# Initial Environmental Evaluation

## Proposed Deep Ice Core Drilling Project on Skytrain Ice Rise, Antarctica

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British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

POLAR SCIENCE FOR PLANET EARTH

Initial Environmental Evaluation
Proposed Deep Ice Core Drilling Project
On Skytrain Ice Rise, Antarctica

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### 1. Introduction

This Initial Environmental Evaluation (IEE) has been carried out by the British Antarctic Survey (BAS) for a proposed deep ice core drilling project on Skytrain Ice Rise, Antarctica.

The IEE has been prepared in accordance with Annex I of the *Protocol on Environmental Protection to the Antarctic Treaty* (1998).

### 2. Description of the Proposed Activity

BAS, in collaboration with the Department of Earth Sciences, Cambridge University, plans to carry out a deep ice core drilling project on Skytrain Ice Rise, Antarctica, situated in the south west of the Ronne Ice Shelf to the north of the Ellsworth Mountain Range. The project is funded in full by the European Research Council Advanced Grant to Prof. Eric Wolff (University of Cambridge), with partner Dr Robert Mulvaney (UKRI-BAS). Additional collaboration for recovery of a short rock core from beneath the ice is funded by a CASS project with Dr Patrick Harkness (Glasgow University) and Prof Mike Bentley (Durham University), with UKRI-BAS partners.

The chosen drilling site (79°44.53'S, 078°33.82'W) is on a local dome of altitude 784 m above sea level, where ice approximately 616 m thick sits on a flat basal topography approximately 168 m above sea level. The aim is to retrieve an ice core through the full depth of the ice to the base, and if possible a small sample of the basal sub-ice material. Ice cores will be transported frozen to the UK and sampled and distributed amongst the collaborating institutes for laboratory analysis. The objective is to obtain a new, and definitive, ice core palaeoclimate record from the region where the West Antarctic Ice Sheet (WAIS) drains into the Ronne Ice Shelf, complementing the existing UK Berkner Island (located centrally in the Ronne), Fletcher Promontory (located at the south western corner of the Ronne) ice cores and those of the WAIS ice core programme of the USA. The drilling project is planned to be carried out at a temporary field camp over a single austral summer season 2018/19.

### 3. Description of the Environment

The Skytrain Ice Rise is an ice dome, rising to an altitude of around 784 metres above sea level. There is no ice-free ground in the local vicinity, and no known biota; the nearest ice free ground is in the Ellsworth Mountains, more than 50 km distance from the proposed drill site. The drilling project does not require visits to any ice-free areas elsewhere in the region. Surface radar profiles have already been undertaken at the site in the past, and it has therefore already been subject to minor human disturbance. There is currently a depot of drilling equipment, drill fluid and fuel at the proposed site. There are no protected areas on the Skytrain Ice Rise.

## 4. Alternatives to the Proposed Activity

Three alternatives have been examined:

i) Do nothing
ii) Drill Elsewhere in Antarctica
iii) Use Alternative Drilling Technologies

All three alternatives were considered not viable for scientific, technical or health and safety reasons.

## 5. Impact Assessment

The area likely to be impacted by the deep ice-core drilling project is estimated at approximately 0.5 $km^2$ for the field camp, and a 616 m x 135 mm borehole. The tractor traverse used to depot equipment adds to the cumulative impact of the project. The main environmental impact that has been identified is the use of Exxsol D60 drilling fluid.

In addition, minor environmental impacts may occur as a result of the field camp, including the production of a small quantity of hazardous and non-hazardous waste including sewage, possible contamination of snow caused by minor spills and leaks of fuel or drilling fluid, and air pollution and particulate deposition from generator emissions. The likelihood of non-native species becoming established as a result of this project is very low.

## 6. Mitigating Measures

An environmental briefing will be given by the BAS Environment Office to all those taking part in the proposed deep ice core drilling project on Skytrain Ice Rise.

Appropriate measures are recommended to mitigate any adverse impacts from the proposed activity. These include:

- **Site selection**: The drill site has been previously visited. There will be no visitation of ice free ground. There are no protected areas on the Skytrain Ice Rise
- **Drilling methods**: Most of the drilling fluid will be recovered from the borehole using a bailer attached to the drill. The borehole will be closed at all times other than during drilling to prevent the evaporation of the drilling fluid.
- **Biosecurity**: The provisions of the BAS Biosecurity Handbook will be followed wherever applicable. All equipment will be checked prior to deployment from Rothera Station to ensure that it is free of soil and non-native biota.
- **Waste management**: All waste, other than grey water and urine, will be correctly packaged and labelled in accordance with the BAS Waste Management Handbook, and removed from Antarctica.
- **Spill response**: Spill kits including absorbents will be available for use to respond to any spill of fuel or drill fluid.
- **Air quality**: Daily visual checks of generator exhausts will be carried out, and maintenance will be undertaken as required to reduce the impact of atmospheric emissions.

- **Aesthetics/Wilderness:** The location of the camp, depots and associated traverses will be recorded on the Ops GIS. The accidental loss of any equipment or waste to the environment will be prevented by sound drilling methods and experienced operatives, and good camp management. Any loss event will be recorded.

**7. Environmental Monitoring and Management**

During the deep ice core drilling project, compliance with BAS environmental policy and the mitigation measures outlined in this IEE will be the responsibility of the BAS Field Leader, Dr Robert Mulvaney.

**8. Conclusion**

This IEE indicates that the proposed deep ice core drilling project on Skytrain Ice Rise is likely to have no more than a minor or 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.

**Initial Environmental Evaluation**
**Proposed Deep Ice Core Drilling Project**
**On Skytrain Ice Rise, Antarctica**

# 1. INTRODUCTION AND SCOPE

This Initial Environmental Evaluation (IEE) has been carried out by the British Antarctic Survey (BAS) for a proposed deep ice core drilling project on Skytrain Ice Rise, Antarctica. It has been prepared in accordance with Annex I of the *Protocol on Environmental Protection to the Antarctic Treaty* (1998). The Revised Guidelines for Environmental Impact Assessment in Antarctica (Resolution 1, 2016) were also consulted during its preparation.

# 2. DESCRIPTION OF THE PROPOSED ACTIVITY

## 2.1 LOCATION OF THE PROPOSED ACTIVITY

The proposed deep ice core drilling will take place at a site on the Skytrain Ice Rise, Antarctica, situated in the south west of the Ronne Ice Shelf, to the north of the Ellsworth Mountains. The chosen drilling site (79°44.53'S, 078°33.82'W) is on a local topographic dome with an altitude of about 784 m, where ice approximately 616 m thick sits on a flat basal topography approximately 168 m above sea level (Figure 1).

## 2.2 PRINCIPAL CHARACTERISTICS OF THE PROPOSED ACTIVITY

### 2.2.1 Aim and objectives

The proposed activity is a collaborative project between BAS and the University of Cambridge, with additional minor involvement of Glasgow and Durham Universities.

The project aims to drill through the ice sheet to bedrock, retrieving an ice core from the entire ~616 metres. Upon reaching the bed of the ice sheet, we plan to deploy a percussive rock drill in an attempt to recover up to 30 cm of a narrow diameter core (around 25 mm) of rock or sediment. The ice core (and any small amount of basal rock/sediment) will be transported to the UK and distributed amongst the collaborating institutes for laboratory analysis. The principal scientific objective is to obtain a new, and definitive, ice core palaeoclimate record from a region where the West Antarctic Ice Sheet (WAIS) drains into the Ronne Ice Shelf.

