iSTAR
Initial Environmental Evaluation

iSTAR

ANTARCTICA

BAS Environment Office

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British Antarctic Survey,
High Cross, Madingley Road,
Cambridge, UK, CB3 0ET.

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

iSTAR -INITIAL ENVIRONMENTAL EVALUATION

CONTENTS

Non-Technical Summary

Introduction

The Ice Sheet Stability Programme (iSTAR) is a Natural Environment Research Council (NERC) project. The aim of the project is to investigate the stability of the West Antarctic Ice Sheet (WAIS). By gaining a better understanding of what is causing rapid ice loss from the Pine Island Glacier in the Amundsen Sea more accurate predictions can be made about future sea level rise.

This Initial Environmental Evaluation has been prepared in accordance with Annex I of the *Protocol on Environmental Protection to the Antarctic Treaty* (1991).

Programme Description

The iSTAR programme is split into two main themes. One theme is focussed on studying the processes of ocean forcing on the WAIS and the other theme focuses on how the ice sheet responds to this forcing. Within the Ocean Forcing theme there are two projects, iSTAR A and iSTAR B which will focus investigations on the Amundsen Sea and the research teams will be based on the RRS James Clark Ross.

- iSTAR A - "Ocean2ice" will focus on studying the processes bringing warm water onto the continental shelves and towards the ice shelves. The project is made up of four components which will collect data on temperature, salinity and depth in the Amundsen Sea.
    - Seal Tagging
    - ADCP Swath bathymetry
    - Deployment of underwater equipment including CTD's, sea gliders, and auto subs
    - Radiosonde Balloon Deployment
- iSTAR B - "Ocean under ice" aims to understand how oceanographic processes beneath the floating ice shelves of Pine Island Bay lead to changes in the melt rate of the ice shelves. Measurements of the water properties beneath the glacier will be taken as well as the rate at which the base of the glacier is melting into the ocean. This will be undertaken by an Autonomous Underwater Vehicle deployed from the RRS James Clark Ross as well as high precision autonomous radars which will be deployed on the ice shelf surface.

Within the Ice Sheet Response theme there are also two projects, iSTAR C and iSTAR D. These are focussed on Pine Island Glacier, Thwaites Glacier and Union Glacier and will be undertaken by research teams working and travelling over the ice by tractor traverse.

- iSTAR C –"Dynamic Ice" aims to understand how processes which are thinning the floating ice shelf are also influencing the thinning on the trunk and tributaries of Pine Island Glacier. Radar and seismic surveys will be obtain images of the bed topography and the internal architecture of the glacier. Remote sensing by satellite will be used to measure the changes of the glacier in areas that cannot be accessed on the ground. Eleven GPS stations will be installed to monitor the movement of the ice and any changes in its flow.

- iSTAR D – "Ice Loss" will look at the how ice loss from the Amundsen Sea is affecting global sea levels. The project is split into three main parts.
  - A Neutron probe and radar will be used to measure snow density to determine snow accumulation and densification rates.
  - GPS & Cosmogenic dating will measure how fast the earth's crust is uplifting in response to the removal of past ice. This will involve collecting rock samples from rare outcrops as well as installing three GPS systems at each sample site to measure the motion and uplift of the earth.
  - A series of ice cores will be collected to identify ice accumulation rates and to determine if this affects the rate of thinning on the glacier.

- Support Activities

  One main fuel depot storing approximately 32,000 litres of AVTUR has been established and is subject to a previous IEE. A 70 day mobile expedition comprising of over-snow vehicles, fuel, science equipment and personnel will be undertaken in both the 2013/14 season and the 2014/15 season to support the iSTAR C and D projects. This will consume up to 19,000 litres of AVCAT over the two seasons. 22 separate field camps will be established in each season for 12 staff members. An overwinter depot will be set up at the end of the traverse in 2013/14 to store equipment and fuel. This will be the start point of the 2014/15 traverse.

Programme Schedule

The overall iSTAR programme will operate over a period of six years. Work started in 2010 (and is not covered in this assessment) and the core field research is anticipated to continue until the end of the 2014-15 Antarctic summer season. After that, some of the GPS stations will remain in operation, with annual visits, for 2 more years, after which they will be removed.

Description of the Environment

- The Amundsen Sea is an arm of the Southern Ocean covered by ice for the majority of the year. Pine Island Glacier flows into Pine Island Bay which is approximately 65 km long and 50 km wide on the southeast extremity of the Amundsen Sea.
- The Pine Island Glacier drainage basin covers an area of approximately 165,000 km^2 and has an elevation ranging from sea level to 2300m. Between 2206 and 2008 the mean temperature on the glacier was -20° C with a mean summer temperature of -9° C. Mean summer wind speed was 7 $m\ s^{-1}$ (13 knots) from a predominantly easterly direction.

- Most life known to exist at the proposed Nunatak sites is microbial in nature and micro invertebrates have been recorded such as tardigrades, nematodes and rotifers. Higher plant life is absent and mosses are extremely rare.

Alternatives

Four alternative options have been examined these are;

- Do Nothing
- Do the activity elsewhere
- Do the activity with alternative science
- Do the activity with alternative logistics

All four alternatives were considered not viable for scientific, technical or practical reasons.

Impact Identification and Mitigation

The iSTAR programme covers a wide array of activities which could give rise to a multitude of environmental impacts. Where potential negative environmental impacts have been identified mitigation measures have been proposed to reduce, minimise or avoid these impacts.

The activities which have the potential to result in a medium to high severity of environmental impact are listed below and the relevant mitigation measures to reduce the impact have been outlined.

- iSTAR A – Seal Tagging could cause distress and harm to seals and potentially impact on their behaviour, so poses a medium risk to the individuals involved. However, the proposed tagging technique has been endorsed by the Seal and Mammal Research Unit and undergone ethical review by the University of St Andrews and was approved in June 2013. Only seals in good health will be chosen and the tags will fall off after the annual moult. A small number of seals relative to the overall population size will be tagged.

- iSTAR D – Misuse of the neutron probe could result in a radiation leak or expose personnel and the environment to a radioactive source. Local rules have been well documented to ensure appropriate operation of the probe by trained personnel who will be co-ordinated by a Radiation Protection Advisor. A risk assessment has been completed. The probe will be carried in a Type 'A' box which is resistant to impact and radiation monitors will be used to check daily dosage rates.

- iSTAR D – Deployment of the GPS systems and collecting samples on the nunataks could result in damage to the local geology and biota and reduce the wilderness value of the locality. Where possible samples will be collected which are loose pebbles or boulders avoiding the use of rock saws. GPS sites will be sensitively chosen to minimise the aesthetic impact of the installation. The recommendations in the SCAR Code of Conduct for conducting science in a terrestrial environment will be followed as well as the advice in the BAS Biosecurity Handbook to reduce the risk of non native species being imported to the locality.

- Support Activities – Large quantities of fuel will be transported and stored in the field during the programme. This increases the risk of a fuel spill occurring in the field and impacting on what is currently a pristine environment. Robust and reliable transfer and storage equipment has been sourced for this project. Appropriate staff have been trained in spill response and a spill kit will be carried with the tractor train at all times. Fuel stores left overwinter will be well marked and have individual GPS positions recorded. Methods to recover fuel bladders and drums are set out in the Traverse Operations Manual. Carbon emissions associated with the fuel use are unavoidable but have been minimised through good planning, and using efficient means of transportation. Carbon emissions will be calculated for inclusion in the BAS carbon report.

Conclusion

This IEE indicates that the proposed iSTAR Programme is likely to have no more than a minor and transitory impact on the Antarctic environment, provided the recommended mitigation measures identified are carried out. It is concluded that this activity should be allowed to proceed, and that a Comprehensive Environmental Evaluation (CEE) is not required.

Section 1

INTRODUCTION

1 INTRODUCTION

1.1 Background to Project

The Ice Sheet Stability Programme (iSTAR) is a Natural Environment Research Council (NERC) research project, aimed at investigating the stability of the West Antarctic Ice Sheet (WAIS). The Amundsen Sea and Pine Island Glacier are the main focus of the study because this region has seen some of the greatest rates of ice loss in Antarctica over the last decade. The overall purpose of the programme is to gain a better understanding of the processes affecting ice sheet stability in order to make more accurate predictions about their future behaviour and the subsequent impact on sea level rise.

iSTAR is a collaboration of research institutes involving NERC, British Antarctic Survey (BAS), and the Universities of , Bristol, Cambridge, Durham, East Anglia, Edinburgh, Leeds, Newcastle, Reading, Southampton, St. Andrews and UCL.

1.2 Statutory Requirements

To ensure the protection of the Antarctic environment, the Antarctic Treaty nations adopted the Protocol on Environmental Protection to the Antarctic Treaty in 1991 (hereafter referred to as the Environmental Protocol). The UK enforces the provisions of the Protocol through the 'Antarctic Act 1994 and Antarctic Act 2013' and 'Antarctic Regulations 1995/490 (as amended).

<u>Annex I – Environmental Impact Assessment (EIA)</u>
One of the guiding principles of the Environmental Protocol is that an EIA be carried out before any activity is allowed to proceed. It states that activities should be planned and conducted on the basis of *'information sufficient to allow prior assessments of, and informed judgements about, their possible impacts on the Antarctic environment'* (Article 3, Environmental Protocol).

Annex I of the Environmental Protocol sets out the detailed regulations for EIA in Antarctica, and establishes a three-stage procedure based on different levels of impact. The levels are:

- Preliminary Assessment;
- Initial Environmental Evaluation (IEE); and
- Comprehensive Environmental Evaluation (CEE).

An IEE is for activities, which are likely to have a minor or transitory impact on the Antarctic environment. It is considered that an IEE is appropriate for the iSTAR programme. In the UK the IEE is subject to review by the Foreign and Commonwealth Office (FCO), which also makes the final decision on whether the activity should proceed.

<u>Permits</u>
The Environmental Protocol also states that certain activities within Antarctica require a permit before being undertaken. Those activities relevant to the iSTAR programme include the following;

- Mineral resource activities for scientific research; and
- The taking of, or harmful interference with, fauna or flora.

The relevant permits applications for these activities have been submitted to the FCO.

Other activities associated with the iSTAR programme will be covered by the BAS Operating Permit, which is organised directly between BAS and the FCO.

1.3 Purpose and Scope of Document

The purpose of this IEE is to provide sufficient information on the iSTAR programme for an informed judgement by the FCO to be made on the possible environmental impact of these activities on the Antarctic Environment and whether they should proceed. The scope of this document covers the iSTAR projects known as iSTAR A, B, C and D and directly-associated logistics. Other iSTAR activities already been completed have been subjected to a previous IEE and are not included in this assessment.

The document has been split into the following sections;

- Section 2 provides a description of the overall programme and the individual projects;
- Section 3 outlines the alternatives considered at the outset of the programme;
- Section 4 identifies the potential environmental impacts including cumulative impacts;
- Section 5 outlines the mitigation measures that are proposed to minimise and avoid those impacts identified in Section 4.
- Section 6 provides the conclusions of the IEE.

A non technical summary has been included at the beginning of the document to provide an overview of the IEE in a clear, concise and non technical manner as well as outlining the conclusions achieved.

Section 2

PROGRAMME DESCRIPTION

2 PROGRAMME DESCRIPTION

2.1 Programme Overview

The iSTAR programme is split into two main themes (see Table 1). One theme is focussed on studying the processes of ocean forcing on the WAIS and the other theme focuses on how the ice sheet responds to this forcing.

Within the Ocean Forcing theme of investigation there are two projects, iSTAR A and iSTAR B. iSTAR A will focus on the processes bringing warm water onto the continental shelves and towards the ice shelves. iSTAR B will focus on the processes occurring beneath the ice shelves.

Within the Ice Sheet Response theme there are also two projects, iSTAR C and iSTAR D. iSTAR C will focus on the response of the glacier to the movement of the grounding line and iSTAR D will look at the overall impact of changes in the Amundsen Sea ice mass balance on global sea levels.

The logistical support required for the whole iSTAR programme commenced in 2011 and a separate IEE was undertaken. The tractor trains that will be used for the ice sheet traverse (iSTAR C & D) were landed on the Abbott Ice Shelf from RRS Ernest Shackleton in January and February 2012. These were driven to the starting point for the traverses in 2013. The oceanographic moorings in support of the ocean forcing projects (iSTAR A) were deployed in February and March 2012 from RV Araon, and will be recovered during the main iSTAR research cruise in 2014.

