PRELIMINARY RESULTS FROM AN INVESTIGATION OF ENVIRONMENTAL CONTAMINATION AT MCMURDO STATION, ANTARCTICA

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INTRODUCTION

The United States Base situated on McMurdo sound is unquestionably the largest year round Antarctic operation. The overwintering complement of some 200 increases to over 1000 persons during the austral summer. If the continent is divided into 45 degree segments, then it is estimated that some 70% of the gasoline and kerosene used in Antarctica pass through the sector which includes this base (Boutron & Wolff 1989). The effect of human occupation upon this fragile environment may be indexed in other ways. For example, Campbell & Claridge (1987) note severe reduction in the snow and ice cover around McMurdo due to human activity and the mechanical modification to the landscape. This in turn has led to extensive alteration of local climatic conditions and hence soil properties, which may have implications for the endolithic micro-organism dominated ecosystems found further afield (Siebert & Hirsch 1988).

The mechanical activities which have led to these highly significant deleterious changes in the area include waste disposal. Campbell & Claridge (1987) remark upon the litter problem found downwind of McMurdo and Scott bases which they attribute largely to bad housekeeping practices. However, there have been relatively few studies of the chemical modifications associated with human activity in Antarctica published in the open scientific literature. This is surprising given the large volumes of waste disposed of to landfill, by open burning or direct to the sea. These practices have the capacity to irreversibly damage the delicate Antarctic ecosystems.

This Technical Note reports the preliminary findings of a continuing survey of contaminant levels in a sewage sample and sediments recovered from the vicinity of McMurdo base. The results give considerable cause for concern and their significance is discussed.

METHOD AND MATERIALS

a) Heavy Metals

Aqueous samples were acidified (10-20% HCl) upon collection to ensure good long term preservation.

Analysis of acidified aqueous samples was carried out by atomic absorbtion spectrophotometry using an IL 157 machine operated in flame mode. Where appropriate, deuterium background correction was used.

b) Qualititative assessment of organic compounds

Samples (11) for general organic screening were collected in acid washed glass bottles, subsequently rinsed in pesticide residue analysis grade hexane. These were transported under refrigeration at 4C to the analysing laboratory. Organics extracted into 10ml of PRAG hexane were analysed by gas chromatography without further cleanup. This procedure was designed to qualitatively assess the organic constituents of the sample as far as possible. Analysis was conducted on a Hewlett-Packard 5890 Gas Chromatograph fitted with an HP 5970 Mass selective detector. Identification of compounds was by comparison with the US National Bureau of Standards Mass Spectral Library. Only compounds recorded as having a match quality greater than 90% were considered to be positively identified.

c) PCB analysis

Sediment samples taken using an orange peel grab or a pipe dredge were stored in polythene containers and transported frozen to the analysing laboratory. Measurements were carried out using a two stage cleanup of hexane/acetone extracts with concentrated acid and florisil. This was followed by analysis using gas chromatography with electron capture detection. Full details of the method are given in Creaser & Fernandes (1986).

RESULTS

a)Heavy metals

		Cd	Cu	Pb	Zn	Cr	Ag
Detection Limit (ppm)		0.01	0.01	0.05	0.01	0.02	0.05
SAMPLE	011B	N/D	0.07	0.05	0.10	N/D	N/D

LOCATION: 011B: Aqueous sample from McMurdo base old sewage outlet 5 October 1988

b)Qualititative assessment of organic compounds

SAMPLE 011B

Using the method described above, in excess of 105 peaks were isolated from this sample of sewage effluent being discharged at McMurdo base directly to sea. Mass Spectra for individual peaks were compared with standard spectra held on the US National Bureau of Standards Library. Peaks identified with a probability of 90% or greater are listed below:

1-ethyl-4-methyl-benzene
1,2-dimethyl benzene (*)
decane
1-methyl-3-(1-methylethyl)-benzene
undecane
2-ethyl-1,4-dimethyl-benzene
naphthalene (*)
1,2,3,4-tetrahydro-1-methyl-naphthalene
4-methyl dodecane
2,10-dimethyl undecane
1-ethylidene-1H-indene (**)
tridecane
1,1'-biphenyl (*)
2-ethyl naphthalene (**)
1,3-dimethyl naphthalene (**)
tetradecane
1,2-dimethyl naphthalene (**)
pentadecane
cyclotetradecane
phosphonic acid, dioctadecyl ester

In addition there were a large number of compounds variously identified as alkyl benzenes, alkyl naphthalenes and aliphatic hydrocarbons to a lesser probability. This is consistent with gasoline (or something similar) with the high boiling fractions removed by evaporation. The compounds marked (*) are US EPA priority pollutants. Compounds marked (**) belong to the group of polynuclear aromatic hydrocarbons (PAHs).

The form of the analytical trace (Figure 1). suggests that sewage as broadly indexed by the series of peaks around thirty minutes retention time, comprised a relatively minor component of this discharge at the time of sampling.

c) PCB analysis

Analysis of the sediments taken from the ice wharf, Winter Quarters Bay, 22 February 1989, in the vicinity of McMurdo Base (Figure 2) contained between 242 and 1500 ug/kg PCBs on a dry weight basis corrected for extraction efficiency. The mean value of all six samples was 721 ug/kg with a standard deviation of 594.8 ug/kg. Chromatographic profiles of the samples sugest that Aroclor 1260 or an equivalent PCB technical mix is the major component except in one sediment sample where a mixture of Aroclor 1254 and 1260 appears to be present.

