WASTE DISPOSAL IN THE ANTARCTIC: THE CASE AGAINST INCINERATION

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ABSTRACT

The Scientific Committee on Antarctic Research (SCAR) has recently published recommendations on waste disposal in the Antarctic. The use of incineration is advocated as a preferred means of disposing of combustible waste. This study questions the SCAR strategy and the following points are made:

1)There is no independent verification of the data from which SCAR have derived the values upon which the recommendations are based. A comprehensive waste audit has not been carried out for Antarctica.

2)Incinerators used in Antarctica are unlikely to be fitted with exhaust gas scrubbers and electrostatic precipitators. It is likely therefore that most will fail to meet operational guidelines such as those now proposed, for example, in the UK.

3)Emissions of toxic chemicals to the atmosphere from the incinerators will be inevitable whether or not emission controls are fitted. These will include heavy metals, dioxins and polynuclear aromatic hydrocarbons.

4)Quantities of ash contaminated with these toxic compounds will be produced. While these are likely to be removed from the Antarctic Treaty area, they may subsequently be dumped at sea with unknown effect.

5)Incineration will cause the widespread dispersion of toxic contaminants within the Antarctic particularly in the sensitive coastal areas. Many of the chemicals likely to be evolved from combustion processes are toxic, persistent or bioaccumulative.

6)The toxic effects of these chemicals in Antarctic ecosystems are largely unknown. Ways in which differences between temperate and Antarctic ecosystems could be important are illustrated hypothetically using the example of the marine microlayer.

7)Uncertainties exist with respect to many aspects of incinerator operation in the Antarctic. These include the operational characteristics of the plant, the scale of emissions from them, and the environmental effects of these emissions.

8)It is concluded that in the light of these uncertainties the precautionary measure of removing all waste from the Antarctic should be adopted.

INTRODUCTION

The fourth Recommendation of the Antarctic Treaty Consultative Meeting (ATCM XIII-4) held in 1985 resulted in an invitation to the Scientific Committee on Antarctic Research (SCAR) to offer advice on waste disposal operations in Antarctica. Advice was sought concerning procedures, standards and logistics in relation to the circumstances of operations in the Antarctic and with regard to cost effectiveness. In part, this Recommendation also sought a comprehensive review of the waste disposal aspects of the Annex to a previous ATCM Recommendation (ATCM VIII-11) and also recalled Recommendations ATCM VI-4 and ATCM XII-4. This latter had previously resulted in SCAR recommending points for consideration in any revision of the Code of Conduct. In the context of any Recommendations it is worth noting that SCAR considers that "human activity by its very nature generates pollution and waste" (p36).

The response of SCAR to ATCM XIII-4 is contained in a document entitled "Waste disposal in the Antarctic" (SCAR 1989). This was compiled partly on the information supplied by National Operators in response to two circulars sent out in 1986 and 1987. It is expected that this document will form the basis of updating the waste disposal practices at ATCM-XV in Paris in October 1989. The report recommends a waste management strategy to be adopted by the National Operators which is designed to reduce both waste generation and disposal in the Antarctic. Of the thirty recommendations made by the expert panel, thirteen relate to waste management planning. The remaining seventeen deal with waste disposal measures and of these no less than four deal with disposal of waste by incineration. They are detailed in Appendix 1: Recommendations 16, 17, 18 & 28. Number 28 is included since it relates to incineration of wastes aboard vessels.

Consideration of the SCAR report makes it clear that incineration of materials is one of their preferred options for waste disposal. Excluding empty fuel drums, 70% of waste generated is combustible (p23). Overall, waste production is in the region of 4 cubic metres per person per year which reduces after incineration of combustible wastes to about 1.3 cubic metres per person (p24). The apparent advantages are in terms of reduced weight and volume to be retrograded (removed from the continent) or disposed of (according to current practice) to landfill, sea-ice or inland ice-pits. On the basis of replies from 16 National Operators it appears that some 5000 cubic metres of incinerable waste are produced annually (p29). There is no indication of the likely accuracy of these estimates. This is of importance since there are apparent inconsistencies.

