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Hazardous Substances in Antarctica

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King George Island - Historic Fuel and waste store. Source: Wikipedia

Abstract

The continent of Antarctica is one of the most inhospitable places on the planet, with human survival in this region being totally dependent on the regular and substantial supply of goods and materials from overseas. Energy, primarily in the form of oil, gas and Diesel, form a vital component to this survival in maintaining the functionality for all Antarctic Base stations, field camps and their associated logistics.

The transportation, use, storage and disposal of these energy sources has however, in some cases, left a legacy of contamination to areas of the foreshore, seabed and underlying soils. Early expeditions and fledgling base stations were often ill equipped with both the knowledge and facilities to adequately mitigate the adverse environmental effects associated with these substances, and failed to employ the robust and extensive environmental management systems that are present today. Effects on the environment, from anthropogenic sources were historically poorly understood and mismanaged, which has led to a several highly contaminated sites in areas close to current human habitation. In addition, the impacts of human activity on the Antarctic wilderness are often more readily recognizable than anywhere else on the planet. This is due to the absence of any native human population, the relatively recent colonisation of the land and the continent housing some of the most delicate ecosystems of any area on this planet. A significant number of these impacts have arisen on the ice-free ground close to the majority of Antarctic scientific research stations and where significant sites of scientific interest are also located.

This review will examine the historic legacy of contamination in Antarctica through the use, storage and disposal of hazardous substances, the short and long terms effects on the fauna and flora of the regions, as well as the legislative framework that currently protects both the Ross Dependency and Antarctica as a whole.

Introduction

In 1959 the Antarctica Treaty was signed by 12 countries, which were all actively involved in scientific research at locations in the Antarctic and sub Antarctic islands and had a vested interest in maintaining and preserving the interests of their countries and the territorial regions they claimed (Vidas, 2002). At this time there was only limited presence on the continent with the major bases and stations that are occupied today still in their infancy, or having yet to be established. During the 1970's and early 80's however, the fluctuating price of oil, as well as the emerging geological data that indicated the presence of various minerals and energy sources in Antarctica, prompted several of these consultative parties to draft the Convention for the Regulation of Antarctic Mineral Resource Activities (CRAMRA). Such a convention would be designed to manage mineral exploitation on the continent should it become feasible to do so (Carol, 1983). Furthermore, with renewable energy technologies still requiring substantial development the need was quickly recognised that if a long term substantial habitation was to be established on Antarctica, the primary limiting factor would centre on the production of energy for heat, lighting, transport, cooking and sanitation (Waller, 1989).

In 1988 the CRAMRA convention was signed as part of the Antarctic Treaty System by 33 of the member states in order to provide clarification to the mineral extraction debate following the absence of any other robust legislation that could be applied to this issue (Waller, 1989). A year after

the convention was signed however, France withdrew its support with Australia following soon after. A need was recognised to protect the continent's wilderness and natural environment over the potential short term gains of limited mineral exploitation, which resulted in the signing of the Madrid Protocol for the Environmental Protection to the Antarctic Treaty in 1991 (Madrid, 1991; Tin *et al.*, 2009). This protocol was aimed at improving environmental measures through a commitment to a comprehensive monitoring and management program of substances and activities that could cause a potential risk to the surrounding environment (Jaffe *et al.*, 1994). A complete ban on mineral extraction, with the exception for scientific purposes, came into force under Article 7 of the treaty, and environmental principles began to be monitored under different aspects of the Protocol.

In addition to the treaty and protocols associated with it, each territory is also governed by the legislation pertaining to that country. Scott Base is therefore part of the Ross Dependency and must also comply with the environmental protection legislation in New Zealand law. This includes the HSNO act 1991, for the use storage and disposal of hazardous substances that may be harmful to both humans and the environment. This piece of legislation combines with the Health and Safety in Employment act (HSE) to form a comprehensive framework of measures to protect humans and the environment through a series of controls on hazardous substances that can be used/stored/disposed of, based on the likely risk through identified exposure pathways (MfE, 2016).

What is a Hazardous Substance?

A hazardous substance is something that possesses one or more of the following properties that exhibits them at a level or degree that exceeds a standardized threshold value. These can be properties such as explosiveness, being flammable, or having the ability to oxidise a material (i.e. accelerate a fire). They can also be corrosive, or possess acute, or chronic toxicity to humans through any form of contact such as inhalation, ingestion etc. and be ecotoxic, with or without bioaccumulation (i.e. They possess the ability to kill living organisms either directly, or from the build-up of toxic products in the environment) (Worksafe, 2016).