DISCUSSION

The heavy metal content of the effluent discharged from the old sewage outlet at McMurdo Base sampled on 5/10/88 is generally lower than determined for samples 006A and 007A taken the previous year (9/2/87) and reported in Johnston & Stringer (1988). Zinc, present at levels similar to those in this effluent are nonetheless capable of causing developmental abnormalities in shellfish (see eg Hunt & Anderson 1989). In contrast to the previous samples, lead was detected in the effluents. This may be due to the discharge of gasoline residues since the organic screen analytical profile revealed organic components consistent with this. No iridescent surface film was reported at the time of sampling, and volatile components (low boiling fractions) appear under represented, although there is substantial evidence of resolved alkanes. It therefore seems possible that these materials result from routine washings of a hard standing or mechanical workshop area subject to gasoline spills.

Three US EPA priority pollutants were identified in the discharge: 1,2-dimethyl benzene, naphthalene and biphenyl. Substituted naphthalenes were also extensively represented. The discharge of PAHs and substituted benzenes into Antarctic waters is of great concern given the toxicological properties of these materials known from temperate regions where they have been more extensively studied.

The PAHs such as biphenyl and naphthalene have attracted considerable toxicological interest as a group. While debate may exist concerning regulatory difficulties given the extensive natural sources of these compounds (see eg Payne et al. 1988), the general environmental problems associated with this group are now well documented. (see: Mix 1988; Malins et al. 1984). Platt & Mackie (1979) describe the extensive contamination of sediments with PAHs at South Georgia, Antarctica, resulting from whaling operations on the island some 24 years after such operations ceased.

Much published material concerns the toxicological properties of the PAH benzo[a]pyrene. This is known to be carcinogenic in aquatic animals with a delay between exposure and manifestation of effect. (Black et al. 1988; Hawkins et al. 1988; Mix 1988). This probably arises as a result of the direct covalent combination of benzo[a]pyrene and/or its metabolites with DNA and blood proteins (see eg Varanasi et al. 1981; Gupta et al. 1982 Shugart et al. 1987; Dunn et al. 1987; Smolarek 1988). Shugart (1988) describes direct evidence of interference with DNA metabolism using an index of DNA integrity. Naphthalene has been demonstrated to have lower toxicity than some other PAHs in tests on bacterioplankton (Hudak & Fuhrman 1988). This,in turn, may be related to differences in physical properties.

The use of physical properties to predict toxicological behaviour has grown in recent years. In particular, use of the log octanol/water partition coefficient to predict bioaccumulative potential is gaining increasing acceptance. (see: Galassi et al. 1988) On the basis of published values (Tetra Tech 1985), naphthalene and its derivatives would be expected to have less bioaccumulative potential than most other PAHs. This supposition may not be reliable. Hawker et al. (1988) note that data supporting a general kinetic theory of bioconcentration of lipophilic compounds fall in a band from which a direct relationship with the simple octanol water partition coefficient rather than logarithmic transforms could be inferred. This may be of importance given the pronounced seasonality of lipid reserves in high and low latitude zooplankton (Hargrave et al. 1989) and requires further evaluation.

Although natural mechanisms of degradation are known for many PAHs (see: Hammel et al 1986), under Antarctic conditions decay is likely to be highly reduced. Kamens et al. (1988) have demonstrated that PAH halflife increases under conditions of low angle sunlight and low temperatures. While the metabolic aspects of the activity against DNA may be temperature dependent (Smolarek et al. 1988), any benefit of low temperature may well be offset by the increased exposure risk entailed by increased half-life. Biotransformation appears to be concentration and salinity dependent. In a temperate system, turnover rates of PAHs (including naphthalene) were similar at a number of sites, with clear seasonality at each site but no clear relationship between sites (Shiaris 1989). Moreover the adsorption of these substances to sediment does not appear to limit their potential for bioactivity (Metcalfe et al. 1988). It is likely that these chemicals contribute substantially to mutagenic and toxic properties of municipal sewage sludges (Mumma et al. 1988) and other changes, for example, in lysosomal and specific enzyme activity in molluscs exposed to a spectrum of pollutants (Moore 1988).

The fate of alkyl benzenes discharged to the environment will depend largely upon the side chains present on the benzene ring. Both photodegradative and microbiologial processes may play a part (Guittonneau et al. 1988; Ward & Larson 1989). In turn these processes will be limited by the extremes of the Antarctic environment and hence halflives will be considerably increased over values recorded in the literature for temperate regions (see: Ware 1988). This in turn could be expected to significantly alter the toxicological behaviour of these compounds. Given the known environmental problems associated with the discharge of such compounds to the aquatic environment, coupled with the lack of information on their behaviour and fate in Antarctic systems, the discharge of such materials should be prevented. Under the present and projected guidelines for waste disposal (see: SCAR 1989) there appears to be no specific provision against such practices.

