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The importance of diet on exposure and effects of persistent organic pollutants on human health in the Arctic

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Mother and child in Northwest Russia (Photo J.Ø. Odland)

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Contents

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1 Abstract

The high levels of organic contaminants in the Arctic have caused serious concern regarding the health conditions of indigenous populations in Arctic areas. The exposure to pollutants through the diet is of central concern and today food safety is essential in daily life in developed countries. However, the consumers trust varies according to their countries regulatory systems and the opinion, highly influenced by the persuasive power of the media. The main objective of this study is to describe the importance of diet on exposure and possible health effects of persistent organic pollutants (POPs), based on a literature review.

Estimates of effects are still difficult based on current knowledge, but the combination of improved methodology and selection of risk groups is considered to be a good step further in the process. The most effective strategies are those developed with the affected people strongly engaged in the decision making process. Any strategies based on traditional food substitution should ensure that the value of the dietary components is sustained. It is essential that countries ratify and implement multinational environmental agreements, especially the protocols on POPs and metals to the Stockholm Convention and other multinational environmental agreements.

Based on current knowledge about global trends and activities on risk management, there are likely to be minor decreases in POP levels in Arctic populations in Greenland, Eastern Russia, Western Alaska and Eastern Canada by the year 2010. There are likely to be major decreases in POP levels in these same populations by 2030. Levels of POPs in populations in the Faeroe Islands, Norway, Sweden and Finland are already reasonably low and will possibly only decline marginally by 2030.

In order to improve our understanding of health effects associated with contaminant exposure in the Arctic, we recommend that circumpolar epidemiological studies should be performed in a larger scale. POP related effects are still one of the key issues. Also, the role of “new” POPs should be investigated. For exposure assessment, epidemiological studies should consider mixtures of contaminants and nutritional interactions. Epidemiological studies on nutritional benefits of traditional food should be incorporated in risk assessment profiles. There is a need for a more differentiated view on human dietary exposure to xenobiotics. Risk should not be evaluated alone, but seen in relation to benefits from specific diets.

2 Introduction

The high levels of organohalogenated contaminants in the Arctic have caused serious concern regarding the health conditions of indigenous populations in Greenland and Canada (AMAP 1998). Recent data indicate development of a similar situation in the Barents Region, especially the Russian Arctic. The exposure to pollutants through the diet is of central concern and today food safety is essential in daily life in developed countries. However, the consumers trust varies according to their countries regulatory systems and the opinion, highly influenced by the persuasive power of the mass media. The main objective of this study is to describe the importance of diet on exposure and possible health effects of persistent organic pollutants (POPs), based on a literature review. The report discusses the most recent scientific information, to prepare the basis for recommendations and dietary advice in the years to come. The study focuses on the coastal population in the European Arctic. The study areas are shown in Figure 1. The work has been integrated in the AMAP Human Health Group (all project partners belong to the group), and has been an important contributor to the AMAP process. Conclusions and recommendations in this report are for this reason closely connected to and not in conflict with the conclusions and recommendations found in the second AMAP Human Health Report (AMAP 2002, *in press*).

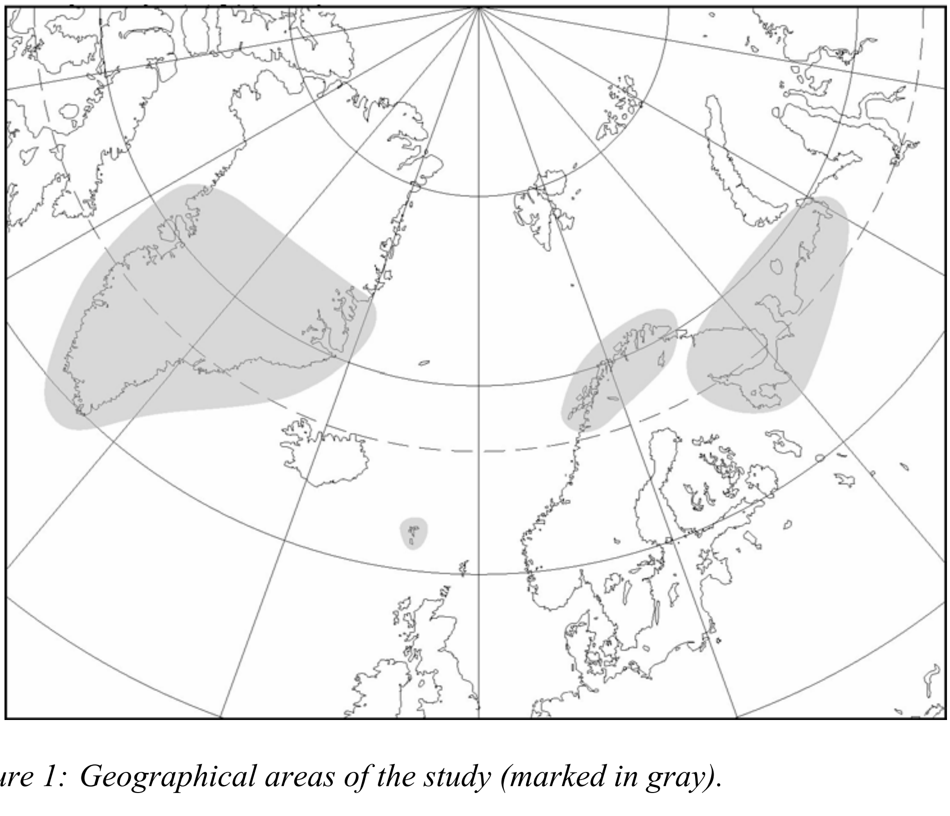

Figure 1: Geographical areas of the study (marked in gray).

3 Relevant POPs in Euroarctic coastal populations

Most research and ongoing monitoring work on persistent toxic substances in the Arctic has been focused on industrial compounds and by-products (e.g. PCBs and dioxins), pesticides (e.g. Lindane, DDT-group and cyclodiene analogues), as well as heavy metals (e.g. mercury, lead and cadmium) (AMAP 1998, Jensen *et al*. 1997, Hansen *et al*. 1996, Lønne *et al*. 1997). This fact is also reflected by the United Nations Environment Programme (UNEP) facilitated treaty on Persistent Organic Pollutants (POPs) (Fisher 1999). However, during the last few years there has been an increased interest in “new” toxic substances and metabolites.

The group of “new” environmental toxins include a number of organic compounds and compound classes. Some of the modern and more persistent polar pesticides currently in use belong to this group (e.g. diazion, fenitrothion and hexizinone). Other examples are nitro- and polycyclic musk and their metabolites from personal care products. Among the industrial chemicals and by-products, phthalates, octachlorostyrene (OCS), polychlorinated naphthalenes (PCN), polybrominated diphenyl ethers (PBDE), polychlorinated paraffins (PCA) as well as perfluoroorganic compounds (e.g. perfluorooctane sulfonate - PFOS) are found. Especially the three latter groups have recently received attention. The synthetic musks, phthalates and the new generation pesticides are, due to their distribution and accumulation pattern, generally not considered as a particular problem in the Arctic. None of these “new” compounds are on the UNEP list of most unwanted POPs.

Long-range transport allows many POPs to reach remote areas such as the Arctic, where only a few local sources for these contaminants exist. Depending on geographic location, weather condition and the physical-chemical properties of the contaminant, transport to and within the northern regions can be carried out via the atmosphere, water currents, sea-ice drift and the great Arctic rivers (AMAP 1998, Burkow and Kallenborn 2000). Due to their persistency and high lipophilicity several of these compounds tend to bioaccumulate, presenting a possible risk for humans living on lipid-rich marine food. Among the many thousands of man-made bulk-chemicals in use today, only a limited number have been tested or evaluated for their hazard potential. In understanding the possible consequences for human health and the Arctic environment, extensive evaluation is needed. The fact that the consequences often are observed decades after emission to the environment should always be kept in mind. Evaluation criteria must include long-range transport ability, persistence, bioaccumulation potential and hazard for human health and the environment. In the following some key information is given for the most common and debated POPs known from non-occupational exposure in the Arctic. A more comprehensive overview of relevant contaminants in Euroarctic populations is discussed in the human health part of the second AMAP Report (AMAP 2002, *in press*). An overwiev of production, uses and sources of exposure to some of the major POPs is shown in Table 1, and toxicological characteristics of selected POPs are presented in Table 2.

Table 1: Production, uses and sources of exposure to some of the major persistent organic pollutants.

