Review

Human health implications of environmental contaminants in Arctic Canada: A review

J. Van Oostdam [a,*], S.G. Donaldson [a,b], M. Feeley [c], D. Arnold [c], P. Ayotte [d],
G. Bondy [c], L. Chan [e], É. Dewaily [d], C.M. Furgal [f], H. Kuhnlein [e], E. Loring [g],
G. Muckle [h], E. Myles [i], O. Receveur [j], B. Tracy [k], U. Gill [l], S. Kalhok [m]

[a] Environmental Contaminants Bureau, Safe Environments Program, Health Canada, Rm 4-046, BMO Building, 269 Laurier Avenue W.,
AL4904B, Ottawa, ON, Canada K1A 0K9
[b] Carleton University, 1125 Coloney By Drive, Ottawa, ON, Canada K1S 5B6
[c] Health Canada, Food Directorate, Bureau of Chemical Safety, Banting Research Center, Tunney's Pasture, Ottawa, ON, Canada K1A 0L2
[d] Unité de recherchen santé publique (Centre hospitalier universitaire de Québec - Centre hospitalier de l'Université Laval),
Université Laval, 945 Ave Wolfe, Ste. Foy, Québec, Canada G1V 5B3
[e] Centre for Indigenous Peoples' Nutrition and Environment, Macdonald Campus of McGill University, 21,111 Lakeshore Road,
Ste.-Anne-de-Bellevue, Quebec, Canada H9X 3V9
[f] Départment Science Politique et Unité de recherche en santé publique (Centre hospitalier universitaire de Québec - Centre hospitalier de
l'Université Laval), Université Laval, 945 Ave Wolfe, Ste. Foy, Québec, Canada G1V 5B3
[g] Environmental Contaminants Research Division, Inuit Tapiriit Kanatami, 170 Laurier Avenue West, 12th Floor, Ottawa, ON,
Canada, K1P 5V5
[h] École de psychologie et Unité de recherche en santé publique (Centre hospitalier universitaire de Québec - Centre hospitalier de l'Université
Laval), Université Laval, Ste Foy, Québec, Canada G1K 7P4
[i] AXYS Environmental Consulting Ltd., Suite 300, 805 8th Ave SW, Calgary, Alberta, Canada T2P 1H7
[j] Faculté de Medicin, Nutrition, Université de Montreal, CP6128, Succursale Centre Ville Montreal, QC, Canada H3C 3J7
[k] Health Canada, Environmental Health Directorate, Radiation Protection Bureau, 775 Brookfield Road, AL 6302D1, Ottawa, ON,
Canada K1A 0L2
[l] Health Canada, Health Products and Food Branch, 2nd Floor, Qualicum Twr A, 2936 Baseline, AL 3302C Nepean, ON, Canada K1A 0K9
[m] Indian and Northern Affairs, Northern Science and Contaminants Research Directorate, 10 Wellington Street, Gatineau, Quebec,
Canada K1A 0H4

Abstract

The objectives of this paper are to: assess the impact of exposure to current levels of environmental contaminants in the Canadian Arctic on human health; identify the data and knowledge gaps that need to be filled by future human health research and monitoring; examine how these issues have changed since our first assessment [Van Oostdam, J., Gilman, A., Dewaily, É., Usher, P., Wheatley, B., Kuhnlein, H. et al., 1999. Human health implications of environmental contaminants in Arctic Canada:

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* Corresponding author. Tel.: +1 613 941 3570.
  E-mail address: jay_van_oostdam@hc-sc.gc.ca (J. Van Oostdam).

a review. Sci Total Environ 230, 1–82]. The primary exposure pathway for contaminants for various organochlorines (OCs) and toxic metals is through the traditional northern diet. Exposures tend to be higher in the eastern than the western Canadian Arctic. In recent dietary surveys among five Inuit regions, mean intakes by 20- to 40-year-old adults in Baffin, Kivalliq and Inuvialuit communities exceeded the provisional tolerable daily intakes (pTDIs) for the OCs, chlordane and toxaphene. The most recent findings in NWT and Nunavut indicate that almost half of the blood samples from Inuit mothers exceeded the level of concern value of 5 μg/L for PCBs, but none exceeded the action level of 100 μg/L. For Dene/Métis and Caucasians of the Northwest Territories exposure to OCs are mostly below this level of concern. Based on the exceedances of the pTDI and of various blood guidelines, mercury and to a lesser extent lead (from the use of lead shot in hunting game) are also concerns among Arctic peoples. The developing foetus is likely to be more sensitive to the effects of OCs and metals than adults, and is the age groups of greatest risk in the Arctic. Studies of infant development in Nunavik have linked deficits in immune function, an increase in childhood respiratory infections and birth weight to prenatal exposure to OCs. Balancing the risks and benefits of a diet of country foods is very difficult. The nutritional benefits of country food and its contribution to the total diet are substantial. Country food contributes significantly more protein, iron and zinc to the diets of consumers than southern/market foods. The increase in obesity, diabetes and cardiovascular disease has been linked to a shift away from a country food diet and a less active lifestyle. These foods are an integral component of good health among Aboriginal peoples. The social, cultural, spiritual, nutritional and economic benefits of these foods must be considered in concert with the risks of exposure to environmental contaminants through their exposure. Consequently, the contamination of country food raises problems which go far beyond the usual confines of public health and cannot be resolved simply by risk-based health advisories or food substitutions alone. All decisions should involve the community and consider many aspects of socio-cultural stability to arrive at a decision that will be the most protective and least detrimental to the communities.