Current waste disposal recommendations (SCAR 1989) are that sewage and domestic wastes be flushed to sea. This is intended to prevent the undesirable changes in soil microflora noted, for example, by Boyd et al. (1966) as a result of human activity. In particular, thermophilic strains of bacteria were found to have persisted over extremely long periods. Disposal of untreated or primary treated sewage to sea may also exert deleterious effects upon marine ecosystems in Antarctica. Egidius (1988) notes that acquired bacterial plasmid linked resistance may be transferred from sewage organisms to entirely different species. The problem may be further exacerbated by the admixture of what is essentially industrial waste. Sewage bacteria have the capacity to become resistant to contaminants. Metal resistant bacteria have been isolated from sewage sludge dump sites (Timoney & Port 1982) and sewage effluent (Nakahara et al. 1989; Sokari et al. 1988). Viruses also may be dispersed widely (Hurst 1989) and accumulate in filter feeding organisms (Mesquita 1988) in a viable state.

Colwell (1988) notes that bacterial and viral pathogens may survive for long periods of time in seawater and remain viable. This depends upon environmental physico-chemical parameters (Evison 1988; Pettibone et al. 1987). Under some circumstances the multiplication of enteric bacteria in estuarine environments has been observed (Rhodes & Kator 1988).

Recently, the abundance of viruses in aquatic systems has been found to be much higher than previously thought (Bergh et al.1989) raising concern further at the possible exchange of genetic determinants of resistance and pathogenicity between sewage bacteria and free living organisms.

The behaviour of sewage bacteria in Antarctic aquatic environments remains under-researched. It is possible however that assumptions that UV light and exposure to seawater will kill these organisms are as invalid as in more temperate regions. Given this, the current practice of sea discharge may be regarded as in contravention of

Article IX of the Agreed Measures for the Conservation of Antarctic Flora and Fauna with respect to the importation of exotic species/disease causing organisms. National Operators in the Antarctic should give consideration to either the installation of mechanical and biological treatment for sewage effluents with ozone disinfection (see: Venosa & Isaac 1988) or to retrograding human wastes, as part of a precautionary approach to the protection of the Antarctic environment.

The levels of PCBs recorded from sediment samples taken at the ice wharf in Winter Quarters Bay constitute grounds for very grave concern. The values are equivalent to or exceed values recorded from industrial/urban areas. Connell (1987), for example, reports levels up to 810 ug/kg in Long Island Sound. In Mediterranean sediments only two sites (Marseille and Naples Bay) gave values in excess of the highest value recorded at McMurdo (Fowler 1987). Similarly only two values recorded from the highly populated Queensland area in Australia exceeded the maximum values recorded at McMurdo (Richardson et al. 1987). Levels in Baltic sediments, moreover, which are generally regarded as highly polluted, appear to be consistently below these values (Olsson 1987). In Southern Lake Michigan the McMurdo values were only exceeded in the harbour sediments tested. Sediments from lake areas proper were on average an order of magnitude below the values reported here (Swackhamer & Armstrong 1988). The levels are also markedly in excess of background PCB levels recorded in UK soils (Creaser & Fernandes 1986).

The only plausible explanation for the high recorded levels of PCBs in Winter Quarters Bay sediment is a substantial spill of transformer fluids or capacitor dielectrics. In other areas of the Antarctic, trace level PCB contamination of lichen and moss has been recorded (Bacci et al. 1986) probably as a result of atmospheric global cycling as discussed by Larsson & Sodergren (1987) and Larsson & Okla (1987). Atmospheric transport of PCBs and chlorinated pesticides has been documented in the high Arctic (Patton et al. 1989) and evidence of deposition is given by Gregor & Gummer (1989). A characteristic of these studies is the large volume of environmental medium which requires processing to allow detection of PCB residues at levels below 2ng/l. It is clear therefore that atmospheric deposition cannot account for the elevated levels of PCBs found.

The PCB contamination is likely to persist in the sediment which will act as a reservoir of contamination (see Clarke et al. 1983). This in turn will allow transfer to the food chains (Scura & Theilacker 1977; Mowrer et al. 1977). Transfer may well be facilitated by the appearance of PCB resistant phytoplankters as described for the highly polluted Hudson Estuary (Cosper et al. 1987 & Cosper et al. 1988). PCB resistance in diatom species was found to be associated with decreased tolerance to nitrogen limitation. This may be of significance to Antarctic diatoms in the area (Mortain-Bertrand 1988) which constitute a major part of the McMurdo sound food web (Hopkins 1987) which includes an extensive sub-ice zooplanktonic community (Foster 1989). The directness of Antarctic food chains (see eg Lowry et al. 1988) indicates that this reservoir of PCBs could pose a particular threat to wildlife in the area. It is likely that exposures to elevated levels of PCBs in food over normal background levels could result in changes in PCB kinetics such as biological half-life (see Subramanian 1987).