Contaminant	**Production and uses**	**Sources of Arctic exposure**
Dibenzo-*p*-dioxins and furanes (PCDD/PCDF)	By-product from combustion, bleaching and metallurgic industry.	Mainly long-range transport. Some local industrial sources exist. Incineration processes.
Polychlorinated biphenyls (PCB)	Thermal and electrical insulators, and industrial used oils. Restricted use. Total world production estimated to 1.3 mill. tons.	Mainly long-range transport. Some local sources identified, including wastegrounds, old electrical equipment and military installations.
Hexachlorocyclohexanes (HCH)	Currently produced as an insecticide on fruit, vegetables and forest crops (Lindane). Many countries still use large amounts of Lindane. World production of 0.7 mill. tons of Lindane and 10 mill. tons of the technical HCH. The use of the technical HCH is banned/restricted in many western countries.	Long-range transport. Some local use as insecticide and for control of head lice and scabies caused by mites.
Hexachlorobenzene (HCB)	Chemical by-product, limited use as fungicide in the 1960s. HCB is banned or restricted in many countries. Global annual emission is 23 tons.	Mainly long-range transport. Minor local sources including industry and leakage from landfills.
DDT group	Pesticide used extensively until 1970. Banned in most western countries, but still in use for the control of malaria spreading mosquitoes. Total global usage of 2.6 mill. tons.	Long-range transport. Minor local use as incecticide.
Chlordanes	Broad spectrum insecticide used on agricultural crops and for termite control. Banned in many countries since the early 1980s. Total global usage of 80 000 tons.	Long-range transport.
Toxaphenes (CHB)	Used as pesticide and to control ticks and mites in livestock. Banned in most countries since the early 1980s. Total world usage of 1.3 mill. tons.	Mainly long-range transport.

Table 2: Toxicological characteristics of selected persistent organic pollutants.*

Contaminant	Acute oral lethality (LD_{50} rats, mg/kg bw)	Terato-genity	Hormonal effect (relative to estradiol)	Human carcino-genity	Tolerable daily intake (WHO; µg/kg bw)
Dibenzo-*p*-dioxins and furanes (PCDD/PCDF): 2,3,7,8-TCDD	0.013-0.043	+	-	Possible	0.00001
Polychlorinated biphenyls (PCB): Aroclor 1260	1300	0	+	Possible	1.0
Hexachlorocyclohexanes (HCH)	88 (γ)	0 (γ)		Possible	0.3 (total)
Hexachlorobenzene (HCB)		0	+	Probable	
DDT group: DDT	113	0	++ (*o,p*)	Possible/	20
DDE	880	0	0 (*o,p*/*p,p*)	Possible	20
Chlordanes	335-430	0	+	Probable	0.05 (total)
Toxaphenes (CHB)	80-90	+/0		Possible	0.2

* Adapted from AMAP 1998.

3.1 Dibenzo-*p*-dioxins and dibenzofurans

Dioxins (PCDD/Fs) is often used as the common name for polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), two structurally similar families of compounds that include 75 and 135 congeners, respectively. Dioxins are mainly released through all sorts of domestic and industrial incineration processes at relative low temperature (below 800 degrees celcius) with chlorine present, as well as during the manufacture of industrial chemicals including PCB and pesticides (Alcock and Jones 1996, Fiedler 1996). Through establishment of pollution controls, there has been a significant reduction in the emission to the environment.

Dioxins and furans are insoluble in water, lipophilic and persistent in the environment. Especially the 2,3,7,8-tetrachlorinated dioxins are known to bioaccumulate, while the more predominant congeners from combustion processes are known to be biodegraded. Due to binding to particulate matter, the dioxins are normally regarded as a major problem close to the source. In addition to a few local sources, these compounds enter the Arctic ecosystem via airborne long-range transport but not to the same extent as other chlorinated POPs. Lipid rich food of animal origin is the primary source of human exposure. Typical sum values reported in human milk from the Arctic are in the range 10-40 pg/g lw (lipid weight) (AMAP 1998), but data on human plasma from the Arctic are sparse.

Chloracne is well documented after dioxin exposure. Other possible effects include immunotoxic, carcinogenic, reproductive disturbances and acute toxic reactions (Fiedler 1996, Whysner and Williams 1996). In a Dutch study, ten Tusscher *et al*. (2001) reported perinatal exposure to background dioxin levels to be rather high. PCDD/Fs were found to influence the respiratory system negatively by spirometric assessment. In conclusion, the perinatal background dioxin exposure was inversely associated with the FEV1/FVC ratio. In animal models, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin is found to be the most potent member of a class of chlorinated hydrocarbons that interact with the aryl hydrocarbon receptor (AhR) (Grassman *et al.* 1998). Comparisons of biochemical changes show that humans and animal models have similar degrees of sensitivity to dioxin-induced effects.

3.2 Polychlorinated biphenyls

The polychlorinated biphenyls (PCBs) are a group of 209 congeners, which were commercially produced and sold mainly as Aroclor, Clophen and Sovol mixtures (Safe 1994). In addition, several PCB-congeners are atropisomers (exist as enantiomeric pairs due to restricted rotation of the bond between the two phenyl ring system). PCBs have been used extensively since 1930 for a variety of industrial and commercial uses, but are now phased out in many western countries. PCBs have found widespread applications including as dielectric fluids in transformers and large capacitors, as heat exchange fluids, in lubricating oils, as paint additives, in plastics and in sealants. At present, the major source of PCB exposure seems to be environmental recycling of PCBs from former usage. PCBs are still present in older electrical transformers and at a number of contaminated industrial and waste sites throughout the Arctic. However, PCBs have primarily contaminated the Arctic ecosystem through long-range transport from southern regions. The world-wide PCB production has been estimated to be 1.3 million metric tons (Breivik *et al.* 2001).

The physiochemical properties of PCBs including low water solubility, high stability (particular those lacking unsubstituted positions on the biphenyl ring system) and semi volatility, favor atmospheric long-range transport and accumulation in lipid rich media. Thus, the main source of human exposure is through food, however, inhalation and dermal routes are likely under occupational exposure. Typical sum values in plasma are in the range 1-60 μg/L (AMAP 1998).

Historical levels are not always easy to compare with today's measurements due to changing trace analytical techniques and quantitation methods. In addition sum PCB values are often reported based on different quantitation methods (e.g. as Aroclor 1260 or a selected number of congeners) making comparison difficult. Co-elution with other chlorinated compounds like chlorobornanes and cyclodiene pesticides has previously made proper analytical interpretation difficult.

The most persistent congeners in lipid media are PCB 153, 138, 180, 170, 118 and 99. Although regarded as persistent, some PCBs depending on chlorine substitution, are transformed in the environment by biotic and abiotic processes. Natural occurring microorganisms are capable of degrading the low chlorinated PCBs with vicinal (in neighbour positions) hydrogen atoms. The presence of PCB metabolites in animals and humans formed by the action of CYP (cytochrome

P450) and phase-II enzymes are recognized (Boon *et al.* 1989), but so far not implemented in today's environmental monitoring. Reports have shown that the most abundant hydroxy-PCBs in human blood samples equals the presence of some abundant PCB congeners with sum values in the range 0.1-10 µg/L plasma (Bergman *et al*. 1994, Sandau *et al.* 2000a, Hovander *et al*. 2002). Metabolism also includes the formation of diols, phenolic conjugates and glutathione conjugates. Methyl sulfone metabolites are also reported to bioaccumulate (Letcher *et al.* 1998), but are present in substantial lower amounts compared to the hydroxy compounds.

Several possible adverse effects have been suggested related to PCB exposure, including effects on the immune system, the thyroid gland, cancer, reproduction and cognitive development (Safe 1994). Some of their toxicity may be linked to the biotransformation products. Due to structural similarities (with hydroxy groups in *para*- or *meta*-position), the hydroxy metabolites are assumed to have hormonal activities (Connor *et al*. 1997). The non-*ortho* and mono-*ortho* substituted PCBs are planar with properties similar to the dioxins. The concepts of toxic equivalency factors (TEF) and dioxin like toxic equivalents (TEQ) and their limitations in practical application are discussed thoroughly by Starr *et al.* (1999). Comparing implications of using TEF or total PCB approaches for assessing toxic effects in wildlife has been examined by Giesy and Kannan (1998). There are several advantages and limitations associated with each method used. Toxic effects due to coplanar PCBs occur at relatively smaller concentrations than those due to non-dioxin-like PCBs, and therefore the TEF approach derives the risk assessment of PCBs in the environment. There is a need for further refinement of the TEF approach for more accurate risk assessment. In the recent AMAP study (AMAP 2002, *in press*) TEQ in breast milk from Arctic Russia has been calculated solely on the basis of the selected PCB congeners in the program. Even so, the TEF values associated pointed out a rather high TEQ burden. While we still have no information about the most potent congeners in these areas, we can suspect that the real TEQ burden probably is higher than the calculated. In the same study, samples from Eastern Greenland are found to be high in dioxin activity. Conclusively, there must be a public and scientific concern for contaminants demonstrating dioxin-like activity in the Arctic areas, and congener specific analyses are needed to calculate the total TEQ exposure.

On the molecular level, Bonefeld-Jorgensen *et al.* (2001) have studied the effect of highly bioaccumulated polychlorinated biphenyl congeners on estrogen and androgen receptor activity. They have demonstrated in cell cultures that different congeners, like PCB 138, 153 and 180 can compete with binding of the natural ligand to two nuclear receptors, and thus possess the ability to interfere with sexual hormone regulated processes.