Figure 1. Location of study area

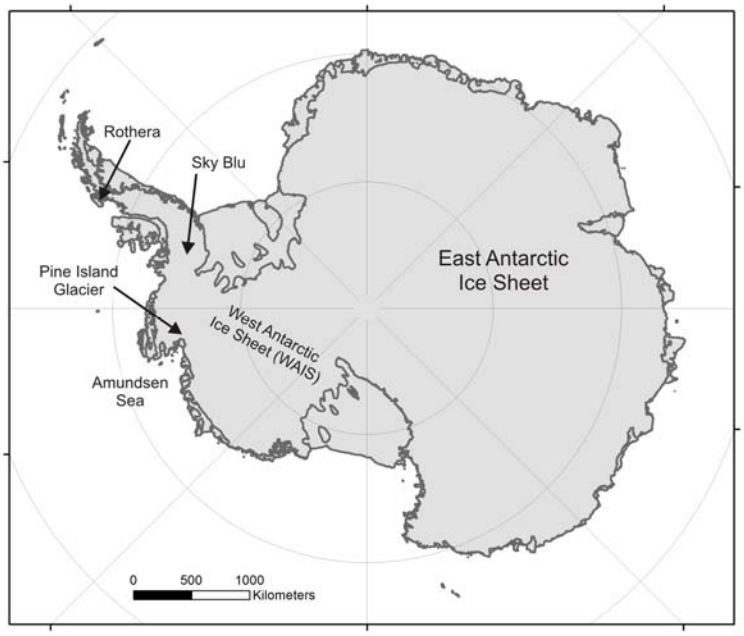

Figure 2. Detailed map of study area

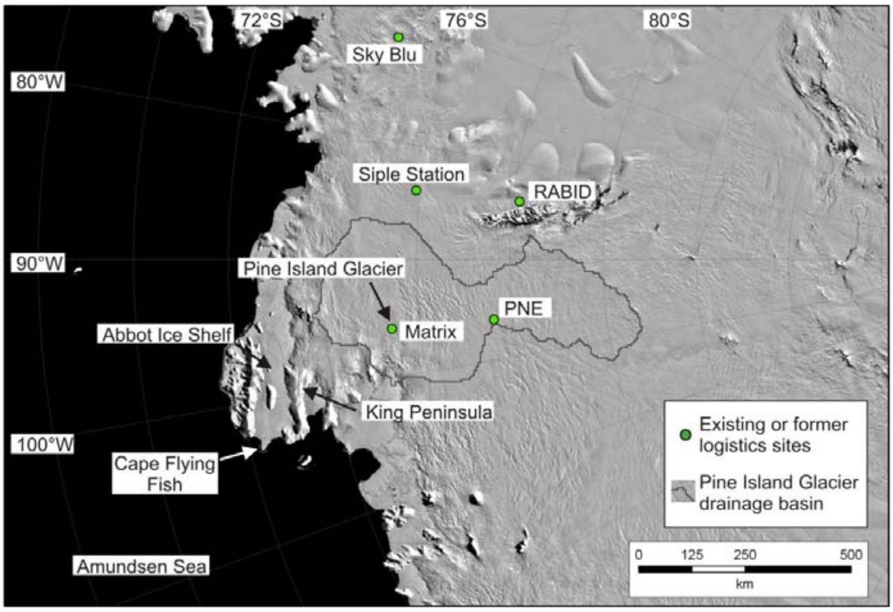

Table 1. Programme Breakdown

Programme Name	iSTAR			
iSTAR Theme	**iSTAR Project**	**Project Name**	**Location**	**Brief Summary of activity**
(i) Ocean Forcing	**iSTAR A**	"Ocean2ice" Processes and variability of ocean heat transport towards the ice shelves in the Amundsen Sea Embayment	Amundsen Sea	• Undertaking oceanographic profiles in ice covered areas (CTDs, sea gliders, auto-subs & moorings) • Radiosonde Balloon Deployment • Seal Tagging
	iSTAR B	"Ocean under ice" Ocean circulation and melting beneath the ice shelves of the SE Amundsen Sea	Pine Island Glacier Bay and ice shelf	• Use of autonomous underwater vehicle under the ice shelf • High precision autonomous radar on the ice shelf
(ii) Ice Sheet Response	**iSTAR C**	"Dynamic Ice" Dynamic control of the response of Pine Island Glacier	Pine Island Glacier	• Deployment of GPS stations • Radar surveys • Seismic surveys • ADIOS deployments
	iSTAR D	"Ice loss" The contribution to sea-level rise of the Amundsen Sea sector of Antarctica	Pine Island Glacier & Union Glacier	• Use of neutron probe and radar to collect density and accumulation data on snow profiles • Rock Sampling Deployment of GPS stations • Ice core samples

2.2 Programme Schedule

The overall iSTAR programme will operate during a period of six years. Initial work commenced in 2010 (and is not covered in this assessment) and the core field research is anticipated to continue until the end of the 2014-15 Antarctic summer season. After that, some of the GPS stations will remain in operation, with annual visits, for 2 more years, after which they will be removed. The key milestone activities are listed below.

2.2.1 Timetable for Ocean Forcing theme:

- Nov 2010-Jan 2011: Preliminary cruise on RVIB Nathaniel B. Palmer, deploying two moorings.
- Nov 2011: Equipment sent south for 2012 cruise.
- Jan-Mar 2012: Cruise on RV Araon to deploy further nine moorings in the Amundsen Sea.
- Antarctic Summer 2013-14: Science cruise on RRS James Clark Ross, retrieving moorings, deploying CTD, seal tagging, and Autosub and glider deployments.

2.2.2 Timetable for Ice Sheet Response theme:

- Jan 2011: Fact-finding fieldwork exercise with US NSF tractor-train to Pine Island Glacier.
- Nov 2011: Equipment sent south for 2012 field season.
- Dec 2011: Tractors "Polar 1" and "Polar 2" tested during the annual resupply of Halley Station.
- Jan-Feb 2012: Tractors landed on Abbot Ice Shelf and driven to winter depot on King Peninsula.
- Nov-Dec 2012: Tractors moved depots from Abbott Ice Shelf and King Peninsula to newly established depots at Kenfield Nunatak and on Pine Island Glacier in preparation for the following season's traverses. Tractors moved to Sky Blu for the winter.
- Antarctic Summer 2013-14: First season of science traverse and nunatak field work.
- Antarctic Summer 2014-15: Second season of science traverse and nunatak field work. Removal of fuel depots.

2.3 Description of Projects

2.3.1 iSTAR A – "Ocean2ice"

The iSTAR A project will assess how the ocean transports heat towards the ice shelves in the region surrounding PIG, in the Amundsen Sea. Figure 3 illustrates the intended location of study.

The work will focus on understanding the processes by which warm ocean water spills onto the continental shelf and how it becomes modified on the shelf. The study will explore how these processes may vary through time, from hours and days (driven by tides, synoptic weather systems or eddies) to decades and centuries (driven climate change).

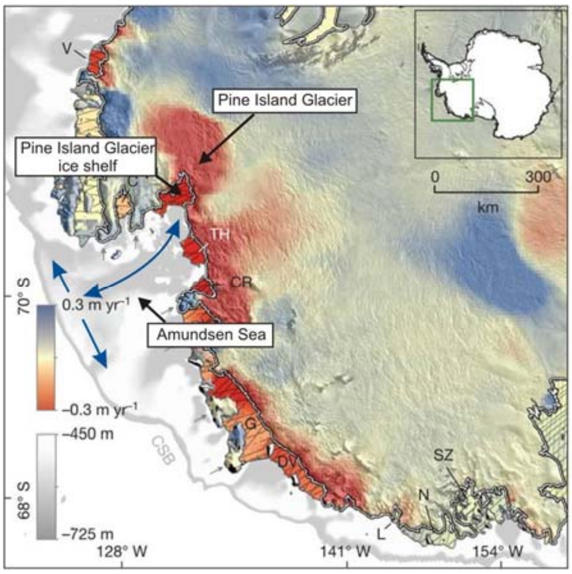

Figure 3.

Area of field activities for the iSTAR A and iSTAR B projects. Modified from Pritchard et al., 2012, doi:10.1038/nature10968. Colours indicate ice surface elevation change, greyscale idicates seabed depth.

iSTAR A activities will take place in the area covered by the blue arrows, iSTAR B activities will take place in the area of Pine Island Glacier ice shelf and the adjacent ocean.

The project is comprised of four separate components as listed below:

1. <u>Seal Tagging</u>

The primary purpose of seal tagging on this project is to collect data which will enable oceanographic profiles to be created of the sea in ice covered areas at the terminus of the PIG. The tags will stay on the seals long enough to collect data throughout the Antarctic winter. As the seals dive under the water, temperature and salinity data will be collected. Once the seals resurface the data will immediately be relayed via satellite link to the Sea Mammal Research Unit (SMRU) at the University of St. Andrews.

Up to 20 Weddell, Elephant and/or Crabeater seals will be captured during the project. The seals will be caught either on islands or sea ice using nets, then weighed and measured to determine size, body condition and suitability prior to being anaesthetised. Using established procedures covered in the UK by Sea Mammal Research Unit (SMRU) Home Office Project Licences, they will be lightly anesthetized by intramuscular IV injection of the anaesthetic Zoletil. A small telemetry device (10.5 x 7 x 4 cm, 545 g) known as a CTD- SRDL will be glued with epoxy resin to the fur on or at the back of the head. A blood sample will also be taken before the seal is released. The procedure outlined has undergone ethical review by the University of St Andrews and was approved in June 2013.

The telemetry devices, consisting of a printed circuit board and lithium battery are imbedded in a solid block of epoxy, which is not biodegradable.

Wintertime CTD data are scare and the data that the seal tags collect are not practically obtainable by any other means. In addition the tags will also provide new information on the geographic movements and behaviour of seals in relation to oceanographic conditions in an area of the Antarctic where no information is currently available.

It is a statutory requirement of the Environmental Protocol that this type of specialist activity i.e. disturbing fauna or flora be covered by a Section 12 permit. A permit application has been submitted to the FCO.

2. Acoustic Doppler Current Profiler (ADCP) Swath bathymetry

Ship-based ADCP data and swath bathymetry will be recorded for the duration of the cruise.

3. Under water equipment deployment

i) CTD - ~200 profiles obtained over the continental shelf seaward of Pine Island Glacier
ii) Sea gliders – Up to three Sea gliders will be deployed over the continental shelf and shelf break seaward of Pine Island Glacier
iii) Autosub might be deployed over the continental shelf, seaward of Pine Island Glacier. This will be sea ice dependent (more likely to be deployed if heavy sea ice is frustrating attempts to gather data from the ship), and will involve up to 9 missions.

4. Radiosonde balloon deployment
Up to 40 radiosonde balloons will be deployed over the continental shelf seaward of Pine Island Glacier to collect data on atmospheric conditions.

2.3.2 iSTAR B – "Ocean Under Ice"

This project aims to understand how oceanographic processes operating beneath the floating ice shelves of Pine Island Bay lead to changes in the melt rate experienced by the ice shelves. Simultaneous measurements of the water properties beneath the glacier and of the rate at which the base of the glacier is melting into the ocean will be taken.

Observations will be made of the distribution of water properties beneath the ice shelves and the circulation and mixing processes that determine that distribution. In order to do this an Autonomous Underwater Vehicle (AUV) equipped with a range of instrumentation will be used. The vehicle will be deployed from the RRS James Clark Ross and will operate unattended beneath the ice for periods of up to 36 hours before being returned to the ship.

In addition to the work under the ice, high precision autonomous radars will be deployed on the ice shelf surface. These will measure the changes in ice thickness caused by basal melting to the order of 1mm over a 1 km range. The radars are engineered to allow year-round autonomous operation and monitoring of the gradual change of ice thickness with time.

Eight radar systems will be deployed in the field by personnel who will be flown to specific locations on the ice sheet in January and February of 2014. It is intended that all systems will be removed in January and February of 2015. Figure 3 illustrates the intended location of both aspects of the iSTAR B project.

The data collected on this project will be used to model the flow of water beneath the glacier and in the sea to the north of it. Using this model it will be determined how heat that is transported by ocean currents melts the ice shelf. This will allow better predictions to be made on how future changes in climate will impact PIG and the subsequent rise in sea level.

2.3.3 iSTAR C – "Dynamic Ice"

The aim of the iSTAR C project is to understand how processes responsible for thinning the floating ice shelf are also influencing the thinning on the trunk and tributaries of PIG. The study will involve taking measurements of the bed beneath PIG to determine how it influences rates of propagation and rates of thinning.

Data will be collected from the glacier during two field seasons, 2013/14 and 2014/15. Each field season will involve a 70 day, 1000 km-long traverse described in Section 2.4.2 comprised of 12 science and support staff. (Personnel involved with iSTAR D parts 1 and 3 will also be present on the traverse.) See Figure 4 for the location and route of the traverse.