The potential interaction of this PCB contamination reservoir with marine mammals is also of great concern. Apart from possible reproductive effects as described for seals in the North Sea (Reijnders 1986), Tanabe (1989) has recently called for a re-examination of PCB toxicity due to growing concern about the role of the co-planar PCBs (Tanabe 1987, 1988). These congeners may be regarded as functional homologues of the highly toxic chlorinated dioxins. There is evidence also that bioactive chlorinated dibenzo-furans are present in transformer and capacitor fluids (Brown et al. 1988). These compounds are potent interferents with a variety of cellular and whole body functions in mammals (Safe 1984).

Currently, analysis is being carried out on a variety of biological samples with a view of determining the seriousness of any food chain contamination. Immediate action should be taken by the National Operator in question (in this case, the United States) to establish the extent of this serious contamination problem in both terrestrial and marine systems. An evaluation is neccessary of the likely quantities of this material lost from the base and of whether PCB continues to enter the marine environment. A full environmental study should be commissioned with a view to establishing a remediation programme.

CONCLUSION

Analysis of McMurdo Base sewage effluent indicated that the discharge consisted of domestic effluent combined with non-domestic waste. The analytical trace obtained strongly suggested that gasoline residues were present and evaluation of the materials present identified at least three priority pollutants present in the discharge. The introduction of living bacteria particularly in admixture with such materials constitutes a clear violation of Article IX of the Agreed Measures for the Protection of Flora and Fauna.

Sediment samples taken at the ice-wharf in Winter Quarters Bay upon analysis revealed extremely high levels of PCBs, comparable or in excess of those found in sediments in industrialised areas of the world.

The environmental implications of these findings are discussed. It may be concluded that waste disposal practices on the base have not taken sufficient account of the delicate Antarctic environment. It is suggested that a new precautionary philosophy in conjunction with an extensive program of remediation be adopted as a matter of urgency.

REFERENCES

Bacci, E., Calamari, D., Gaggi, C., Fanelli, R., Focardi, S. & Morosini, M. (1986)
Chlorinated hydrocarbons in lichen and moss samples from the Anarctic peneisula.
Chemosphere 15 (6): 747-754

Bergh, O., Borsheim, K.Y., Bratbak, G. & Heldal, M. (1989)
High abundance of viruses found in aquatic environments
Nature 340: 467-468

Black, J.J., Maccubbin, A.E. & Johnston, C.J. (1988)
Carcinogenicity of benzo[a]pyrene in rainbow trout resulting from embryo microinjection.
Aquatic Toxicol. 13: 297-308

Boutron, C.F. & Wolff, E.W. (1989)
Heavey metal and sulphur emissions to the atmosphere from human activities in Antarctica
Atmos. Environ. 23 (8): 1669-1675

Boyd, W.L., Staley, J.T. & Boyd, J.W. (1966)
Ecology of soil micro-organisms of Antarctica.
In: Antarctic sols and soil forming processes, Antarct. Res. Ser. Am. Geophys. Union, Vol. 8,Washington pp125-159

Brown, J.F., Carnahan, J.C., Dorn, S.B., Groves, J.T., Ligon, W.V., May, R.J., Wagner, R.E. & Hamilton, S.B. (1988)
Levels of bioactive PCDF congeners in PCB dielectric fluids from capacitors and transformers.
Chemosphere 17 (9): 1697-1702

Campbell, I.B. & Claridge, G.G.C
Antarctica: Soils, weathering processes and environment
Developments in Soil Science 16: 329-343

Clarke, R.G., Richardson, B.J. & Waid, J.S. (1983)
Residence of polychlorinated biphenyls (PCBs) in a spillage site.
Environmental Biogeochemistry Ecol. Bull. (Stockholm) 35: 533-539.

Colwell, R.R. (1988)
Microbial effects of ocean pollution.
In: Environmental Protection of the North Sea Ed: Newman, P.J. & Agg, A.R. publ Heinemann, pp375-389

Connell, D.W. (1987)
Polychlorinated Biphenyl (PCBs) in Long Island Sound
Special Report 79 Ref: 87-2: Marine Sciences Research Center, SUNY at Stony Brook.

Cosper, E.M., Snydr, B.J., Arnold, L.M., Zaikowski, L.A. & Wurster, C.F. (1987)
Induced resistance to polychlorinated biphenyls confers cross resistance and altered environmental fitness in a marine diatom.
Mar. Environ. Res. 23: 207-222

Cosper, E.M., Wurster, C.F. & Bautista, M.F. (1988)
PCB-resistant diatoms in the Hudson River estuary
Estuarine, Coastal and Shelf Science 26: 215-226

Creaser, C.S. & Fernandes, A.R. (1986)
Background levels of polychlorinated biphenyls in British soils.
Chemosphere 15 (4): 499-508

Dunn, B.P., Black, J.J. & Maccubbin, A. (1987)
32P-postlabeling analysis of aromatic DNA adducts in fish from polluted areas.
Cancer Res. 47: 6543-6548

Egidius, E. (1988)
Importance of microbial life in the marine environment.
In: Environmental Protection of the North Sea Ed: Newman, P.J. & Agg, A.R. publ Heinemann p365-374

Evison, L.M. (1988)
Comparative studies on the susrvival of indicator organisms and pathogens in fresh and seawater.
Wat. Sci. Tech. 20 (11/12): 309-315

