction camp or station water supply.	High	Area-specific	Long (approx. 50 year lag time before release to sea)	Very Low	Due care and attention when refuelling, reinforced through training and documented procedures.  Fuel transfer and storage equipment to be maintained to highest possible standards.  Absorbents and response equipment to be kept on site. Some spilled fuel may be absorbed by snow surface and recovered.  Oil Spill Contingency Plan to be prepared for construction site.
General construction activities	Increased quantity of solid and liquid waste (including sewage and grey water)	Contamination of snow	Certain	Local	Medium  High for grey water	Very Low	Site to be checked for litter at end of every day.  All waste to be removed from Antarctica for re-use, recycling or safe disposal.  If practicable, sewage to be treated or incinerated on site. Solid residue or ash to be removed from Antarctica.
	Construction camp	Loss of wilderness value	Certain	Local	Medium	Very low	Construction camp will be decommissioned and removed from Antarctica.

**Table 11. Impact Matrix – Operational activities at Halley VI.**

Activity	Output	Predicted Impact	Probability	Extent	Duration	Significance/ Severity	Mitigating or Preventative Measure
Shipping and cargo handling at ice edge	Atmospheric emissions	Minor but cumulative contribution to atmospheric pollution including greenhouse gas emissions.  Local fallout of particulates and heavy metals.	Certain	Local to global	Very Long	Low	Light refined fuel (e.g. MGO ) with low-sulphur content to be used if practicable.  Ships engines maintained to highest standards. Fuel filtration and fuel injection systems to reduce emissions.  When practicable, resupply vessel to operate on one engine only to reduce emissions.
	Disturbance to non-nesting penguins and seals at ice edge	Increased energy expenditure	High	Area-specific	Very Short	Very Low	All staff briefed on minimising disturbance to fauna.
	Release of anti-fouling paint from ships hull to marine environment.	Toxic to marine organisms	Certain	Area-specific (ship route in Weddell Sea)	Short	Very Low	Use of antifouling paints on ships hull which do not contain organotin compounds.
	Solid and liquid waste, including sewage	Introduction of faecal bacteria  Nutrient –enrichment and contamination of sea water by heavy metals and organic pollutants from sewage.	Certain	Area-specific (ship route in Weddell Sea)	Short	Very low	All wastes to be managed in accordance with BAS Waste Management Handbook. Most waste stored on-board for discharge at Port Reception Facilities.  Food waste macerated before discharged to sea.  Sewage treated aboard supply vessel and effluent discharged at sea.
	Ballast water discharge	Transfer of non-native species	Low	Local	Long (if non-native species survives and breeds)	Very Low (if no survivors) High (if breeds)	Exchange of ballast water to be undertaken at deep sea locations only.  BAS Ballast Water Management Plan to be followed.
Bulk fuel transfer and storage	Fuel spills of > 205 litre	Snow contamination.  Atmospheric pollution	High (small spills)	Area-specific	Long (approx. 50 year lag time)	Very Low (small spills)	Fuel system designed and located to minimise risk of spills.

Activity	Output	Predicted Impact	Probability	Extent	Duration	Significance/Severity	Mitigating or Preventative Measure
	Maximum spill size 20,000 litre	<p>due to volatilisation</p> <p>No immediate biological impact but possible delayed impact to marine environment</p> <p>Possible indirect impact on science.</p> <p>Possible indirect impact on station water supply.</p>	Unlikely (large spills) >1000 litres		before release to sea)	Medium (large spills >1000 litres)	<p>Equipment and fuel tanks to be maintained to highest standards.</p> <p>Staff trained in refuelling procedures, and spill response.</p> <p>Production of Halley VI Oil Spill Contingency Plan.</p> <p>Some spilled fuel may be absorbed by snow and cleaned up. Absorbents and response equipment to be kept on site.</p>
Use of vehicles and station generators	Atmospheric emissions	<p>Minor but cumulative contribution to local and global atmospheric pollution including greenhouse gas emissions</p> <p>Local fallout of particulates and heavy metals.</p> <p>Possible direct impact of pollution on science.</p>	Certain	Local to global	Very Long	Medium (if affects operation of CASLab research)	<p>Implement a range of energy efficiency measures (e.g. use of passive design features and efficient power generation).</p> <p>Consideration to be given to fitting catalytic converters or scrubbers to BAS vehicle fleet.</p> <p>Maintain vehicles and generators to highest standards.</p> <p>Vehicles not be left idling unnecessarily.</p> <p>If practical, install renewable energy systems (e.g. solar, wind) to reduce use of fossil fuels by station generators.</p> <p>Site CASLab in sector minimally impacted by emissions from main station facilities.</p>
	Minor fuel spills during refuelling and operation	<p>Contamination of snow. Possible indirect impact on science.</p> <p>Possible indirect impact on station water supply.</p>	High	Area-specific	Long	Very Low	<p>Due care and attention when refuelling, reinforced through education and training.</p> <p>Equipment to be maintained to highest possible standards.</p> <p>Absorbents and other response equipment to be kept on site. Some spilled fuel may be absorbed by snow surface and recovered.</p> <p>Oil Spill Contingency Plan to be prepared for Halley VI.</p>