3.3 Hexachlorocyclohexanes

Hexachlorocyclohexanes (HCHs) are a group of organochlorines existing in eight isomeric forms including the often reported α-, β- and γ-HCH, the latter one more commonly known as the pesticide Lindane. α-HCH is chiral and hence exist as an enantiomeric pair (mirror images). The γ isomer Lindane is used as an insecticide on fruit, vegetables and forest crops. Many countries still use large amounts of

Lindane. There are some minor registered uses of Lindane in some circumpolar jurisdictions for the control of head lice and scabies caused by mites. Technical grade HCH, mainly containing the α isomer and only 15% γ-HCH, was once used as an insecticide. The total world production is estimated to 0.7 million metric tons of Lindane and 10 million tons of technical HCH (Li 1999).

The physiochemical properties of HCH makes them easily long-range transported to the Arctic, and HCH can partition into all media of the environment. Biodegradation seems to be the dominant decomposition pathway in soil and water. Like other persistent organic pollutants, most human exposure to HCHs comes from food consumption including plants and animal products containing the pesticide. HCH is not a major contaminant in drinking water. HCHs, especially β-HCH, accumulate readily in fatty tissues and are excreted slowly via faeces, breast milk and urine. Because of its persistency, β-HCH is found at highest concentration of the isomers normally reported in human samples. Typical plasma levels in the Arctic populations are in the range 0.1-2 μg/L (AMAP 1998).

High HCH exposure can affect the liver, the nervous system, the kidney, the reproductive system and the immune system. HCH is regarded as a possible carcinogen (ATSDR 1994, Coosen and van Velsen 1989).

3.4 Hexachlorobenzene

Hexachlorobenzene (HCB) was introduced in 1945 as a fungicide for seed treatment. HCB is also a by-product of the industrial manufacture of chlorinated solvents, in metallurgical processes, and a known impurity in several pesticide formulations that are currently in use. HCB is banned in many countries or its use has been severely restricted. Estimated current global annual emission is 23 metric tons (Bailey 2001).

HCB is very persistent and bioaccumulates in animals. Dietary intake is the major route of human exposure, with highest concentrations found in oils and fats, meat, poultry and fish. Exposure via inhalation or through drinking water is considered to be low. Typical plasma levels in Arctic populations are in the range 0.3-2 μg/L (AMAP 1998). HCB is transformed to both pentachlorophenol (PCP) and conjugates, however, the elimination appears to be small compared to the adipose deposits (To-Figueras 2000).

In addition to inducing porphyria, HCB has a broad range of toxic effects in experimental animals including immunotoxicity, endocrine effects and cancer (Fisher 1999).

3.5 The DDT group

The use of 1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane (*p,p'*-DDT) as pesticide has been declining in the temperate regions of the Northern hemisphere since the 1960s and especially since the 1970s when it was banned by many western nations (Mellanby 1992). DDT was commonly used as a pesticide on a variety of agricultural crops, and is still in use for the control of mosquitoes that spread malaria. Total global usage is estimated to 2.6 million metric tons until 1992 (Voldner and Li 1995). *p,p'*-DDT is easily metabolized to 1,1-dichloro-2,2-bis(*p*-

chlorophenyl)ethene (*p,p'*-DDE) and 1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethane (*p,p'*-DDD). The DDE/DDT ratio can be used to assess the age or closeness to the contamination source. The isomers *o,p'*-DDT and *o,p'*-DDD, two minor isomers of the DDT group, are chiral.

The persistency of the DDT group in the environment and its continued entry into the Arctic region via atmospheric long-range transport, has meant that DDTs are detectable in almost all compartments of the ecosystem and in human tissues. Levels of total DDT in human tissue in the Arctic are considerably higher than those in southern populations, reflecting the greater consumption of high trophic level species for food. Typical plasma levels are in the range 1-9 μg/L (AMAP 1998). DDT and its metabolites are stored in fatty tissue and are excreted very slowly. Due to the lipohilicity, DDT and its metabolites are found in breast milk and can readily cross the placental barrier.

Evidence suggests that the DDT group may suppress the immune system, mimic hormones and be a possible human carcinogen (Fisher 1999). Desaulniers *et al*. (2001) have explored modulatory effects of neonatal exposure to TCDD, PCBs, *p,p*'-DDT, and *p,p*'-DDE on mammary tumor development in rats. They have found that neonatal exposure to high doses of the DDT group could favor development of mammary lesions, but also delay the development of palpable tumors. Longnecker *et al.* (2001) have established an association between maternal serum concentration of DDE and preterm and small-for-gestational-age babies at birth. This is a major contributor to infant mortality and, if this association is found to be causal, it should be included in any assessment of the costs and benefits of vector control with DDT.

3.6 Chlordanes

Technical chlordane is a mixture of *cis*- and *trans*-chlordane, *cis*- and *trans*-nonachlor, heptachlor and other chlordane isomers (Dearth and Hites 1991). The total number of compounds is at least 147, of which 10 are major ones. Most chlordanes are chiral and hence found as racemates in the technical product. Chlordane was manufactured from late 1940s as a broad spectrum insecticide used on agricultural crops and for termite control. Total global usage is estimated to 78 000 metric tons (Barrie *et al.* 1992), and action to ban chlordane has been taken in many countries. It is not registered for use in circumpolar jurisdictions and enters the Arctic ecosystem primarily via long-range transport. The chlordanes are highly volatile, lipid soluble and hence readily accumulate in fatty tissues in the marine food web. In general, only small amounts of chlordane are found in human tissues. However, relatively larger amounts (one or two orders of magnitude) of *trans*-nonachlor and the metabolites oxy-chlordane and heptachlor *exo*-epoxide are found. The chlordanes are one of the most abundant environmental pollutants. Typical values (sum chlordanes) in human plasma are in the range 0.2-2 μg/L (AMAP 1998). The compound class is a possible carcinogen and is believed to affect the immune system (Fisher 1999).

3.7 Toxaphenes

Toxaphene is an insecticide mixture introduced by Hercules (USA) consisting of several hundred chorinated bornanes (CHBs, major product), camphenes (PCC), bornenes and bornadienes, containing six to ten chlorine atoms (Muir and de Boer 1995, de Geus *et al*. 1999). Comparable mixtures were used under the brand names Strobane and Melipax. Most of the CHBs are chiral. Toxaphene is one of the most heavily used pesticides, with a total world production of 1.3 million metric tons until 1993 (Voldner and Li 1993). It was primarily used on cotton, cereal grains, fruits, nuts, vegetables, as well as to control ticks and mites in livestock. Toxaphene and comparable mixtures are now banned in most countries.

The major constituent CHBs are semi-volatile and enters the Arctic region via long-range atmospheric transport. The compounds are persistent (half-life in soil up to 12 years), lipid soluble, readily absorbed and are commonly found in human tissue. Absorbed CHBs may be transformed and excreted, however, some congeners remain for prolonged periods. The two most common congeners are an octachlorobornane (Parlar no 26) and a nonachlorobornane (Parlar no 50). Values reported in human plasma are in the range 0.1-1 μg/L for both congeners (Deutch and Hansen 2000).

Several adverse effects including being a possible human carcinogen are reported (de Geus *et al.* 1999). However, structure-activity models have shown that the most toxic CHB congeners are not accumulated (Parlar *et al.* 2001). Bonefeldt-Jorgensen *et al.* (1997) have studied the effect of toxaphene on estrogen receptor functions in human breast cancer cells. The results indicate that toxaphene can disturb hormonal signals mediated by the estrogen receptors, and suggest that these environmental chemicals have potential endocrine disrupting activities which may affect the reproductive health and increase the risk for carcinogenesis.

4 Updated knowledge of levels and trends of POPs in humans in Arctic coastal populations

The most recent levels of POP in human plasma sampled in Euroarctic areas are shown in Table 3. It is difficult to assess human exposure to POPs. Several studies have measured environmental toxins in human fat or milk, both matrices useful indicators for long time exposure. For practical reasons human blood plasma is used. Plasma is also the preferred matrix for short-lived pesticides.

Examination of environmental contaminants in maternal samples from the arctic regions of the eight circumpolar countries has confirmed that the plasma levels of certain POPs are generally higher in the samples of Arctic peoples who consume traditional foods (e.g. the Inuit of Greenland and of Arctic Canada). For Greenland Inuit in particular, the levels of PCBs, HCB and total chlordanes are higher than those in maternal samples from Canada and other circumpolar countries, and likely reflect the higher consumption of these traditional foods.

Table 3: Levels of selectecd persistent organic pollutants in human samples.*

Contaminant	Levels in plasma
Sum PCBs (as Aroclor 1260)	Inuit population: 7-1100 µg/L Russia: 1-17 µg/L Norway: 2-17 µg/L
β-HCH	Inuit population: 0.1-3 µg/L Russia: 0.1-12 µg/L Norway: 0.1-0.4 µg/L
Hexachlorobenzene	Inuit population: 0.1-8 µg/L Russia: 0.1-1.4 µg/L
DDT group (*p,p'*-DDT and *p,p'*-DDE)	Inuit population: 0.7-30 µg/L Russia: 0.3-18 µg/L Norway: 0.2-5 µg/L
Chlordanes (oxychlordane and *trans*-nonachlor)	Inuit population: 0.5-65 µg/L Russia: nd**-1.0 µg/L Norway: 0.1-0.5 µg/L
Toxaphenes (Parlar 26 and 50)	Inuit population: nd**-4.7 µg/L Russia: nd**-0.8 µg/L Norway: nd**-0.8 µg/L

* From AMAP studies.
** Not detected

Other key findings include higher levels of total DDT in a non-indigenous population from Arkhangelsk compared to any other region, indicating a possible use of this pesticide locally or in Russian agricultural regions from which food is transported to the Arkhangelsk region. For β-HCH the highest levels were also seen in Arctic Russia among the non-indigenous peoples.