Foster, B.A. (1989)
Time and depth comparisons of sub-ice zooplankton in McMurdo Sound, Antarctica
Polar Biol. 9: 431-435

Fowler, S.W. (1987)
PCBs and the Environment: The Mediterranean marine ecosystem.
In: PCBs and the Environment, Ed: Waid, J.S. Publ. CRC Press, Boca Raton. Vol III pp209-239

Galassi, S., Mingazzini, M., Vigano, L., Cesareo, D., & Tosato, M.L. (1988)
Approaches to modeling toxic responses of aquatic organisms to aromatic hydrocarbons.
Ecotoxicol. Environ. Safety 16 (2): 158-169

Gregor, D.J. & Gummer, W.D. (1989)
Evidence of atmospheric transport and deposition of organochlorine pesticides and polychlorinated biphenyls in Canadian Arctic snow.
Environ. Sci. Technol. 23 (5): 561-565

Guittonneau, S., Laat, J. de, Dore, M., Duguet, J.P. & Bonnel, C. (1988)
Etude comparative de la degradation de quelques molecules aromatiques simples en solution aqueuse par photolyse UV et par photolyse du peroxyde d'hydrogene.
Environ. Technol. Lett. 9: 1115-1128

Gupta, R.C., Reddy, M.V. & Randerath, K. (1982)
32p-postlabeling analysis of non radioactive aromatic carcinogen-DNA adducts
Carcinogenesis 3 (9): 1081-1092

Hammel, K.E., Kalyanaraman, B., & Kirk, T.K. (1986)
Oxidation of polycyclic aromatic hydrocarbons and dibenzo[p]dioxins by Phanerochaete chrysosporium ligninase.
J. Biol. Chem. 261 (36): 16948-16952

Hargrave, B.T., Bodungen, B. von, Conover, R.J., Fraser, A.J., Phillips, G., & Vass, W.P. (1989)
Seasonal changes in sedimentation of particulate matter and lipid content of zooplankton collected by sediment trap in the Arctic ocean off Axel Heiberg Island.
Polar Biol. 9: 467-475

Hawker, D.W. & Connell, D.W. (1988)
Influence of partition coefficient of lipophilic compounds on bioconcentration kinetics with fish.
Wat. Res. 22 (6): 701-707.

Hawkins, W.E., Walker, W.W., Overstreet, R.M., Lytle, T.F. & Lytle, J.S. (1988)
Dose-related carcinogenic effects of water borne Benzo[a]pyrene on livers of two small fish species.
Ecotoxicol. Environ. Safety 16: 219-231

Hopkins, T.L. (1987)
Midwater food web in McMurdo Sound, Ross Sea Antarctica
Mar. Biol. 96: 93-106

Hudak, J.P. & Fuhrman, J.A. (1988)
Effects of four organic pollutants on the growth of natural marine bacterioplankton populations.
Mar. Ecol. Prog. Ser. 47: 185-194

Hunt, J.W., & Anderson, B.S. (1989)
Sublethal effects of zinc and municipal effluents on larvae of the red abalone Haliotis rufescens
Mar. Biol. 101: 545-552

Hurst, C.J. (1989)
Fate of viruses during wastewater sludge treatment processes.
CRC Critical Reviews in Environmental Control 18 (4):

317-343.

Johnston, P.A. & Stringer, R.L. (1988)
Trace metals in soils and effluents from Antarctica
Greenpeace QMC Technical Note No: 3: 13pp

Kamens, R.M., Guo, Z., Fulcher, J.N. & Bell, D.A. (1988)
Influence of humidity, sunlight and temperature on the daytime decay of polyaromatic hydrocarbons on atmospheric soot particles.
Environ. Sci. Technol. 22 (1): 103-108

Larsson, P. & Okla, L. (1987)
An attempt to measure the flow of chlorinated hydrocarbons such as PCBs from water to air in the field.
Environ. Poll. 44: 219-225

Larsson, P. & Sodergren, A. (1987)
Transport of polychlorinated biphenyls (PCBs) in freshwater mesocosms from sediment to water and air.
Water, Air & Soil Poll. 36: 33-46

Lowry, L.F., Testa, J.W. & Calvert, W. (1988)
Notes on winter feeding of crabeater and leopard seals near the Antarctic peninsula.
Polar Biol. 8: 475-478

Malins, D.C., McCain,n B.B., Brown, D.W., Chan, S., Myers, M.S., Landahl, J.T., Prohaska, P.G., Friedman, A.J., Rhodes, L.D., Burrows, D.G., Gronlund, W.D. & Hodgins, H.O., (1984)
Chemical, pollutants in sediments and diseases of bottom dwelling fish in Puget Sound, Washington.
Environ. Sci. Technol. 18: 705-713

Mesquita, M.M.F. (1988)
Effects of seawater contamination level and exposure period on the bacterial and viral accumulation and elimination processes by Mytilus edulis
Wat. Sci. Technol. 20 (11/12): 265-270

Metcalfe, C.D., Cairns, V.W. & Fitzsimons, J.D. (1988)
Experimental induction of liver tumours in rainbow trout (Salmo gairdneri) by contaminated sediment from Hamilton Harbour, Ontario.
Can. J. Fish. Aquat. Sci. 45 (12): 2161-2167