Activity	Output	Predicted Impact	Probability	Extent	Duration	Significance/Severity	Mitigating or Preventative Measure
Operation of station	Generation of hazardous and non hazardous waste	Danger to wildlife if scattered by wind.  Contamination of snow.	Certain	Local	Long	Very Low	All waste to be removed from Antarctica for re-use, recycling or safe disposal.  Procedures outlined in BAS Waste Management Handbook to be followed.
	Sewage/ grey water	Contamination of snow	Certain	Area-specific	Long	Low	Sewage treatment plant to be installed at Halley VI. Treated sludge to be removed from Antarctica
	Light pollution	Loss of scientific data because of light impacting sensitive scientific cameras for imaging airglow and aurora.	Medium	Local	Long	Medium	External lighting designed to minimise light pollution.  Use of low-pressure sodium light bulbs
	Disturbance to electromagnetic and meteorological observations due to station activities	Loss of scientific data	Medium	Local	Long	Medium	Site planning and zoning for electromagnetic observation equipment and for meteorological boundary layer measurements.  All electrical equipment to meet or exceed European Electromagnetic Compatibility standards.
	Station buildings and human activities	Loss of wilderness value	Certain	Local	Long	Very low	Halley VI will be aesthetically stimulating and blend sympathetically into the environment. It will be decommissioned and removed from Antarctica at the end of its lifetime.
Recreational visits to emperor penguin colony	Possible disturbance to breeding penguins	Increased energy expenditure	Low	Area-specific	Short	Very Low	Staff to follow 'Guidance for Visitors to the Antarctic' – Recommendation XVIII-1.  Site specific guidelines to be prepared for visits by BAS staff to emperor penguin colony.
Science	Scientific releases to the environment e.g. meteorological balloons	Contamination of snow	Certain	Regional	Long	Very Low	Unavoidable impact.  Meteorological balloons flown according to standard international practice.
	Irretrievable science tunnels and parts of aerial arrays.	Contamination of snow	Certain	Area-specific	Long	Very Low	Unavoidable impact.

### 6.5.1 Impacts identified in matrices

The impact matrices show that the environmental impacts from the construction and operation of Halley VI are predicted to be:

- air pollution and particulate deposition from atmospheric emissions produced by the combustion of fossil fuels;
- disposal of grey water and human wastes and abandoned materials buried under the snow; and
- contamination of snow and ice by minor fuel spills and leaks.

Of these impacts the most significant are judged to be air pollution and particulate deposition. The major source of additional atmospheric emissions, compared with operations today, will be from the extra ship visits to Halley during the construction phase. The matrices indicate that the environmental impacts identified to be of medium to high significance, such as a major fuel spill (>1000 litres), will be of very low to low probability.

Impacts of medium significance to scientific research at Halley VI are predicted, in the same way as today. Impacts predicted are the potential loss of atmospheric observations due to light pollution from station buildings and disturbance to electromagnetic observations from station electrical equipment and vehicles. There will also be some air pollution from station fossil fuel generators and vehicles that can affect air chemistry measurements, and disturbance to the snow surface could affect meteorological boundary layer experiments.

Prevention and mitigation measures have been identified in the impact matrices to avoid or minimise all the predicted impacts.

BAS expects that the operation of Halley VI will have substantially reduced environmental impact compared to Halley V because of the reduced station population, improved environmental management procedures, and the introduction of new technology to reduce fossil fuel consumption, minimise waste disposal, and recycle and reuse waste water. In addition, Halley VI is being designed with a much longer design life (>25% longer) than its predecessors, and to be capable of being easily decommissioned and removed when it eventually closes, and this will contribute to reducing the overall impact.