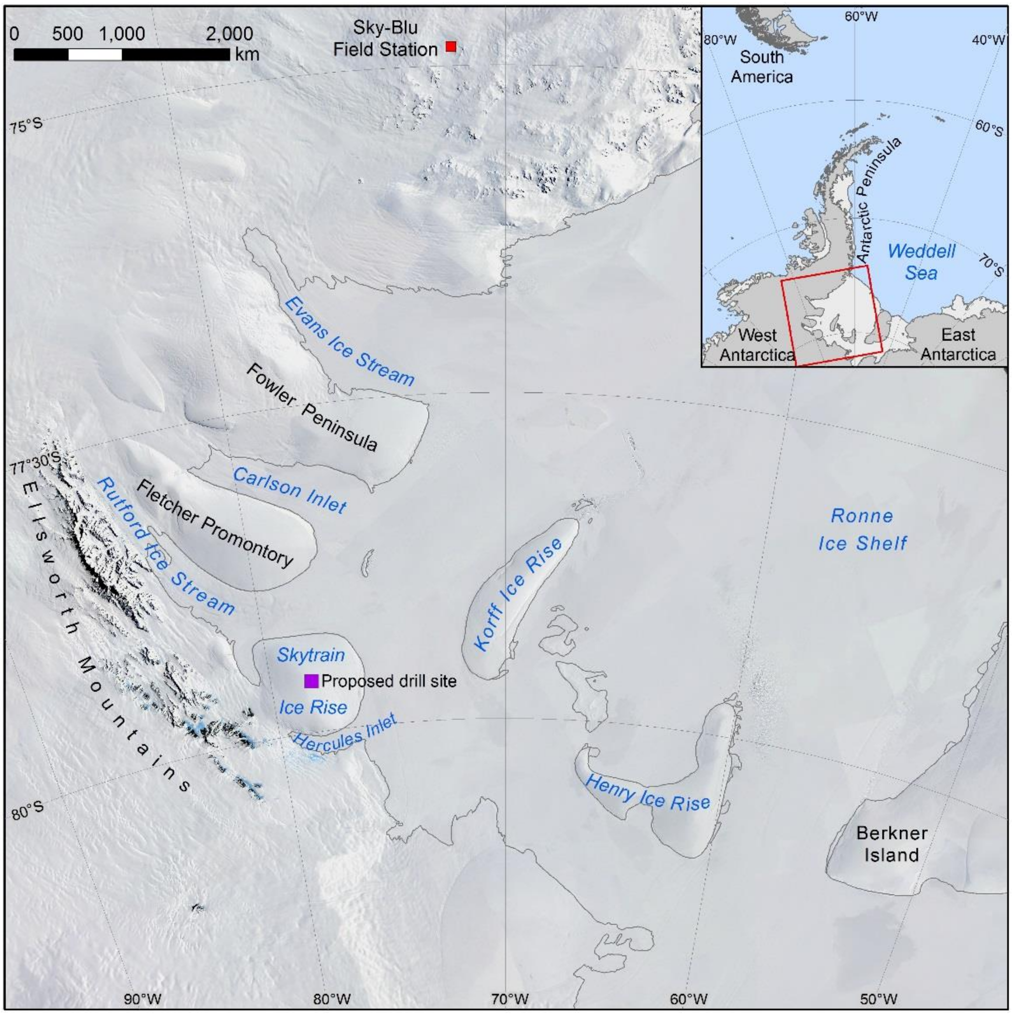


**Figure 1** Location of proposed drilling site on Skytrain Ice Rise, with Sky Blu Field Station identified.

### 2.2.2 Field Camp

A field camp will be established on a local topographic dome ~784 m above sea level close to the centre of Skytrain Ice Rise. The logistic operation to establish the camp will be via BAS Twin Otter aircraft operating out of Rothera and the Sky Blu blue ice runway. To limit the need for Twin Otter flights, the majority of camp and drilling infrastructure is already on-site, having been deployed in an earlier season by ship to the Ronne Ice Front, and then by over-snow traverse to the site. Uplift of equipment at the end of the project will be mainly by BAS traverse logistics, with some equipment and all of the ice cores removed by Twin Otter to Rothera.

The camp will consist of a maximum of 6 pyramid tents for accommodation, a toilet and a shower, and two work tents for messing and equipment repair. An area of about 15 m x 4.5 m will be covered over with a wooden floor comprising approximately 3000 kg of new timber compliant with the International Standards for Phytosanitary Measures No. 15 (ISPM 15) and covered with a ‘Weatherhaven’ shelter, to accommodate the mechanical drill system. A trench (12 x 3 x 3 m) will be dug and covered with a wooden roof of approximately 1100 kg of new timber compliant with ISPM 15, to serve as an ice core storage facility.

A 16 kVA diesel generator (fuelled on a mixture of Avtur and 2-stroke oil at a ratio of 50:1) will be installed at the field camp to operate the drilling equipment and to supply power to the field camp. Further 2kVA and 1kVA petrol generators will be kept on site to service low power requirements when the main generator is not running.

Close to the field camp will be located a depot containing 35 x 205 L drums of AVTUR fuel (total 7185 litres), 2 x 205 L drums of petrol (total 410 litres) and 45 x 205 L drums of Exxsol D60 drilling fluid (total 9225 litres).

Some UAS flights will be carried out in the vicinity of the camp to collect photographic images and videos.

### 2.2.3 Drilling methodology

The deep drilling will be carried out during one austral summer field season using an electromechanical drill, similar to that described in Mulvaney et al. 2007 and Mulvaney et al. 2014.

The drill consists of a drilling head with ice cutters mounted on a rotating inner barrel driven by an electric motor. The inner barrel is contained within an outer barrel, which is connected to an anti-torque device. This device is designed to grip the borehole walls to counter the rotational torque generated by the drilling action. Ice chippings generated by the drilling are mixed with drilling fluid, and carried by an internal slurry pump to the top of the inner barrel by a series of flights, where the slurry is filtered, the chips captured within the chamber for recovery, and the fluid returned to the borehole.

The drill is suspended by a wire cable with internal conductors carrying power from the snow surface to the drill. The drill has an overall length of 9 m, and weighs 170 kg. It is capable of taking a 98 mm diameter core of approximately 1.1 m in length on each drilling run, in a borehole 135 mm diameter. Raising and lowering the drill in the borehole is controlled by a winch and a mast at the surface which is rotated to the horizontal to facilitate extraction of the ice core from the barrel. Power is provided by the 16 kVA diesel generator.

A typical drilling run, which includes lowering the drill to the bottom of the borehole, drilling 1.1 m of core, returning the drill to the surface, and removing the core and chippings, takes approximately 30 minutes at 300 m depth.

### 2.2.4 Drilling fluids

As the borehole depth increases, fluid is added to the borehole to maintain a pressure in the borehole and prevent reduction in diameter of the borehole due to ice deformation. In addition, it is a well-recognised characteristic of ice core drilling that the quality of cores deteriorates rapidly beyond a depth of about 120 m if drilled in a dry hole without the use of fluids (essentially, the ice becomes brittle with depth, and the mechanical working during the drilling fractures the ice into small pieces which cannot be used for the modern range of analytical techniques). For this reason, all deep ice cores are drilled using fluid filled holes, and the deep ice core drills are optimised to use in fluid filled holes, relying on the fluid for transport of chips away from the drilling head. Based upon extensive laboratory analysis of deep ice core drilling fluids carried out at the University of Copenhagen (Talalay and Gundestrup, 1999), the most appropriate fluid for use at Skytrain Ice Rise has been identified as Exxsol D60. For this project, only a partial column of the fluid (up to 150 m) will be used at the bottom of the borehole without Solkane 141b densifying agent, an Ozone Depleting Substance (ODS) which in the past was commonly used with Exxsol D60 to increase the density of the fluid mixture (e.g. compare Mulvaney et al. 2007 for a project that used Solkane densifier with Mulvaney et al. 2014 which did not use a densifier).