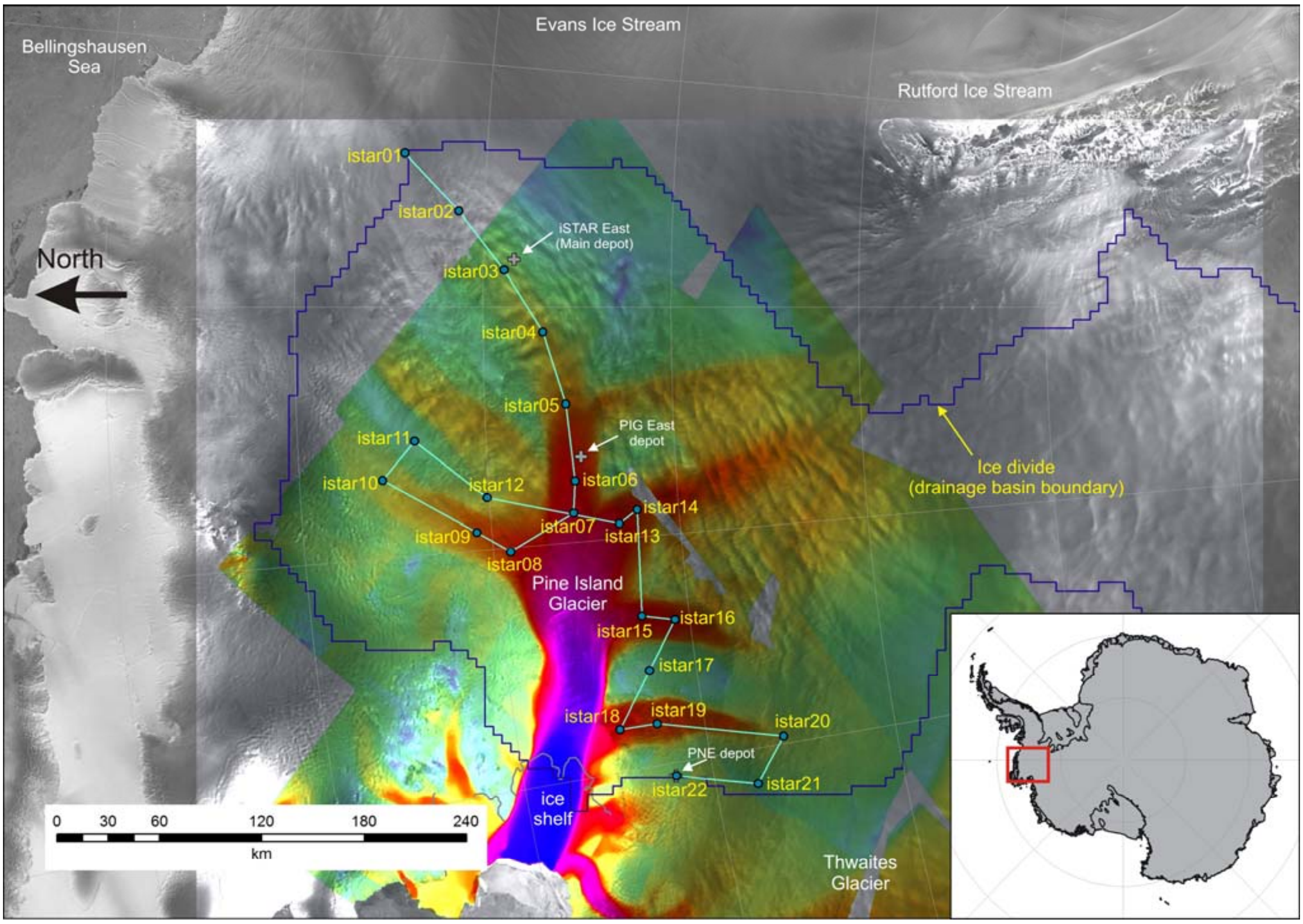

Figure 4. Proposed iSTAR tractor-train traverse route.

During this science traverse, radar and seismic surveys will be conducted to obtain images of the bed topography, the internal architecture of the glacier and strain rates. Remote sensing by satellite will be used to measure the changing configuration of the glacier in areas that cannot be accessed on the ground.

In addition eleven GPS stations will be installed in 2013/14. Each station will comprise of 2 wind generators, a solar panel, 4 sealed lead acid batteries, a GPS receiver and an antenna. The locations of the eleven sites are given below. The GPS stations will measure the movement of the ice and any changes in its flow. They will be removed in 2014/15.

Table 2. iSTAR C - GPS station co-ordinates

Traverse Station	Co-ordinates
iSTAR_06	W 093.7183, S 75.4557
iSTAR_07	W 094.4597, S 75.4399
iSTAR_08	W 095.07, S 75.09
iSTAR_09	W 094.6306, S 74.9559
iSTAR_13	W 094.69, S 75.67
iSTAR_14	W 094.2306, S 75.805
iSTAR_15	W 096.73, S 75.75
iSTAR_16	W 096.8979, S 75.9264
iSTAR_17	W 097.93, S 75.74
iSTAR_18	W 099.0726, S 75.6167
iSTAR_19	W 099.0748, S 75.8031

In addition to these main GPS stations, 26 "ADIOS" (Aircraft Deployable Ice Observation Systems) instruments will be installed on the ice sheet surface. As with the main GPS systems (above), the ADIOS will track the movement of the ice. Precise locations for these deployments will be finalised during the traverse but will be within the Pine Island Glacier – Thwaites Glacier region (Figure 4). The ADIOS are designed to be deployed from an aircraft (BAS Twin Otter) and hence can be installed in crevassed areas where access on the ground is not possible. This also precludes retrieval afterwards, and at the end of their lifetime, the instruments will be abandoned. The expected lifetime is 2 years. After this period, battery power will be exhausted and the instruments will most likely be buried (snow accumulation is anticipated to be of the order of 1 m per year). Ice flow speeds in the deployment region are high and the instruments will reach the ocean and fall to the seabed within 50 years.

Each instrument comprises a ~3 m plastic tube with an aluminium nose-cone and fins. Inside the tube is a small GPS receiver and telemetry system. Once deployed, this measures the instrument's location and transmits the signal back to the UK via an Iridium satellite link. The details of each sensor are: total weight 10.7 kg, comprising 4.6 kg polypropylene (non-toxic, non-bioaccumulating), 5 kg aluminium, 1 kg batteries (Lithium Sodium Chloride, containing 46.8 g lithium), 100 g PCB electronics, 10 g capacitors and 20 cm diameter parachute (UV-degradable Kevlar and bio-degradable nylon).

The heavily crevassed areas of this part of the ice sheet are also some of the most important for understanding the propagation of dynamic changes in the ice from the grounding line up into the catchment basins. Hence, data from these areas is particularly valuable and the eventual loss of the instruments is accepted.

The data collected during iSTAR C will be used to verify a set of computer simulations of the dynamics of PIG. Each of these will test a particular aspect of the glacial flow, and allow current knowledge and hypotheses to be tested against real data. The resulting models will be demonstrably more reliable in simulating past changes on the glacier and enable more accurate predictions to be made on future changes to the glacier and the consequential contribution to sea-level rise.

Overall, this programme will deliver significant improvements in understanding of how glaciers in general interact with their beds, and very specific lessons about PIG as one of the most rapidly-changing and significant glaciers on the planet.

2.3.4 iSTAR D – "Ice Loss"

The aim of iSTAR D is to understand the contribution that ice lost from the Amundsen Sea sector of West Antarctica is making to rises in sea level. Over the past twenty years satellite data have provided significant evidence of the ice lost from PIG. However limitations in the application of this data now require ground proofing.

iSTAR D is split into three main components.

1. *<u>Neutron probe & radar</u>*

   Two neutron probes will be used to measure profiles of snow density from which accumulation and densification rates can be determined. This work will be undertaken as part of the science traverse described in Section 2.4.2 over a seventy day period. See Figure 4 for the route of the traverse.

   The procedure involves either auguring a 5 cm diameter access hole to a depth of approximately 12 metres or, using the 13 cm boreholes that will be produced by the ice coring (see iSTAR D Part 3 iCORES pg 20).

   Once in position in the hole, the probe will be slowly raised up to the surface by a cable and winch system. Signals from the probe travel up the cable to a logger and are recorded on a computer. The profiling speed is approximately 3m per hour. Neutron probe measurements will be taken at each location along the traverse (see Figure 4).

   Should the probe become stuck within the borehole, it is proposed that glycol will be used to release it. A safe system of working has been outlined in the local rules for the operation of the neutron probe which are included in Annex A. These have been approved by the BAS Health and Safety Office. A risk assessment of the use of the probe has also been included in Annex B.

   Each probe contains an Americium 241 Beryllium sealed source of 1.85GBq. The sources will remain sealed throughout the duration of the project. At the end of the 2013/2014 season the probes will be stored overwinter at the PNE depot (See Figure 4.) They will be returned to the UK at the end of the 2014/2015 season.

A GPS position will be recorded and an aluminium marker pole with a flag attached to it will be left at each hole to ensure the sites are easily visible when revisited in 2014/2015. Each hole will be protected by short lengths of 5 cm diameter white plastic plumbing piping. The poles and plastic pipes will be removed in 2014/15.

To complement the neutron probe data, three different radars will record data of the layering within the snowpack along the traverse. This will allow the results from the neutron probe to be extrapolated between locations and enable the ground-based observations to be correlated with corresponding ones from satellites. Two radars will be operated by the science teams on the traverse. A third will be mounted in a plane which will over-fly the traverse route in 2014/15.

2. *GPS & Cosmogenic dating*

This part of the iSTAR D project will aim to gather further historical data about the ice sheet and measure how fast the earth's crust is uplifting in response to the removal of past ice.

In parallel to the neutron probe and radar activities a separate team of scientists based at Union Glacier will visit three nunataks (rare exposures of the Earth's crust) south of the Pine Island Glacier basin. At each nunatak site samples of erratic boulders (ice-transported rocks) will be taken for further geo-morphological analysis. Fifteen samples of approximately 2-4 kg in mass will be collected per nunatak site. Most samples will be taken as whole boulders however a small number of bedrock samples will be also required and these will be obtained using a battery operated saw.

Once analysed, the samples will provide evidence of historical ice sheet retreat. The samples will be taken along an altitudinal transect so that the full ice sheet thinning trajectory through time can be established. Where possible, samples will be taken at an approximate 10m vertical separation.

A Section 12 permit from the FCO has been applied for as per the requirements of the Protocol on Environmental Protection with regard to collecting rock samples from Antarctica.

In addition one autonomous battery-operated GPS receiver will be installed on the bedrock of each nunatak to determine the motion and uplift of the earth. The batteries will be sealed lead acid batteries installed within sealed aluminium enclosures. They will remain in place for three seasons and be removed in the 2016/2017 season. Annual servicing flights will ensure that they remain in working order during that period. Once the GPS is removed a monument (small metal plate bolted to the rock) will remain insitu to provide a precise location reference point from which future scientific work can be compared.

The two scientists involved in the field work will stay at the established summer field base at Union Glacier. Day trips to the nunataks will be conducted by Twin Otter plane. No overnight stays in the field are planned.

3. *iCORES*

The iCORES team will aim to collect data relating to ice accumulation on Pine Island Glacier to determine whether changes in the accumulation rates are impacting the thinning of the glacier.

Ten sites have been chosen which are listed below. This project will be part of the second science traverse (2014/15 season) described in Section 2.4. 2. At each site a 50m deep ice core will be dry drilled (i.e. without drilling fluids or hot water). Each ice core will be cut by a band saw in the field to one quarter sections lengthways for retrograde freezing to the UK. The remaining three quarters of the core will be left on site. The quarter sections will be analysed in the UK for stable water isotopes and major ionic chemistry at high resolution to reveal seasonal cycles which will allow the cores to be accurately dated and provide accumulation rate histories.

Table3. iSTAR D - iCores station co-ordinates

Traverse Station	Co-ordinates
iSTAR_01	S74.565 W86.913
iSTAR_04	S74.319 W90.524
iSTAR_06	S75.4557 W93.7183
iSTAR_07	S75.4339 W94.4597
iSTAR_08	S75.09 W95.07
iSTAR_10	S74.442 W93.448
iSTAR_13	S75.67 W94.69
iSTAR_15	S75.75 W96.73
iSTAR_18	S75.6167 W99.0726
iSTAR_20	S76.404 W99.828

2.4 Description of Support Activities

2.4.1 Fuel Depot

The main fuel depot for iSTAR has already been created at iSTAR East (iSTRE) located at S75 10.227 W89 00.423 and is subject to a previous IEE. The details provided here are for information only. The fuel stored at the depot is listed below;

- 31,223l of AVTUR in 6 bladders
- 6 x 205l drums Petrol
- 3 x 205l drums Avtur
- 1 x 205l drum of Kerosene
- 13 x jerry cans of Petrol

It is the intention that this depot will be in place for approximately two years and may be restocked periodically by BAS Twin Otter, ships, or tractors. The depot is positioned on snow ~50 km from the top of the ice divide. The closest rock outcrop is approximately 200 km away and the nearest known crevasses are ~150 km away. Empty drums will be removed periodically and all drums will be removed on abandonment of these depots.

If necessary, the science traverse will also make use of other BAS Operations depots (i.e. not specific to iSTAR), e.g. PIG East Depot (Figure 4) as directed.

2.4.2 Science Traverse

A 70 day mobile expedition comprising of over-snow vehicles, fuel, science equipment and personnel will be undertaken in both the 2013-2014 season and the 2014-2015 season. This is hereafter referred to as 'the science traverse' and is referred to above in the iSTAR C and D projects sections 2.3.3 and 2.3.4. The traverse route will be 1000 km long (Figure 4). During the 2013/14 field season the traverse will go from location iSTAR_01 to iSTAR_22, where the main traverse infrastructure will be left over the 2014 austral winter. In the 2014/15 field season the same route will be followed in reverse. Each traverse will comprise 12 people, comprising 4 traverse staff provided by BAS and 8 people for the iSTAR C and iSTAR D science projects (from UK Universities and BAS science staff).

The route of the science traverse is provided in Figure 4. The current location of the vehicles is at Sky Blu, where they have been overwintered in preparation for the coming season. The rest of the infrastructure equipment, plus some pre-deployed scientific cargo, is at the iSTAR East Depot. All personnel and remaining equipment, particularly the scientific equipment, will be flown to Sky Blu or iSTAR East from Rothera on BAS aircraft.