## 7. ASSESSMENT AND VERIFICATION OF IMPACTS AND MONITORING

### 7.1 STATION ENVIRONMENTAL MONITORING

Once the final design and technical specification for the construction and operation of Halley VI are known, BAS will establish a station environmental monitoring programme to measure the actual impacts of the project in Antarctica. As a minimum, BAS will carry out the monitoring outlined in Table 12.

**Table 12. Station environmental monitoring to be undertaken at Halley VI.**

Parameter	Data recorded	Frequency recorded	Reporting
Atmospheric emissions	Emissions of CO <sub>2</sub> (tonnes) calculated on basis of fuel consumed by station generators and vehicles	Once a month	Total emissions each season reported in the Annual BAS “Greening” report.
Fuel spills	Spills of AVTUR, petrol and lubricating oils (litres) into the environment	When occur	Small spills recorded in station spill logbook. All major spills (>10 litres) reported immediately to BAS Cambridge
Wastes	Non-hazardous wastes (e.g. paper, card, metal, fuel drums) (m <sup>3</sup> ) Hazardous wastes (e.g. batteries, chemicals, paints) (m <sup>3</sup> or litres) Sewage sludge/ash (m <sup>3</sup> )	Twice per season when waste removed by ship from Antarctica	Total amounts of wastes removed each season reported in the Annual BAS Waste Management Report

In addition, the building contractor will be given strict environmental conditions to adhere to as part of the contract documents. BAS will be providing a full time Halley VI Project Manager on site during the construction phase to ensure these conditions are met. Day-to-day visual inspections of the construction site will be carried out by the BAS Project Manager, and photographs and video will be taken. If environmental conditions are not met, then the BAS Project Manager will have the authority to stop works until mitigation measures are taken and deemed satisfactory.

### 7.2 GLACIOLOGICAL MONITORING OF THE BRUNT ICE SHELF AND STANCOMB–WILLS ICE STREAM

A long-term glaciological monitoring programme has been implemented by BAS to measure and predict the behaviour of both the Brunt Ice Shelf and Stancomb–Wills Ice Stream. The monitoring programme was established in 2001, and is now fully operational.

### 7.2.1 Daily GPS monitoring

A continuous GPS station at Halley V, in the Simpson Building, provides staff with a daily recording of the position (latitude, longitude) and elevation of the building. An irregular movement, for example, or unusual elevation fluctuation or jump in the latitude and longitude, could be interpreted as crack propagation. Detection of an anomaly is investigated immediately and further investigation undertaken. At Halley, further visual observations and re-survey of the GPS network are made, whilst at BAS, Cambridge the latest satellite imagery is acquired and the raw GPS data is checked and analysed.

### 7.2.2 Monthly GPS monitoring

The GPS network surrounding Halley is measured every three months to establish if there is any unusual movement in the ice which might indicate a potential calving event. It provides accurate baseline length measurements of a simple network surrounding the station. Any increase or anomalous change in a baseline length implies the onset of crack extension and would instigate visual inspection and more detailed monitoring.

### 7.2.3 Long-term satellite monitoring

Long term remote sensing databases for the Brunt Ice Shelf and Stancomb–Wills Ice Stream include RADARSAT, ERS–SAR and Landsat imagery from 1992, 1997, 2000, 2001 and 2003, ice front survey positions (of varying reliability) from 1915, 1956, 1958, 1959, 1968, 1978, 1986, 1997, 2000, 2001 and 2003 and a recently acquired aerial photograph survey from the 2002/03 season. Furthermore, the continuous GPS station at Halley has provided latitude, longitude, x,z,y coordinates, elevation and ice velocity since 1999 (see Figure 18). Previous literature and archived data from prior expeditions also provide sporadic velocity measurements from 1959, 1956–70, 1960, 1966–67, 1969, 1968–71, 1972–83 and 1995–96.

### 7.2.4 Survey work at the proposed location of Halley VI

During the 2004/05 season, BAS glaciologists will complete an extensive survey at the proposed location of Halley VI. This work includes;

- topographic survey of the station area at a 2.5km resolution;
- horizontal strain measurements;
- vertical strain measurement (firn compaction);
- density depth profiles; and
- installation of two Automatic Weather Stations.

In addition, during the 2005/06 season a Ground Penetrating Radar (GPR) survey is planned to provide subsurface data and images of the internal structure of the ice shelf thus detecting variations between air, ice and water. This allows the detection of internal crevassing, rifts and crack extension.