Exxsol D60 is a complex hydrocarbon mixture. It is a petroleum-derived aliphatic cycloparaffinic hydrocarbon. It is a highly volatile substance which will rapidly evaporate and degrade in the atmosphere. It is readily biodegradable and has a low ecotoxicity. Appendix 1 contains the safety data sheet for Exxsol D60.

### 2.2.5 Termination of drilling operations

Once retrieved, the cores will remain depoted on site until an opportunity arises to fly them to freezer storage at Rothera using BAS Twin Otter aircraft. Later, the cores will be shipped via the BAS research vessel RRS *Ernest Shackleton* or *RRS James Clark Ross* to Europe for analysis.

When drilling has been completed, the drilling fluid will be recovered from the borehole and the top of the borehole will be sealed. The field camp, drilling equipment, wooden floor of the drilling trench, unused fuel and drilling fluid, and any remaining waste, will be removed from Antarctica for reuse or safe disposal mainly via BAS traverse logistics, and a limited amount flown by Twin Otter to Rothera; ice cores will be flown to Rothera.

### 2.3 AREA OF DISTURBANCE OF THE PROPOSED ACTIVITY

The area of disturbance at the drill site is estimated at a maximum of 0.5 $km^2$, including the field camp and fuel depot. The bore-hole will descend to a depth of ~616 m, and will be 135 mm in diameter over most of its depth.

The location of the associated tractor traverse used to depot equipment is recorded on the BAS Operations GIS.

### 2.4 DURATION AND INTENSITY OF THE PROPOSED ACTIVITY

Preparations for the proposed deep ice core drilling commenced during the 2017/18 austral summer, when a field depot of drilling equipment, living units, fuel (AVTUR), D60 solvent bulk drilling fluid and 60 ice core boxes was input to Skytrain Ice Rise. This activity was covered by the IEE for the BEAMISH science campaign. The remaining small amount of equipment (sensitive electronics, and a further 60 ice core boxes) will be flown into the site during the drilling season.

The proposed drilling project is planned to be undertaken during one single austral summer season, 2018/19. This assumes that the field party can be successfully input to Skytrain Ice Rise in early November 2018. A temporary field camp will be established which will remain for the duration of the project, after which it will be removed. The drilling infrastructure will be comprise of a wooden drill trench floor covered by a Weatherhaven shelter, a drilling winch and tower system, generators and a centrifuge for recovering fluid from the chips.

Nine personnel will spend a total of 70 - 80 days in the field (though it is likely two of the personnel will leave the field at the mid-point of the project when the speed of ice core recovery slows). At the end of this season, the field camp and drilling infrastructure, including the wooden floor, will be removed from Skytrain Ice Rise, as well as all empty fuel and fluid drums, unused and recovered drilling fluid, unused fuel, ice cores and waste.

## 3. DESCRIPTION OF THE LOCAL ENVIRONMENT

Skytrain Ice Rise is quasi-circular ice ridge projecting north east from the eastern side of the Antarctic Peninsula towards the Ronne Ice Shelf, bounded by the Rutford Ice Stream and the Hercules Inlet. The chosen drill site is on a local topographic dome with a surface altitude of around 784 m metres above sea level, and a flat base about 168 m above sea level. There is no ice-free ground in the vicinity, and there are no known biota present.

The Skytrain Ice Rise is in Domain O in the Antarctic Environmental Domains Analysis. This domain consists entirely of ice sheet and contains no mapped geology. Climactically the environment is cold with an average air temperature of -28.6 ° C and a low level of solar radiation. The environment is quite flat with an average slope of 4.93 °.

There are no protected areas (ASPAs, ASMAs or HSMs) on Skytrain Ice Rise.

The site has been visited in the past, and has therefore already been subject to minor human disturbance. Surface borne radar studies were carried out by BAS in an earlier season.

# 4. ALTERNATIVES TO THE PROPOSAL

## 4.1 DO NOTHING

This alternative has been considered and rejected on the grounds of the highly important scientific benefit that will be gained from carrying out the project. The significance of the project has been verified as of exceptional importance by the award of €3.1 M grant for the project in the highly-competitive European Research Council Advanced Grants to the project PI Prof Eric Wolff (Cambridge University) and partner Dr Robert Mulvaney (BAS).

Ice cores provide the best possible records of the history of climate change and atmospheric composition. Major deep ice core drilling projects (greater than 500m in depth) have been carried out at more than twelve locations in Antarctica since 1968. Figure 2 shows the locations of previous deep ice core drilling sites in Antarctica.

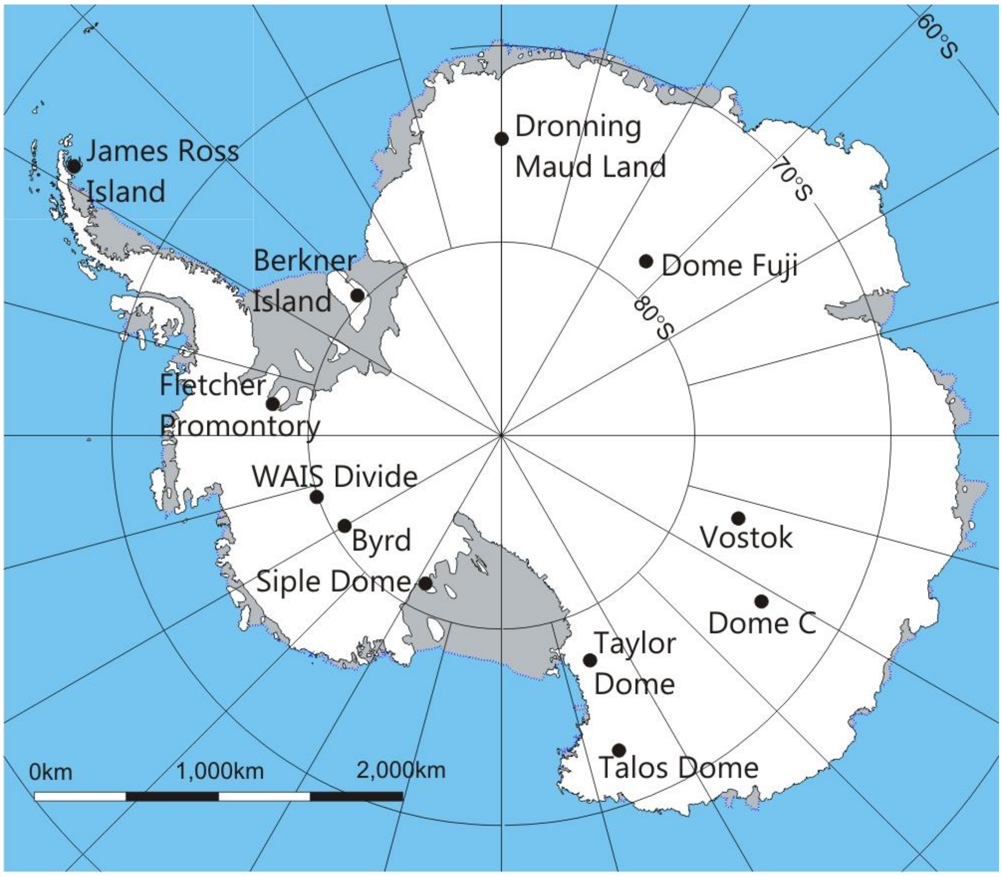


**Figure 2.** The location of previous ice core drilling sites (>500m depth) in Antarctica (plus the recent UK 364m site on James Ross Island

The outline of climate history provided by the longest records of Antarctic deep ice core drilling projects (Vostok, Dome C and Dome F) should now be complemented by understanding how climate changes have affected different regions of Antarctica. The WAIS Divide ice core, which spans a timescale of almost 70,000 years, shows similar climate patterns to the longest cores, but with important differences during rapid climate change (such as the last deglaciation). Indeed, the analysis of other coastal cores of a similar timescale, such as Berkner Island, Fletcher Promontory, Taylor Dome, Siple Dome and Talos Dome suggest that Antarctic climate did not follow a single or uniform pattern of change. This apparent discontinuity with central East Antarctic records poses severe tests on existing models of climate change. It is also clear from figure 2 that the drilling of a deep ice core at Skytrain Ice Rise will complement geographical coverage WAIS and Ronne sectors of Antarctica.