2.4.2.1 Tractor Train & Skidoos

The traverse infrastructure known as the 'tractor train' consists of the following:

- 2 x Kässbohrer Pistonbully PB300 Polar tractors;
- 2 x long poly sleds, each with four fuel bladders attached on top;
- 1 x short poly sledge

- 3 x metal cargo sledges, one of which carries an accommodation caboose.
- A number small wooden or plastic utility sledges

The tractors, named Polar 1 and Polar 2, will tow the fuel, personnel, and science equipment. Each tractor has a blade installed to shovel snow and they are able to tow large loads at reasonable speeds with good fuel efficiency. Fuel consumption of both tractors over two seasons will be approximately 19,000 litres of AVCAT.

The tested combined total weight towed by the two tractors (including their own weight) during the deployment phase was 79 tons. The heaviest load towed by one tractor is over 43 tons. The average speed of the tractors is anticipated to be 12 km/h based on the use of the vehicles during the initial deployment phase.

The poly sleds are an innovative new type of sledge designed for towing fuel. They consist of a 21-m long sheet of high molecular weight (HMW) polyethylene, with metal towing hitches on both ends. This plastic is light, wear-resistant, and much more flexible than metal sledges. The two main poly sleds will carry four fuel bladders, each capable of holding 1,500 US gallons of AVCAT or AVTUR fuel (approximately 20 tons in weight when the bladders are full). In total up to 12,000 US gallons of fuel can be transported in this manner. One spare bladder will be available on the spill kit sledge to facilitate fuel transfers and for emergency use.

A third, shorter, poly sled is used to tow four skidoos behind the tractor train when these are not in use. The more traditional sledges in the tractor train are steel Lehmann cargo sledges. These are heavy, solid sledges used to transport fuel barrels, field and scientific equipment. Additional cargo will also be carried on the back of the tractors.

Skidoos and utility sledges (nansen, komatik, or pulk) will be used for smaller groups working away from the main tractor train, and to tow some of the scientific equipment during the traverse. The skidoos have four-stroke engines, giving better fuel economy, more torque, and lower emissions than past two-stroke models.

A comprehensive fuel spill kit will be carried as part of the science traverse on a single Komatik or Siglin sledge to ensure easy access and deployment. The equipment includes;

- Spare bladder;
- Spate pump and hoses;
- Emergency bladder repair kit; and
- Overpack drum containing spill mats and drum funnels.

2.4.3 Field Camps

During the science traverse the accommodation caboose is intended mainly as a shelter, work space, cooking area, and transportation area rather than a sleeping area. It consists of a modified shipping container mounted on one of the Lehmann sledges, and is fitted out with a kitchen, snow melting system, generators, batteries, and communications equipment. Toilet and shower facilities are also included. Solid human waste and all garbage will be contained and returned to Rothera for disposal; liquid human waste and strained grey water will be disposed of on site.

During the science traverse, tents will be erected both for accommodation and for additional working space if required. These field camps will be occupied for several days at a time while experiments are carried out. It is anticipated that 22 separate camps will be established during each season's traverse, for a maximum of 12 people. When the traverse reaches location iSTAR_22, a camp will be established for up to two weeks whilst the overwinter depots is established and final activities completed.

Power at the field camps will be provided by batteries, solar panels and small generators (1-3 kW). During travel, the batteries will be charged from the vehicle engines. Cooking will use bottled propane gas, electricity and paraffin; potable water (from snow melting) and heating will come from AVTUR-fuelled Webasto heaters.

2.4.4 Overwinter depot

Once the 2013/14 traverse is completed, most of the traverse equipment will be left at station iSTAR-22 over the 2014 austral winter. This is the same location as an existing US-NSF field camp with typical activity and infrastructure required for major fixed-wing (LC-130) and field operations. The US camp is scheduled to be closed and decommissioned prior to the arrival of the iSTAR traverse.

The major iSTAR infrastructure (tractors, caboose, sledges, fuel, and equipment) will be placed on 2 m-high berms of snow. This is a long-established and effective technique which greatly reduces the burial of equipment by snow over the winter. It was used regularly in the region by the US Antarctic Program (USAP) whilst they operated a summer-only (up till 1988) facility at Siple Station (S 75° 55', W 083° 55'), approximately 300 km East of Pine Island Glacier.

Two categories of equipment will not be stored on berms.

- Batteries will be buried ~1 m below the snow surface to protect them from the coldest of the winter air temperatures. These will be located away from the berms, marked sufficiently well that successful re-location can be guaranteed after two winters (i.e. one more than expected), and an absolute position determined by GPS receiver.

- The two neutron probes will be buried ~1 m below the snow surface to protect them from the coldest of the winter air temperatures. These will be located away from the berms, marked sufficiently well that successful re-location can be guaranteed after two winters (i.e. one more than expected), and an absolute position determined by GPS receiver.

2.4.5 Removal of Science Traverse Equipment

Completion and demobilisation of the second science traverse in the 2014-2015 season will mark the end of the core iSTAR Programme fieldwork component. Personnel and scientific equipment will be uplifted by BAS Twin Otter from the final traverse location to Rothera. From then onwards, BAS will re-deploy the traverse infrastructure (vehicles, sledges, fuel bladders, accommodation caboose) for other operational tasks. The details of these future tasks have yet to be determined but they will most likely include transfer of fuel and heavy equipment to deep-field locations in West Antarctica in support of scientific projects. If no tasks are scheduled immediately after the second science traverse, the tractor train will be moved to Sky Blu.

2.5 Duration & Intensity of Activities

Table 5 provides a summary of the duration of each project and how many personnel are involved over a specific period of time.

Table 5. Duration and Intensity of Proposed Activities

iSTAR Theme	iSTAR Project	Duration and intensity	Dates of activity
(iii) Ocean Forcing	iSTAR A	• 45 day cruise on board JCR 24 hour working • 7 x scientists	January – February 2013-2014
	iSTAR B	• 15 day cruise on board JCR • 1 scientist x 10 days in the field	January 2013-2014
(iv) Ice Sheet Response	iSTAR C	• 5 x scientist x 70 days in the field • 4 scientists x 70 days in the field	2013-2014 Season 2014-2015 Season
	iSTAR D (part 1) Neutron Probe & radar	• 1 x scientist x 10 days at Rothera; 3 scientists x 70 days in the field • 1 x scientist x70 days in field	2013-2014 Season 2014-2015 Season
	iSTAR D (part 2) GPS	• 2 scientists x 10 days in the field - BAS support staff 1 day per Nunatak (x3) • BAS support staff 1 day per Nunatak (x3) • BAS support staff 1 day per Nunatak (x3)	2013-2014 Season 2014-2015 Season 2015-2016 Season 2016-2017 Season
	iSTAR D (part 3) iCores	• No activity • 2 scientists x 70 days in the field	2013-2014 Season 2014-2015 Season
Support Activities	Fuel Depot	• 500 metre radius disturbance zone around depot	2013-2014 Season 2014-2015 Season
	Science Traverse	• 4 (5 in 2014/15) x support staff x 70 day traverse covering a distance of 1000 km by 2x Pistonbully tractors towing a variety of sledges. • Max width of tracks created will be 30metres. (Up to four skidoos will also cover part of this distance) • Skidoos to travel maximum of 100km outside of traverse route for research purposes.	2013-2014 Season 2014-2015 Season
	Field Camps	• iSTAR C & D (part 1 and 3) – 12 science and support staff • 22 x separate camps over 70 day period. 10 camps to be established for a 2-3 days, 2 camps to be established for up to two weeks.	2013-2014 Season 2014-2015 Season

Section 3

DESCRIPTION OF THE ENVIRONMENT

3 Description of the Environment

3.1 Amundsen Sea

The Amundsen Sea is an arm of the Southern Ocean off Ellsworth Land and Marie Byrd Land in Western Antarctica. It is bounded by Cape Flying Fish, the north western tip of Thurston Island to the east and Cape Dart on Siple Island to the west. The Pine Island and Thwaites Glaciers both flow into the Amundsen Sea. PIG flows into Pine Island Bay which is approximately 65 km long and 50 km wide on the southeast extremity of the Amundsen Sea. The Amundsen Sea is covered by ice for the majority of the year.

3.2 Pine Island Glacier

The Pine Island Glacier drainage basin covers an area of approximately 165,000 km^2 and has an elevation ranging from sea level to 2300 m. It comprises a main basin and a southern lobe (Figure 2).

The proposed iSTAR science traverses will be undertaken in the main basin the basin is dominated by the fast-flowing (up to 3.75 km a^{-1}) Pine Island Glacier and its tributaries. Within the main basin there is no ice-free ground. The area is not a known habitat for any native flora and fauna. The area is known to have been visited on a number of occasions, including a US tractor-train in 1960/61 and BAS geophysics field projects in 2006/7, 2007/8, 2010/11 and 2011/12, as well as the deployment traverse for iSTAR in 2012/13. There are no protected areas in the region of the iSTAR traverses.

Meteorological records are available from an un-calibrated Automatic Weather Station operated on Pine Island Glacier between December 2006 and February 2008. The mean temperature over this period was around -20° C; mean summer temperature was -9° C. Mean summer wind speed was 7 m s^{-1} (13 knots) from a predominantly easterly direction (i.e. blowing down the glacier).

3.3 Nunataks

Three nunataks (rare exposures of the Earth's crust) south of the Pine Island Glacier basin will be visited as part of the project. At each nunatak site samples of erratic boulders (ice-transported rocks) will be taken for further geo-morphological analysis. Whilst there are low levels of biological material recorded for these nunataks some lichens are known to be present. Most life is microbial in nature and micro invertebrates have been recorded such as tardigrades, nematodes and rotifers, but not micro arthropods as yet. Higher plant life is absent and mosses are extremely rare.

Section 4

ALTERNATIVES

4 ALTERNATIVES

4.1 Do nothing

The Antarctic Ice Sheet contains a major reservoir of freshwater. Changes to the ice sheet will induce large changes in global sea level and freshwater flux to the ocean, which in turn can affect ocean circulation and climate. Although many factors contribute to sea level rise, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007) identified the cryosphere as the largest source of uncertainty in predictions of future sea level rise over the coming 50-200 years.

The proposed activity will improve understanding of key processes that affect ice sheet stability. It will enable the incorporation of this understanding into models leading to an improved ability to predict future ice sheet behaviour. This 'do nothing' alternative has been considered and rejected on the grounds of the important scientific benefit that will be gained from carrying out the programme.

4.2 Do the activity elsewhere

PIG drainage basin is a critical location for ice sheet stability studies and in particular, their link with ocean circulation in the Amundsen Sea. This makes it the most appropriate location for the proposed activity. In 2010, the UK Natural Environment Research Council recognised this and approved funding for a major Research Programme focused specifically on Pine Island Glacier and the adjacent Amundsen Sea.

PIG currently contributes more to global sea level than any glacier in the world. Its speed increased by almost 50% between 1992 and 2007 (Rignot, 2008) and acceleration continues (Scott et al., 2009). The grounding line has retreated inland by up to 20 km since 1996 (Joughin et al., 2010), concurrent with lowering surface elevation and changes in the glacier's dynamics (e.g. Wingham et al., 2009). These changes gave a reported increase in ice discharge from PIG of ~30 Gt yr^{-1} between 1996 and 2007 (Rignot et al., 2008). Oceanographic models of the nearby continental shelf suggest these changes in the glacier coincide with a period of warmer waters crossing the Amundsen Sea continental shelf and reaching the underside of the glacier's ice shelf and grounding line (Thoma et al., 2008).

The option of using an alternative location has been rejected on the grounds that the proposed studies will enable more accurate predictions to be made with regard to climate change and the impact on global sea level rise.

4.3 Do the activity with alternative science

The Amundsen Sea and Pine Island Glacier are the main focus of the study because this region has seen some of the greatest rates of ice loss in Antarctica over the last decade. This has been established in the past largely with the use of satellite observations.

The overall purpose of the programme is to gain a better understanding of the processes affecting ice sheet stability in order to make more accurate predictions about their future behaviour and the subsequent impact on sea level rise. In order to do this, on the ground (and in the ocean) observations are now required. An array of different scientific methods and techniques are proposed for each part of the iSTAR Programme in order to gain as much data as possible about the complex interactions of the processes taking place. These are considered to be the most appropriate techniques currently available.

4.4 Do the activity with alternative logistics

The option of completing the proposed activities with alternative logistics and alternative vehicle routes were considered in the original IEE (2011). At NERC's request, BAS conducted a feasibility study which included an assessment of the alternative logistics approaches. The study concluded that the majority of the options considered were financially constrained, impractical, and unable to deliver the requirements of the programme or were simply unachievable. The options which were considered logistically possible did not appear to provide a long-term legacy of improved logistical capability and were therefore also rejected.

The use of the iSTAR tractor train is a new and innovative approach. It is proving to be more cost effective, efficient and reliable as a method of delivering both the logistics and science support for a project as large, complex and remote as iSTAR, than any other traditional method.