During 2005/06 vertical and horizontal strain measurements will also be re-surveyed. Finally, BAS is acquiring regular satellite imagery of the Brunt Ice Shelf and analysis of the images will enable the determination of velocity maps of the entire ice shelf. Installation of permanent GPS stations at risk zones, and linear motion sensors to detect crack propagation and initiation, are currently being investigated and a repeated aerial photographic survey planned.

### 7.2.5 Other glaciological studies

BAS carried out an extensive seismic survey in the 2002/03 and 2003/04 seasons to provide accurate bathymetry of the seabed beneath the Brunt Ice Shelf and an estimate of water column thickness. Also, three current moorings are presently situated in the Weddell Sea in the proximity of the Brunt Ice Shelf. On retrieval these instruments will provide velocity, temperature, conductivity and sediment samples. In combination, these data will enable the determination of background oceanographic forces acting on the ice shelf.

In summary, BAS has introduced a wide ranging and comprehensive glaciological monitoring programme of the Brunt Ice Shelf, and this will not only provide an early warning of any possible major calving event which could impact Halley V, but also improve the basic understanding of ice shelf dynamics and crack propagation in Antarctic ice shelves.

## 7.3 SNOW AND ATMOSPHERIC CHEMISTRY MONITORING

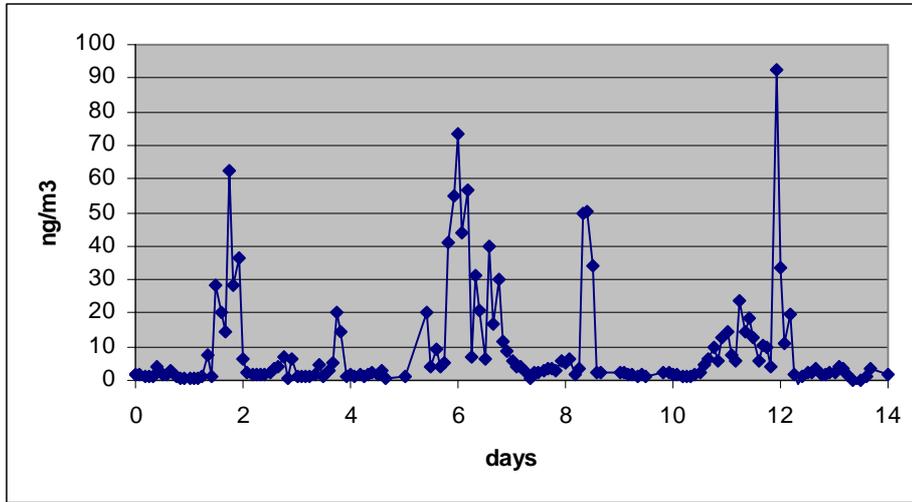
Halley is considered to be an ideal location for polar atmospheric chemistry research due to its remote location. Aerosol and snow sampling have been conducted at the station for several years.

The Clean Air Sector laboratory (CASLab) has been operational at Halley since 2003. The laboratory primarily provides a platform for conducting measurements of atmospheric chemistry, which are part of specific science programmes. Surface ozone measurements and aerosol sampling are conducted routinely. Since 1983, BAS scientists working at Halley have also contributed to ongoing greenhouse gas sampling ( $\text{CO}_2$ ,  $\text{CO}$ ,  $\text{CH}_4$ ,  $\text{SF}_6$ ), which forms part of the U.S. National Oceanic and Atmospheric Administration (NOAA) Climate Monitoring and Diagnostics Laboratory (CMDL) program. This sampling is now carried out from the CASLab.

An aethalometer is located at the CASLab and continually measures the concentration of black carbon aerosol in the atmosphere (Wolff and Cachier, 1998). The instrument has been at Halley V since 1992, and a replacement was installed in 2003, which will also be run at Halley VI. Records show a number of events of high concentrations of black carbon that are clearly due to contamination from the station generators and vehicles. Figure 29 shows data for the first two weeks in January, one of the busiest times at Halley.

The aethalometer measurements are used to indicate when local contamination of scientific samples from station activities may be occurring. Background levels of about  $0.2\text{--}2\text{ngm}^{-3}$  are seen when the wind is not blowing from the direction of the station generators. But during contamination episodes concentrations can peak at  $90\text{ngm}^{-3}$ , with extremes of up to  $600\text{ngm}^{-3}$ .