For example, an incinerator system proposed for McMurdo Station of 61 cubic metres (p29) per day capacity, if operated to 25% of throughput potential could, in itself, process in excess of 5000 cubic metres annually. A comprehensive waste audit for Antarctica, on lines suggested by the USEPA (EPA 1988) has not been carried out. Hence, difficulties can be expected in verifying any effect of the SCAR (1989) Recommendations concerning waste management planning (if adopted at ATCM XIV) since accurate, baseline values are not available. The question must also arise as to the reliability of the estimates given by the national operators. Since SCAR (1989) does not report the raw data, it becomes impossible to independently verify the figures upon which their recommendations are based.

Quite apart from any doubts about the quality of the data, there are a number of serious doubts about the desirability of incineration in any form. Open burning is the most widespread form of incineration and the SCAR panel rightly recommends that operators should cease this practice. Instead they recommend that a process of emission-controlled burning using dedicated incinerator plant be instituted. While this apparently represents an improvement over uncontrolled open burning, substantial questions remain. In this respect the information contained in Section 4.6.2 of SCAR (1989) is misleading since emissions will remain of significance. The remainder of the present document considers the potential environmental problems of incineration in the Antarctic, questions the validity of the SCAR panel recommendations and the wisdom of pivotal reliance upon incineration for waste disposal there. It is concluded that only complete removal of all wastes will avoid compromise of the delicate Antarctic ecosystem.

INCINERATOR SPECIFICATION

On the basis of the information contained in the SCAR report it is possible to identify the likely specifications of incinerators deemed suitable for Antarctic operation. In this context, the use of brazier type burners must be regarded as an extension of open burning practice. A major consideration is the availability of factory constructed units requiring a minimum of on-site construction. Designed to work using supplementary fuel to assist combustion, incinerators accepting 1 cubic metre of waste upwards are thought by SCAR (1989) most likely to be deployed. In this regard the observation that discarded or contaminated fuels may be used for this purpose may be significant in view of Recommendation 10 that all national operators should establish a long term program to remove existing abandoned fuel drums.

In practice, use may be made of marine incineration plant (eg Rauma-Repola Unex Series) 30-200 kg/hr range on the

smaller bases. In these, charging is a manual operation and emission control is simply by means of optimised combustion. A significant problem associated with such plant is the carry over of ash due to fire bed agitation during charging. This may result in the discharge of particulates. No post-combustion controls are fitted.

Above this capacity, plant designed for batch operation, with different charging modes, is available. Some may have the facility for heat recovery plant to be fitted. An example is the Warren Engineering range of Controlled Air incinerators (CA-range). CA-15 incinerators from this range are in operation at Casey, Davis and Mawson bases in Antarctica. Supplementary fuel is used. The batch nature of the process results in less fire bed disturbance than the continuous charging method. A starved air heat distribution method is used to minimise fuel consumption in a reduced size secondary chamber. Emission control of this type of incinerator is dependent upon control of firing parameters by a trained operator. There is no post combustion train emission control. The operation of this type of incinerator using continuous charging can result in substantially lowered emission standards.

Incinerators of this capacity and general design are widely in use in industrialised countries. For example in the UK a variety are available. The Hoval V.O.T. incinerator range has a capacity of between 35 & 70 kg of waste per hour with three or four charges per day. No post combustion emission control is fitted. These are sold on the basis that they can incinerate a variety of waste. The Hoval CV range has a capacity of 200-400kg waste per day of mixed composition and has the facility for a heat exchanger to be fitted. The Hoval Multizon system can be configured to deal with between 700 and 14,400 kg waste per day and has the option of flue gas scrubbers. It incorporates a secondary thermal reactor whose operational parameters are controlled by primary air input and atomised water injection.

Another major company, Incinco produces the Firestream II range of incinerators designed to deal with between 88 and 1256 kg per hour. This is a modular system with secondary chamber operating at a temperature of between 800 and 1200C. Like the Warren CA range this is designed to minimise support fuel combustion with parts of the burn cycle taking place unsupported. The Firestream range is designed to handle between 25 and 750 kg/h and incorporates a less sophisticated secondary chamber arrangement. Finally, the Universal range of incinerators have a capacity of between 360kg and 2000kg per 8 hour charging for the "S" range. These employ a secondary combustion chamber approach. The "H" range of plant has in excess of two tonnes capacity per day and the option of heat recovery plant attachment. Such machinery is widely

employed in the incineration of clinical waste and there are some 600 such plants in the UK alone (DoE 1989).