Section 5

IMPACT IDENTIFICATION & MITIGATION

5 IMPACT IDENTIFICATION & MITIGATION

Environmental impacts associated with each iSTAR project have been identified in this chapter. Mitigation measures to minimise or avoid these impacts have been suggested beneath each impact.

Table 6 provides a summary of those impacts and provides a qualitative measure of the probability of the impact occurring and the severity of the impact if it were to occur.

A staff briefing will be provided to members of the iSTAR Programme prior to deployment in the 2013/2014 season. This will provide an overview of this IEE and specific guidance on compliance with the mitigation measures committed to within this document.

5.1 iSTAR A – "Ocean2ice"

5.1.1 Seal Tagging

Potential Impact: During the seal tagging activity there is a possibility that the animal could become distressed or harmed. Up to 20 seals will be tagged.

Mitigation: Whilst the seal is sedated the heart and respiratory rate of the animal will be carefully monitored and should there be a need to reverse the procedure rapidly Dopraxam and adrenaline will be available. After approximately 30 minutes the seal should have sufficiently recovered to resume normal behaviour and will be released.

The team will use established procedures covered in the UK by Sea Mammal Research Unit (SMRU) Home Office Project Licences. The procedure outlined above has undergone ethical review by the University of St Andrews and was approved in June 2013. The scientists involved in this work both have between 20 – 30 years worth of experience in handling and tagging seals. In addition a Section 12 Permit from the FCO has been applied for as per the Protocol on Environmental Protection.

Potential Impact: Change in behaviour of seal due to telemetry device.

Mitigation: Studies of seals which have been fitted with telemetry devices have been undertaken and there is no known long term affect on the animals. animals (McMahon, C. R., Field, I. C., Bradshaw, C., White, G. C. & Hindell, M. A. Tracking and data-logging devices attached to elephant seals do not affect individual mass gain or survival. Journal of Experimental Marine Biology and Ecology 360, 71 – 77, 2008).The tags will drop off at the seals' next moult (9 months later) and be lost in the sea.

5.1.2 Swath Bathymetry

Potential Impact: Whilst the multi-beam echo sounder is in operation sound waves will be emitted beneath the ship which may affect the hearing of marine animals in the vicinity and result in a change of behaviour. Approximately 3000 line-km of swath bathymetry will be collected over the Amundsen Sea continental shelf.

Mitigation: Prior to the operation of the echo sounder a cetacean watch will be undertaken to ensure that no marine animals are close to the ship. Studies by the Scientific Committee on Antarctic Research (SCAR) published in Antarctic Science Vol 17, (2005) concluded that the risk of a temporary threshold shift (i.e. negative impact to hearing) to marine animals to be low even in a small volume a few metres below a transducer. The likelihood of this activity to cause a negative impact is therefore low.

5.1.3 Ocean Deployed Equipment

Potential Impact: Deploying equipment into the sea bears the risk of becoming waste if it is not retrieved. Marine wildlife may be displaced if the equipment is deployed when animals are in the vicinity of the ship. It is anticipated that a total of around 200 CTD deployments will be made, with a similar number of VMP deployments.

Mitigation: All the equipment that is to be deployed from the ship including CTDs, gliders, MVPs, VMPs and autosubs have proven track records and will have been tested by the proposed teams prior to deployment. Risk assessments will be completed for all equipment that is to be deployed. Every effort will be made to retrieve the equipment because it will contain the data required to complete the research. Should any equipment not be retrieved due to a malfunction or other reason this will be logged on the BAS, Accident, Incident, Near Miss and Environment (AINME) database. Prior to the deployment of any equipment from the ship, a cetacean watch will be undertaken to ensure that no marine animals are close to the ship.

5.1.4 Radiosonde Deployment

Potential Impact: Waste materials will be generated once the balloon has burst and the radiosonde has fallen either into the sea or landed on the glacier.

Mitigation: The manufacturers of the radiosonde have undertaken lifecycle assessments to try to reduce the environmental impact. The balloon itself is latex and bio-degradable. Modern alkaline batteries are used which do not contain heavy metals. The other parts of the radiosonde are made up of high density polyethylene, polypropylene, expanded polystyrene, hot melt adhesive and steel sheet. Should the radiosonde land in the ocean it will sink and is of a large enough size to be a deterrent to animals wanting to eat it.

5.2 iSTAR B – “Ocean under ice”

5.2.1 Autonomous Radar Deployments

Potential Impact: Air pollution will occur as a result of deployment of the radars from aircraft flying over the PIG. Eight radars will be deployed as pairs in four locations: 75°S 101°W, 75°06'S 101°06'W, 75°12'S 099°30'W, 75°12'S 101°30'W.

Mitigation: Whilst it is recognised that the contribution of this activity to regional and global atmospheric pollution will be minor there will be a small cumulative effect. In order to minimise this impact multiple radar systems will be deployed on each flight to minimise the number of flights required. A plan will be devised to ensure that there will be optimal sequencing of site visits.

Potential Impact: Equipment may be left in the field, if markers are not easily recoverable.

Mitigation: The equipment has been designed to be recovered after being left in the field for a season and each site location will be recorded with a GPS waypoint. Site markers of a sufficient height will be positioned so that even after snow accumulation of 12 months they will still be visible to the naked eye.

5.3 iSTAR C – "Dynamic Ice"

5.3.1 GPS Deployment – Ice sheet

Potential Impact: Possible non-recovery of main GPS systems from ice sheet during 2014/15 season. Total number to be deployed is 11 systems.

Mitigation: The intention is to leave the GPS systems in the field for a ~ 12 months before revisiting, retrieving the data and removing them. All equipment will be tested prior to deployment and the GPS systems will be re-located after 12 months with the use of a site marker. Markers will be of sufficient length (e.g. 4m) to not get buried over the winter.

5.3.2 ADIOS instrument deployments

Potential Impact: Non-retrievable devices impacting wilderness and aesthetics of the region.

Mitigation: The total number of instruments required has been minimised by developing accurate deployment techniques (optical target-sight fitted to the aircraft). The construction materials for each device have been selected for low toxicity and degradability. The design of each device has been adapted to ensure that power consumption and battery requirements are minimised. The deployment locations are well-known and will be regularly tracked until the end-of-life of each device is reached.

5.3.3 Radar and seismic surveys

Potential impact
Equipment is powered by battery, petrol engine or AVCAT-powered hot-water boiler. Batteries could leak; fuel could be spilled when refuelling.

Mitigation
All equipment is designed for remote field use. Only sealed, gel batteries are used; these are contained in protective housing or box. All equipment will be well maintained prior to use and during the time in the field. Experienced staff will operate the equipment and will be briefed on spill response procedures

Potential impact
Excess explosives remaining after the seismic surveys have been completed. Explosives packaging (mostly cardboard) must be burned to comply with Health & Safety guidelines.

Mitigation
- Excess explosives will be either removed from the area by the departing tractors at the end of the fieldwork for deployment elsewhere, or destroyed by controlled detonation.
- Impact of burning the packaging minimised by using small pit dug in the snow; only small quantities are burned at a time and the fire is continuously monitored; once completed, the pit is re-covered with fresh snow.

5.4 iSTAR D – "Ice Loss"

5.4.1 Operation of Neutron Probe

Potential Impact: The greatest hazard associated with the neutron probe is a radiation leak that exposes personnel and the environment.

Mitigation: A separate risk assessment has been completed for the operation and transportation of the neutron probe. This is included in Annex B.
Except when in use, the neutron probes will be stored in Type A containers, giving protection against accidental damage of severity equivalent to a major transport accident. If the probe gets stuck during operation within the borehole it may be necessary to release it with the use of glycol. In order to do this personnel may be exposed to the unshielded probe for a short period of time. Procedures have been designed to ensure that should this occur, exposure rates are low and pose no risk to the health of personnel or the environment. Glycol contamination of the ice would result, however the environmental risk associated with this is low.

5.4.2 GPS Deployment – Nunataks

Potential Impact: To install the three GPS systems on the nunataks proposed to be visited, drilling of the bedrock will be required. The potential impact of this could result in permanent damage to extremely rare geological outcrops.

Mitigation: To mitigate this impact, sites will be carefully selected to avoid visually sensitive areas, in particular nunatak summits. Recommendations in SCAR's Environmental Code of Conduct for terrestrial scientific field research in Antarctic will be followed.

Potential Impact: Each GPS system will be powered by a lead acid battery which could lead to the potential leak of battery acid over time.

Mitigation: Each battery will be sealed inside an aluminium container to avoid any potential spillage.
Potential Impact: Each installation will be comprised of a solar panel, wind turbine and aluminium support. There is the potential impact that during installation packaging materials could become waste if left in the field or get blown away.

Mitigation: Careful choice of packaging materials will be undertaken during the planning and packing phases of the project to ensure that packaging materials are suitable to take into a windy location and that they can easily be removed from the field. Whilst in the field additional care will be taken and appropriate methods applied to ensure that waste will not be blown into the field and lost. All waste must be removed from the field via Rothera and packed according to the BAS Waste Management Handbook.

Potential Impact: The intention is to leave each installation in the field for three consecutive seasons after which the aforementioned equipment will be removed but a small metal plate will remain indefinitely for future scientific reference. The impact of this is that a site which currently is considered to be remote will lose some its wilderness value.

Mitigation: Sensitive site selection will help to mitigate this impact. In addition the sites have been visited on previous scientific expeditions and are therefore not entirely pristine in nature. Marking and logging the sites will provide an accurate record of where science has been undertaken and will aid future comparative research.

5.4.3 Rock Sampling on Nunataks

Potential Impact: Aesthetic damage to the nunataks may occur as a result of removal of rock sampling and the use of a rock saw. Up to twenty five samples of approximately 2-4kg in mass will be collected at each of the three nunataks.

Mitigation: To mitigate this impact, sites will be carefully selected to avoid visually sensitive areas, in particular nunatak summits. In addition where possible whole cobbles will be taken as samples rather than sawing samples off a larger rock or outcrop. Where it is unavoidable to use the rock saw, dust creation will be minimised with the use of snow. Sawn edges will be rounded off to give a more natural look to the rock. A Section 12 permit from the FCO has been applied for as per the requirements of the Protocol on Environmental Protection with regard to removing rock samples from Antarctica.

Potential Impact: Damage to geology, flora and fauna from personnel accessing the site. Importation of non-native species to ice free areas.

Mitigation: To ensure that there will be minimal damage to the locality the scientists will avoid areas of sensitive morphological features or areas with visible biota. All equipment and materials required for the proposed activity will be thoroughly cleaned before dispatch to Antarctica. Practices in SCAR's Environmental Code of Conduct for terrestrial scientific field research in Antarctica and the BAS Bio-security Handbook will also be followed.

5.4.1 Auguring (for the neutron probe work) and Ice Coring

Potential Impact: Using generators to power the auger or corers will require the use of petrol and oils in the field. The auger requires a 2 kW generator and the ice coring requires a 5kVA generator. There is a low risk of a fuel spill associated with this activity. In addition the use of batteries could lead to the potential leak of battery acid. Waste will be generated as a result of this activity.

Mitigation: All equipment will be well maintained prior to use and during the time in the field. Experienced staff will operate the equipment and will be briefed on spill response procedures outlined in the BAS Traverse Operations Manual (2013). All waste must be removed from Antarctica via Rothera and packed according to the BAS Waste Management Handbook.

5.5 Support Activities

5.5.1 Science Traverse & Field Camps

Potential Impact: Aesthetic damage and reduction of wilderness value may occur as a result of the science traverses in areas which have not been visited previously.

Mitigation: A log of all the fuel depots, camps and traverse routes will be maintained at BAS for future reference by the Traverse Leader. A record of equipment which is deployed and left in the field temporarily or permanently will also be made by the Traverse Science Leader. Justification for the project to be undertaken in the PIG basin has been provided in the Alternatives Section 4.3.

Potential Impact: Human waste, general rubbish and hazardous waste will be generated at field camps and by the science activities. Based upon an average adult producing 1.8 litres of urine and faeces per day the Science Traverse and field camps will generate approximately 1,500 litres.

Mitigation: All staff will comply with the BAS waste management policy and will follow the procedures outlined in the BAS Waste Management Handbook (BAS, 2013) and summarised below.

- All wastes (except for urine, grey water and explosives packaging) will be packed in appropriate containers and returned to Rothera. The traverse will be supplied with a copy of the waste management guidelines for field parties, and colour coded waste sacks for the separation and disposal of wastes.
- Solid human waste and waste food will be collected in UN approved containers and returned to Rothera for incineration.
- Urine and grey water from domestic use will be disposed on-site at each location along the traverse.
- Excess explosives will be destroyed by controlled detonation.
- Explosives packaging will be destroyed by supervised open burning, as required by Health and Safety protocols. All other open burning is prohibited.
- Wastes will be stored appropriately to ensure that wind blow does not occur as outlined in the Traverse Operations Manual (2013).

Potential Impact: Snow drifts will occur during windy conditions where camps and depots have been positioned. These will temporarily change the local topography. In addition explosives will be used to make the traverse route safe by infilling crevasses, again changing the local topography.

Mitigation: Small snow drifts and the evidence of the traverse route will dissipate through natural processes once the infrastructure is removed. The traverse itself is merely a temporary safe route identified and not a permanent track. Evidence of the route taken will quickly be covered by snowfall.