**Figure 29.** Plot of black carbon levels ( $\text{ngm}^{-3}$ ) during the two-week period 1–14 January 1995 at Halley V.



#### 7.4 ENVIRONMENTAL AUDIT

BAS plans to undertake an environmental audit of Halley VI during construction in 2006/07 or 2007/08 and in the first season of operations in 2008/09 to assess and verify the environmental impacts predicted in the CEE.

## 8. GAPS IN KNOWLEDGE AND UNCERTAINTIES

The major gaps and uncertainties in the environmental impact assessment of the construction and operation of Halley VI are the:

- Natural variability of the hostile environment at Halley VI, such as weather, sea ice or ice shelf conditions. For example, in extreme circumstances it may not be possible for the resupply ship to reach Halley because of heavy pack ice, as happened to the RRS *Ernest Shackleton* in 2001/02 season.
- The final design and detailed technical specification for the construction and operation of Halley VI will not be known until September 2005. Key technical uncertainties are the:
  - logistics transport and cargo supply, including charter of an ice-strengthened cargo vessel and possible use of aircraft to transport some of the construction team to Antarctica;
  - size and type of construction camp, including the number of construction staff, power generation system and sewage treatment;
  - station design, including the nature, layout, type, shape and dimensions of the buildings, fuel storage, power generation system, water recycling system and sewage treatment.
- Inability to be precise about the actual environmental impacts of Halley VI and the extent to which these impacts will be less than those observed at Halley V. Impacts have been evaluated on the basis of expert judgement, using the results of environmental monitoring carried out at Halley V and the 50 years of BAS experience of operating on the Brunt Ice Shelf. BAS considers, therefore, that it has a good general understanding of the possible impacts of Halley VI, but they need to be checked and reassessed once the detailed design specification for the station has been agreed.
- Changes in future activities at Halley VI over its design life of 20 years, especially the progressive introduction of renewable energy technology and developments in the BAS global science programme beyond 2010.

A key design criterion for Halley VI is that the station will minimise environmental effects and comply with the Environmental Protocol. The predicted impact of Halley VI will not depend, therefore, on the final design chosen. The environmental effects of Halley VI will be substantially reduced compared to Halley V by having fewer people working at the new facility, decreasing fossil fuel consumption and water use and improving sewage disposal and waste treatment.

## **9. CONCLUSION**

The UK considers that the construction and operation of Halley VI Research Station on the Brunt Ice Shelf will have more than a minor or transitory impact on the Antarctic environment. The implementation of the preventative and mitigation measures outlined in this draft CEE will reduce environmental impacts, and BAS considers the overall impact of Halley VI will be substantially less than Halley V.

The UK concludes that the global scientific importance and value to be gained by the construction and operation of Halley VI and the continued operation of the research facility by BAS on the Brunt Ice Shelf outweighs the more than minor and transitory impact the station will have on the Antarctic environment and fully justifies this activity proceeding.

## 10. AUTHORS OF THE DRAFT CEE AND CONTACT DETAILS

This draft CEE has been prepared by Dr John Shears and Mr Rod Downie, Environmental Office, British Antarctic Survey, and Dr Liz Pasteur, Poles Apart. The draft CEE has been approved and endorsed by the UK Government. It was released on 4 February 2005 and is available for download via the BAS website ([www.antarctica.ac.uk/halleyvi/cee.html](http://www.antarctica.ac.uk/halleyvi/cee.html)).

The UK welcomes comments and feedback on this draft CEE.

If you would like further information on the CEE of Halley VI or would like to respond with comments then please contact:

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## 12. LIST OF REFERENCES

- Allan, D. (1983) Halley Wildlife Report. Unpublished report. Z/1983/N. BAS, Cambridge.
- Anderson, P.S. (2002) Analysis of acoustic dot echo signature over an Antarctic ice shelf: the possible remote sensing of Antarctic petrels. *Antarctic Science*. 14(2), 185–194.
- Aslin, P. (1986) Halley Wildlife Report. Unpublished report. Z/1986/N. BAS, Cambridge.
- Aslin, P. (1987) Halley Wildlife Report. Unpublished report. Z/1987/N. BAS, Cambridge.
- Blake, D. (2003) Halley – at the edge of ice-station design. *Civil Engineering*, 156, 168–174.
- Bonner, W.N. (1989) The natural history of seals. London, Christopher Helm.
- British Antarctic Survey (2004a) Halley Research Station. Leaflet. BAS, Cambridge.
- British Antarctic Survey (2004b) Halley Research Station Design Concept Competition. Leaflet. BAS, Cambridge.
- British Antarctic Survey (2004c) Halley Bulk Fuel Storage and Transfer Procedures. Unpublished procedure. BAS, Cambridge.
- British Antarctic Survey (2004d) Waste Management Handbook. BAS, Cambridge.
- British Antarctic Survey (2004e). British Antarctic Survey Handbook. BAS, Cambridge.
- Buro Happold and Lifschutz Davidson (2004) Halley VI. Stage 2 proposals. Submission to RIBA/BAS design competition.
- Department of Environment, Food and Rural Affairs (2000) The Ozone Layer. DEFRA, London.
- Doake, C.S.M., H.F.J. Corr, K.W. Nicholls, A. Gaffikin, A. Jenkins, W.I. Bertiger and M.A. King (2002) Tide-induced lateral movement of Brunt Ice Shelf, Antarctica. *Geophysical Research Letters*, 29 (8), 1226.
- Downie, R.D. and J.R. Shears (2003) Halley V Oil Spill Contingency Plan. BAS, Cambridge.
- Eicken H. (1992) The role of sea ice in structuring Antarctic ecosystems. *Polar Biology* 12: 3–13.
- FaberMaunsell and Hugh Broughton Architects (2004) British Antarctic Survey Halley VI Research Station Stage Two Report. Submission to RIBA/BAS design competition.
- Farman, J.C., B.G. Gardiner and J.D. Shanklin (1985) Large losses of Total Ozone in Antarctica reveal seasonal ClO<sub>x</sub> /NO<sub>x</sub> interaction. *Nature*, 315, 207–210.
- Foreign & Commonwealth Office. Antarctic Treaty Annual Exchange of Information. Annual Reports from 1998/99–2002/03.
- Hayes, K. (2003) The lifetime of Halley and risk of the Brunt Ice Shelf calving: preliminary results. *Geophysical Research Abstracts*, 5, 20.
- Hayes, K. (2004) Brunt Ice Shelf: Lifetime of Halley. Unpublished report. BAS, Cambridge.
- Hopkins/Expedition/atelier ten. (2004) Halley VI Concept Design, Design Report. Submission to RIBA/BAS design competition.
- Hulbe, C.L., R. Johnston, I. Joughin and T. Scambos. (2003) Marine ice modification of fringing ice shelf flow. Abstract. Tenth Annual WAIS Workshop, Sterling, Virginia.
- Knox G.A. (1994) The Biology of the Southern Ocean. Cambridge University Press. 444 pp.
- König-Langlo, G., J.C. King and P. Pettré (1998) Climatology of the three coastal Antarctic stations Dumont d’Urville, Neumayer and Halley. *Journal of Geophysical Research*, 103, 10,935–10,946.

- Lovegrove, I (1991) Halley V – Phase III construction. Unpublished report. AD11/2Z/56/3. BAS, Cambridge.
- Marchant, S. and P.J. Higgings (co-ordinators) (1990) Handbook of Australian, New Zealand and Antarctic birds. Melbourne, OUP.
- Piatkowski, U. and K. Pütz. (1994) Squid diet of emperor penguins (*Aptenodytes forsteri*) in the eastern Weddell Sea, Antarctica during late summer. *Antarctic Science*, 6(2), 241–247.
- Rankin, A.M. (2004) Effect of generators on local snow and aerosol chemistry at a coastal Antarctic research station. Unpublished report. BAS, Cambridge.
- Renfrew I.A. and P.S. Anderson. (2002) The surface climatology of an ordinary katabatic wind regime in Coats Land, Antarctica. *Tellus A*, 54 (5), 463–484.
- Suttie, E.D. and E.W. Wolff (1993) The local deposition of heavy metal emissions from point sources in Antarctica. *Atmospheric Environment*, 27A (12), 1833–1841.
- Upton, M., T.H. Pennington, W. Haston and K.J. Forbes (1997) Detection of human commensals in the area around an Antarctic Research Station. *Antarctic Science*. 9(2), 156–161.
- Warren, S.G. and Clarke, A.D. (1990) Soot in the atmosphere and snow surface of Antarctica. *Journal of Geophysical Research*, 95 (D2), 1811–1816.
- Whittamore, L. (1992) Halley 4 Waste Clearance. Unpublished report. AD6/2Z/1992/EV1. BAS, Cambridge.
- Woehler, E.J. (1993) The distribution and abundance of Antarctic and Subantarctic penguins. SCAR, Cambridge.
- Wolff E.W. and H. Cachier (1998) Concentrations and seasonal cycle of black carbon in aerosol at a coastal Antarctic station. *Journal of Geophysical Research*, 103(D9), 11,033–11,041.
- Wolff E.W., M.R. Legrand and D. Wagenbach (1998). Coastal Antarctic aerosol and snowfall chemistry. *Journal of Geophysical Research*, 103(D9), 10,927–10,934.