## 4.2 DRILL ELSEWHERE IN ANTARCTICA

This alternative has been considered and rejected on the grounds that the Skytrain Ice Rise ice cap has been selected as the one of the best sites in the SW Ronne region for obtaining a high resolution climate record of this region using the <1000m ice core drilling capability of the UK. Results from radar surveys by BAS show that Skytrain Ice Rise has approximately 616 m depth of ice sitting over flat bedrock topography, an accumulation rate equivalent to approximately 30 cm of water per year, a surface temperature of -27°C and a bedrock temperature of around -20°C. Experience from Berkner Island and Fletcher Promontory suggests that it is the best location for a deep ice core to capture the climate record of this sector of Antarctica over the past >120,000 years, thus incorporating the period of the Last Interglacial when the climate was warmer than our present interglacial climate, sea levels were 6-9m higher and the WAIS might have collapsed.

The International Partnerships in Ice Core Sciences (IPICS), endorsed by SCAR and officially approved as an IPY project by the IPY Committee, has released five White Papers describing the science strategy for ice core research over the 10 to 15 years. One of these White Papers, entitled “History and Dynamics of the Last Interglacial period from Ice Cores” ([http://pastglobalchanges.org/ini/end-aff/ipics/documents](http://pastglobalchanges.org/ini/end-aff/ipics/documents)) calls for additional ice core drilling site to expand the number of regional ice cores from Antarctica (see Figure 3).

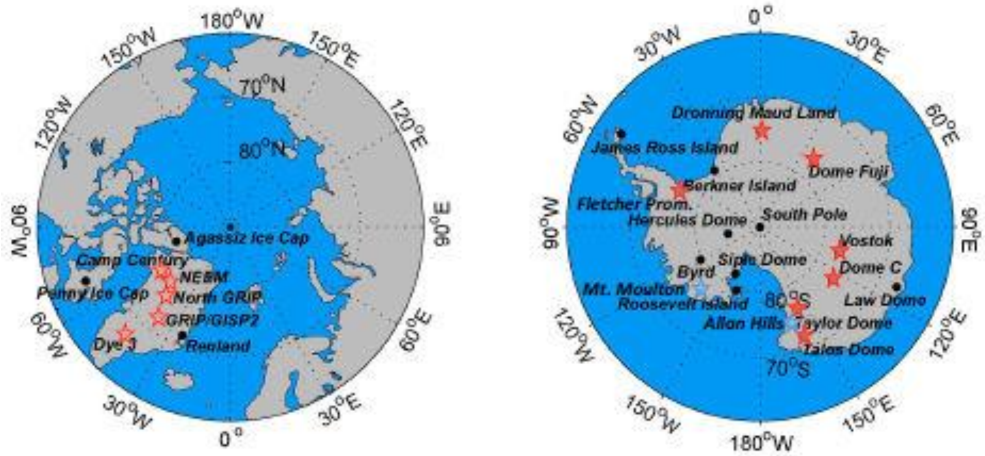


**Figure 3.** Locations of deep ice cores containing sections from the last interglacial are shown with red stars. Filled star indicates complete intact Eemian record; open star indicates records that contain Eemian ice but are either not complete or not stratigraphically intact (that is, sections are missing and/or not in order).

## 4.3 USE ALTERATIVE DRILLING TECHNOLOGIES

Two alternative drilling technologies have been considered.

### 4.3.1 Thermal Drilling

This alternative has been considered and rejected on the grounds that it:

- may result in a poor quality ice core;
- is more energy intensive than electro-mechanical drilling.

Thermal drilling replaces the cutter head, as used in an electro-mechanical drill, with an annular ring of electrically heated wires that melt an annulus of ice. The melt water is mixed with antifreeze, and drawn away from the head of the drill into a chamber. Using thermal drilling, the borehole must also be filled with bulk drilling fluid to avoid hole closure. Thermal drilling usually requires a strong ethylene glycol mixture, or pure ethanol, as the drilling fluid.

The major scientific disadvantage of thermal drilling is the thermal shock applied to the ice core, which initiates the cracking of the ice, damaging the core, and commonly soaking the core with contaminated liquid which is miscible with the ice. This can result in a poor quality ice core, which will compromise the quality of the chemical analysis, and hence the climate record, obtained.

Thermal drilling is also more energy-intensive, requiring greater quantities of fuel, with a resulting increase in atmospheric emissions and the deposition of particulates in the immediate surface snow layer, while returning a scientifically compromised ice core that is unlikely to meet the quality criteria for the range of analyses planned.

Poor quality core, and the energy intensive nature of thermal drilling, mean that this technique is now rarely used in Antarctica where an ice core is to be recovered.

### 4.3.2 Alternative Drilling Fluid

This alternative has been considered and rejected on the grounds that:

- Some alternative drilling fluids may pose a risk to human health or well-being;
- Others may pose a fire hazard;
- Use of an inferior substitute could result in the loss of the drill, which would compromise the scientific objective of the project.

The main purpose of the drilling fluid is to prevent the closure and sealing of the borehole due to the plastic deformation of the surrounding ice, while allowing the drill to recover cores of sufficient quality for analysis in the brittle ice zone. The fluid density must match as close as possible to the density of pure ice, be liquid at ice sheet temperatures, immiscible with ice and of low viscosity to allow passage of the drill in the borehole. It is also required to transport the ice chips away from the drill head and up to the chip-chamber in the drill.

Bulk drilling fluids that have been used in the past include n-butyl acetate (possibly with the addition of an HCFC densifier) and Exxsol D30 or D60 petroleum based solvents, also with the addition of an HCFC densifier.

Talalay and Gundestrup (1999) have reported on the possible health effects associated with the use of n-butyl acetate as a bulk drilling fluid. It is toxic and can cause eye irritation, narcosis and further effects on the nasal and respiratory systems. It is also teratogenic (i.e. causing embryonic malformation). It has therefore been assessed by BAS that the risk to human health is too great to use n-butyl acetate as a drilling fluid.

Exxsol D30 or D60 do not have significant health risks associated with them, but do normally require a significant quantity of densifier (up to 30%). Densifiers are used to raise the density of the bulk fluid to match the ice density (0.917 Mg $m^{-3}$) - critical in preventing borehole closure. The densifier identified as most suited to ice drilling is HCFC-141b, an ODS which has an Ozone Depleting Potential (ODP) of 0.11. This substance was used for the Berkner Island deep ice core drilling programme. However, the use of a densifier has been rejected in this project in favour of a shallow column of pure D60 –the inevitable borehole closure is acceptable providing the drilling project can be completed in a single season, as planned.

In Greenland, a new class drilling fluid based on a coconut oil extract has been used in a recent drilling project, but left *in situ* in the borehole at the end of drilling. The oil does not evaporate and is difficult to clean from the cores, or from the clothing of the drillers. We have considered using this fluid, but have rejected it for the Skytrain Ice Rise project in favour of the D60 (without the HCFC densifier) as we consider the use of an existing stock of D60 recycled from the James Ross Island drilling project, and then the recovery of the fluid from the borehole, leaves a lesser environmental impact. D60 is also substantially easier to work with in a BAS field camp environment where washing clothes and routinely taking showers is difficult (these are the normal procedures when using the newer coconut oil extracts in Greenland drilling projects).

# 5. IDENTIFICATION AND PREDICTION OF IMPACTS, AND MEASURES TO MINIMISE OR MITIGATE THOSE IMPACTS

The following predicted impacts and mitigating measures are based upon BAS experience of operating similar deep ice core drilling projects (for example, Berkner Island 2002-2006, James Ross Island, 2007/08, Fletcher Promontory 2011/12).