Berms and larger drifts, particularly at the overwinter depots, will be levelled when no longer required. If this proves impractical they will clearly marked with flagged bamboos leaving their positions identifiable for as long as they vary significantly from the surrounding topography.

5.5.2 Fuel transfer and storage depots

Potential Impact: The large volumes of fuel that will be transported in bladders during the overall iSTAR programme present the risk of a fuel or oil spill. In the event of this happening localised pollution and contamination of snow and ice could occur. Up to 12,000 US gallons of fuel will be transported on the traverse, in 8 independent bladders.

Mitigation: The primary focus will be on spill avoidance. Methods will concentrate on techniques developed and in use by United States Antarctic Programme (USAP) for identical operations with fuel bladders. An Oil Spill Contingency Plan has been prepared for the iSTAR Traverse.

The fuel sledge assemblies comprise a double-thickness polyethylene layer for enhanced protection. Gate valves on all bladder fittings will ensure a backup system to the dry-break couplings. Repair kits for bladders and sledges will be carried on sledge specifically for fuel spill equipment. This will be the responsibility of the tractor train team who will undertake regular visual inspections throughout each day to ensure that the bladders are intact. Should a leak occur which cannot be sealed, fuel will be transferred to a spare bladder using spate pumps and hoses with dry-break couplings. Minor drips and spills will be contained by absorbent pads.

Potential Impact: Once a depot is left unattended for the winter, any subsequent fuel leak could potentially result in near-complete emptying of a bladder and the loss of more than 5,000 litres of fuel into the adjacent snowpack. Failure to secure bladder vents correctly would result in fuel loss during the winter driven by the weight of snow accumulation. Careless digging to remove snow around the bladders could also cause a tear.

Mitigation: The main risks to the fuel bladders which could result in a leak are associated with movement and transport- related operations; once a fuel sledge assembly is in-place and properly prepared, the chances of disturbance are negligible and any resulting leak is highly unlikely. Each fuel sledge assembly will be placed on a snow berm, followed by a period of regular checking for any disturbances and leaks. It is anticipated that this will involve checks every few hours over a continuous period of at least 2 days. The full period will be dictated by the length of time required for the other over-winter preparations and the schedule for uplift of personnel by BAS aircraft. Any leaks identified during this period will be addressed, either by repairs or by transfer to a spare bladder. A further checking period of at least two days will follow any repair or fuel transfer. Only plastic-bladed shovels will be used for any digging in the vicinity of the fuel bladders.

Critical to the over-winter integrity of the fuel sledges will be correct close-down procedures, especially the secure closing and locking of bladder vents. Dry-break couplings on the bladders will be backed up by gate valves on all fittings. A written procedure will be followed by trained and experienced personnel for the complete close-down sequence. Any waste absorbents or contaminated fuels must be removed from the field as hazardous waste and returned to Rothera before being disposed of. Procedures are outlined in the BAS Waste Management Handbook.

Potential Impact: Fuel leak from drummed fuel at depots.

Mitigation: Overpack drums are stored with the drummed fuel at the iSTRE depot location. Leaky drums can be placed inside the overpack drum which acts as secondary containment prior to the fuel being pumped elsewhere. Absorbents are stored on the oil spill sledge which will travel with the main tractor train.

Potential Impact: Minor spills and fuel leaks could occur during daily vehicle or generator refuelling. Spilled fuel would pass quickly through the surface layer of snow, and be absorbed by it. A small quantity may also evaporate. There would be no biological effect of a minor fuel spill or leak.

Mitigation: The tractors are fitted with a plumbed-in hose reel fuelling system, so minor fuel spills and drips should be limited to refuelling skidoos and generators. BAS minimises the risk of accidental fuel spills through careful attention to fuel management, at its stations and in the field. All reasonable precautions will be taken to ensure that minor fuel leaks and spills do not occur. Any minor fuel spills will be stopped as quickly as possible. A drum funnel and smaller fuel funnels will be provided to prevent spills. Absorbent mats and pads will be provided for immediate response to minor fuel spills and will be in place during any fuel transfers. Used absorbents will be treated as hazardous waste and returned to Rothera. Further information is provided in the Oil Spill Contingency Plan. A log of any fuel spills is to be kept for reporting on the AINME system.

Potential Impact: Failure to re-locate buried batteries and neutron probes at the depot after the winter; permanent loss of these items (undamaged) to the environment. These items will not be placed on top of berms, but buried ~1m beneath the snow surface to protect them from the coldest of the winter air temperatures, so they could become buried more deeply than the other parts of the depot.

Mitigation: Depot components (batteries and neutron probes) to be buried will be placed well away from berms to avoid any snowdrift enhancing burial. Each will be well-marked and both absolute and relative positions determined by GPS. Markers will be of sufficient height (e.g. 4m) that successful re-location can be guaranteed after two winters, i.e. one more than is expected.

5.5.3 Ship, aircraft and tractor train operations

Potential Impact: Air pollution will result from ship operations, deployment and uplift of the traverse parties (personnel and equipment) by BAS aircraft, traverse vehicle exhaust emissions (tractors and skidoos), and the use of petrol generators for electrical power.

Fuel consumption of the tractors during both the Science Traverses will be approximately 19,000 litres of aviation fuel (AVCAT). Fuel consumed by skidoos and generators is expected to be up to 4,000 litres of unleaded petrol. Fuel consumed for domestic use will be relatively small quantities of propane gas and paraffin. Emissions will be the standard products of combustion of these fuels, including carbon monoxide, carbon dioxide, nitrous oxides, sulphur dioxide, heavy metals and particulates.

The greenhouse gas emissions associated with the use of the AVCAT / AVTUR and petrol during the tractor train, and all other logistics (iSTAR ship time and flights) will be calculated for inclusion in the BAS carbon report.

Meteorological data indicate that emissions will generally be rapidly and thoroughly dispersed by the strong and regular winds. The main polluting activities will be the Science Traverses where emissions will be distributed in small quantities along the route rather than in one concentrated area. Due to the mobile nature of the activity it is unlikely that background levels will be significantly exceeded. The most extreme scenario would be the unexpected need for excessive vehicle use at a prolonged camp occupation. In this case, heavy larger particles, such as soot, are likely to have relatively short maximum transport distances, with background levels in surface snow samples probably being reached within 2 km downwind of any location.

Mitigation: Daily visual checks will be made of exhausts. Engines will be serviced at the required intervals and any maintenance to reduce atmospheric emissions carried out as required. Vehicles and generators will be shut down when not needed.

5.5.4 Import of Cargo

Potential Impact: Through the unintentional importation of non-native species carried on equipment and general cargo, the local ecosystems (particularly in ice free areas) within Antarctica could be impacted if the non-native species become established. Whilst there is a low probability of this occurring in the most of the locations proposed within this IEE, if the impact were realised the severity could be significant.

Mitigation: All equipment and materials required for the proposed activity will be thoroughly cleaned before dispatch to Antarctica. Practices in the BAS Bio-security Handbook and SCAR's Environmental Code of Conduct for terrestrial scientific field research in Antarctica will also be followed.

5.6 Cumulative Impacts

A cumulative impact is the combined impact of past, present and future activities over time or space. Previous expeditions to depot fuel and equipment have been carried out in the Pine Island Glacier region to aid the logistics of the iSTAR programme. These activities were assessed in a separate IEE and their impacts were considered to be less than minor or transitory in nature.

The iSTAR Programme is a collaboration of a number of different scientific projects covering a raft of scientific disciplines and techniques which are all focussed on the overall aim of improving understanding of ice sheet stability within this region. Individually these projects would not require the production of an IEE. However considered as one entire project it was considered appropriate to assess the impacts of the iSTAR programme collectively in one IEE.
Should the iSTAR Programme be extended for longer than described in this document or in different localities, further considered of the impacts will be made and an update to the IEE provided.

Table 6. Probability and Severity of Impacts

Activity	Effect	Possible Impact	Probability of impact occurring	Severity of impact	Preventative or mitigating measures
Ocean Forcing Theme – iSTAR A & B					
1. Seal Tagging	• Seals caught & sedated • Telemetry device fitted	• Distress and harm to seal • Change in behaviour due to telemetry device	Medium	Medium	• Seals to be selected based on apparent health. • Small number of seals to be tagged relative to population size. • Monitoring of heat rate and respiratory rate during sedation. • Fine adjustments to the sedation level are possible in the field and reversal drugs (Dopraxam and adrenaline) will be available. • Using technique endorsed by SMRU since 1986 • Tag will fall off during annual moult
2. ADCP Swath bathymetry	• Multi-beam Ecosounder operated beneath ship	• Damage to hearing of marine animals • Displacement of marine animals	Low Low	Low Low	• Cetacean watch prior to operation • SCAR Action Group considers the risk of temporary threshold shift to be very low, (only in a small volume a few metres below transducers) (2005 – Antarctic Science Vol 17).
3. Ocean deployed Equipment (CTDs, gliders, autosub, MVP, VMP)	• Equipment deployed at sea • Risk that equipment is irretrievable • Noise created by acoustic instrumentation	• Unexpected source of waste at sea • Displacement of marine animals due to noise of equipment	Low Low	Low Low	• All equipment designed to be retrieved • All equipment will be tested prior to deployment and only standardized techniques used. • Releases with a proven track record and long battery life, will be used. • Risk assessments completed for equipment deployment • Cetacean watch prior to operation
4. Autonomous radar deployments	• Aircraft flights required to deploy radar • Radars deployed on ice shelf	• Air pollution • Possible non recovery of systems in 2015	High Low	Low Low	• Deploy multiple systems per flight and minimise transit through optimal sequencing of site visits • Site markers to be of sufficient height for ease of re-location.

Activity	Effect	Possible Impact	Probability of impact occurring	Severity of impact	Preventative or mitigating measures
Ice sheet Response – iSTAR C & D					
5. Deployment of GPS Systems on ice sheet	• Equipment installed on ice sheet for a minimum of 12 months • (transportation covered below in Science Traverse)	• Possible non recovery of systems in 2015	Low	Low	• Systems designed to provide an accurate location • All equipment will be tested prior to deployment • Only equipment with a proven track record and long battery life will be used. • Risk assessments completed for equipment deployment
6. ADIOS deployment	• Instruments are non-retrievable	• Impact on wilderness and aesthetics of the region	High	Low	• Instruments buried after 2 years and will fall to ocean bed in 50 years. • Total number of instruments minimised • Low toxicity and degradability of components • Power consumption and battery requirements minimised.
7. Radar surveys; seismic surveys	• Battery- and generator-powered equipment • (transportation covered below in Science Traverse) • Use of small generators • Use of explosives	• Damaged batteries may leak • Fuel spill • Local snow contamination. • Excess explosives remaining once fieldwork completed	Low Low High	Low Low Low	• All batteries sealed and installed inside bespoke containers. • Staff briefed on spill response • Excess explosives removed from area or destroyed by controlled detonation • Packing burned to comply with Health & Safety requirements. Minimise impact using small pit dug in the snow and covered with fresh snow afterwards.
8. Auguring and Ice Coring	• Use of generators, fuel, batteries	• Fuel spill • Damaged batteries may leak acid	Low	Low	• Experienced staff to use equipment • Equipment to be well maintained • Staff to be briefed on spill response procedures
9. Use of Neutron Probe	• Use of neutron probe in pristine environment	• Radiation Leak • Excessive exposure to radioactive source • Impact on future science • Unexpected waste if probe is irretrievable • Glycol contamination	Low	High	• Risk Assessment completed for probe use • Only trained personnel to use equipment • Probe transported in Type A 'resistant to impact' box • Radiation Emergency plan to be followed should a transport crash occur • Radiation Monitor to be carried • Retrieval plan included in local rules document

Activity	Effect	Possible Impact	Probability of impact occurring	Severity of impact	Preventative or mitigating measures
Ice sheet Response cont.					
10. Deployment of GPS on nunatak	• Rock drilling to install equipment • Installation of solar panel, wind turbine and aluminium support • Equipment installed on nunataks for minimum of 12 months • Metal plates left in situ permanently	• Damage to rare outcrops of earth's crust • Damaged batteries could leak acid • Waste left in field from components or packaging materials • Loss of wilderness • Loss of wilderness	High Low Low High High	Medium Medium Medium Medium Low	• Careful selection of sites to avoid sensitive or visually important areas (avoid summits) • All acid in sealed batteries inside sealed aluminium containers • Equipment tested to ensure it will withstand winds • Careful choice of packaging to minimise volumes of waste and reduce wind blow during installation • Careful selection of sites to avoid sensitive areas (e.g. avoid summit) • SCAR Code of Conduct to be followed. • Small plates chosen to minimise impact.
11. Rock Sampling on Nunatak	• Collection of whole or part of erratic boulders or bedrock	• Aesthetic damage	High	Low	• Careful selection of sites to avoid sensitive areas (e.g. avoid summit) • Remove whole cobble where possible to avoid leaving fragments
	• Rock Saw Sampling	• Aesthetic damage and dust	Medium	Low	• Careful selection of sites to avoid sensitive areas (e.g. avoid summit) • Minimise saw use • Round off cut edges to look more natural • Use snow to reduce dust
	• Personnel accessing sampling site	• Damage to geology, flora and fauna	Low	High	• Team to walk on bedrock only • Avoidance of wet areas, zones of sensitive morphological features or areas with visible biota • Follow SCAR Code of Conduct

Activity	Effect	Possible Impact	Probability of impact occurring	Severity of impact	Preventative or mitigating measures
Support Activities					
12. Science Traverse	• Increased footprint of BAS operations	• Aesthetic Damage • Reduction of wilderness and pristine nature of localities • Impact on future science	High	Low	• Some locations have previously been visited. • Log of depots, camps and traverse routes to be kept at BAS for future reference • Log to be kept of all equipment deployed and any equipment which is not retrieved
13. Fuel transfer and storage depots	• Fuel spills and leaks • Failure to re-locate after winter storage	• Contamination of snow • Loss (undamaged) to the environment	Low	Medium -low	• All staff will be trained in documented fuel handling and spill response procedures. • Only robust, reliable fuel storage and transfer equipment will be used. • Spill equipment to be carried on specially allocated sledge travelling with tractor train. • Fuel spills to be logged on AINME. • Separate items well-marked and positions determined by GPS • Markers of sufficient height for re-location to be guaranteed after two winters, although only one is scheduled.
14. Ship, aircraft and tractor train operations.	• Atmospheric emissions	• Minor but cumulative contribution to regional and global atmospheric pollution inc. greenhouse gas emissions	High	Low	• Most efficient logistics planned to reduce fuel burn (and cost). • Use of well maintained and regularly serviced equipment. • Daily checks of exhausts. • Shut down vehicles and generators when not in use.