## 13. ACRONYMS

Acronym	Meaning
AGO	Automated Geophysical Observatories
AIS	Advanced Ionospheric Sounder
ATCM	Antarctic Treaty Consultative Meeting
ATCP	Antarctic Treaty Consultative Party
AVTUR	Aviation Turbine Fuel Jet A-1
AWS	Automatic Weather Station
BDSP	Building Services Engineering Consultancy
BAS	British Antarctic Survey
CASLab	Clean Air Sector Laboratory
CEE	Comprehensive Environmental Evaluation
CEP	Committee on Environmental Protection
CFC	Chlorofluorocarbon
CHP	Combined Heat and Power
CMDL	Climate Monitoring and Diagnostics Laboratory
DHC	DeHavilland Canada
DROMLAN	Dronning Maud Land Air Network
EIA	Environmental Impact Assessment
ERS SAR	Earth Resource Satellite Synthetic Aperture Radar
ETFE	Ethylene Tetrafluoroethylene
EOI	Expression of Interest
GPS	Global Positioning System
GPR	Ground Penetrating Radar
GSAC	Global Science in the Antarctic Context
HF	High Frequency
IGY	International Geophysical Year
ISO	International Organization for Standardization
LANDSAT	Satellite which acquires images of earth from space
LED	Liquid Electronic Display
LPM	Low Power Magnetometer
MARPOL 73/78	International Convention for the Prevention of Pollution from Ships 1973, as modified by the Protocol of 1978
MGO	Marine Gas Oil
NERC	Natural Environment Research Council
OSCP	Oil Spill Contingency Plan
PV	Photovoltaic
RADARSAT	Satellite which acquires synthetic aperture radar imagery of earth from space
RIBA	Royal Institute of British Architects
RRS	Royal Research Ship
RWDI	Rowan Williams Davies and Irwin Consultants
SCAR	Scientific Committee on Antarctic Research
SHARE	Southern Hemisphere Auroral Radar Experiment
SuperDARN	Super Dual Auroral Radar Network
UK	United Kingdom
UN	United Nations
USA	United States of America
VHF	Very High Frequency
VLF	Very Low Frequency
VOC	Volatile Organic Compound
WMO	World Meteorological Organisation

## 14. APPENDICES

### Appendix 1. Schedule of accommodation planned for Halley VI.

#### Domestic accommodation

Type of Space	Number of Persons / size
Winter sleeping accommodation	16 Single occupancy rooms
Summer sleeping accommodation	28 Single occupancy rooms
Transitee summer accommodation	8 Single or 4 double occupancy rooms
Bulk baggage store Cleaners room (sleeping)	To suit sleeping accommodation location and layout
Boot Room(s) Cleaners Room(s) (domestic)	To suit domestic accommodation layout
Kitchens; Day Stores Dining Rooms	16 winter; 52 summer +20%
Food Storage -20°C	Minimum 40m <sup>2</sup>
Food Storage – ambient temperature	Minimum 50m <sup>2</sup>
Food Storage +4°C	Minimum 10m <sup>2</sup>
Laundry(s) Washrooms and Toilets	Size and number to suit sleeping accommodation location and layout
Lounge(s)	16 winter; 52 summer
Quiet Room(s)	16 winter; 52 summer
Bar + Bar Store	16 winter; 52 summer
Medical Room	1 Doctor
Gymnasium	16 winter; 52 summer
Library	15 people max.
Internet Room and Communal Office	10 people max.
Telephone Room	1 person
Photographic Facility	
Other Leisure Facilities	As proposed by designers.