From the above, it is apparent that only the larger plant is fitted with emission control devices and that these tend to be secondary combustion chambers only, rather than gas scrubbers or electrostatic precipitators. As noted below this is likely to be due to cost considerations and unavailability of such devices for the smaller type of incinerator likely to be projected for Antarctic use. Due to the relatively limited market it is unlikely that suitable modular emission control equipment will be designed and produced. The extreme operating conditions in the Antarctic would require specialised design fixes to problems of operating "wet" systems which would add to capital costs. Problems could be experienced with water contamination in fuel freezing and this could significantly affect incinerator operation, causing heavy emissions. If wet solid waste is to be burned then the possibility of partial occlusion of the chimney by frozen condensate may be important. The emission of vapours during drying may also be of importance. Certainly if scrubbers are used then plume reheat will be necessary to not only preserve plume buoyancy but also to prevent freezing of water vapour. This will add significantly to operational costs.

With such a variety of incinerator configuration available it is impossible to predict how any given design will perform with respect to emissions without extensive on site testing. Following widespread problems in the UK with this size of plant, the UK Department of the Environment have recently produced draft guidelines to cover the operation of both existing and new plant in this size range. For new plant maximum emissions of hydrogen chloride are set at 0.1 g cubic metre of flue gas, carbon monoxide not to exceed 0.15g/cubic metre and particulates limited to 0.1 g/cubic metre. Existing plant will be required to meet these guidelines within 7-8 years of implementation of the legislation. During this period a particulates level in the plume of 0.5g/cubic metre will be permitted. (HSE 1989)

The UK industry anticipates that much existing plant,even with modifications, will be unable to meet these guidelines. The economics of control devices for new plant will result in an increasing centralisation of such incinerator operations (ie fewer with higher capacity). This follows from the cost of construction and fitting of flue gas scrubbers and precipitators on small units. In engineering terms this is not regarded as cost-effective since control equipment does not increase linearly in cost relative to the capacity of the incinerator served. Fitting or retrofitting such equipment can multiply capital costs by a factor of two or three. In view of the remit afforded by ATCM XIII-4 to consider cost effectiveness, it is understandable that SCAR

(1989) considers that while further reduction of emissions from incinerators with secondary combustion chambers can be achieved with additional particulate control equipment "the initial reduction is so great that further reduction is probably not warranted." This clearly contradicts the later statement (Recommendation 16) that emissions should be reduced to the maximum extent practicable and indicates the weighting given to cost considerations.

It is reasonable to assume therefore that present incinerators in the Antarctic are likely to operate at well below the UK guideline standards. New plant, since it is likely to be of a size where the cost of emission controls are prohibitive is likely also to operate below these standards.

SCAR (1989) observe correctly that "Atmospheric emissions from the incineration of solid wastes vary considerably depending on the amount of refuse, the loading of the incinerator combustion chamber and incinerator design" (p29). This rightly makes it clear that the process of emission control is a highly subjective process in the absence of a scrubbing/precipitation train. Due to the likely variability of the waste stream, it is highly unlikely that the optimum conditions neccessary to prevent emissions of partially oxidised pollutants will be maintained at all times, even with a trained operator,. Startup and cooldown time are particularly problematic. With a scrubber train in operation, pollutant emission will still occur, though to a lesser extent.

The note by SCAR (1989) (p28) that particulates may be removed by scrubbers and precipitators (despite later statements denying the neccessity of such plant p29) raises the question of disposal of effluents generated by control equipment. Scrubber brines will be highly contaminated and should be removed from the Treaty Area (Recommendation 23). Emission control equipment will also produce flyash in addition to the quantities of bottom ash produced by normal operation. This ash will be contaminated with heavy metals, chlorinated dioxins and polynuclear aromatic hydrocarbons. As non-combustible waste this would presumably be subject to Recommendation 19 which allows sea-dumping outside the Treaty area after removal, subject to London Dumping Convention (LDC) provisions. Such ash would not meet requirements as to contaminant level and specific provisions are needed to ensure that it is removed to the home country of National Operators and that dilution with other inert waste does not occur in order to allow dumping operations at sea.