Activity	Effect	Possible Impact	Probability of impact occurring	Severity of impact	Preventative or mitigating measures
Support Activities cont.					
15. Operating field camps	• Waste generated • Snow drifts around camp structures and use of explosives to infill crevasses allowing safe transport.	• Contamination of ice. • Visual impact if scattered by wind. • Change to local topography	Low Low	Low Low	• All staff to be briefed on environmental protection including waste handling. • All waste (except urine and grey water) to be removed from the field in accordance with the BAS Waste Management Handbook. (Explosive packaging to be burnt in the field as per H&S regulations) • Camps to be cleared each day to prevent wind scatter. • Berms will be levelled when no longer required. • Drifts that may accumulate especially around depots will naturally dissipate. • Impact on crevasses, and evidence of the route taken, will be obscured by natural processes.
16. Importation of cargo	• Possible importation of non-native species	• Potential ecosystem alteration. • Impact on future science.	Very low	Medium (High if species become established)	• BAS Vehicle Cleaning Guidelines, SCAR / COMNAP Guidelines, CEP & BAS Bio security Handbook will be followed where appropriate. • All procedures include measures to ensure that soils, seeds and propagules are not transported to Antarctica. • Vehicles, cargo and personal clothing must be cleaned prior to importation. • If soil, seeds or propagules are accidentally imported they must be carefully collected and removed. Disposal may include incinerated at Rothera or removed from Antarctica.

Section 6

CONCLUSIONS

6 CONCLUSIONS

The iSTAR programme is an ambitious and complex scientific undertaking which will be operating in remote Antarctic locations predominantly on the Pine Island Glacier and in adjacent areas of the Amundsen Sea. Due to the rapid and significant changes in ice loss in this region the outcome of the studies will provide a greater international scientific understanding of ice sheet stability and subsequent impacts on global seal level rise.

The four main projects iSTAR A - "Ocean2ice", iSTAR B – "Under the ice", iSTAR C – "Dynamic Ice", and iSTAR D - "Ice Loss", have been described within this IEE and the associated activities assessed for possible negative environmental impacts. For each impact identified mitigation measures have been provided. Some of these mitigation measures have already been included into the design of the activity whilst others will be put in place in the field during the operation.

This IEE indicates that the proposed iSTAR Programme is likely to have no more than a minor and transitory impact on the Antarctic environment, provided the recommended mitigation measures identified in this report are carried out. It is therefore concluded that this activity should be allowed to proceed, and that a Comprehensive Environmental Evaluation (CEE) is not required.

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8 AUTHORS OF THE IEE

This Initial Environmental Evaluation was prepared by Dr Andy Smith, Clare Fothergill and Rachel Clarke, British Antarctic Survey.

Further information or copies of this IEE can be obtained from:

Clare Fothergill
Environmental Manager
British Antarctic Survey
High Cross, Madingley Rd
Cambridge, CB3 0ET
United Kingdom

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10 ANNEX A – Local Rules for Neutron Probe

This document contains the Local Rules agreed for the ISTAR project and will cover staff from the following institutions:

SCOTT POLAR RESEARCH INSTITUTE
UNIVERSITY OF READING
UNIVERSITY OF LEEDS
UNIVERSITY OF EDINBURGH
UNIVERSITY OF BRISTOL
BRITISH ANTARCTIC SURVEY (BAS)

These are the radiation employers for the ISTAR workers

ISTAR LOCAL RULES FOR THE USE OF NEUTRON PROBES IN ANTARCTICA

Location:

1. Rothera
2. Pine Island Glacier catchment area

Prepared by: E M Morris

Date: 10/07/13

Review Date: 10/07/14

Scope

These Local Rules comprise the guidelines for the safe use of Ionising Radiations for the ISTAR project and are written in accordance with the Ionising Radiations Regulations 1999 (IRR99) and the associated approved code of practice (ACoP). They apply to use of the Modified Wallingford Neutron Soil Moisture Probe as part of the Ice Geophysical Logging System (IGLS) in Antarctica under the particular conditions of the iStar project. They apply to normal day-to-day work, and to contingency arrangements in case of a reasonably foreseeable accident. Working in line with these rules will ensure safe working with this material and compliance with the Ionising Radiation Regulations.

Relation to other Local Rules

The **ISTAR Local Rules** have been developed from Local Rules used by CEH-Wallingford covering use of Wallingford neutron probes on a daily basis for soil water measurement since 1980. These **CEH Local Rules** were adopted by BAS when the Wallingford probe was first used in BAT in 1997, and were extended by the University of Cambridge (**SPRI Local Rules**) to cover the modified probe used annually in the Arctic since 1999 and in Antarctica (Patriot Hills) in 2006. The **University of Leeds Local Rules** developed for use in Antarctica in 2009 have been consulted and, where appropriate, material from these rules has been incorporated into the following sections.

Description of the radiation source/device

The Modified Wallingford Neutron Soil Moisture Probe consists of

1. a steel can (hereafter referred to as "the probe") containing a sealed fast neutron source and a slow neutron detector. The neutron source is a X20 Americium 241-

Beryllium sealed capsule (Special Form certificate USA/0659/S) of nominal strength 1.85 G Bq (50mCi).

2. a plastic transport shield with polypropylene moderator. The probe is connected to a data logger via steel geophysical logging cable wound on a winch (length 40 – 250 m)

The modifications to the standard Wallingford probe were approved by the NRPB Radiation Protection Adviser on 20 March 2003 (report Number NRPB/RPA/VR/5/8419).

The Modified Wallingford Neutron Probe is stored and transported in a Type A container suitable for rigorous carriage in exacting conditions consisting of a lockable aluminium case of dimensions 1170 mm (L) x 360 mm (W) x 300 mm (H) with carry handles at each end. The box is divided into compartments and lined with closed foam so that the probe and its shield cannot move within the box.

Combined neutron + gamma radiation dose rates have been established by the Health Protection Agency (formerly the National Radiological Protection Board), and are:

230 μSv h^{-1} in contact with the exposed probe
20 μSv h^{-1} at 1m from the exposed probe
30 μSv h^{-1} in contact with the shielded probe
$<$0.5 μSv h^{-1} at 1m from the shielded probe

Designated Areas

When the neutron probe is stowed in its carrier inside the Type A box accessible radiation dose rates are sufficiently low and do not give rise to the need to designate Controlled or Supervised Areas.

When the probe is removed from its carrier, a region extending 10 m from the unshielded neutron probe is designated as a controlled area.

BAS will be the employer in charge of the controlled area.

Dose Investigation Level

A formal investigation by the appropriate radiation employer will be conducted if any person accumulates a dose of the specified level in any calendar year. The investigation will be carried out at the first instance of an accumulated dose of this level being recorded. In view of the fact that the activities being used are low, and classified workers will not be required, a whole-body dose investigation level (DIL) of 2 mSv per annum and a time-averaged dose limit of 0.5 μSv hr^{-1} will be used.

As a matter of good practice workers using the probe on the traverse will record time and circumstance of exposure daily. This will make it possible to estimate whether the extremity DIL of 50 mSv per annum has been reached.

Radiation Protection Supervisor (RPS)

The radiation protection supervisor (RPS) is:

Andrew M Smith British Antarctic Survey

Tel: 01223 221400
amsm@bas.ac.uk

Radiation Protection Advisors (RPAs)

The Radiation Protection Advisers (RPAs) of the iSTAR Radiation Employers are:

David Plumb, University of Cambridge, Health and Safety Division
Tel: 01223 339531
drp21@admin.cam.ac.uk

Ian Haslam, University of Leeds, Dept of Wellbeing, Safety and Health
Tel: 0113 3434203
i.k.haslam@leeds.ac.uk

R Collins (Radman Associates) for the University of Reading
rhc@radman.co.uk

Tony Butterworth , University of Bristol, Health and Safety Office
Tel: 0117 928 8323
A.R.Butterworth@bristol.ac.uk

Colin Farmery, Radiation Protection Unit, The University of Edinburgh
0131 650 2818
Colin.Farmery@ed.ac.uk

Sharon Ely, (The Health Protection Agency) for the British Antarctic Survey
Tel: 0113 269 9616 direct.
Sharon.ely@hpa.org.uk

Hazard Assessment

The potential hazards are:

1. unconnected probe falling to the bottom of the access hole
2. snow falling into access hole, resulting in probe becoming trapped
3. damage to the probe possibly affecting the integrity of the shielding
4. loss or theft of the probe;
5. fire;
6. accident during transport.
7. Proximity of probe to person

Summary of actions to mitigate hazards

1. The written safe system of work (Appendix 1) includes the requirement for the probe operator to connect the probe to its cable at least 10 m away from the access hole, to

check cable connections before use and to carry equipment to dig down to retrieve the probe if it falls to the bottom of the access hole.

2. The written safe system of work (Appendix 1) includes the requirement for the probe operator to shield the access hole from drifting snow and carry glycol to release the probe if it becomes trapped.

3. The written safe system of work (Appendix 1) includes the requirement for the probe operator to take due care in moving the probe. The contingency plan for accidents involving the neutron probe (Appendix 2) includes actions to minimise hazards arising from physical damage to the probe during use.

4. The security arrangements detailed in Appendix 3 are designed to minimise the chance of loss or theft of the probe and comply with the advice received from counter-terrorism officers. The written safe system of work (Appendix 1) includes the requirement for the probe operator to comply with the security arrangements.

5. The contingency plan for accidents involving the neutron probe (Appendix 2) includes actions to minimise hazards arising from fire.

6. The probe is transported in a Type A container designed to protect the probe from impact. The probe will only be transported by the operator, by British Antarctic Survey ships/aircraft or by a commercial logistics company authorised to transport radioactive material.

7. The written safe system of work (Appendix 1) includes the requirement for the operator to keep as far away as is practicable from the source when the probe is in use and return the probe to its shielded carrier when it is moved from one measurement position to another.

Training and Authorisation

Only authorised staff may work with ionising radiations unsupervised. To become authorised workers must meet the following requirements:

1. Have received basic general information and instruction in radiation protection and the use of the Neutron Probe and have been instructed in their radiation employer's specific arrangements for radiation protection and current legislative requirements.

2. Have received instruction from their Radiation Protection Supervisor in the control measures and recording requirements in their areas, and of the specific details for their proposed procedures.

3. Have received, and this has been documented, appropriate PRACTICAL training with the neutron probe in field conditions.

4. Have completed and had countersigned a Registration/Proposed Scheme of Work form, and seen and agreed the risk assessment for the work and the resultant control measures. Registration/Proposed Schemes of Work forms cover specific procedures using defined radionuclides and amounts of activity, and therefore radiation workers are authorised to carry out only those procedures for which they have an authorised Registration or SoW, signed by the PI and the RPS. An appropriate risk assessment must be prepared, involving the user, PI and the RPS.

Other staff can only carry out work involving radioactive substances <u>in the presence</u> of a member of staff who holds the appropriate full authorisation.

Other staff may enter a Controlled Area containing a shielded neutron probe for a purpose agreed in advance by the RPS, provided that they follow a written safe system of work (Appendix 4), have seen and agreed the appropriate risk assessment and the RPS is nearby. The public dose limit of 1 mSv exposure per annum must not be exceeded even in the worst-case scenario.

Appendix 1. Written Safe System of Work for neutron probe experiments

1. Controlled areas exist around the neutron probe.

2. The system of work is designed to ensure that all persons receive less than 3/10ths of a relevant dose limit and that all doses received are as low as reasonably practicable.

3. Persons transporting or using the probes must wear their personal dosemeter.

4. Personal dosemeters are the means of verifying that the wearer receives less than 3/10ths of the relevant dose limit; they are issued to individual persons AND ARE NOT TRANSFERABLE.