There are very few Arctic populations for which more than one or two sequential data sets are available, so it is very difficult to assess any time trends for the environmental contaminants of concern. Most environmental monitoring in the Arctic has taken place only over the last five to ten years, and this has enabled a much better assessment of the spatial variation in contaminant levels but may be too short a time span to detect any time trends.

5 Dietary intake and food safety systems in Europe

Governmental control generally involves the operation of surveillance schemes. This method normally involves analysis of prescribed numbers of samples of food for pesticides on annual basis. The most detailed surveillance system is in Sweden (about 9000 samples analysed in 1996). Countries with substantial export of fruits and vegetables often appear high on the list (e.g. Holland). In the UK 30 % of the food consumed is estimated to contain measurable residues of pesticides, and 1 % contains residues above the maximum residue limit. We have reasons to believe that the amount of food containing pesticide levels above the maximum residue limit is considerably higher in the Arctic areas and especially in the Russian Arctic (Klopov *et al.* 1998). Although the actual risk for the consumer in most western countries is low and it is likely that natural toxins present a far greater risk, the situation seems to be quite different for some Arctic populations.

In Western Europe residues of pesticides are a problem from time to time (Shaw 2000). In the 1998 UK survey, 80 % of UK-grown pears were found to contain the growth regulatory pesticide chlormequat. The fact that this pesticide is not approved for use in the UK probably indicates illegal use. Lindane in continental-style chocolates and lindane in milk are two other focused issues the last years. Increased concentrations of lindane in cows milk in 1995 might be connected to the hot summer and slightly malnourished animals, mobilising their fat reserves. Illegal use of pesticides is suspected to be a greater problem in the Russian Arctic. Both published AMAP data and other studies (Klopov *et al.* 1998) based on human blood and breast milk samples support this view.

A Norwegian survey on the levels in foodstuffs and dietary intake of dioxins and PCBs (SNT 1997) showed that the analysed foodstuffs were low in dioxins and dioxin-like PCBs. The highest concentrations were found in fatty marine food such as cod liver and brown crabmeat. Commercial cod liver oil is refined during production and not regarded as a problem.

The average weekly dietary intake of dioxins and PCBs in the Norwegian population based on data from household budget surveys, expressed as pg toxic equivalents (TE), was estimated to be well below the tolerable weekly intake recommended by the Nordic Expert Group (SNT 1997). However, for consumers of fish liver and crab from areas locally contaminated with dioxins and PCBs, it is likely that the intake of TE may exceed the tolerable weekly intake. Fatty seafood, especially fish liver and crabmeat, from such areas should not be used for food.

Contaminant levels of fish used in the Norwegian diet have big local variations. Fish from the Barents Sea and the Norwegian Sea is normally known to have very low concentrations of contaminants. A substantial part of the fish used in the general diet is caught in these areas. Local fjords might have higher levels of POPs, leading to restrictions in utilisation of fish, fish liver and crabmeat. For milk and meat products local variations seem to be minor, based on the homogeneity of tests. Recently, eggs of sea gulls are reported to be highly PCB contaminated.

The Norwegian consumer investigations of 1992-94 give estimates of how much food is brought into the house holding, but will not give exact information about the amount actually being eaten. For some foodstuff the consumption will be overestimated (bought in and stored in big quantities; fresh food with short turnover). For others the use will probably be overestimated (bought and eaten outside the household; forgotten in the registration). On this basis, the fish consumption is probably higher than the registered, while the meat consumption might be lower than the estimate.

The registration of the two food items with highest concentrations of dioxins and PCBs, cod liver and crabmeat, must be assessed with considerable caution. Shrimps and crab are registered in the same group. A shift from the estimated 75/25 % balance to a 50/50 balance will double the intake of dioxins. Another problem is the lack of information on fish liver consumption (high in some areas), giving only rough estimates of the average intake. Generally, the amount of food items registered in the Norwegian consumers investigation are higher than the amount registered in individual dietary questionnaires. This probably leads to an overestimation of the dioxin intake. The under-reporting of fish consumption will probably work against this. Generally, for population groups consuming fish liver or crabs, the intake of dioxins is supposed to be underestimated. However, recent data from a preliminary study in a high fish consumption community in Northern Norway did not show elevated levels of PCB and pesticides (Furberg *et al.* 2002). These observations clearly demonstrate some of the problems associated with food safety, and the situation is even worse in areas where food tables are non-existent. Recent Norwegian recommendations regarding consumption of sea gull eggs due to high levels of POPs, especially PCBs, concluded that children and fertile women should totally avoid seagull eggs (SNT 2002). Thomsen *et al.* (2001) have reported concentrations of brominated flame retardants in plasma samples from three different occupational groups in Norway, finding large variations of individual concentrations within the groups. The conclusion was that Norwegian populations are exposed to a variety of brominated flame retardants (e.g. PBDE), probably with food as a major source. A more complete assessment of the human exposure pathways is needed before we can give public health advices.

6 Dietary studies in the European Arctic

Levels of persistent organic pollutants in selected food items are shown in Table 4. Dietary surveys serve several purposes, namely to describe and analyze the food choice and nutritional adequacy of the diet and to assess the role of food components as sources/carriers of anthropogenic pollutants including POPs, heavy metals and radionuclides. Dietary surveys have been performed among Arctic populations both as part of the AMAP Human Health program and as independent studies, discussed in the second AMAP Report, Chapter on Human Health (AMAP 2002, *in press*). In particular, a very large body of dietary information has been accumulated in Canada over the last twenty years by the Center for Indigenous Peoples' Nutrition (CINE) (Kuhnlein *et al.* 2001, Kuhnlein 1997, Kuhnlein *et al.* 1996, Kuhnlein and Receveur 1996). A recent project of the Russian Federation, addressing persistent toxic substances, diet and human health in the indigenous populations of the Russian Arctic will bring new understanding for a "white spot" of knowledge reaching from the Kola Peninsula to the Chukotka Peninsula.

There are large variations in dietary patterns of the European Arctic, but the general tendency is clear that traditional or country food consumption is gradually decreasing, as imported foods are becoming more available and culturally acceptable to Arctic Peoples. This is most clearly shown by the use of dietary indicators, e.g. human blood lipid profiles of n-3 and n-6 polyunsaturated fatty acids (PUFA) where the n-3 to n-6 ratio is a strong marker of mainly marine lipid rich food (marine mammals) but also inland fish and game. The high relative content of n-3 fatty acids in the traditional foods presumably provides some protection against cardiovascular diseases and diabetes. On the other hand human blood levels of marine acquired n-3 fatty acids are strongly associated with POPs, because the main sources of POPs are fatty tissues (blubber) from marine animals.

In general it is difficult to directly compare dietary survey data obtained by different methods, e.g. interview versus recording or food frequency questionnaires. In the second place some studies report their dietary survey results as intake frequency or weight of listed food items whereas others report calculated dietary nutrient profiles. Some dietary surveys only measure and report only on traditional food intake whereas others measure the total diet. Therefore comparisons between countries and even between ethnic groups within countries in most cases can only be qualitative. This should be taken into consideration in the planning of sampling methods in future dietary surveys as well as in more standardized ways of reporting. For our purpose, the aim should be at least to report both daily intakes e.g. gram per day (not portions) and daily nutrient intakes in absolute and relative units.

The diets of Arctic Indigenous Peoples consists of both traditional food, and imported (market) foods. Although it varies by country, locality, sex and age group, the traditional food yields 10-40% of the total energy intake and this percentage has decreased over the last 30-40 years. The traditional foods are the main contributors of protein, fat, and minerals (Fe, Zn, Se, I), vitamin D, and especially of the essential long chain n-3 fatty acids. The ratio between n-3 and n-6 fatty acids in human lipid fractions can serve as a good indicator of the relative intake of traditional food.