INCINERATOR EMISSIONS

Under perfect operating conditions, theory predicts that no environmentally damaging emissions will be produced by incinerators. Unfortunately it is never possible to achieve theoretically perfect conditions and it is now widely accepted that all incinerators emit a variety of materials (DoE 1989).

Visible emissions from incinerators may consist of gross particulates and partially carbonised material. A visible plume indicates incomplete combustion. In extremely inefficient cases, black smoke may be produced. In most operations with this size of incinerator, a pale brown coloration of the plume is generally noticeable for part of the time even in the larger scale plant fitted with extensive emission control devices.

CHLORINATED SUBSTANCES

Perhaps the best known components of incinerator emissions are the polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). Because of their extremely dangerous properties, the processes leading to these emissions have been widely studied (see: Commoner et al. 1987). These compounds are formed in the post combustion zone of incinerator plant and are thought to arise as a result of chlorine combining with phenolic fragments derived for example from the lignin contained in paper. Particulates also play an important role: it appears that PCDD/PCDF synthesis takes place in association with particulates in areas of the incinerator at a temperature of between 250-300C (Commoner et al. 1987).

Chlorine can be provided either organically bound as in PVC or as inorganic salt. Both lead to the formation of reactive hydrogen chloride. Interestingly, some controversy surrounds the possible role of PVC as a chlorine supply. Karasek & Dickson (1987) showed no increase in PCDD/PCDF relative to increased PVC in the incinerator feed. However this may well be due to fortuitous placing of the emission control devices in the area of maximum PCDD/PCDF formation as discussed by Commoner et al. (1987) since Marklund et al. consider that increased chlorine input will result in higher levels of these compounds in the ash and flue gas. SCAR (1989) anticipate this by suggesting in their recommendations that PVC not be combusted in unsuitable incinerators (Recommendation 16) and that (Recommendation 8) use of PVC products be restricted (p30 & 38) and that they be separated out of waste streams. If any waste segregation were achieved it would represent a triumph of hope over experience. Quite apart from the difficulties of positively identifying PVC in a mixed plastics waste stream it presupposes a will to do so which is not suggested by current disposal activities of most National Operators. In any case dioxins will still be emitted. Without conclusive

proof that PVC restriction will totally prevent dioxin and other halo-organic formation, use of incineration in Antarctica poses unacceptable risks.

Extremes of temperature could well exaggerate dioxin production. Rapid cooling of the stack gases is likely upon discharge into air at low ambient temperature. This could conceivably, in still air conditions, create a PCDD/PCDF formation zone in the plume after it leaves the stack with carried-over particulates acting as catalysts. The practice of burning chemical wastes (SCAR 1989 TABLE 4) under any circumstances should be stopped.

Undoubtedly then, significant quantities of PCDD/PCDF will be released to the Antarctic environment by the use of incinerators for waste disposal. Unfortunately, it seems that precise figures are simply not available for plant of small scale (see eg DoE 1989). This effectively means that the SCAR (1989) Recommendations are not based upon any hard emissions data for PCDD/PCDF and must therefore be regarded as largely conjectural with respect to statements of emission quality relative to these (or indeed other) compounds. On the basis of figures published for municipal incinerators in the Netherlands it can be calculated that between 1 & 5 mg PCDD per ton of refuse burned will be evolved (Olie et al. 1982).

Other materials of environmental concern are also likely to be mobilised as a result of incinerator operations. Even in large scale incinerators, the precise operational characteristics are often poorly understood. For example with hazardous waste incinerators Cundy et al. (1989) note that design philosophy tends to be very conservative and based upon "rule of thumb". As with much industrial plant, incinerator design advances tend to be through empirical guidelines developed from operational experience rather than through the predictive ability of theory.