Hazardous substances may also possess more than one hazardous property. For example, the majority of flammable products, such as petrol Diesel etc. are also toxic, both to humans and the environment. Classification of these substances therefore provides a tool to quickly and easily assess the risk involved in using such a substance, as well as indicating what potential handling, storage and disposal provisions may be required (Worksafe, 2016).

The controls assigned to a hazardous substance vary according to the hazard classification of material and type of hazard. For example, certain ecotoxic products, such as oils, may require bunding around the storage container to prevent any leaks, or spillages of the oil from the container entering the ground, or nearby seawater. Highly flammable substances must be stored at prescribed distances from ignition sources so as to prevent fire, whilst other materials, such as explosives, may require tracking throughout the lifecycle of the product (HSNOCOP 2015). This is to ensure the material remains with the people, or organizations that have been trained to use/store or dispose of it safely and with appropriate regard to environmental considerations. These provisions, placed around the use storage and disposal of a substance, are called lifecycle controls, as they are present for the entire lifecycle of the substance and can, in some cases, apply for any amount or, more often, when that substance exceeds a certain threshold quantity or concentration. This is a risk based approach that provides the necessary provisions and control related to the likelihood and implications if an accident were to occur. The more hazardous a substance is to humans and / or the

environment the greater number of controls it is likely to possess, such as approved handler certification and tracking requirements (EPA, 2016).

Hazardous substances can also affect people and the environment in different ways. Human health effects may be exhibited as a chronic symptom, such as personality changes, sleep disorders, memory loss, cancer, fertility problems, or as acute symptoms such as skin sensitivity, vomiting, nausea, shortness of breath etc. (EPA, 2016). The seriousness of these environmental and health risks are why managing such substances becomes increasingly important, especially when used in remote locations such as Antarctica. From a human perspective medical attention in Antarctica is not always available and intensive patient care may be several hours' flight time, even from well provisioned and staffed base camps. From an environmental perspective, the breakdown of organic hydrocarbons in Antarctica occurs at a much slower rate than anywhere else on the planet, due to the cold temperatures reducing microbial activity in the underlying soils. The logistics of cleanup procedures are also invariably expensive and often difficult to implement due to the inclement and unpredictable nature of the climate (Saul *et al.*, 2005).

The Madrid Protocol

Antarctica has been regarded as the 'last great wilderness on earth', with the Madrid Protocol formulated under the Antarctic Treaty System in 1991, is an attempt to protect this wilderness from potential future threats from mankind, such as those from hazardous materials.

The Protocol has six annexes, related to:

- Environmental impact assessment
- Conservation of Antarctic fauna and flora
- Waste disposal and management
- Marine pollution prevention (MARPOL)
- Area protection and management
- Liability

In marine ecosystems surrounding Antarctica activities are primarily governed by the provisions of the following legislative documents:

- Madrid Protocol, 1991
- Antarctic Treaty, 1959
- Convention for the Conservation of Antarctic Seals, 1972
- Convention for the Conservation of Antarctic Marine Living Resources, 1982
- International Convention for the Prevention of Pollution from

Arguably one of the significant drivers to the signing of this treaty was the lengthy campaign mounted by the environmental group Greenpeace (Fogg, 1992). This included the construction and operation of an Antarctic base from 1987-1991 called the *World Park Base*. This was located at Cape Evans on Ross Island and was set up as a non-governmental year-round research and campaign station.

The idea of a 'World Park' was formulated by Greenpeace in an attempt to prohibit any form of commercial exploitation, such as the extraction of oil and minerals on the continent, with the exception of the limited activities required for scientific research. Commercial extraction of hazardous substances, particularly oil, is often fraught with environmental impacts, and even with modern techniques and management practices accidents do still occur. Greenpeace recognised this in their campaign, which was significantly strengthened in 1989 when the bulk oil tanker the 'Exxon Valdez' ruptured its hull and caused a significant oil spill in Alaska (Greenpeace, 2016). With months of costly clean up, severe environmental impacts and daily pictures of seabirds coated in thick crude oil being displayed on the news, this disaster severely undermined the oil company's assurance that drilling extracting and transporting oil around ecologically sensitive areas such as those of Antarctica could be conducted in a safe environmentally friendly manner.