Table 4: Typical levels of persistent organic pollutants in selected food items.*

Country	**Food item**	**Concentration of POPs**
North-West Russia	Arctic char muscle	Sum PCBs: 26.6 µg/kg ww Sum HCHs: 2.9 µg/kg ww Sum DDTs: 5.65 µg/kg ww Sum Chlordanes: 3.01 µg/kg ww Sum CHBs: 35.4 µg/kg ww
	Cod muscle	Sum PCBs: 9.6 µg/kg ww Sum HCHs: 1.42 µg/kg ww Sum DDTs: 2.12 µg/kg ww Sum Chlordanes: 1.75 µg/kg ww
	Ringed seal blubber	Sum PCBs: 710-4200 µg/kg ww Sum HCHs: 34-180 µg/kg ww HCB: 14-28 µg/kg ww Sum DDTs: 490-3600 µg/kg ww Sum Chlordanes: 180-470 µg/kg ww
Greenland	Whale blubber	Sum PCBs: 3700-5400 µg/kg ww Sum DDTs: 2700-4100 µg/kg ww Sum Chlordanes: 1800-2400 µg/kg ww Sum CHBs: 3000-3500 µg/kg ww
	Cod liver	Sum PCBs: 63-107 µg/kg ww Sum HCHs: 7-9 µg/kg ww HCB: 12-20 µg/kg ww Sum DDTs: 60-98 µg/kg ww Sum Chlordanes: 40-57 µg/kg ww
	Salmon muscle	Sum PCBs: 75 µg/kg ww Sum HCHs: 14 µg/kg ww HCB: 7 µg/kg ww Sum DDTs: 40 µg/kg ww Sum Chlordanes: 15 µg/kg ww Sum CHBs: 300 µg/kg ww
Faeroe Islands	Pilot whale muscle	Sum PCBs: 640 µg/kg ww Sum DDTs: 280 µg/kg ww
	Whale blubber	Sum PCBs: 17000-39000 µg/kg ww γ-HCH: 500 µg/kg ww Sum DDTs: 10000-24000 µg/kg ww
	Cod liver	Sum PCBs: 52-68 µg/kg ww Sum HCHs: 4-5 µg/kg ww HCB: 9-11 µg/kg ww Sum DDTs: 42-50 µg/kg ww Sum Chlordanes: 22-30 µg/kg ww
	Halibut muscle	Sum DDTs: 780 µg/kg ww

Table 4: Contd.

Country	Food item	Concentration of POPs
Northern Norway	Cod liver	Sum PCBs: 240 μg/kg ww Sum HCHs: 11 μg/kg ww HCB: 41 μg/kg ww Sum DDTs: 309 μg/kg ww Sum Chlordanes: 196 μg/kg ww
	Cod muscle	Sum PCBs: 1.1 μg/kg ww Sum HCHs: 0.1 μg/kg ww HCB: 0.2 μg/kg ww Sum DDTs: 1.0 μg/kg ww Sum Chlordanes: 0.3 μg/kg ww
	Seagull eggs	Sum PCBs: 1830 μg/kg ww
	Reindeer fat	Sum PCBs: < 80 μg/kg ww Sum HCHs: < 20 μg/kg ww Sum DDTs: < 10 μg/kg ww
	Harp seals blubber	Sum PCBs: 3800 μg/kg ww Sum DDTs: 3000 μg/kg ww
	Shrimp muscle	Sum PCBs: 0.1 μg/kg ww Sum HCHs: 0.1μg/kg ww HCB: 0.3 μg/kg ww Sum DDTs: below detection limit Sum Chlordanes: below detection limit

* Data from Fromberg *et al*. 1999, SNT 1997, Stange *et al.* 1996 and AMAP 1998.

On the other hand the imported foods are the main contributors of carbohydrates, water-soluble vitamins, vitamin A, and calcium. In general the composite diets are sufficient regarding most nutrients. However, the nutrients most at risk are vitamin A, vitamin C, and folic acid due to the low intake of vegetables and calcium (low intake of milk products). The iodine intake of inland indigenous populations is sometimes below recommended levels.

Chemical analyses of food items of animal origin have provided ample proof that traditional food is a major source of POPs and heavy metals (Hg/MeHg, Cd and sometimes Pb). Exposure estimates of heavy metals calculated from dietary intake data show good correlation with human tissue concentrations. Dietary exposure estimates of POPs have so far only been compared with human body burdens of POPs on a population basis. Correlation between estimates of individual dietary intakes and individual blood levels of xenobiotics are not yet available. However, several studies show very significant positive associations between n-3 fatty acids in human lipid fractions and blood levels of both POPs and mercury which makes the connection between intake of marine mammal fat (e.g. blubber) and organic pollutants highly probable. It is also evident that the POP concentration in animal fat varies with the age and sex of the animals and the geographic location (AMAP 1998).

The uptake, metabolism, and excretion of organochlorine compounds is influenced by genetic factors. The tissue levels are influenced by various lifestyle factors such as smoking (Lagueux *et al.* 1999, Deutch and Hansen 2000, Deutch 1999, Deutch and Hansen 1999) and body mass index (Deutch *et al.* 2002). Therefore identification of individuals at risk of accumulating high POP burden is not just a question of dietary exposure, but also a more complex question of interacting genetic and biochemical factors. These should receive more attention in future studies.

7 Risk assessment of exposure to levels of POPs presently found in the Arctic

In the risk assessment of exposure to contaminants, epidemiological research should be used if available. However, epidemiological studies are few and cover only a few substances and only some of the possible clinical endpoints. In most cases risk assessment is based on animal studies. Of the contaminants in the Arctic MeHg is the most investigated. Of the several relevant endpoints the neurotoxic effects are the best described by epidemiological methods.

7.1 Neurotoxicity

The neurobehavioral performance of an individual is affected by several factors. The particular outcome may depend on characteristics of the exposure as such, i.e. the severity and chronicity as well as the question whether other exposures occurred at the same time. Also, the effect depends on the vulnerability of the subject, as indicated by age and premorbid status. Especially with prenatal exposures, the time of the neurobehavioral assessment is of importance, as the effects may not become apparent until the nervous system has matured sufficiently to express the dysfunctions. Epidemiologic data are not a prerequisite for risk assessment. In fact, opportunities for epidemiological studies of neurotoxicity may arise only when prevention has failed, whether or not a risk assessment has been carried out, and whether the origin of the exposure is natural or anthropogenic. Given the fact that neurotoxic exposures continue to occur, the best possible epidemiological studies should be carried out so that the unfortunate incidents will at least result in useful information that can provide a better basis for intervention. Frequently, several exposure factors must be determined, as the exposure under study is associated with other chemical exposures originating from the same source, e.g. PCBs and mercury in the Arctic originating from sea mammals. Given the fact that neurobehavioral function varies considerably within a population, even similar exposure circumstances may be associated with widely different performance results in a group of exposed subjects. Also, despite results of functional tests remaining well within the expected interval, differences can still be considerable between groups of individuals with different levels of exposure. Further, the individual may not be aware of any dysfunctions, but even minimal changes can in some cases have severe implications for daily life. These considerations are important to keep in mind when interpreting neurobehavioral data

7.2 Biological guidelines

Throughout the years, a number of biological guidelines (see also table 2) have been issued, discussed in the human health part of the second AMAP Report (AMAP 2002, *in press*).

In the Canadian Arctic 43% of the blood samples from Inuit women from North West Territories/Nunavut had blood PCB at Levels of Concern (LOC). Of these 87% were less than 20 µg/L and none exceeded 100 µg/L. Among women of child-bearing age in the Greenland regions of Disko Bay, Ilullissat, Nuuk and Ittoqqortoormiit (Scoresbysund), the LOC values of > 5 µg/L for PCBs as Aroclor 1260 was exceeded by 95, 52, 81 and 81% of the mothers, respectively (Deutch and Hansen 2000). In Ittoqqortoormiit, 12% of pregnant women exceeded the Canadian Action Level of 100 µg/L for PCBs (as Aroclor 1260), while 52% of non-pregnant women exceeded this blood guideline. These markedly higher proportions of the populations exceeding the LOC values reflect the considerably higher PCB levels in Greenland Inuit.

The corresponding value for maternal blood samples from the Lofoten region of Norway, Sweden and Finland were 70%, 68%, and 7.7% respectively. These higher level of exceedances of the Canadian LOC among the Norwegian and Swedish mothers may be due to higher fish intakes and resulting higher PCB levels. Table 5 presents a more detailed overview of blood guidelines.

7.3 Combined effects

Arctic residents are exposed to a variety of contaminants present in the food chain. POPs are composed of numerous compounds, most of them are accumulating in the food chain and in humans. It is then difficult to discriminate which compound is responsible of any associated observed effect. That makes any risk assessment of limited relevance for regulators. Similarly, concomitant exposure to MeHg and POPs is often observed.

In The Faeroe Island, prenatal exposure to PCBs was examined by analyses of umbilical cord tissue from 435 children from a Faeroes birth cohort, established in 1986/87 (Grandjean *et al.* 2001, 1997, 1992). Among 17 neuropsychological outcomes determined at age 7 years, the cord PCB concentration was associated with deficits on the Boston Naming Test, the Continuous Performance Test reaction time, and, possibly, on long-term recall on the California Verbal Learning Test. The association between cord PCB and cord-blood mercury (r=0.42) suggested possible confounding. While no PCB effects were apparent in children with low mercury exposure, PCB-associated deficits within the highest tertile of mercury exposure indicated a possible interaction between the two neurotoxicants. PCB-associated increased threshold were seen at two of eight frequencies on audiometry. No deficits occurred on evoked potentials or contrast sensitivity. The limited PCB-related neurotoxicity in this cohort appears to be affected by concomitant MeHg exposure.