Mix, M.C. (1988)
Shellfish diseases in relation to toxic chemicals
Aquatic Toxicol. 11: 29-42

Moore, M.N. (1988)
Cytochemical responses of the lysosomal system and NADPH-ferrihemoprotein reductase in molluscan digestive

cells to environmental exposure to xenobiotics.
Mar. Ecol. Prog Ser. 46: 31-89

Mortain-Bertrand, A. (1988)
Photosynthetic metabolism of an Antarctic diatom and its physiological responses to fluctuations in light.
Polar Biol. 9: 53-60

Mowrer, J., Calambokidis, J., Musgrove, N., Drager, B., Beug, M.W. & Herman, S.G. (1977)
Polychlorinated biphenyls in cottids, mussels and sediment in Southern Puget Sound, Washington.
Bull. Environ. Contam. Toxicol. 18 (5): 588-59

Mumma, R.O., RAshid, K.A., Raupach, D.C., Shane, B.S., Scarlet-Kranz, J.M., Bache, C.A., Gutenmann, W.H. & Lisk, D.J. (1988)
Mutagens, Toxicants and other constituents in small ity sludges in New York State.
Arch. Environ. Contam. Toxicol. 17: 657-663

Nakahara, H., Yonekura, I., Sato, A., Moriyama, K., Kobayashi, Y., Mori, T. & Chino, M. (1989)
Plasmid-determined resistance to silver in Enterobacter cloacae isolated from sewage.

Olsson, M. (1987)
PCBs in the Baltic Environment
In: PCBs and the Environment, Ed: Waid, J.S. Publ. CRC Press, Boca Raton. Vol III pp181-208

Patton, G.W., Hinckley, D.A., Walla, M.D. & Bidleman, T.F. (1989)
Airborne organochlorines in the Canadian High Arctic
Tellus 41 (B): 243-255

Payne, J.F., Kiceniuk, J., Fancey, L.L., Williams, U., Fletcher, G.L., Rahimtula, A. & Fowler, B. (1988)
What is a safe level of polycyclic aromatic hydrocarbons for fish: subchronic toxicity study on winter flounder (Pseudopleuronectes americanus)
Can. J. Fish. Aquat. Sci. 45 (11): 1983-1993

Pettibone, G.W., Sullivan, S.A. & Shiaris, M.P. (1987)
Comparative survival of antibiotic resistant and sensitive fecal indicator bacteria in estuarine water.
Appl. Environ. Microbiol. 53 (6): 1241-1245

Platt, H.M. & Mackie, P.R. (1979)
Analysis of aliphatic and aromatic hydrocarbons in Antarctic marine sediment layers.
Nature 280: 576-578

Reijnders P.J.H. (1986)

Reproductive failure in common seals feeding on fish from polluted coastal waters.
Nature 324: 456-457

Rhodes, M.W. & Kator, H. (1988)
Survival of Escherichia coli and Salmonella spp. in estuarine environments
Appl. Environ. Microbiol. 54 (12):2902-2907

Richardson, B.J., Smillie, R.H. & Waid, J.S. (1987)
Case Study: The Australian ecosystem
In: PCBs and the Environment, Ed: Waid, J.S. Publ. CRC Press, Boca Raton. Vol III pp241-263

SCAR (1989)
Waste disposal in the Antarctic
Publ. Australian Antarctic Division 53pp

Scura, E.D. & Theilacker, G.H. (1977)
Transfer of the chlorinated hydrocarbon PCB in a laboratory marine food chain.
Mar. Biol. 40: 317-325

Shugart, L.R. (1988)
Quantitation of chemically induced damage to DNA of aquatic organisms by alkaline unwinding assay.
Aquatic. Toxicol. 13: 43-52

Shugart, L., McCarthy, J., Jiminez, B. & Daniels, J. (1987)
Analysis of adduct formation in the bluegill sunfish (Lepomis macrochirus) between benzo[a]pyrene and DNA of the liver and hemoglobin of the erythrocyte.
Aquatic Toxicol. 9: 319-325

Shiaris, M.P. (1989)
Seasonal biotransformatin of naphthalene, phenanthrene and benzo[a]pyrene in surficial estuarine sediments
Appl. Environ. Microbiol. 55 (6): 1391-1399

Siebert, J. & Hirsch, P. (1988)
Characterisation of 15 selected coccal bacteria isolated from Antarctic rock and soil samples from the McMurdo dry valleys (South Victoria LAnd)
Polar Biol. 9: 37-44

Smolarek, T.A., Morgan, S. & Baird, W.M. (1988)
Temperature induced alterations in the metabolic activation of benzo[a]pyrene to DNA-binding metabolites in the Bluegill fry cell line BF-2

Sokari, T.G., Ibiebele, D.D. & Ottih, R.M. (1988)
Antibiotic resistance among coliforms and Pseudomonas spp. from bodies of water around Port Harcourt, Nigeria.