The idea of prohibiting the extraction of minerals and resources gained significant traction partly due to the campaigns from pressure groups but also in response to the lifting of the oil embargo imposed by the organisation of petroleum exporting countries and the subsequent falling price of crude oil (Nowlan, 1991). Greenpeace subsequently closed down and completely dismantled the base in 1992, in part due to the signing of the protocol, but also due to the logistical costs and environmental footprint caused by maintaining a station in Antarctica.

With the protocol in place, governments and organisations operating in Antarctica now possessed a framework in which it operate under. Concerns have however often been raised by environmentalists that treaty members frequently seem loathe to adopt all the aspects of environmental protection and management regimes required by the protocol. Breaches of existing rules can be found in many case studies such as the French project to build an airstrip through the centre of a penguin rookery (Elzinga, 1991). Whilst never being formally recognised as an issue unofficially pressure is generally applied outside of the formal meeting process in order to resolve such an issue and not cause formal political hostilities. An approach which is typical for a wide variety of environmental concerns, as well as other treaty related matters (Stürchler and Elsig, 2007).

A legacy of contamination - managing effects and mitigating risk

Despite the signing of the Madrid protocol, as well as the limited number of base stations and human habitation in Antarctica at the time, a legacy of contamination from hazardous substances still exists to this day. Traditionally the primary method to remediate an area of heavily contaminated land was to "dig it up and ship it out" an approach which is still practiced in some situations. This is however an often costly and labour intensive procedure, with more modern approaches based around managing the risk and the associated source receptor pathways. Alternative methods such as employing impermeable membranes to provide a barrier between the contaminated area and the environment, as well as diluting the sample with uncontaminated soils to bring levels below target soil guideline values are some of the approaches that have been employed as an alternative to straightforward removal and disposal (MfE, 2016).

There is also the issue of whether complete remediation of the site would incur a greater environmental footprint than just leaving the area in situ. For example, excavation can, in some instances, re-suspend or re-mobilize contaminants, which may cause an increase in contaminant bioavailability and consequently elevate contaminant levels in food chains (Perelo, 2010).

Several of the countries with a historic legacy of occupancy in Antarctica have attempted to remove abandoned infrastructure, with non-governmental organisations also involved in this clean up (Rogers *et al.*, 2012). It has been estimated that the volume of abandoned and unconfined waste on the continent, extrapolated from a few well documented sites, may be in exceedance of 1,000,000 m³, with the volume of hydrocarbon-contaminated sediment being of a similar order (Sual and Stephens). Areas such as Cape Hallet and Fossil Bluff have had extensive remediation work completed (Antarctic Treaty Consultative meeting 2012). In other instances however, rather than being removed or remediated some of the sites, identified as potentially contaminated, have instead just been classified in the Antarctic Treaty List of Historic Sites and Monuments and left in situ (Saul and Stephens, 2015).

Following the International geophysical year in the late 1950's a number of base stations were established, which have subsequently been abandoned e.g. Wilkes station and such infrastructure can attract wide-ranging opinions with such an area being perceived as environmentally hazardous, or culturally valuable, or possibly both (Evans 2011). Even at a modern facility such as Scott Base, certain buildings remain, including the Trans Antarctic Expedition hut, that have been found to contain asbestos and whilst the majority of this material is effectively encapsulated the issue remains how to effectively conserve and preserve such a building, whilst managing the risks associated with access and remediation (pers comm. Simon Trotter- Ops and Planning manager Antarctica NZ).

Other major forms of contamination in Antarctica include the accidental spillage of hydrocarbons during storage and distribution of fuels from tanks, drums, pipelines, bladder systems, or abandoned vehicles (Waterhouse, 2001). Secondary sources of contamination can also include fugitive movement of engine and lubrication oils used in road vehicles and aircraft (Kennicutt *et al.*, 1998) as well as experimental oil introductions (Webster 2003) as part of ongoing and historic scientific experiments. In addition, minor contributions to hydrocarbon soil contamination can also arise from the deposition of particulate matter from Diesel generators and base station waste incinerators, or emissions from vehicles burning fuel (Caricchia *et al.*, 1993).

The management of hydrocarbon spillage is also reliant on understanding the relationship between the various parameters of soil dynamics, such as moisture, microbial activity, hydrophobicity, and ground temperature. Examination of this microbial activity, including that of certain hydrocarbon-degrading bacteria, can also be used to elucidate the typical level of contamination in that particular soil. Organisms such as *Rhodococcus*, *Sphingomonas*, and *Pseudomonas* species have been shown to exhibit elevated populations in such contaminated soils. Microbial diversity has however been shown to decline overall with this increased hydrocarbon concentration (Saul *et al.*, 2005).