Neurotoxic effects of MeHg might be attenuated by protective effects of nutrients such as selenium (Se) and n-3 polyunsaturated fatty acid. Increased intake of these nutrients would be expected in a population such as the Inuit who consume relatively large quantities of fish and marine mammals. Although the protective effects of Se on MeHg toxicity have not been adequately documented in humans (National Research Council 2000), there is strong evidence from animal studies that Se can influence the deposition of MeHg in the body and some evidence that Se can protect against Hg toxicity (Ganther *et al.* 1972). Especially the n-3 PUFA docosahexaenoic acid (DHA) is essential for brain development (Crawford *et al.* 1976). DHA deficiency impairs learning and memory in rats (Greiner *et al.* 1999). Studies have shown that supplementation of n-3 PUFA can enhance visual acuity and brain development in preterm infants (Bjerve *et al.* 1992, Uauy *et al.* 1990), but it is not clear whether increased levels of these nutrients during the fetal period can protect full term infants against neurotoxicity associated with prenatal exposure to environmental contaminants.

Table 5: Guideline values for levels of selected environmental contaminants in human tissues.

Contaminant	Tissue	Guideline value	Organization/ country
DDT/DDE	Plasma/Serum	200 µg/L (total DDT)	WHO
PCBs[1]	Plasma/Serum	For women of reproductive age (µg/L): < 5: Tolerable 5-100: Concern > 100: Action	Canada
PCBs[1]	Plasma/Serum	For men and post-menopausal women (µg/L): < 20: Tolerable 20-100: Concern > 100: Action	Canada
PCBs[1]	Breast Milk	50 µg/L: For protection of infants	Canada
Mercury (total)	Whole Blood	< 20 µg/L: Normal acceptable range 20-100 µg/L: Increasing risk > 100 µg/L: At risk	Canada
Cadmium	Whole Blood	5 µg/L (for occupational exposure)	Canada
Lead	Whole Blood	100 µg/L: Action level	Canada, USA

[1]PCBs measured as Aroclor 1260

7.4 Health outcomes are multifactorial

Many health end points are multifactorial and environmental stressors could contribute to a various extent to the etiology of these diseases. Compared to the roles that lifestyle and genetic factors play in the etiology of most diseases, contaminants are likely to play a modest role. However, they are preventable and their presence in the remote Arctic is unethical.

In risk assessment based on epidemiological studies covariates that should be considered as possible confounders are many. In epidemiological studies on children at least these factors should be included: Maternal and paternal age at childbirth, parity, smoking, education, maternal and if possible, fathers intelligence, employment status, migration, risk factors in past medical history, weight, height, breastfeeding, age at examination, sex, gestational age, number and age of siblings, day care, home environment, and type of delivery.

7.5 Epidemiological studies in the Arctic

Except for mercury and POP induced neurodevelopmental effects studied in the Faeroe Islands (Grandjean *et al.* 2001, 1997, 1992), POPs and the immune system in Nunavik (Canada) (Belles-Isles *et al.* 2002, Dewailly *et al.* 2000) and pregnancy outcomes and metals in the Kola Peninsula (Odland *et al.* 2001, 1999a, 1999b, 1999c), very few major environmental epidemiological studies have been conducted in the Arctic. There are several reasons for this situation. Conducting

Arctic studies is extremely difficult due to the remoteness of communities, e.g. the cultural context, climate, small size populations, and social and behavioral confounders. The specificity of the Arctic raises the question of how far results and conclusion from epidemiological studies conducted outside the Arctic can apply to this region. Mixtures of contaminants are different. Due to the diffuse properties of contaminants, the exposure profile found in the Arctic might differ from those reported at mid-latitudes where local sources could contribute to the mixture. Patterns of exposure could be influenced by hunting and fishing seasons, and constant exposure versus occasional high exposure could have different toxic consequences. Arctic residents consume wild animals and plants. This country food contains specific nutrients, which could influence or counteract the toxicity of contaminants. For example, Inuit are exposed to similar amounts of Hg as the Faeroe's people, but their selenium intake is much higher. Finally aborigine people may have specific genetic background that might influence their susceptibility to toxic agents.

The Inuit from the east coast of Greenland who consume large amount of marine mammals have the highest proportion of PCB blood concentrations, exceeding the guidelines used by Canada, followed by west coast Greenland Inuit populations and Inuit populations from the Baffin and Nunavik regions of eastern Canada. Similar patterns can be seen for exceeding the mercury blood guidelines (used by Canada and USA) but the data are more limited. When the new US-EPA mercury guidelines are applied it can be seen that most Inuit populations and a significant proportion of several other populations exceed these guidelines. Lead levels are also elevated among some Inuit groups in Arctic Canada and Greenland and these are also reflected in the increased proportions exceeding the action level. It seems that most of the lead comes from the use of lead shot for hunting of game rather than from long range atmospheric transport. Coastal populations from the Faeroe Islands have higher levels of PCBs and markedly higher proportions exceeding the PCB blood guideline than Caucasians from Arctic Canada (AMAP 2002, in press).

7.6 Studies on risk assessment

In many studies on risk assessment, exposures have not been entirely ”pure” and most have included more than one neurotoxicant. The Faeroes studies offer some insight and a potential for separating the effects, because PCB and mercury showed only a moderate association, and because lead exposures were very low (Grandjean *et al.* 1992). However, the most serious problem in interpreting research on this field may rather be that PCBs in the environment is not one well-defined chemical but consists of 209 congeners. Several of the congeners are thought to be neurotoxic (Sauer *et al.* 1994), but few of them are included in routine analyses and as a result they are not considered in risk assessment of persistent congeners. Further, PCBs occur in conjunction with other organochlorine substances, such as *p,p*'-DDE, which may contribute to their combined toxicity. The PCB exposure estimate may not address differences in PCB profiles and other contaminant profiles in different settings, and comparison between epidemiological studies must therefore be performed with caution.

Among the reasons for different study outcomes are differences in concomitant exposures and nutritional factors. In addition, imprecision in exposure assessment and outcomes as well as statistical power needs to be taken into account. For seafood-mediated exposures, confounding due to n-3 polyunsaturated fatty acids must be considered, because these nutrients are essential also for the development of the nervous system. Thus, birth weight and fatty acid status are important cofactors to consider.

Whenever possible risk assessment of contaminants should be based on epidemiological evidence, however, Arctic epidemiological studies are few in number. Serious consideration should be given to the cohort study on neurological disorders associated with prenatal MeHg (Faeroe Island) and the study of immune dysfunctions in children exposed prenatally to POPs (Nunavik). As human exposure to contaminants is to a mixture of many different substances simultaneously it is not reasonable and presumably not even possible to deal with the risk of single substances in epidemiological studies. The effect study from the Faeroe Islands has shown that there are negative effects related to both mercury and PCBs and perhaps DDT, DDE and other organochloric substances. Similar exposure levels as observed in the Faeroe Islands can also be found in Greenland. It seems likely that the negative effects, although small in the Faeroe Islands, can be found at other places with a similar exposure. Henceforth it is the responsibility of the public health authorities to decide on a suitable undertaking in order to reduce the exposure levels of humans. Careful considerations should be given to the possible negative effects on public health, which could be caused by changes in life-style.

In the risk assessment of exposure at levels presently found in the Arctic it is reasonable to conclude that the traditional diet in the Arctic contains xenobiotic substances which have a negative influence on health.

8 Toxicological consequences of persistent organic contaminants in food.

The health of humans is largely determined by the quantity and the quality of the diet, which means, that it should provide sufficient nutrients, both macro- and micro nutrients, and contain a low level of harmful pathogenic micro organisms and toxic compounds. In many cases chemical contaminants are unavoidable in food. MeHg occurs at a natural background level in marine mammals and fish, and PCBs and pesticides are globally spread and bioaccumulated in the marine food chains with the result that some Arctic peoples are exposed to these components, often at a level in excess of internationally accepted limits for safe intake (AMAP 1998).

Animal experiments have demonstrated that there are interactions between toxicants. It has been shown that specific components of the diet modulates the toxicity of specific toxicants whether these are ingested via the food or absorbed via other routes. Many examples point to the importance of interactions between dietary components and toxicants after absorption in the body. Such interactions occur at every level of biological organisation from the molecular to the whole organism or even population. Some may be synergistic, others antagonistic. Some may involve direct chemical reactions between the nutrient molecule and the toxicant, for example the reaction between the micro nutrient selenium and mercury, others may occur by indirect action at the molecular level, such as enhanced gene expression by toxicants. At the moment we are beginning to understand the molecular basis of the regulation of gene expression by dietary factors, and how genetic changes can effect response to toxicants. Recent advances in technology and a more detailed understanding of disease etiology, has increased the possibility to study molecular determinants of disease risk. Research programmes still provides new mechanistic models for effects of toxicants and at the same time increases the understanding of interactions between toxicants and between toxicants and nutrients. In addition, development of a system of relevant and applicable biomarkers of effects will be of importance for future studies of risks from dietary contaminants. The body of present knowledge clearly points to the importance of considering the composition of the diet when evaluating the response to toxicants in human populations.