#### Technical accommodation

Type of Space	Size and use
Vehicle Workshop & Storage	Sufficient size to garage, service, strip down & overhaul the largest piece of plant proposed to be used on site.
Snow Runway (ski-way)	Landing and take-off of ski-mounted Twin Otter aircraft 100m long; 50m wide To the north (on plan) furthest away from science zone
Air Support Caboose Summer use only.	Standard Caboose Close to ski-way to house passengers and small freight out of the weather whilst waiting for an aircraft
Bulk Fuel Storage	Sufficient bulk storage to provide fuel for the station for 2 years (AVTUR)
Drummed Fuel Storage	Maximum 2000 x 205 litre drums (AVTUR) Minimum depends on bulk storage capacity or aircraft / vehicle requirements
Waste Management Facilities	Facilities to deal with sewage & domestic waste, other liquid wastes and chemicals, hazardous wastes

Type of Space	Size and use
General Store Room	Minimum 10m <sup>2</sup> General storage
Maintenance Store Room	Size to suit 2 years stock holding of facility maintenance spares. May be split into warm and cold stores
Carpenters Workshop	Minimum 10m <sup>2</sup>
Mechanical Workshop	Minimum 10m <sup>2</sup>
Electrical Workshop	Minimum 10m <sup>2</sup>
Server Room	To house main computer servers.
Communications Room	2 Radio Operators. Long, Medium & Short Range Communications Air traffic control.
Base Commander's Office	Base Commander + visitor; private office
Operations Room	20 people seated; briefing room
Field Opps Room	Minimum 60m <sup>2</sup> and 4m high Packing, preparing, drying and storing equipment for field operations
Boot Room(s)	Dressing/undressing outdoor clothing and boots. Storage and drying

### Science accommodation

Type of Space	No. Persons / size	Type of Use
<b>Main Science Laboratory</b>		
Warm Store Room	40m <sup>2</sup>	Store room for materials / equipment that would be damaged by freezing
Cold Store Room	20m <sup>2</sup>	Store room for materials / equipment that would not be damaged by freezing
Office Space	10 winter 24 summer	Office – computers and filing
Laboratory A	15m <sup>2</sup>	Racks of electronic equipment
Laboratory B	15m <sup>2</sup>	Racks of electronic equipment
Server Room	15m <sup>2</sup>	Server room
Met. Operations Room	30m <sup>2</sup>	Computers and instrumentation
Ozone Laboratory	15m <sup>2</sup>	Dobson Ozone Spectrophotometer
Electronics Workshop	10m <sup>2</sup>	Clean Workshop
Mechanical Workshop	10m <sup>2</sup>	Dirty Workshop
Field Preparation Room	35m <sup>2</sup>	Preparation & testing of equipment ready for use in the field. Packing and unpacking
Toilet, Washroom		Unisex Toilets, Ablutions
Kitchenette		Facility to wash hands and make hot drinks
Cleaner's Room		Storage for cleaning materials
Boot Room	Up to 20 People	Dressing/undressing outdoor clothing and boots. Storage and drying
<b>Clean Air Sector Laboratory</b>		
Clean Air Laboratory	8 people 15m <sup>2</sup>	Computers. Racks of instrumentation. Needs to be >1km from station generators
Optical Laboratory	3 people 8m <sup>2</sup>	Houses optical instruments and equipment
In-use Gas Store	5m <sup>2</sup> . One year supply	Warm gas cylinder store (above boil point of gas)
Gas Store	One year supply	Cold gas cylinder store (below boil point of gas)
Boot Room	10 people	Dressing/undressing bulky, wet outdoor clothing and boots. Storage and drying
Wet Laboratory	15m <sup>2</sup>	Or located in the main Science Laboratory

Type of Space	No. Persons / size	Type of Use
Cleaners Room		
<b>Other Science Structures and Caboooses</b>		
Magnetometer and Riometer Shaft	Space for 2 people	Shaft and tunnel with small heated room at the end. Located >1km from station activities in radiofrequency quiet site
SHARE Caboose	Approx 6m x 2.4m x 2.4m	Housing radar instrumentation; bench for repairs, storage for spares / tools. Office space. Close to SHARE radar
Optical Caboose	Approx 6m x 2.4m x 2.4m	Housing optical instrumentation; bench for repairs, storage for spares / tools. Office space. Extremely dark site
Advanced Ionospheric Sounder (AIS) Caboose	Approx 6m x 2.4m x 2.4m	Housing AIS instrumentation; bench for repairs and storage for spares / tools. Office space
Balloon and Radio Sonde Caboose	Approx 6m x 2.4m x 2.4m	Storage of 72 helium cylinders; Inflation and releasing of balloons

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*Image:* Aerial photograph of Halley V, looking towards the edge of the Brunt Ice Shelf and the Weddell Sea.