Hydrocarbons are introduced to the environment of Antarctica from both natural and man-made sources. Studies have shown the Cyanobacteria in soils and meteorites can produce significant quantities of long-chain *n*-alkanes and/or *n*-alkenes (Clemett *et al.*, 1998), however the vast majority of hydrocarbon presence in Antarctica is sourced primarily from human activity. This is generally concentrated around current or historic scientific research stations and field camps. Such spills can affect entire food webs, and the behavior of a spill in such a cold dry environment can dramatically differ from that in a temperate region, thus making it particularly important to implement procedures to minimize risk and effectively clean up any spills.

The majority of human activities in Antarctica need energy in the form of hydrocarbons for power generation, heating, and vehicle and aircraft operations. In 2004 the American base at McMurdo Sound included an estimated storage capacity of 34,000,000 L of fuel, primarily as light fractions

special aviation fuel (Aislabie, et al., 2004). Current storage capacity will be at least equal to if not greater than this quoted figure. Other Hydrocarbon fuels stored in smaller volumes include 'mogas', which is a military grade of petrol, as well as heavier fractions, such as lubricating and engine oils. All of this aviation fuel is distributed from McMurdo Station to the nearby airfields via aboveground pipelines, as well as being transported to Scott Base by road tanker. A refuelling station is also present at Marble Point, on the mainland, which can cater for up to 560 000 L storage capacity for helicopters operating in the Dry Valleys, and is replenished from offshore pumping from refuelling sea vessels (Aislabie, et al., 2004).

Due to this extensive storage of hydrocarbons at large bases such as McMurdo Station these areas also contain some of the most extensive contamination in the region, with widespread hydrocarbon concentration in underlying soils having been found in the locality of the fuel storage or distribution areas. These include helicopter pads, truck stop refuelling areas and mobile tanker storage areas (Kennicutt, 1998).

Hydrocarbon contamination of soils has also been observed from scientific drilling projects. For deep core samples the drill rig is generally required to be lubricated by kerosene, which is poured in significant quantities down the excavated area, with no prescribed methodology for its retrieval. Contamination from this form of human activity has been most notably documented in the Dry Valley Drilling Project at sites including Lake Vida and New Harbour (Cameron *et al.*, 1977).

As well as historic 'minor but continuous' spills from these hydrocarbon storage and refueling areas occasionally a large spill will also occur, which in general is related to an accident occurring on a marine vessel discharging fuel oil from a ruptured tank. Such an incident occurred in 1989 when an Argentine resupply vessel ran aground on a reef on the Antarctic Peninsula near the America base of Palmer station. This resulted in a fuel spill in excess of 600,000 Litres and was the largest documented marine oil spill ever to occur in Antarctica (BAS, 2016). Effects associated with this spill were however relatively minor and restricted to a few Kilometers from the wreck due to the surrounding geography and climatic conditions. This therefore had a relatively minor effect on seals, fish and whale species in the region, but served as a warning that future oil spills may not be as benign.

As with spills in more northerly latitudes, oil on the water's surface can quickly attach to the feathers of marine based birds, which causes them to lose their ability to repel water and become less buoyant. Mammals such as seals also die from drowning and freezing with the oils toxicity even affecting the microscopic invertebrates at the base of the food chain (Saul *et al.*, 2005).

An oil spill in a polar environment can be particularly serious as the substance behaves differently at lower temperatures becoming more thick and viscous and therefore harder to remove and disperse. Microbes also take longer to degrade the long chain hydrocarbons and any oil trapped in ice may require several years before it can disperse. Furthermore, as alluded to earlier cleanup and remediation requires significant resource and finance which may be difficult to obtain for a large scale situation (BAS, 2016).

Current measures that have been adopted in attempt to mitigate such effects include the use light fuels such as diesel that evaporate and disperse more readily than heavy fuel oils. All vessels entering waters close to Antarctica are expected to be ice-strengthened and carry current charts and adequate GPS systems for effective navigation (Tin *et al.*, 2009; BAS, 2016).