A theoretical model for diet-toxicant interaction is shown in Figure 2, showing the dose related negative effect of a given toxicant and the effects of the same toxicant ingested through two different diets. The toxicant will *per se*, as an xenobiotic, theoretically exert negative effect at all dosage levels, disregarding a potential hormetic effect at the very low levels of intake. However, when ingested from different diets the response may be altered depending on the nutritional composition of the diets.

The model shown in Figure 2 can illustrate why different studies so often reaches different conclusions. One example is MeHg, where the Faeroese study reported developmental effects in children related to dietary intake from pilot whale meat (Grandjean *et al.* 1997), while no effects were observed at a similar exposure level in the Seychelles study (Davidson *et al.* 1998) where the mercury was provided through a fish diet. In contrary to the Faeroese study, in the Seychelles study there was a better performance among the children who had the highest exposure *in-utero* compared to the group with the lowest exposure (Davidson *et al.* 2000). This is interpreted by the authors as an influence by nutrients that overweighs the negative effects of MeHg. This example clearly points to the need to evaluate diet in environmental monitoring programmes together with the toxicants in order to provide a relevant risk information.

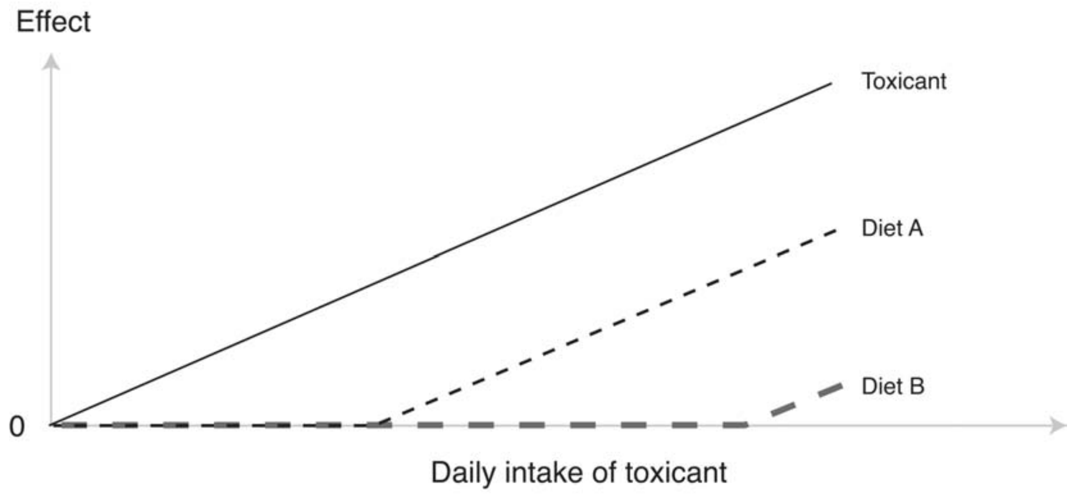

Figure 2: Theoretical model for the modifying effect of various diets on the effect of a toxicant (as a function of toxicant intake).

Traditional risk assessments for non-cancer effects are commonly based on determination of a NOAEL (no observed adverse effect level) from controlled studies in animals. An "acceptable safe" daily dose for humans is then derived by dividing the NOAEL with a safety factor, usually 10 to 1000, to account for sensitive subgroups of the population, data insufficiency, and extrapolation from animals to humans. This procedure do not take into account any forms of interactions, and the use of the NOAEL has become controversial because of the inherent uncertainties. There is an increasing interest in new approaches based on dose-response modelling techniques. Crump (1984), suggested application of the lower 95% confidence limit of the dose corresponding to a predefined increase (usually 5% or 10%) over the background rate. The author defined the Benchmark Dose (BMD) as the estimated dose that correspond to the specific risk above the background risk, while the BMDL is the lower 95% limit. This notation has now become standard usage in risk assessment (Budtz-Jorgensen *et al.* 2001). However, as the benchmark calculations depend on the assumed dose-response model, which will depend on nutritional conditions (Figure 2), neither this approach will provide a universal estimate of the real risk from a given toxicant under varying environmental conditions, and the BMDL can only be taken as indicative of approximate orders of magnitude.

The risk management process is, based on scientific evidence and taking into account certain societal factors, administratively to set guidelines for tolerable exposure, the TDI (tolerable daily intake). As the scientific basis for doing this is ambiguous the TDIs should only be regarded for what they are; namely an administrative tool for regulation of human exposure to potential harmful chemicals, and not as an indication of a real risk level.

In some cases the TDI is fixed at a level below the toxicologically determined reference dose (RfD) with the intention to minimise the use of a hazardous compound. This is true for some pesticides like DDT. In other cases the reverse attitude is taken and the TDI is above the RfD. An example is MeHg, where the RfD is calculated by US-EPA to be 0.1 μg/kg body weight/day, while WHO recently decided to maintain the PTWI (provisional tolerable weekly intake) of 3.3 μg/kg bw corresponding to 0.47 μg/kg/day. This is justified from the point of view that the US-EPA RfD will limit fish consumption to a level far below what is recommended for protection from cardiovascular diseases. On the other side a RfD to TDI ratio <1 indicates the presence of a potential environmental problem calling for a reduction of environmental MeHg of anthropogenic origin.

9 Conclusions and abatement strategies

Well-designed epidemiological studies with standardised questionnaires are now being created and validated. Estimates of effects are difficult based on current knowledge, but the combination of improved methodology and selection of risk groups will be a good step further in the process. Data from these studies are of outmost importance to design local abatement strategies.

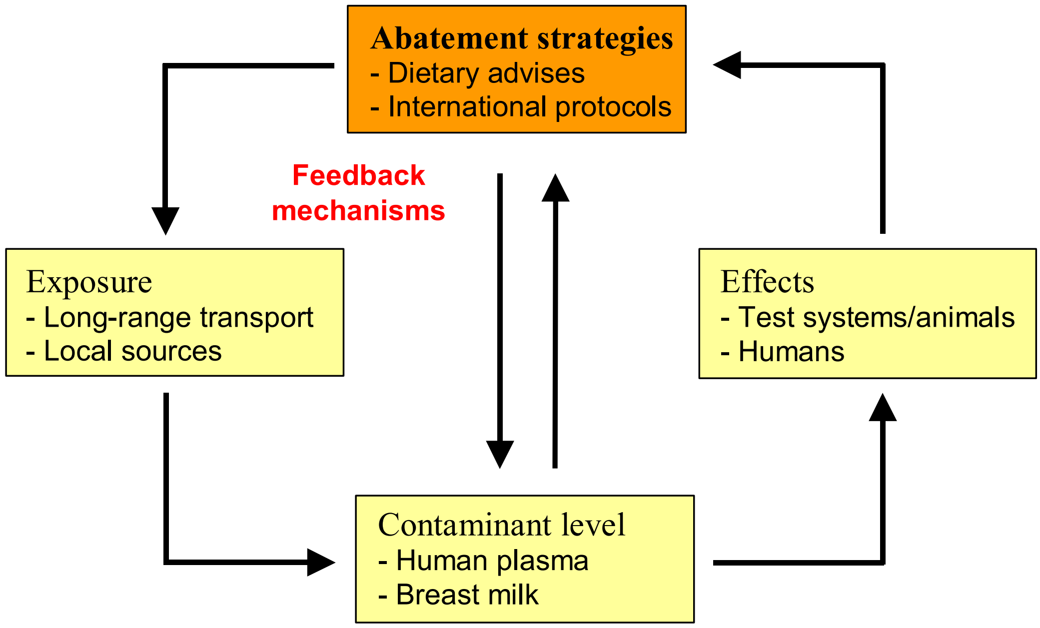

Figure 3: Interactions and feedback mechanisms for POPs: Exposures, levels, effects, and abatement strategies including dietary advice.

A model for interactions and feedback mechanisms for POPs; exposures, levels, effects, and abatement strategies including dietary advice is demonstrated in Figure 3. Possible local abatement strategies are visualized in Figure 4. The most effective strategies must be adapted locally with the community they are designed to assist. Once evaluated for their effectiveness, they can be used as case studies to assist the development of risk reduction strategies in other parts of the Arctic. The best strategies are those developed with the affected people strongly engaged in the decision making process. Any strategies based on traditional food substitution should ensure that the value of the dietary components is sustained.

It is essential that countries ratify and implement multinational environmental agreements and especially the protocols on POPs and metals to the Stockholm Convention and other multinational environmental agreements, as these will be the only effective long-term solutions for reducing human exposure to POPs and metals.

The complexity of changing conditions and the need for inclusion of multiple determinants of health in regulatory measures, makes forecasting future population trends very difficult. Based on current global trends and activities to manage risks, there are likely to be minor decreases in POPs and minor increases in mercury levels in Arctic populations in Greenland, Eastern Russia, Western Alaska and Eastern Canada by 2010. Major decreases are likely to occur in both POPs and mercury levels in these same populations by 2030. Levels of POPs and metals in populations in the Faeroe Islands, Norway, Sweden and Finland are already reasonably low and will possibly only decline marginally by 2030. These predictions will be heavily influenced by prompt ratification and implementation of the Stockholm Convention and other multinational environmental agreements.