SCAR (1989) note the improvement in emissions quality by the use of a secondary chamber on the incinerator plant and imply that emissions from such plant are of negligible significance. Lighty et al. (1989) note that the purpose of a secondary combustion chamber in a hazardous waste incinerator is partly to prevent the presence of products of incomplete combustion (PICs) in the off gases. The primary limitations to the success of the second chamber are usuallly chemical kinetics, in turn controlled by time, temperature, turbulence and excess oxygen in the burner system. Unless these are tighly controlled PICs will be emitted. This is made more likely with increasing heterogeneity of the feedstock. It seems unrealistic to expect then that the relatively unsophisticated plant likely to be used in Antartica, dependent largely upon manual adjustment of instrumental parameters will be capable of

satisfactory emission standards. This is of particular relevance to batch garbage incinerators since the dynamics of the fire bed in the first chamber will affect the efficiency of the secondary combustion zone and constant "trimming" is required as in normal oil/solids boilers to maintain optimum conditions. In this respect it is significant that much plant of lower capacity is advertised as requiring minimal operator attendance.

The importance of combustion dynamics may be illustrated by the observation that the simple combustion of propane to carbon dioxide and water may contain 83 steps comprising free radical chain reactions. Hence, under sub-optimum conditions potential exists for a variety of PICs to be formed from combusting mixed waste. In many cases there may be no observable correlation between carbon monoxide levels and organic emissions in the off gases (Staley et al. 1989) and this has implications for using CO as a monitor of combustive efficiency. The crucial role played by excess air is illustrated by the finding of Huffman & Staley (1987) that levels of PICs generally increased with higher levels of excess air in a single chamber research combustor.

Such factors are probably responsible for the wide spectrum of organic compounds known to be discharged as a result of municipal waste incineration. DoE (1989) reports a figure of 400 individual compounds which are found in the grate residues and stack discharges. Mowrer & Nordin (1987) identified chloroacetic acids at levels between 4.9 & 17 ug/cubic metre in the stack discharge from a municipal incinerator. Oberg et al. (1987) document halogenated phenols in stack gases from municipal waste incineration at ug/cubic metre quantities. Oberg & Bergstrom (1987) observe that PCDD/PCDF production co-varies with the presence of these compounds in stack gases. Recently, Schwind et al (1988) have isolated bromo-chloro-dibenzodioxins in municipal ash. This serves to illustrate the complexity of potential reactions leading to emissions from incineration of municipal waste. Emissions from incineration of similar wastes in the Antarctic are likely to be equally complex despite efforts to control the quality of the feedstock. Due to the smaller scale of the proposed operations and hence smaller fire-beds and combustion zones, it is possible that small disturbances may cause disproportionate emissions as compared to larger, better studied plant. This requires research.

POLYNUCLEAR AROMATIC HYDROCARBONS

A further group of potentially important compounds are likely to be discharged as a result of waste combustion. These are the polynuclear aromatic hydrocarbons (PAHs). Essentially composed of two or more fused benzene rings with or without additional substituted structures these compounds

arise as a result of the combustion of natural vegetation (see eg Laflamme & Hites 1978). There is thus a general background level in the environment. Recently, it has become apparent that combustion of fossil fuels and other anthropogenic sources including waste incineration and wood burning (Kamens et al. 1988) are significant sources of these compounds to the environment. Recently Jones et al. (1989 a & b) have noted that levels of PAH in archived wheat, forage crops and agricultural soil may be closely related to underlying air quality in the past. Jones et al. (1988) describe PAH levels in Welsh soils and suggest the importance of human activity coupled with long term atmospheric transport in determining the ambient levels of these compounds. Many are listed by the US EPA as priority pollutants. Significantly, the combustion of diesel fuel can also lead to the production of PAHs (Bayona et al. 1988) in association with particulates. This may be of significance given the likelihood of diesel being used as supplementary fuel in Antarctic incinerators.