## 5.1 USE OF DRILLING FLUID

The use of a drilling fluid is an unavoidable impact if BAS is to successfully drill for an ice core of high scientific value. We have chosen to continue to use Exxsol D60 hydrocarbon mixture (see Section 2.2.4, and 4.3.2) since the alternatives are more difficult to handle, and we already have stocks of D60 in Antarctica that have been recovered from earlier UK deep drilling operations and can be recycled for use in the current proposed project. 9225 L of D60 drilling fluid in 45 x 205L drums has been depoted on the site ready for this drilling project.

### 5.1.1 Mitigating Measures

The borehole will be closed at all times other than during drilling to reduce the evaporation of the drilling fluid.

The BAS will also attempt to recover >99% of the remaining 150 m fluid column from the bottom of the borehole once drilling is complete. BAS has developed a fluid bailer (Figure 4), which allows for a 2m column of drilling fluid to be recovered each time it is lowered into the borehole. The bailer will be attached securely to the top section of the drill. The slots at the top of the bailer, shown in Figure 4, allow the fluid to enter the bailer. The valve at the bottom allows for the liquid to be released from the bailer into a drum once it is recovered from the borehole. Up to 75 lifts will be required to recover the fluid, taking approximately four days. A modification to the bailer for the final 2m allows for even the remaining liquid in the borehole to be recovered.

There is a risk that the borehole without the fluid will close more rapidly than anticipated. Whilst drilling, this can be overcome by re-drilling the particular section. However, when using the bailer, the borehole cannot be re-drilled. Therefore it will be necessary to carefully monitor the force required to move the bailer through the borehole. If the risk of losing the equipment becomes too high, bailing will stop immediately.

All recovered fluid will be stored in the drums used to deliver fluid to the field, and flown to Rothera for further re-use in a future drilling operation, or for return to the UK for safe disposal.

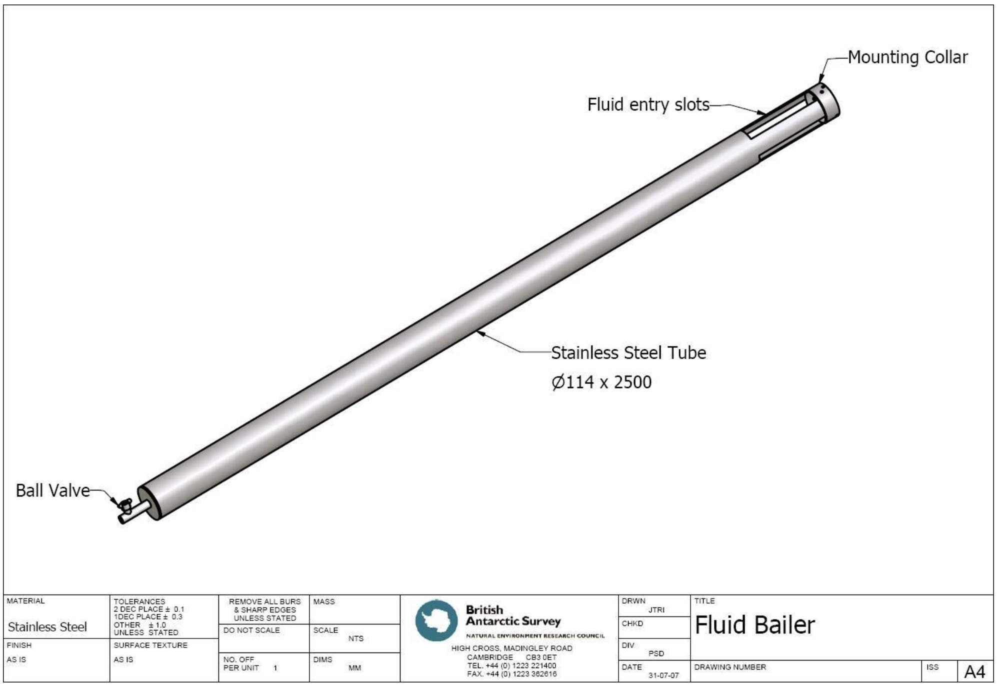


**Figure 4.** Fluid bailer developed by BAS for the Proposed Deep Ice Core Drilling Project on Skytrain Ice Rise

The first recovery of drilling fluid from a borehole in Antarctica was undertaken in 2006, under very different circumstances to the proposed Skytrain Ice Rise drilling proposal. 568 litres of fuel and brine solution was removed from a rock/ sediment borehole at Lake Vida, McMurdo Dry Valleys, using a bailer (XXX ATCM/ IP21). Resurgence of fuel and fuel-contaminated soil had been noted from this particular borehole intermittently between 1974-2002, and the site was subject to flooding from the nearby freshwater Lake Vida. In this instance the recovery of the drilling fluid (years after the drilling programme) was required to prevent further pollution caused by the resurgence of the drilling fluid into the lake ecosystem.

The bailer designed by BAS is specifically for ice core drilling projects, and proved effective during the UK drilling project on Mount Haddington, James Ross Island in 2007/08, where all but a few litres of the drilling fluid was recovered post drilling and shipped out of the field (ATCM XXXI/IP54). Recovery of drilling fluid was again successful on Fletcher Promontory in 2011/12. Once the liquid is removed, the borehole will quickly close due to ice deformation.

Note that at Skytrain Ice Rise, the basal temperature is calculated to be close to -20°C (using an ice sheet model of heat flux, based on the surface temperature and accumulation, ice thickness and basal geothermal heat flux) and therefore no liquid water hydrological system is present beneath the ice sheet that could be contaminated and disperse any liquid remaining in the borehole. The base of the ice sheet is ~166 m above sea level, so no interaction with sea water is possible.

## 5.2 ATMOSPHERIC EMISSIONS

Air pollution will result from the input of the field party by aircraft, and the use of diesel and unleaded petrol generators at the field camp. Fuel consumption from the generators used on-site during the field season is estimated at 7185 L of AVTUR and 410 L of petrol. Emissions will include carbon monoxide, carbon dioxide, nitrous oxides, sulphur dioxide, heavy metals and particulates. Using UK Government Guidelines for Greenhouse Gas Reporting (2018) (see https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2018) the use of AVTUR and petrol in the generators will give rise to a combined total emission of greenhouse gases of approximately 19,145 kg $CO_2e$ (carbon dioxide equivalent). Emissions resulting from the fuel used e.g. in aircraft and Pisten Bullys associated with the projects logistics will be calculated and reported in the BAS Annual Environmental Report as part of the overall BAS carbon footprint.

Emissions will generally be rapidly and thoroughly dispersed by the strong and regular winds. There will be some fallout of pollutants in the local area. 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 the drill site. Heavy metals would have greater transport distances. Based on monitoring results from Halley IV Station, it is possible that background levels of heavy metals (e.g. lead) in surface snow samples would be exceeded up to a maximum of 10 km downwind of the site (Suttie and Wolff, 1993).

### 5.2.1 Mitigating Measures

Daily visual checks are to be made of generator exhausts. Any maintenance to reduce atmospheric emissions will be carried out as required. The generators will be shut down when not required.

## 5.3 WASTE

A very minor increase in the quantity of hazardous and non-hazardous waste produced by BAS in Antarctica is expected as a result of the drilling project. Hazardous waste is likely to comprise drilling fluid, batteries and clinical waste. Non hazardous waste is likely to comprise paper, glass, metal and plastic.

Based on experience we will recover about 85% of the drilling fluid, with 15% being lost to evaporation, and some lost from the drill transiting the borehole in the firn layer (the upper 75m of the ice sheet). The fluid will be returned to the original drums, and removed from the site, either to Rothera for storage for a future drilling project, or to the UK for safe disposal.