Minor oil spills are however an increasing form of pollution in Antarctica due to the escalation of shipping activity in the region, primarily from tourist vessels. While these craft often have facilities to

contain waste oil, as well as separate it from water before discharge, the ever greater presence of ships in the area will inevitably increase the frequency with which accidents occur. As well as the Argentinian resupply vessel, in recent years there have also been a number of tourist ship groundings around shallow, or poorly chartered waters. Incidents have also occurred involving fishing boats such as the sinking by an iceberg of the M/V Explorer in the Bransfield Strait in November 2007 (ASOC, 2016a). The environment the ship sank in was fortunately a deep water area and located a significant distance from land or other sensitive marine areas. In addition, the turbulent nature of the Southern Ocean allowed effective dispersal of the oil before it could cause any significant damage despite nearly 180 m³ of Diesel being discharged. Such incidents have also added weight to the establishment of marine protected areas, with the largest of these locations currently proposed off the Ross sea region (CCAMLR, 2016).

Effects

Hydrocarbons that are entrained in Antarctic soils, undergo a naturally occurring processes to breakdown these large carbon chain molecules to simpler lighter fractions that can then be volatilised into the atmosphere (Snape *et al.*, 2003; Tin *et al.*, 2009). Physical processes can also cause these contaminants to dilute and disperse or volatilize, however chemical and biological processes generally transform contaminants to modified compounds. Such mechanisms generally occur for the majority of spill sites in varying degrees that can depend on the soil environment, as well as the hydrocarbon fuels that have been spilled (Campbell *et al.*, 1994).

In general, lighter fractions containing a higher vapour pressure, such as Kerosene and mogas, quickly volatilize from the Antarctic soil (Webster, 2003). These substances are however more mobile due to their low viscosity, and therefore are able to travel through the unfrozen soil active layer below. Heavier fractions of oil, such as lubricating and engine oil, are generally more viscous and less volatile therefore do not appear to migrate far from their area of deposition (Gore *et al.*, 1999). Hydrocarbons have also been observed to pool in spill site areas where the liquids have undergone a downward movement from the initial thawing of the surface layer, but have been stopped by the occurrence of an ice-saturated barrier or 'lens', which generally prevents further migration (Chuvilin *et al.*, 2001). This layer can largely protect the underlying soils from hydrocarbon entrainment, however with a warming continent cracks in the ice cemented permafrost have been shown to allow hydrocarbons to migrate across this layer into frozen soil.

Dissolved hydrocarbons and those associated with particles in surface and subsurface soils can also be mobilized with snowmelt and may be able to migrate to surface waters and the offshore marine environment (Kennicutt *et al.*, 1998).

A quantitative measure of the level of contamination in soils from spills such as those from oil based compounds is known as the total petroleum hydrocarbon (TPH) count. The TPH levels around former and current bases has confirmed this legacy of hydrocarbon contamination in the underlying soils (Kennicutt., et al 1998; Green and Nicols, 1995). It is also most likely that hydrocarbons such as those observed at bases including McMurdo and Scott base have contaminated some of these soils for more than 40 years. Furthermore TPH levels have also been found in elevated concentrations at sites such as Cape Evans and are presumed to be sourced from fuel depots placed there by the men of the Terra Nova Expedition of 1910 (Evans, 2011).

Soil investigation in such sites have discovered that contamination is both from heavy and light hydrocarbon fractions. In addition, surface contamination also appears to have been modified from the combined processes of both abiotic and biotic activity, whereas subsurface contamination in the

same profile generally remains unchanged (Gore *et al.*, 1999). Limited modification, and therefore degradation, appears to have occurred in these soils deep below the surface and this would be expected from the limited microbial activity and lack of sunlight to break these compounds down.

Other substances present in fuel oils that were used in Antarctica have included organic lead and anti-icing agents such as ethylene glycol and diethylene glycol. Antistatic additives have also been identified in some historic military grade fuels, as well as antioxidants, and anticorrosive substances, all of which have been deemed too toxic for modern day applications, but remain entrained in the soils at these contaminated sites. In addition, elevated levels of tetra ethyl lead (used as an additive in petrol) have been detected in soils around historic Petrol storage sites at Scott Base (Saul, 2005), the impact and significance of such fuel additives in these areas are currently not well understood or studied.

Hydrocarbon contamination in soils can be of concern due to its potential detrimental effects on soil properties and characteristics. Therefore it is essential to understand such effects for effective management and remediation of any contaminated soil. Temperature profiles of hydrocarbon contaminated and non-contaminated sites around Scott Base and Marble Point have indicated significant differences depending on the time of year. During conditions when soils are snow-free in dry sunny summer months, daily maximum surface temperatures from hydrocarbon-contaminated soils are often up to 10°C warmer than their equivalent pristine sites (Balks *et al.*, 2002). Such elevated temperatures from hydrocarbon-contaminated sites are thought to be attributed to a decrease in the soil surface albedo effect from the darkening by hydrocarbons near the surface.