HEAVY METALS

Finally, it is well known that refuse incinerator operations can lead to substantial emissions of heavy metals. Nriagu & Pacyna (1988) note that, for example up to 10g of cadmium per ton of waste incinerated may be emitted to the atmosphere. Similarly, up to 20g of lead per ton of material burned may be emitted to the atmosphere. Incinerators thus have the potential to act as highly significant point sources of metals. The origin of these metals are not simply metal components of the waste but include combustible material, for example, pigments, inks, plastic stabilisers, whiteners in addition to the natural metal content of the raw materials used in the combusted product. Hence, it is found that even where materials separation is practised all incinerator emissions contain substantial quantities of metals. Law & Gordon (1979) found mean cadmium levels of 41ppm in bottom ash, 64ppm in fly ash particulates and 1100ppm associated with particulates discharged to the atmosphere from a municipal incinerator fitted with emission controls. Hence refuse incineration in Antarctica will lead to substantial emissions of heavy metals and the production of large quantities of contaminated bottom ash (up to 30% of the dry weight of the feedstock) (Law and Gordon 1979). It should be noted too that in the absence of a particulates scrubbing device the proportion of fly ash escaping as atmospheric particles will increase.

POTENTIAL SIGNIFICANCE OF EMISSIONS

From the foregoing it is apparent that, failing significant advances of incinerator design, the size of plant suitable for Antarctic operation is also of a size likely to give

rise to substantial emissions of environmentally significant materials. This much is certain. What, to a large degree, remains uncertain are the ways in which these substances are likely to interact with the environment.

SCAR (1989) note that most human activity in Antarctica is concentrated upon ice-free land comprising less than 2% of the continental area (p11). It is thus reasonable to assume that much of the impact of incineration as a disposal practice will occur in these predominantly coastal areas. The ice free areas of land and the coastal regions are also the areas of most intense biological activity. SCAR (1989) accept (p19) that "when considering only the ice free coastal areas, man's influence can be significant." and note that a number of studies have shown adverse effects caused by organochlorine compounds (PCBs, DDT) escaping dump sites (p25). Other problems include elevated heavy metal levels near stations, particularly of lead. Astonishingly high lead levels (882ppm) were found in a contaminated soil sample taken from Scott base (Johnston & Stringer 1988) while the same study showed silver to be a common contaminant. Elevated cadmium levels were found in soil samples close to the dumpsite at McMurdo. It has been observed that the practice of open burning tends to concentrate metals at a site (SCAR 1989 p28).

The use of incineration will admittedly help to prevent gross contamination of the kind described above assuming of course that incinerator ashes are responsibly "retrograded" (removed), but at the expense of dispersing materials more widely into the environment. This would affect a relatively limited area of the continent. Boutron & Wolff (1989) note that stations, populations and emissions are very unevenly spread around the continent. They estimate that some 70% of the diesel fuel and kerosene used in Antarctica are imported through the 45 degree sector which includes McMurdo base. These workers also observe that a significant proportion of emitted metals would be expected to fallout within a short distance of the emission point. Moreover, they expect that emissions from coastal stations would tend to be driven away from the continental interior by the katabatic winds. There is no information about the fate of organic emissions.

Atmospheric emissions will be proportionately "knocked down" at distances from the source depending upon precise properties. Among factors affecting this process will be whether or not the emission is gaseous, its solubility in water, weather at the time of release, the size of any particulate association and plume buoyancy. Substantial inputs are likely to occur locally of a wide variety of contaminants described earlier. This will be made more likely by the association of contaminants with particulates liable to early deposition. The marine microlayer is an important area which has not been extensively studied in

Antarctica and which may be particularly vulnerable to incinerator emissions. Although without extensive study the following discussions are necessarily speculative, an illustration is provided in which potential interactions with an important biotope could differ from those in temperate regions. The temperate processes are themselves poorly understood.

THE MICROLAYER

The properties of the marine microlayer in Antarctic waters subject to seasonal ice are unknown but it is likely that it will play as significant a role in Antarctic waters as has been described in more temperate regions. Albright et al.(1980) considered that "it has repeatedly been shown that the the near surface microlayers of both fresh and marine waters are regions which are distinctly different from other portions of the aquatic environment."

Enrichment of such layers with algae, bacteria, fungi and protozoa were described from the mid 1960s, as was the presence in these layers of organic and inorganic dissolved materials (see: eg Garrett 1967). The microlayer comprises an organic film, particles and organisms and is found on virtually all natural bodies of water (Sodergren 1987). Microlayers can be detected by remote sensing. The microlayer or neustonic community is stable in some cases at wind speeds in excess of twenty knots and can reform rapidly after disruption (Hardy 1987).