Batteries will be returned to Rothera: rechargeable batteries will be taken from the Rothera battery store at the start of the season, and returned to the store at the end of the season for use by other projects. Primary cells will be taped, and flown to Rothera and safely removed from Antarctica for disposal.

Approximately 50 kg of waste plastic and paper is generated by the drilling project, and will be removed to Rothera and absorbed into the Rothera waste management system

Based upon an estimated 0.23 kg of waste (excluding sewage and grey water) produced per person per day (derived from Lewis, 1994), it is estimated that a maximum of 145 kg of general waste will be produced by the field party during the one austral summer season.

The field party will also produce sewage, food waste and grey water. Based upon an average adult excreting 1.8 litres of urine and faeces per day, the field party will produce approximately 1150 litres of sewage during the season.

### 5.3.1 Mitigating Measures

Staff involved in the Skytrain Ice Rise Drilling Project will comply with BAS waste management policy and will follow the procedures outlined in the BAS Waste Management Handbook (BAS, 2017). The camp will be cleared of any rubbish or debris each day. All waste, other than grey water and urine, will be removed from the site to Rothera, where it will be removed from Antarctica for safe and controlled disposal. Open burning of waste is prohibited.

All BAS field parties are supplied with a copy of the Field Operations Manual, colour coded waste sacks for the separation and disposal of wastes, and solid human waste drums that are UN approved for clinical waste.

## 5.4 MINOR SPILLS OF FUEL OR DRILLING FLUID

A further, but localised possible impact, could be ice or snow contamination caused by minor spills and leaks of fuel or drilling fluid. The maximum quantity of fuel or drilling fluid that is likely to be spilled at any one time is 205 L, due to a punctured drum. Spilled fuel or drilling fluid 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 close to Skytrain Ice Rise.

### 5.4.1 Mitigating Measures

The BAS makes every effort to prevent accidental fuel spills through careful attention to fuel management, at its stations and in the field.

Members of the field party will be expected to take all reasonable precautions to ensure that minor fuel leaks and spills do not occur. Any minor fuel spills should be stopped as quickly as possible. A drum funnel will be provided to prevent spills. Absorbent mats and pads will be provided for immediate response to minor fuel spills from 205 L drums, though this is likely to be most effective on the hard wooden floor of the drilling Weatherhaven than on unpacked firn. Used absorbents may be drummed and removed to Rothera for safe disposal.

A log of any fuel spills is to be kept and recorded on the BAS accident reporting (AINME) system.

## 5.5 INTRODUCTION OF NON NATIVE BIOTA

There is a very small risk of the introduction of non-native biota, particularly micro-organisms, because of the importation of materials. This risk is very low of species becoming established as the camp is being set up on an ice dome, approximately 150 km from the nearest ice-free ground in the Ellsworth Mountains to the south.

### 5.5.1 Mitigating Measures

All equipment and materials required for the drilling project will be thoroughly cleaned before dispatch to Antarctica. All timber used for the drilling rig infrastructure will be new and comply with the International Standards for Phytosanitary Measures No. 15 (ISPM 15).

All items of cargo will be checked for soil or non-native species prior to being flown from Rothera. The advice and procedures contained within the BAS Biosecurity Handbook will be followed where applicable.

## 5.6 CHANGES IN LOCAL TOPOGRAPHY AND WILDERNESS/AESTHETIC VALUES

BAS logistics and science operations have an impact on the wilderness and aesthetic values in Antarctica.

### 5.6.1 **Mitigating Measures**

The site has been previously visited and therefore subject to minor human disturbance. Log of depots, camps and associated traverse routes to be kept at BAS for future reference

Care will be taken to avoid loss of equipment and waste at the field camp/drill site, and any accidental loss will be recorded on the AINME system. UAS Flights will be in accordance with the BAS UAS Regulations which will minimise the likelihood of UAS loss.

Snow drifts which have accumulated as a result of the field camp will generally dissipate through natural processes once the field camp is removed. Some grooming around the immediate area of the field camp will be carried out using a snow blower.

## 5.7 ENVIRONMENTAL EDUCATION

It is BAS policy to brief all new recruits on Care of the Antarctic Environment before they travel to Antarctica. An environmental briefing will be given by the BAS Environment Office to those personnel involved in the drilling project.

## 5.8 IMPACT MATRIX

Table 1 shows a summary of how the predicted environmental impacts which may result from the drilling project, and how BAS plans to minimise or mitigate these impacts.

| Activity | Output | Possible Impact | Probability of impact occurring | Severity of impact | Preventative or mitigating measures |
|---|---|---|---|---|---|
| Ice Core Drilling | Use of Exxsol D60, at a depth of 620 metres below ice level | Chemical contamination of ice<br><br>Long term ( many millennia ) release into marine environment of small quantity of drilling fluid | Low | Low | The borehole will be closed at all times other than during drilling to prevent the evaporation of the drilling fluid.<br><br>Removal of most of the fluid is planned, using bailer attached to drill cable.<br><br>The provision of a pump system within the drill to transfer chip/fluid slurry from the drill head to a collection chamber.<br><br>A large centrifuge will be used in the drilling camp to recover and recycles fluid absorbed onto the drill chips.<br><br>Oil spill equipment to be with drill for use in event of drill fluid spill. |
| | Possible loss of drill | Non –recovery of drill or fluid from Skytrain Ice Rise | Very low | Very Low | Safe drilling procedures to be followed at all times to reduce risk of loss of drill. Only experienced operatives will use the drill.<br><br>The loss of any equipment will be reported in the AINME system for inclusion in the lost equipment log. |
| Importation of cargo to Skytrain Ice Rise | Introduction of non-native species | Ecosystem alteration if species became established. Increased competition and spread of non-native disease. | Very low | Very Low (if 1 or small number of individuals)<br><br>High (if species become established) | BAS Biosecurity Handbook will be followed where appropriate.<br><br>All procedures include measures to ensure that soils, seeds and propagules are not transported to Antarctica. |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | Cargo, vehicles and personal clothing must be cleaned prior to importation. All equipment to be thoroughly cleaned before packing, and checked at Rothera before flying into the field.<br><br>All equipment to be flown directly to camp via Sky Blu, and not offloaded on ice-free ground.<br><br>If soil, seeds or propagules are accidentally imported they must be carefully collected and removed. Disposal may include incineration at Rothera or removed from Antarctica.<br><br>All timber to be new and compliant with ISPM 15. |
| Operating field camp and the supporting logistics | Waste (hazardous and non/hazardous) | Danger to wildlife if scattered by wind. | Low | Very Low | Environmental briefing for all staff.<br><br>All waste to be correctly packaged, labeled and removed from Skytrain Ice Rise for safe disposal, in line with BAS Waste Management Handbook.<br><br>Site to be cleared each day to prevent wind scatter. |
| | Minor fuel spills and leaks from generators | Chemical contamination of ice | Low | Very Low | Careful attention to fuel handling and management.<br><br>Use of drip trays and funnels to prevent leaks.<br><br>Any minor leaks to be sealed immediately<br><br>Minor spills to be cleaned up with absorbents |
| | Atmospheric emissions from generators | Very minor but cumulative contribution to regional and global atmospheric pollution including greenhouse gas emissions.<br><br>Particulate fallout. | Certain | Very low | Daily checks of vehicles / generator emissions.<br><br>Maintenance to be carried out as necessary. |
| | Snow drifts around temporary field camp | Changes in local topography | Certain | Very low | Use of snow blower to level drifts. |

| | | | | | |
|---|---|---|---|---|---|
| | structures | | | | |
| | BAS Operational footprint | Aesthetic Damage<br>Reduction of wilderness and pristine nature of localities<br>Impact on future science | High | Low | Some locations have previously been visited.<br><br>Log of depots, camps and traverse routes to be kept at BAS for future reference<br><br>Log to be kept of any equipment accidentally lost |

**Table 1 Impacts associated with the Proposed Deep Ice Core Drilling programme, and preventative or mitigating measures**

# 6. ASSESSMENT AND VERIFICATION OF IMPACTS

## 6.1 ENVIRONMENTAL MONITORING

The Field Leader will be responsible for the daily on site supervision of the project, and for implementing the measures to be taken to minimise or mitigate the adverse environmental impacts which may result from the proposed deep ice core drilling project (Table 1). Photographs and video will be taken of the site at all major stages of drilling project, including the clean-up and removal of the camp during the final season.