J. Appl. Bacteriol. 64: 355-359

Subramanian, A.N., Tanabe, S., Tanaka, H., Hidaka, & Tatsukawa, R. (1987)
Gain and loss rates and biological half-life of PCbs and DDE in the bodies of Adelie penguins.
Environ. Poll. 43: 39-46

Swackhamer, D.L. & Armstrong, D.E. (1988)
Horizontal and vertical distribution of PCBs in Southern Lake Michigan sediments and the effect of Waukegan Harbor as a point source.
J. Great Lakes Res. 14 (3): 277-290

Tanabe, S. (1988)
PCB problems in the future Foresight from current knowledge
Environ. Poll. 50:5-28

Tanabe, S. (1989)
A need for reevaluation of PCB toxicity
Mar. Poll. Bull. 20 (6): 247-248

Tanabe, S., Kannan, N., Subramanian, A., Watanabe, S. & Tatsukawa, R. (1987)
Highly toxic co-planar PCBs: Occurrence, source, persistency and toxic implications to wildlife and humans.
Environ. Poll. 42: 147-160

Tetra-Tech Inc. (1985)
Bioaccumulatin monitoring guidance: 1: Estimating the potential for bioaccumulation of priority pollutants and 301(h) pesticides discharged into marine and estuarine waters.
EPA Contract Report No. 68-01-6938. 68pp

Timoney, J.F. & Port, J.G. (1982)
Heavy metal and antibiotic resistance in Bacillus and Vibrio from sediments of the New York Bight.
In: Ecological Stress and the New York Bight: Science and Management ed: Mayer G.F. Publ: Estuarine Research Federation. pp235-248

Varanasi, U., Stein, J.E. & Hom, T. (1981)
Covalent binding of bezo[a]pyrene to DNA in fish liver
Biochem. Biophys. Res. Comm. 103 (2): 780-787

Venosa, A.D. & Isaac, R.A. (1988)
Disinfection
JWPCF 60 (6): 845-852

Ware, G.W. (Editor) (1988)
Reviews of Environmental Contamination and Toxicology Volume 106, Toluene pp189-201, Xylenes pp214-222. Publ.

Springer -Verlag 233pp

Ward, T.E. & Larson, R.J. (1989)
Biodegradation kinetics of linear alkylbenzene sulfonate
in sludge manded agricultural soils.
Ecotoxicol. Environ. Safety 17: 119-130