The importance of the sea surface microlayer to a wide variety of organisms is drawn from the literature by Hardy et al (1987) in a study on Chesapeake Bay. The neustonic community included the eggs and larvae of many commercially and trophically important fish and shellfish and was moreover of critical importance to decapods and fishes during the principle reproductive season. During this time degradation of the layer could have detrimental effects upon the populations of dependent species. Such species included squid, crabs, lobster, hake, bluefish, mullet, mackerel and flounder.

The properties of the surface microlayer were found to be extensively dependent on biogenic materials present. Algae produce a wide variety of extracellular products which may contribute to the character of the layer (see: Fogg, 1966). Although considered largely autochthonous in origin, the microlayer may be modified extensively by allochthonous material as considered by Hardy (1982) Sodergren (1987) notes that this biotope arises from the interaction of buoyancy, electrostatic attraction, physical and chemical adsorption and surface tension.

It was early appreciated that the microlayer environment

might be rigourous due to the conditions likely to be encountered by organisms associated with the films and it was suggested (see eg Duce et al. 1972) that one of the important factors might be anthropogenic contamination of this layer. Hardy et al. (1986) showed that, when present, pollutants also tend to concentrate in natural surface slicks. Hardy et al. (1987) suggested that spatial co-occurence of organisms and pollutants, negative impacts of sea-surface contaminants on eggs and larvae are accentuated. The same will be true of other components of the neuston.

In some cases actual toxicity of the sea microlayer has been demonstrated in areas subject to contaminant input. Kocan et al.(1987) showed an extract of Baltic microlayer to be directly toxic and to affect development of herring eggs. Sea surface microlayer from near Los Angeles also exhibited toxic properties (Cross et al. 1987) as has that of Puget sound (Hardy et al. 1986). Sodergren (in press) has demonstrated the possibility that PICs may be sequestered by the microlayer and hence be passed into the food chain.

The presence of seasonal ice could result in the toxicological role of the microlayer being considerably modified. Progressive deposition of material on seasonal ice will be followed by contaminants entering the microlayer at the thaw which coincides with the period of maximum aquatic production in Antarctica.

In this case, the bulk of the contaminants deposited could enter the food web at a time when maximal transfer of contaminants from one trophic level to the next is assured. Many of the compounds likely to be discharged from incinerator plant could be expected to bioaccumulate since they are persistent and lipid soluble. They are known to be capable of serious interference with biological systems. Bioaccumulation is likely to be exaggerated in comparison to most temperate systems due to the directness of the food chain and the pivotal role of krill (see: El-Sayed 1988). Moreover, this writer notes evidence that krill may be composed of mulitiple stocks. Hence significant potential exists for local inputs to be maximally concentrated over a relatively short period of time. Additionally, it is probable that processes responsible in more temperate areas for breakdown of these materials ie light, humidity, bacterial activity will be restricted under Antarctic conditions.

CHLORINATED COMPOUNDS

The dioxins and dibenzofurans are of toxicological interest since Tanabe (1988) has identified some TCDD homologues (the co-planar PCBS) as a particular threat to marine mammals. Ample evidence exists of effects upon the hormonal and

immune system of mammals. Recent research has centered upon the interactions of these compounds with human populations through the food chain and by direct exposure. This preoccupation is largely explained by events such as the Seveso disaster, the Agent Orange problem, the Missouri contaminated oil problem and has focussed lately on combustion emissions (see: Firestone 1978; Commoner 1987). During this time analytical techniques have progressed from a skin test on rabbits to GCMS detection at the part per quadrillion level in environmental matrices reflecting the effect levels of these chemicals. Behaviour of these compounds in aquatic systems appears to closely resemble the behaviour of PCBs. The toxicological properties of the bulk of emitted chlorinated compounds remain unkown.