Any environmental incident such as fuel spill, poor waste handling, loss of equipment to the environment will be reported on the BAS AINME system for investigation by Environment Office.

# 7. CONCLUSIONS

This Initial Environmental Evaluation indicates that the proposed deep ice core drilling project on Skytrain Ice Rise is likely to have no more than a minor or 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.

# 8. REFERENCES

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## 9. AUTHORS OF THE IEE

This Initial Environmental Evaluation was prepared by Dr Robert Mulvaney and Rachel Clarke, British Antarctic Survey.

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

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United Kingdom

## 10. ACKNOWLEDGEMENTS

We are grateful to MAGIC for preparing the location map of Skytrain Ice Rise and Jamie Oliver for the cover designs.

# Appendix 1
# MATERIAL SAFETY DATA SHEET
### ExxonMobil Chemical Company
### A Division of Exxon Mobil Corporation

**DATE PREPARED: FEB 27, 2003**
**MSDS NO.: 92875549**

**EXXSOL D 60 FLUID**

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## SECTION 1 CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

**PRODUCT NAME:** EXXSOL D 60 FLUID

**CHEMICAL NAME:**
Aliphatic Hydrocarbon 64742-47-8

**CHEMICAL FAMILY:**
Petroleum Hydrocarbon

**PRODUCT DESCRIPTION:**
Clear colorless liquid.

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**CONTACT ADDRESS:**
ExxonMobil Chemical Company
P.O. Box 3272, Houston, Texas 77253-3272

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**** EMERGENCY TELEPHONE NUMBERS: (24 Hours) ****
**** CHEMTREC (800) 424-9300 ****
**** ExxonMobil Chemical Company (800) 726-2015 ****

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NON EMERGENCY TELEPHONE NUMBERS : (8am-5pm M-F)
FOR GENERAL PRODUCT INFORMATION CALL : (281) 870-6000
FOR HEALTH AND MEDICAL INFORMATION CALL : (281) 870-6884

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## SECTION 2 COMPOSITION/INFORMATION ON INGREDIENTS

This product is hazardous as defined in 29 CFR1910.1200.
OSHA HAZARD
Combustible Liquid

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## SECTION 3 HAZARDS IDENTIFICATION

**POTENTIAL HEALTH EFFECTS**

**EYE CONTACT:**
Slightly irritating but does not injure eye tissue.

**SKIN CONTACT:**
Low order of toxicity.
Frequent or prolonged contact may irritate and cause dermatitis.
Skin contact may aggravate an existing dermatitis condition.

**INHALATION:**
High vapor/aerosol concentrations (attainable at elevated temperatures well above ambient) are irritating to the eyes and the respiratory tract, and may cause headaches, dizziness, anaesthesia, drowsiness, unconsciousness, and other central nervous system effects, including death

**INGESTION:**
Small amounts of this product aspirated into the respiratory system during ingestion or vomiting may cause mild to severe pulmonary injury, possibly progressing to death.
Minimal toxicity.

**CHRONIC EFFECTS**
At very high oral doses, this product caused reversible damage to the stomach, liver, and kidney (male only) of rats. These effects are not relevent to humans at occupational levels of exposure.

## SECTION 4 FIRST AID MEASURES

**EYE CONTACT:**
Flush eyes with large amounts of water until irritation subsides. If irritation persists, get medical attention.

**SKIN CONTACT:**
Flush with large amounts of water; use soap if available.
Remove grossly contaminated clothing, including shoes, and launder before reuse.

**INHALATION:**
Using proper respiratory protection, immediately remove the affected victim from exposure. Administer artificial respiration if breathing is stopped. Keep at rest. Call for prompt medical attention.

**INGESTION:**
If swallowed, DO NOT induce vomiting. Keep at rest. Get prompt medical attention.

## SECTION 5 FIRE-FIGHTING MEASURES

| | |
|---|---|
| **FLASH POINT:** | 147 Deg F. METHOD: TCC ASTM D56 NOTE: Minimum |
| **FLAMMABLE LIMITS:** | LEL: 0.7 UEL: 5.3 NOTE: Approximate |
| **AUTOIGNITION TEMP.:** | > 487 Deg F. |

**GENERAL HAZARD**
Combustible Liquid, can form combustible mixtures at temperatures at

or above the flashpoint.
Static Discharge, material can accumulate static charges which can cause an incendiary electrical discharge .
"Empty" containers retain product residue (liquid and/or vapor) and can be dangerous. DO NOT pressurize, cut, weld, braze, solder, drill, grind, or expose such containers to heat, flame, sparks, static electricity, or other sources of ignition; THEY MAY EXPLODE AND CAUSE INJURY OR DEATH.
Empty drums should be completely drained, properly bunged and promptly returned to a drum reconditioner, or properly disposed of.

**FIRE FIGHTING**
Use water spray to cool fire exposed surfaces and to protect personnel.
Isolate "fuel" supply from fire.
Use foam, dry chemical, or water spray to extinguish fire.
Avoid spraying water directly into storage containers due to danger of boilover.
This liquid is volatile and gives off invisible vapors. Either the liquid or vapor may settle in low areas or travel some distance along the ground or surface to ignition sources where they may ignite or explode.

**DECOMPOSITION PRODUCTS UNDER FIRE CONDITIONS**
No unusual

## SECTION 6 ACCIDENTAL RELEASE MEASURES

**LAND SPILL**
Eliminate sources of ignition. Prevent additional discharge of material, if possible to do so without hazard. For small spills implement cleanup procedures; for large spills implement cleanup procedures and, if in public area, keep public away and advise authorities. Also, if this product is subject to CERCLA reporting (see Section 15 REGULATORY INFORMATION) notify the National Response Center.
Prevent liquid from entering sewers, watercourses, or low areas. Contain spilled liquid with sand or earth. Do not use combustible materials such as sawdust.
Recover by pumping (use an explosion proof or hand pump) or with a suitable absorbent.
Consult an expert on disposal of recovered material and ensure conformity to local disposal regulations.

**WATER SPILL**
Eliminate sources of ignition. Warn occupants and shipping in surrounding and downwind areas of fire and explosion hazard and request all to stay clear.
Remove from surface by skimming or with suitable adsorbents. If allowed by local authorities and environmental agencies, sinking and/or suitable dispersants may be used in non-confined waters.
Consult an expert on disposal of recovered material and ensure conformity

to local disposal regulations.

## SECTION 7 STORAGE AND HANDLING

**ELECTROSTATIC ACCUMULATION HAZARD**
Yes, use proper bonding and/or grounding procedure.
Additional information regarding safe handling of products with static accumulation potential can be ordered by contacting the American Petroleum Institute (API) for API Recommended Practice 2003, entitled "Protection Against Ignitions Arising Out of Static, Lightning, and Stray Currents" (American Petroleum Institute, 1220 L Street Northwest, Washington, DC 20005), or the National Fire Protection Association (NFPA) for NFPA 77 entitled "Static Electricity" (National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101).
**STORAGE TEMPERATURE** Deg F:
Ambient
**LOADING/UNLOADING TEMPERATURE** Deg F:
Ambient
**STORAGE/TRANSPORT PRESSURE** mmHg:
Atmospheric
**LOADING/UNLOADING VISCOSITY** cSt:
1.6

**STORAGE AND HANDLING:**
Keep container closed. Handle and open containers with care. Store in a cool, well ventilated place away from incompatible materials.
Do NOT handle or store near an open flame, heat or other sources of ignition. Protect material from direct sunlight.
Material will accumulate static charges which may cause an electrical spark (ignition source). Use proper bonding and/or grounding procedures.
Do NOT pressurize, cut, heat, or weld containers. Empty product containers may contain product residue. Do NOT reuse empty containers without commercial cleaning or reconditioning.