5. When making measurements in the field the operator should stand as far away as is practicable, particularly at near-surface measurement depths. Other persons should be excluded from a controlled area of at least 10 m from the probe unless invited to enter by an authorised worker.

6. The probe may only be used in Antarctica with the consent of the Science Leader (who will also be the RPS). The final decision on whether the probe may be used lies with the Traverse Leader.

7. When transferring the probe from one measurement position at a field site to another it MUST NOT be carried against the body or with the hands around the base of the probe. The following rule applies:

8. The probe should be placed within its carrier (with the source within the polypropylene shield) and inside its Type A box. The box should then be transported to the new site preferably by a method that keeps it away from the body e.g. by placing the box on a sledge.

9. The Type A box should be stowed for transport in a visible position on the transport sledge so that its position is always known. Relative “metal-on-metal” movement during transport could damage the box which should therefore be protected by padding. The load should be lashed so that it can flex as the sledge moves, to minimise vibration and bouncing.

10. If the Type A box is removed from the cargo sledge its location must be marked so it can be retrieved even if covered by drifting snow.

11. When making measurements in the field the operator must check cable connections before use and have the time and means to dig a pit to retrieve the probe if it falls to the bottom of the access hole. This may either be done mechanically (by tractor) or by hand-digging, in which case shovels, bucket, rope, pulley and poles to make a tripod are required. For guidance, a pit of 11.5 m depth will take about 1 week to dig by hand.

12. When making measurements in the field the operator must shield the access hole from drifting snow and carry glycol to release the probe if it becomes trapped**.** For guidance, approximately 10 litres of hot glycol – water mixture should be prepared and delivered to the level of the probe using fine-bore tubing (the “probe rescue kit” , provided with the system).

13. The operator must take due care in moving the probe to avoid mechanical damage to the shielding

14. The operator must comply with the security arrangements outlined in Appendix 3.

Appendix 2. Contingency Plans for Accidents Involving Neutron Probes

The following procedures must be initiated by the probe operator in the event of any of the following accidents:

In the event of fire in a room or out-building in which the probe is located (Antarctica):

1. Clear the area of personnel
2. Raise the alarm
3. Inform the RPS of the situation

Actions following mechanical or fire damage to the probe:

1. Cordon off five metres all around the probe and keep people away.
2. Immediately contact the RPS
3. Despite the potential hazards from the radioactive sources the first priority in the event of a transport accident or incident on site must be to assist injured persons.
4. NEVER HANDLE THE SOURCE - The dose rates near the source are very high. .
5. The RPS should take control of the incident and decide on actions to be taken, if necessary after consultation with an RPA in the UK. Actions should be recorded in an incident log, paying particular attention to recording possible radiation exposure for personnel. For guidance, if the source itself is undamaged it can be moved using tongs to a container of water or snow, which are good moderators. If the carrier is damaged, but not the probe or Type A container, the probe can be stored in the container surrounded by snow in plastic bags. If the source cannot safely be retrieved see section below.

In the event of loss in Antarctica:

1. If it is thought that the radioactive source has been lost or stolen, notify BAS Operations staff at Rothera at the first opportunity.
2. If the probe has not been located within the next 24 hours inform the relevant authorities in the UK.

If the source cannot be retrieved:

Under certain highly unlikely circumstances the general location of the source may be known but it cannot be retrieved. These might include:

(a) Serious transport accident in which it would be unsafe to retrieve the source from the debris

(b) Sledge carrying the probe lost in deep crevasse

In this case secure the area and notify BAS Operations staff at Rothera as soon as possible so the environmental consequences can be assessed. For guidance, in areas of net accumulation of snow it will be safe (if not desirable) to leave the source *in situ*. In ablation areas (e.g. Rothera) specialist clean-up may be necessary.

Appendix 3. Security Arrangements

a) When the probe is being transported by commercial logistics operators, responsibility for ensuring its security lies with the operators.

b) When the probe is stored at Rothera before transfer to a remote field site it must be kept in its Type A container in a locked storage area. Access to the probe should be restricted.

c) At remote field sites the location of the Type A container must either be flagged so the probe cannot be lost in drifting snow or the container must be on the transport sledge.

Appendix 4. Written safe system of work for entering a controlled area

1. Controlled areas exist around the neutron probe

2. The system of work is designed to ensure that all persons entering the controlled area receive less than the public dose limit of 1 mSv per annum and that all doses received are as low as reasonably practical.

3. No person should enter a controlled area unless they are (a) a registered radiation worker following the written safe system of work for neutron probe users (Appendix 1) or (b) a member of the ISTAR team authorised by the RPS to carry out a task in the controlled area and following this safe system of work.

4. Persons entering the controlled area must check visually that the neutron probe is properly shielded. When the probe is in use in the field this means checking that the probe is down the access hole. The time spent in the controlled area must be the minimum possible for the agreed task

5. The safe system for work in Antarctica must be followed to ensure that the worker cannot be immobilised without help in the controlled area.

6. If the neutron probe shielding breaks down, for example if the probe emerges from the access hole, the worker must leave at once. A registered radiation worker should be called in to return the probe to its carrier.

7. In the event of any other accident or incident e.g. fire the worker must leave the controlled area at once and find the RPS

8. Before entering any controlled area the worker must check that the RPS is available.

9. The worker must comply with the security arrangements outlined in Appendix 3.

11 ANNEX B - Risk Assessment for Neutron Probe

Radiation Risk Assessment for Sealed Sources

as required by the Ionising Radiations Regulations 1999

Guidance is available to help you complete this form – please refer to the Safety Office document IR009

Description of work assessed: Field Density measurements with Ice Geophysical Logging System for iStar	**Departmental Code: SPRI/2**
Location of work: Antarctica	**Planned start date: 10/2013**
Name of assessor: E M Morris	**Post/Status: RPS, Senior Associate**

This section is to demonstrate that Best Available Techniques (BAT) are observed in order to minimise the disposal of radioactive waste to the environment and to minimise radiation exposures of the public (refer to relevant EPR permit or Exemption Order as applicable and consult Safety Office/RPA).

Can you use a non-radioactive method? If not, why not?	No. Fine scale density layering can only be measured by radioactive means
Is the activity of the source the minimum necessary for the work? If not, why not?	Yes
The sealed source should be non-dispersible – how is this kept under review? Refer to special form certificates and leak tests where relevant	Regular leak tests are performed on the probe.
What are the arrangements for disposal of the source? This must be considered and documented. Consider the possibility of returning the source to the supplier	A fund of £4k is held for each source to allow for commercial disposal
Has the Best Practical Environmental Option been chosen for disposal? Consult RPS/Safety Office/RPA for advice	Yes
Add further information on how you will minimise environmental and public dose effects that may result from your work. Include security considerations	istar Local Rules and Standard Operating Procedures (SOP) will be followed by all staff using or involved in storage and transport of the neutron probe. Other staff on base will not have access to the probe. Other staff on the traverse will be briefed on good practice and will not enter a controlled area without invitation. An RPS will be on the traverse and will have authority over all staff in radiation matters. Security in transit will be ensured by a specialist shipping company and in Antarctica is ensured by BAS control of all personnel movements to the field. Public access to Rothera is possible via cruise ship, but landings are strictly controlled by base staff, so public access to the probe storage area can be denied.

	Complete this column – consider who might be harmed and how
Employees involved in the work:	None
Others involved in the work:	E M Morris, Peter Lambert, Andy Smith, T Flament
Any pregnant persons involved in the work:	Not planned. However, female staff theoretically could become pregnant while on the traverse.
Source of ionising radiation: for sealed sources specify radionuclide, activity, main emissions and maximum	Am241-Be 50mCi Neutrons, gamma

energy	
Nature of risk: consider external exposure and potential harm – internal exposure need not be considered provided the source remains undamaged and leak tests are up to date	Total gamma and neutron dose rate from source when in the carrier= 0.03 mSv h^{-1}. Estimated total dose rate from source when 2 m below snow surface=0.027 mSv h^{-1}. Total gamma and neutron dose rate at 30 cm from unshielded source= 0.3 mSv h^{-1}.
Estimated dose rate and annual dose to persons directly involved in the work: use data from manufacturer/supplier if available. The Safety Office can also supply data sheets	2.5 mSv/ yr
Estimated dose rate and annual dose to persons not directly involved in the work: consider other staff and members of the public	0.05 mSv/yr
	Describe the control measures
Advice from manufacturer on safe use and maintenance: this must be followed	N/A
Engineering controls and design features in place or planned: refer to critical examination carried out by installer where relevant	Experimental design to promote fast transfer of source to snow and remote measurement so operator can remain outside controlled area for most of experimental period.
Planned system of work: particularly for higher risk activities e.g. beam diagnostics or maintenance – necessary for work in controlled area	Appendix 1 of Local Rules is the Written Safe System of Work
Access restrictions: to areas and enclosures (access to override if applicable)	Access only for RPS, and named workers
Designation of areas: controlled or supervised areas	Controlled areas: Flagged area around measurement site
Local rules:	istar Local Rules apply
Personal protective equipment provided:	N/A
Training: in-lab practical training (refer to induction checklist) and taught courses.	Training provided by RPS and recorded on SPRI Induction check list.
Altered working or additional precautions for pregnant staff: (if annual external whole body dose less than 1mSv there should be no need for additional precautions)	The work is safe for any pregnant woman not directly using the probe. Traverse team members will be informed that any pregnancy must be declared as soon as possible. A pregnant worker will not be allowed to work directly with the probe to ensure that exposure of the foetus is kept well below the 1 mSv annual dose limit for members of the public.
	Consider accident situations and any further controls needed
Possible accident situations, and potential severity: consider consequences of failures in control measures and source leakage	(1) Transfer of probe from sample to carrier impeded for some reason exposing worker to unshielded source for extended period of say 10 minutes. Unlikely to be repeated within a year, hence worst case dose estimated as 0.15 m SV (3 times expected dose for one experiment with no control measures in place) (2) Traffic accident involving tractor train or aircraft. All reasonably foreseeable accidents would not damage the source hence worst case dose estimated as in (1) for 10 minute exposure as unshielded source removed from accident debris (3) Fire. Worst case dose as in (1) and (2) if carrier moderator destroyed (4) Probe cannot be winched up from access hole. No direct consequence but retrieval may

	involve digging down to top of probe and hence expose worker to 0.15 mSv hr^{-1} dose rate for brief period as probe lifted out. Worst case dose less than case (1).
Steps to prevent or to limit consequence of accident: with reference to source leakage, leak tests must be carried out at least every 2 years	(1) Regular leak tests. Tongs provided for handling source at a distance. (2) The sealed source is covered by Special Form Certificate USA/0659/S and therefore meets the regulatory requirements for safe transport. The probe is transported in a box which has been certified by CEH-Wallingford as an acceptable Type A package after tests which include a drop test, a stacking test and a penetration test. The condition of the box is checked regularly. These measures ensure that the source will not leak after any reasonably foreseeable traffic accident. (3) The source is contained in a stainless steel canister (melting point 1527 °C) which would not be damaged in a typical building or aircraft fire. The probe carrier could melt, burn or deform to make it unusable. Without the carrier there is a risk as in (1) of exposure to the unshielded source. Within 10 minutes it should certainly be possible to (a) stick the probe into snow or a container of water or (b) if the type A container has survived, store the probe in the container surrounded by plastic bags of snow which, liquid or frozen, will form an effective moderator. Closed cell polyurethane foam (karrimat), also a moderator, can be used to surround the bags to ensure mechanical stability. It is important that the probe cannot move about within the Type A box during transport. If the carrier is damaged the probe should not be used for further measurements until a replacement has been provided. (4) Follow standard operating procedures to ensure probe not stuck or lost in access hole. If stuck use probe rescue kit to deliver glycol to release probe. If necessary dig snow shaft down to probe head, following line of access hole. Ensure probe then lifted out swiftly to minimize time of expose to unshielded source
Likelihood of accident: High medium or low if above control measures used and maintained	Low for (1) to (4)
Results of previous dosimetry/ monitoring in similar situations:	No perceptible dose ever recorded by users of this probe and similar “Wallingford” probe
Need for classification: Yes/No (only necessary if annual whole body dose likely to exceed 6mSv – please consult RPA if this is considered likely)	No
Any additional actions needed to ensure doses are kept as low as reasonably practicable	Always point the probe away from the body thus maximizing distance of source from the body when it is unshielded
Additional risks and control measures not referred to above: refer to separate risk assessments or add details of significant risks and control measures to this assessment. Consider all hazards associated with the work: e.g. electrical hazards, manual handling, handling of cryogens and other coolants, etc.	

Reference to additional risk assessments	**Istar general field risk assessment**

<u>Assessment Agreed</u> **Research Supervisor/PI/Line Manager: Name: …………………………………** **Date: …………………………………. Signature: ………………………………..**
Specify a revision date for this assessment **Review on or before 30 April 2013……………………………**
Ensure that the assessor and Supervisor are aware that <u>re-assessment</u> will also be required for any significant change in this work, for instance, changed activity limits or different category of workers (including pregnancy).
<u>Seen by RPS:</u> RPS Name: …………………………………… **Date: ……………………………….. RPS Signature: ………….…………………………**
Additional comments from the appointed RADIATION PROTECTION ADVISER (IF THIS ASSESSMENT IS SEEN BY RPA) RPA sign/date