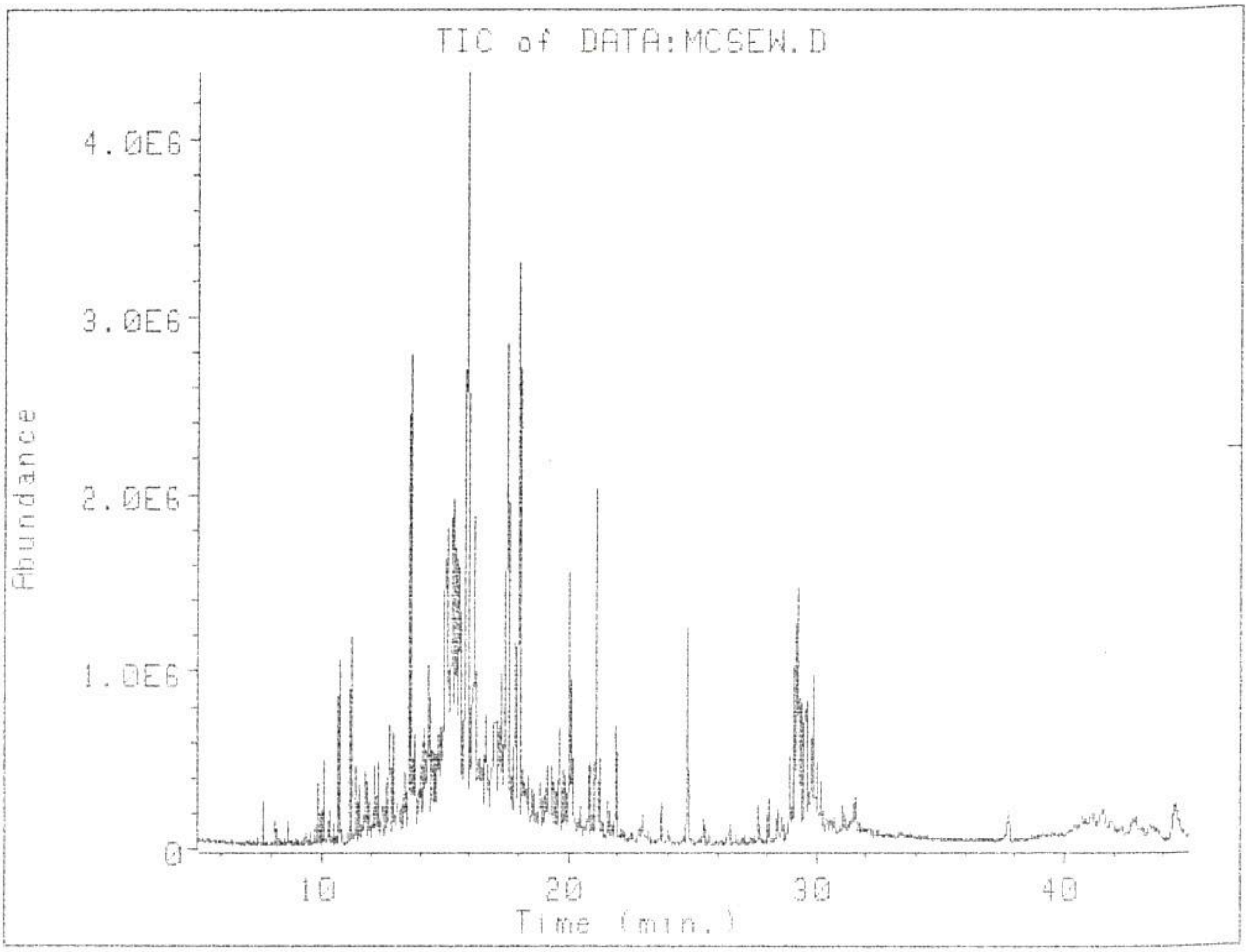

FIGURE 1: Total ion chromatogram of a hexane extract of sewage effluent from McMurdo Base. This appears to consist of domestic sewage in combination with gasoline residues. These components accounted for the majority of identified peaks.

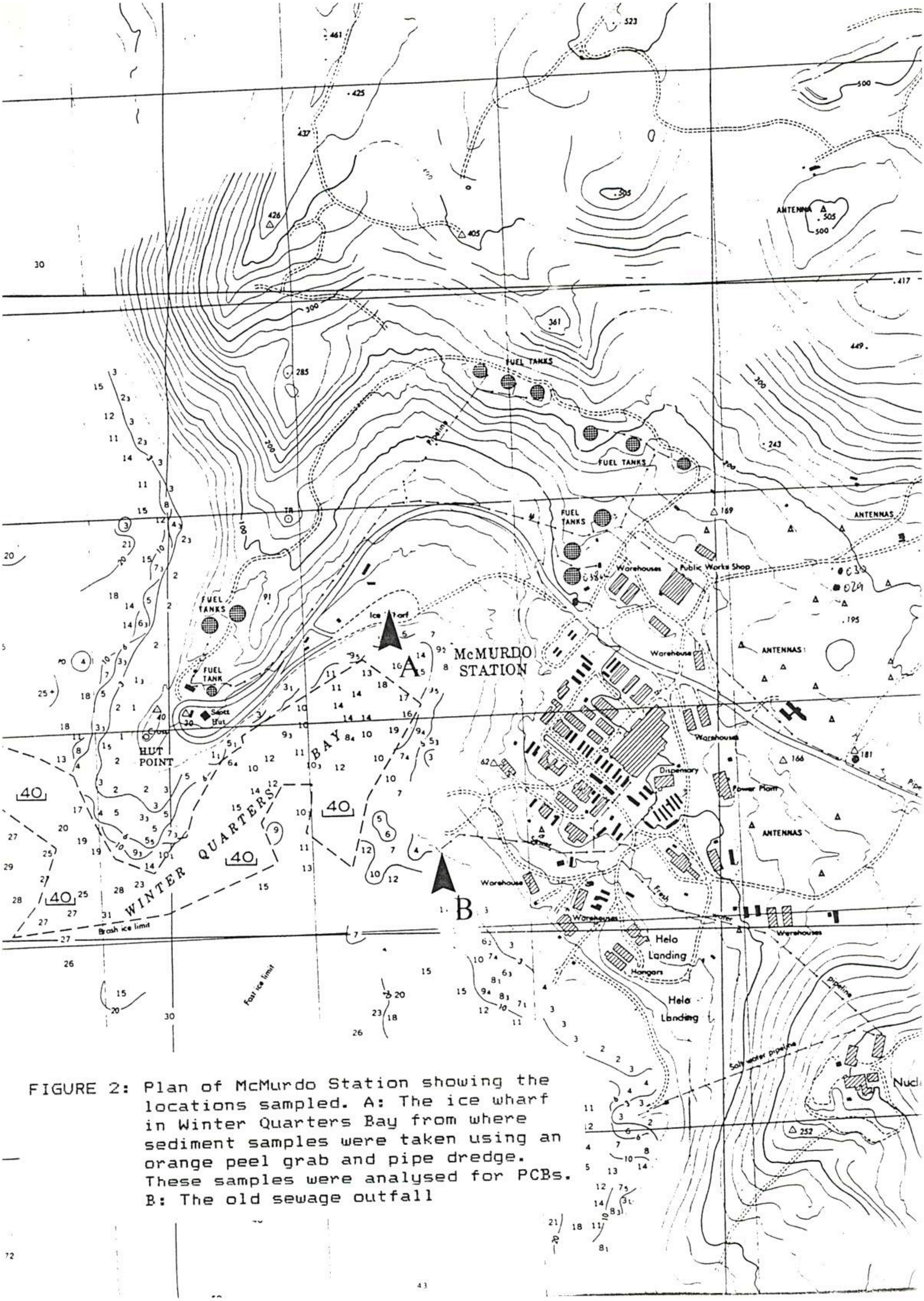

FIGURE 2: Plan of McMurdo Station showing the locations sampled. A: The ice wharf in Winter Quarters Bay from where sediment samples were taken using an orange peel grab and pipe dredge. These samples were analysed for PCBs. B: The old sewage outfall