In contrast however, sites such as those sampled at Bull Pass in the Wright Valley have exhibited hydrocarbon contamination at a subsurface level where no significant difference in soil temperature was detected between a pristine and hydrocarbon-contaminated soils (Balks *et al.*, 2002). Furthermore there is also the potential for hydrocarbons to affect soil moisture content where such contaminated soils become weakly hydrophobic in repelling water due to the presence of hydrocarbons similar to displays of oil being immiscible on a layer of water. No evidence of this hydrophobicity was however detected at pristine sites. This incremental increase in soil hydrophobicity has been considered unlikely to affect the overall moisture entrainment into the soil, with no obvious differences in soil moisture retention able to be observed between hydrocarbon-contaminated and pristine soils at Marble Point, Scott Base or Bull Pass (Saul *et al.*, 2005).

Although one of the main types of hazardous substances present in Antarctica is hydrocarbons another large group of compounds, which include the heavy metals of Lead Copper and Cadmium have also provided significant challenges in protecting the surrounding environment and people occupying those areas. Exposure effects of such metal contaminants has been extensively studied in other environments (Jarup 2003). This however remains understudied and unresolved in many regions such as Antarctica (Chapman and Riddle, 2005). The primary sources of metal contamination in Antarctica are from long-range airborne contamination, seaborne contamination and terrestrial contamination from human activities (Poland *et al.*, 2003).

Liability

Continued an increased activity in Antarctica is likely to further elevate the risk of harm to this unique environment and it is therefore crucial that responsibility for such potential future accidents be appropriately distributed. Such thinking inspired the formation of a liability Annex to the Protocol on Environmental Protection to the Antarctic Treaty. The primary obligation of this Annexure is for member states to ensure their operators take responsibility for any actions that have caused harm

to the Antarctic Treaty area, which is defined as south of 60° Latitude. This piece of legislation was been adopted as a legally binding measure at the 28th Antarctic Treaty Consultative Meeting at Stockholm in 2005 following over 13 years of negotiation, however it will not come into force until it has been ratified by all of the Antarctic Treaty consultative Parties (ASOC, 2016b).

The unique aspects of the Annex are that it establishes liability for proven harm to the Antarctic environment, even if there has been no economic loss or damage. The Annex also employs strict Liability, so it attributes this irrespective of fault. Liability can be attached to a person, group or government, if it is proven that there was a failure to take prompt and effective response actions regardless of whether there was any attempt to undertake preventative measures, or develop contingency plans (Annex VI, 2005).

This liability Annex took over 13 years of negotiation to come into force and underwent several revisions in terms of the scope of its application. This is reflected in the complex and controversial nature of the issues to be addressed, as well as the procedural challenges and often turbulent political climate.

To date this piece of legislation has yet to be ratified with only Sweden, Peru, Poland, and Spain having signed the annex. It is however hoped that the annex will be ratified in the near future and therefore afford significant additional environmental protection to the continent and its flora/fauna (Parliament NZ 2016).

Summary

The continent of Antarctica is governed by a series of international agreements and country dependent legislation that regulates both research activities and tourism. The general consensus is that so far the Antarctic treaty, which underpins a country's involvement in Antarctica, has provided adequate protection to help conserve its environment and natural resources. With the growth in tourism, as well as the increasing interest and establishment of base stations from governments around the world, increased pressure is however being placed on these fragile areas.

Tourists and scientists will also invariably congregate close to ice-free areas, which make up less than 1% of Antarctica. These ice-free areas also contain the majority of Antarctica's flora and fauna, yet only a small proportion have any form of official protection, thus putting many of the species in such areas at risk.

Remediation of sites, where human impact has caused significant damage, has been successfully undertaken at a number of locations in Antarctica. Such campaigns must however operate under challenging environmental conditions, as well as having equipment and a methodology that is easy to install and implement, with low energy and infrastructure requirements. The end result being an operation that will have minimal permanent impact on the environment.

Despite technological advances future contamination of the underlying soils and marine areas will inevitably still occur in Antarctica. Remediation techniques, whilst being technologically advanced, still require significant infrastructure and finance to be successful. Significant awareness, in relation to the use storage and disposal of hazardous substances, does however now exist from the majority of tourist operators and Scientists working in Antarctica. Despite the challenges of ever increasing visitor numbers to the region, management practices and a liability regime are slowly being implemented in the hope of ensuring effects associated with increased human activity can be adequately mitigated and managed for the future.

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