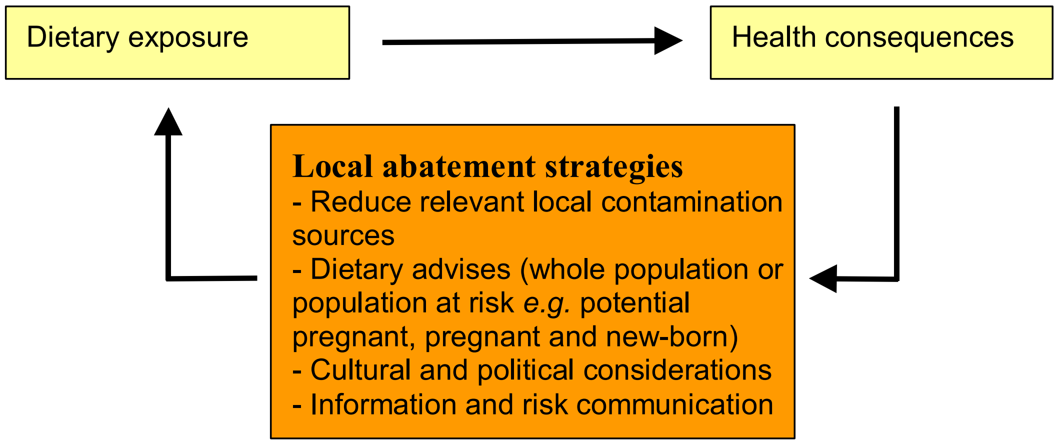

Figure 4: Local abatement strategies.

There remains a key need to fill in data gaps to validate and update exposure and disease estimates for various regions of the Arctic. Special emphasis should be placed on children and youth for whom data are difficult to gather.

In order to improve our understanding of health effects associated with contaminant exposure in the Arctic, we recommend that circumpolar epidemiological studies should be implemented in a larger scale. POPs and mercury related effects are still the key issues. However, the role of new discovered POPs like PBDE, PCN, PCA, PFOS and others should be investigated. For exposure assessment, epidemiological studies should consider mixtures and nutritional interactions. Epidemiological studies on nutritional benefits of traditional food should be incorporated in risk assessment profiles. Tissue banking for samples collected in the course of epidemiological studies, should be carefully organized to allow further assessment of new contaminants and time trend studies.

In conclusion there is a need for a more nuanced view on human dietary exposure to xenobiotics as risk should not be evaluated alone, but seen in relation to benefits from specific diets. Table 6 is a suggestion for a model connecting food consumption and POP contamination (Contamination Impact Factor - CIF) in Greenland. In other areas the information is still too sparce in order to develop such models.

The concept of risk analysis should in the future be replaced by a concept of risk-benefit analysis. This will not allow the presence of xenobiotics in food, as the relative size of the risk component of the analysis will determine the need for a reduction of the contaminant level. The precautionary principle often accepted by administrators, may lead to unintended negative health effects as it often will urge people to refrain from otherwise healthy food.

Table 6: Food consumption and POP Contamination Impact Factor (CIF) in Greenland.

Population group	**Basic food items**	**Consumption factor***	**Contamination factor***	**Impact factor (CIF)***
Greenland (Inuit)	Marine mammals	H	H	H
	Terrestial mammals	M	L	L
	Birds	M	H	H
	Fish	L	L	L
	Imported food	H	L	L

*L=Low, M=Medium, H=High

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12 Abbreviations

AhR: Aryl hydrocarbon receptor
AMAP: Arctic Monitoring and Assessment Programme
BMD: Benchmark dose
BMDL: Benchmark dose lower 95% limit
bw: Body weight
Cd: Cadmium
CHB: Chlorinated bornane
CIF: Contamination impact factor
CLC: Canadian level of concern
CYP: Cytochrome P450 enzyme
DDT group: DDT, DDE and DDD
DHA: Docosahexaenoic acid
FEV1: Forced expiratory volume
FVC Forced vital capacity
HCB: Hexachlorobenzene
HCH: Hexachlorocyclohexane
Hg: Mercury
LOC: Level of concern
lw: Lipid weight
MeHg: Methyl mercury
NOAEL: No observed adverse effect level
OCS: Octachlorostyrene
Pb: Lead
PBDE: Polybrominated diphenyl ether
PCA: Polychlorinated paraffin
PCB: Polychrorinated biphenyl
PCDD/F: Polychlorinated dibenzo-*p*-dioxin and dibenzofuran
PCN: Polychlorinated napthalene
PCP: Pentachlorophenol
PFOS: Perfluorooctane sulfonate
POP: Persistent organic pollutant
PTS: Persistent toxic substances
PTWI: Provisional tolerable weekly intake
PUFA: Polyunsaturated fatty acid
RfD: Toxicologically determined reference dose
Se: Selenium
TDI: Tolerable daily intake
TE: Toxic equivalent
TEF: Toxic equivalency factors
TEQ: Dioxin toxic equivalents
UNEP: United Nations Environment Programme
US-EPA: United States Environmental Protection Agency
WHO: World Health Organization
ww: Wet weight

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ABSTRACT
The high levels of organic contaminants in the Arctic have caused serious concern regarding the health conditions of indigenous populations in Arctic areas. The exposure to pollutants through the diet is of central concern and today food safety is essential in daily life in developed countries. The main objective of this study is to describe the importance of diet on exposure and possible health effects of persistent organic pollutants (POPs), based on a literature review.

Estimates of effects are difficult, but the combination of improved methodology and selection of risk groups will be a good step further. The most effective abatement strategies are those developed with the affected people strongly engaged in the decision making process. Any strategies based on traditional food substitution should ensure that the value of the dietary components is sustained. It is essential that countries ratify and implement multinational environmental agreements and protocols on POP reduction. Based on current global trends and activities to manage risks, there are likely to be minor decreases in POPs in Arctic populations in Greenland, Eastern Russia, Western Alaska and Eastern Canada by 2010. There are likely to be major decreases in POP levels in the same populations by 2030. Levels of POPs in populations in the Faeroe Islands, Norway, Sweden and Finland are already reasonably low and will possibly only decline marginally by 2030.

In order to improve the scientific understanding of health effects associated with contaminant exposure in the Arctic, we recommend that circumpolar epidemiological studies should be implemented in a larger scale. POP related effects are still one of the key issues. Also, the role of the many "new" POPs should be investigated. For exposure assessment, epidemiological studies should consider mixtures of contaminants and nutritional interactions. There is a need for a more nuanced view on human dietary exposure to xenobiotics. Risk should not be evaluated alone, but seen in relation to benefits from specific diets.

KEYWORDS		
Persistent organic pollutants	Human health	Diet

* *Classification*   *A*   *Unclassified (can be ordered from NILU)*
B   *Restricted distribution*
C   *Classified (not to be distributed)*

NORWEGIAN TITLE

Kostholdets betydning for eksponering og helseeffekter av persistente organiske miljøgifter hos arktisk kystbefolkning

NORWEGIAN ABSTRACT

Høye nivåer av organiske miljøgifter i arktiske områder har medført alvorlig bekymring vedrørende helsesituasjonen for urbefolkningsgruppene i området. Eksponering for miljøgifter gjennom maten er av sentral betydning, og matsikkerhet har fått stadig større oppmerksomhet i de industrialiserte land. Hovedmålet med denne litteraturstudien er å beskrive diettens betydning for eksponering og mulige helseeffekter av persistente organiske miljøgifter (POPs).

Effektstudier er vanskelige, men kombinasjonen av bedre metoder og definering av risikogrupper øker muligheten for å få svar på sentrale problemstillinger. De mest effektive tiltaksstrategier utvikles når de utvalgte risikogrupper deltar aktivt i bestemmelsesprosessen. Alle strategier basert på utbytting av tradisjonelle matvarer må ivareta næringsverdien av den opprinnelige dietten. Det er av avgjørende betydning at alle land ratifiserer og implementerer de multinasjonale miljøavtalene vedrørende POPs. Basert på kjente globale trender forventes det en svak nedgang i miljøgiftnivåer i arktiske befolkningsgrupper på Grønland, i det østlige Russland, i det vestlige Alaska og det østlige Canada fram til 2010. Fram til 2030 vil det bli en betydelig nedgang i de samme områdene. Nivåene hos befolkningene på Færøyene, i Norge, Sverige og Finland er allerede lave og vil reduseres moderat fram til 2030.

For å øke vår forståelse om helseeffekter forbundet med miljøforurensing i arktiske områder, anbefales gjennomføring av sirkumpolare, epidemiologiske studier av større omfang. Effektene av de mest kjente miljøgiftene er ennå uklare, samtidig med at de mange "nye" miljøgiftene er dårlig beskrevet. For vurdering av eksponering og effekter, bør epidemiologiske studier også inkludere blandinger av flere typer miljøgifter og diett-interaksjoner. Epidemiologiske studier av ernæringsmessige fordeler med tradisjonell diett, må inneholde en risikovurdering av miljøgiftkonsentrasjoner. Det er behov for et mer nyansert syn på dietteksponering for miljøgifter. Risiko må ikke vurderes isolert, men også sees i sammenheng med fordelene knyttet til de spesifikke diettmønstrene.