## SECTION 8 EXPOSURE CONTROLS/PERSONAL PROTECTION

**EXPOSURE CONTROLS**
The use of local exhaust ventilation is recommended to control process emissions near the source. Laboratory samples should be handled in a lab hood. Provide mechanical ventilation of confined spaces.
See respiratory protection recommendations.

**PERSONAL PROTECTION**
For open systems where contact is likely, wear safety glasses with side shields, long sleeves, and chemical resistant gloves.
Where contact may occur, wear safety glasses with side shields.
Where concentrations in air may exceed the limits given in this Section

and engineering, work practice or other means of exposure reduction are not adequate, NIOSH approved respirators may be necessary to prevent overexposure by inhalation.

**WORKPLACE EXPOSURE GUIDELINES**
ExxonMobil RECOMMENDS THE FOLLOWING OCCUPATIONAL EXPOSURE LIMITS: a TWA of 1200 mg/m3 (184 ppm) based on total hydrocarbon.

## SECTION 9 PHYSICAL AND CHEMICAL PROPERTIES

| | |
|---|---|
| **SPECIFIC GRAVITY at Deg F:** | 0.79 at 60 |
| **DENSITY at Deg F:** | 6.6 lbs/gal at 60 |
| **VAPOR PRESSURE, mmHg at Deg F:** | 0.52 at 68 Approximate |
| **SOLUBILITY IN WATER, wt. % at Deg F:** | Less than 0.01 at 77 |
| **VISCOSITY OF LIQUID, cSt at Deg F:** | 1.6 at 77 |
| **SP. GRAV. OF VAPOR, at 1 atm (Air=1):** | 5.65 |
| **FREEZING/MELTING POINT, Deg F:** | -50 |
| **EVAPORATION RATE, n-Bu Acetate=1:** | 0.1 |
| **BOILING POINT, Deg F:** | 369 to 406 Approximately |

## SECTION 10 STABILITY AND REACTIVITY

**STABILITY:**
Stable

**CONDITIONS TO AVOID INSTABILITY:**
Not Applicable

**HAZARDOUS POLYMERIZATION:**
Will not occur

**CONDITIONS TO AVOID HAZARDOUS POLYMERIZATION:**
Not Applicable

**MATERIALS AND CONDITIONS TO AVOID INCOMPATIBILITY:**
Strong oxidizing agents

**HAZARDOUS DECOMPOSITION PRODUCTS:**
None

## SECTION 11 TOXICOLOGICAL INFORMATION

Please refer to Section 3 for available information on potential health effects.

## SECTION 12 ECOLOGICAL INFORMATION

No specific ecological data are available for this product. Please refer to Section 6 for information regarding accidental releases and Section 15 for regulatory reporting information.

## SECTION 13 DISPOSAL CONSIDERATIONS

Please refer to Sections 5, 6 and 15 for disposal and regulatory information.

## SECTION 14 TRANSPORT INFORMATION

**DEPARTMENT OF TRANSPORTATION (DOT):**
DOT SHIPPING DESCRIPTION: PETROLEUM DISTILLATE, N.O.S., COMBUSTIBLE LIQUID UN 1268, III
Note: In containers of 119 gallons capacity or less this product is not regulated by DOT.

## SECTION 15 REGULATORY INFORMATION

**TSCA:**
This product is listed on the TSCA Inventory at CAS Registry Number 64742-47-8

Clean Water Act/Oil Pollution Act:
This product is classified as an oil under Section 311 of the Clean Water Act (40 CFR 110) and the Oil Pollution Act of 1990. Discharge or spills which produce a visible sheen on either surface water, or in waterways/sewers which lead to surface water, must be reported to the National Response Center at 800-424-8802.

**CERCLA:**
If this product is accidentally spilled, it is not subject to any special reporting under the requirements of the Comprehensive Environmental Response, Compensation and Liability Act. We recommend you contact local authorities to determine if there may be other local reporting requirements.

**SARA TITLE III:**
Under the provisions of Title III, Sections 311/312 of the Superfund

Amendments and Reauthorization Act, this product is classified into the following hazard categories:
Fire.
This information may be subject to the provisions of the Community Right-to-Know Reporting Requirements (40 CFR 370) if threshold quantity criteria are met.

## SECTION 16 OTHER INFORMATION

**HAZARD RATING SYSTEMS:**
This information is for people trained in:
National Paint & Coatings Association's (NPCA)
Hazardous Materials Identification System (HMIS)
National Fire Protection Association (NFPA 704)
Identification of the Fire Hazards of Materials

| | NPCA-HMIS | NFPA 704 | KEY |
|---|---|---|---|
| **HEALTH** | **1** | **1** | 4 = Severe |
| **FLAMMABILITY** | **2** | **2** | 3 = Serious |
| **REACTIVITY** | **0** | **0** | 2 = Moderate |
| | | | 6. 1 = Slight |
| | | | 7. 0 = Minimal |
| | | | 8. |

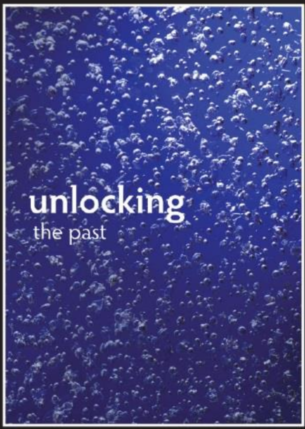
CAUTION: HMIS ratings are based on a 0-4 rating scale with 1 representing minimal hazards or risks, and 4 representing significant hazards or risks. Recommended HMIS ratings should not be used in the absence of a fully implemented HMIS hazard communication program.

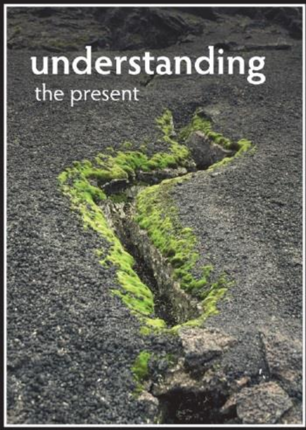
**REVISION SUMMARY:**
Since September 28, 2001 this MSDS has been revised in Section(s):
3

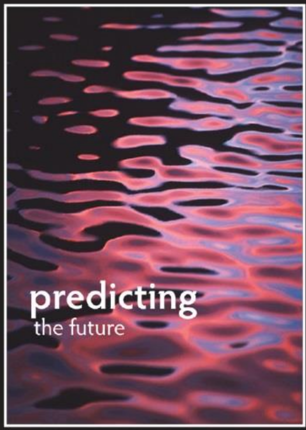
**REFERENCE NUMBER:**
**HDHA-C-25198**

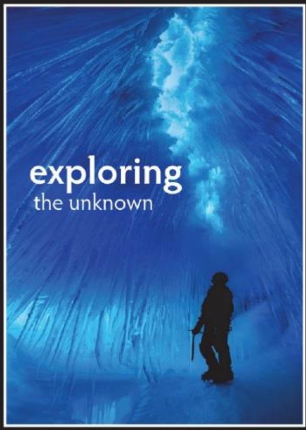
**SUPERSEDES ISSUE DATE:**
**September 28, 2001**

**LAST PAGE**

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