PAHs

The toxicity of the PAHs napthalene and phenanthrene were determined at 13.8 and 0.9 ug/l respectively for marine bacterioplankton. (Hudak and Fuhrman 1988). 48hEC50 values for a variety of PAHS to Daphnia pulex between 0.035 and 6.96mg/l were demonstrated by Smith et al.(1988). Levels are unlikely to reach these values. However, many PAHs are capable of bonding co-valently with DNA to form DNA-adducts (See eg Smolarek et al. 1988) and can thus interfere with genetic material directly. PAHs have also been shown to be immunotoxic in laboratory mammals (Luster et al.1989). The PAH Benzo[a]pyrene has been implicated in carcinogenic effects noted in Beluga whales in the St. Lawrence River (Martineau et al. 1987).

The model described by Thomann (1989) predicts that non polar PAHs should be among the most efficiently accumulated compounds. The polar PAHs (Bayona et al. 1988) may interact directly with the microlayer. It is with the polar fraction that the mutagenicity of diesel particulates is associated. Moreover Kamens et al. (1988) have found that the halflives of PAHs on soot particles increased from hours to days in conditions of low angle sunlight, very low water vapour levels or very low temperatures. The lowest temperature used was -7C. In conditions of total darkness, temperatures much below this and low levels of available water, the toxicological significance of the PAHs could be markedly different from that in more temperate zones where significant degradation occurs (see:eg Shiaris 1989)

HEAVY METALS

Heavy metal emissions are likely to be of significance. In common with the other pollutants released by incineration their toxicological significance under Antarctic conditions may be considerably modified. Bird populations may be particularly compromised if severe local inputs persist (see: Scheuhammer 1987) The potential significance of metal

mobilisation in Antarctic environments has also been discussed by Johnston & Stringer (1988).

CONCLUSIONS

On the basis of the information available, incineration of waste in the Antarctic must be regarded as dependent upon unproven technology. It is possible that SCAR (1989) have underestimated the impact of this type of development in Antarctica. The toxicology of materials in Antarctic ecosystems remains largely unstudied. Although open burning is at present a widely used disposal method for combustible waste and leads to substantial emissions, substitution of the process by incinerators may not reduce the input of contaminants to any great degree. In turn this is due to the fact that most such plant will not incorporate adequate emission control devices. Incineration of any kind should not be viewed as an environmentally sound option and instead a pecautionary approach, removing all wastes from the treaty area, should be implemented. National Operators who feel unable to justify the extra expense involved in waste removal should consider withdrawing from the continent or reducing their presence to accommodate the cost. As a final comment, ATCM Recommendation XIV-2 requires an Environmental Impact Assessment to be carried out for proposed Antarctic developments. The SCAR (1989) report must not be regarded as a general EIA for all incinerators. National Operators should be compelled to prepare an EIA to cover all proposed incinerator developments. The proliferation of incineration, essentially a quick, cheap and dirty solution to the problem of waste disposal, is to be deeply deplored in Antarctica.

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APPENDIX ONE: Waste Disposal Measures Recommended By SCAR (1989):

16: All combustible waste, which is not removed from the Antarctic, should be burnt in incinerators designed to reduce harmful emissions to the maximum extent practicable. PVC, polyurethane foam, polystyrene foam or lubricating oils which contain additives that are widely recognised as products which would produce harmful emissions, should not be burnt unless equipment is installed which neutralises the harmful emissions that will be produced. While burning of wastes is carried out in basic incinerators, no plastics should be burnt and operators should limit particulate emissions as much as practicable.

17:All plastic wastes of unknown composition should be remved from the Antarctic Treaty Area, unless incinerated in circumstances where equipment is installed which neutralises the harmful emissions that may be produced.

18: National Antarctic Operators should work toward eliminating open burning and should not burn any plastics or rubber other than in incinerators where equipment is installed which neutralises the harmful emissions that may be produced.

28: Where ships are not fitted with incinerator facilities, Antarctic ship operators should wherever practicable, stockpile wastes, excluding untreated sewage and domestic effluents, for appropriate disposal at stations, bases, or in deep water at selected sites or outside the the Antarctic Treaty area. The incineration of ship-board wastes should be conducetd at sea, preferably outside the Antarctic Treaty Area, and in accordance with appropriate international agreements.