Contents

1. Introduction

This paper reviews what is known about the human health implications of contaminants (i.e., organochlorines, heavy metals and radionuclides) in the Canadian Arctic, identifies the important knowledge gaps and examines how these issues have changed since the first assessment (Van Oostdam et al., 1999). Specifically, it discusses the knowledge of human exposure to and possible health effects of current levels of environmental contaminants in the Canadian Arctic, and identifies the data and knowledge gaps that need to be filled by future human health research and monitoring.

This paper draws on existing knowledge and incorporates new information from the research and communication activities funded under the human health and communication subprogrammes of the Canadian federal Northern Contaminants Program (NCP), which began in 1991. The NCP was established in response to concerns about human exposure to elevated levels of contaminants in fish and wildlife species that are important to the diets of many northern Aboriginal peoples. Early studies (Wong, 1986) indicated that there was a wide spectrum of substances such as persistent organic pollutants, heavy metals and radionuclides at unexpectedly high levels in the Arctic ecosystem.

Under the first phase of NCP (NCP-I; 1991–1997) research focussed on gathering the data required to determine the levels, spatial patterns, and sources of contaminants in the northern ecosystem (including its people), and the probable duration of the problem. Results generated through NCP-I were synthesised and published in 1997 in the first Canadian Arctic Contaminants Assessment Report (CACAR-I) (CACAR, 1997). In 1998, the NCP began its second phase (NCP-II). NCP-II focuses upon questions about the impacts and risks to human health that may result from current levels of contamination in key Arctic food species as well as determining the temporal trends of contaminants of concern in people, key Arctic indicator species and the environment.

The objective of this paper is to address concerns about possible adverse human health effects in people exposed to the present levels of environmental contaminants in the Arctic. These concerns are especially significant for many northern Aboriginal peoples because of the high proportion of country foods in their diet. These food sources include marine animals

(e.g., whales, walrus, seals, and fish) and terrestrial game. Clearly, contaminants are only some of many factors affecting human health and well-being in the Arctic. Factors such as lifestyle (e.g., alcohol consumption, smoking tobacco products and narcotic use), dietary choices, socio-economic factors, and genetic predisposition are important health determinants that need to be considered when evaluating the results described herein.

1.1. Aboriginal peoples of Canada

The Aboriginal peoples of Canada as defined in s.35 of the Constitution Act, 1982, include the Inuit, the Métis and the First Nations, who in the Arctic include the Dene and Yukon First Nations. All of these peoples are present in Canada's North. For statistical purposes, this section will describe the Inuit of Northwest Territories (NWT), Nunavut, Nunavik (northern Québec) and northern Labrador; the Dene and Métis of the NWT; and the 14 First Nations of the Yukon Territory. Métis are present in the Mackenzie Valley and southern Yukon (Fig. 1.1.1).

About 56,000 (or 7.5%) of Canada's total Aboriginal population of 743,000 live in the country's Arctic region, where they comprise just over half (53%) of the combined population (Table 1.1.1). In Nunavut, the Aboriginal population accounts for approximately 84% of the total population of 24,665. A population break-down by ethnicity in Nunavut shows the Inuit make up 83% of the population. The general pattern in Nunavik is similar, with about 88% of the population being Inuit and 11% non-Aboriginal. The corresponding figures for the NWT are about 28% First Nations, 10% Inuit, 9% Métis, and 52% non-Aboriginal, of the total NWT population of 39,455. Overall, an average 87% of people living in those areas defined as Inuit regions of Canada identified themselves as Inuit. In the Yukon, Aboriginal peoples comprise about 20% of the total population and consist mainly of First Nations and Métis peoples.

Additional 1996 demographic data for Canada's Arctic regions reveals high proportions of the total population between the ages of 0 and 14 years (34%), and between the ages of 25 to 44 years (33%) (Fig. 1.1.2), while the 65 years-and-over age group represents only 3% of the total population of Arctic Canada (Statistics Canada, 2002 (based on 1996 data)). In

Fig. 1.1.1. General locations of Arctic cultural groups (adapted from Van Oostdam et al., 1999).

comparison, the overall population of Canada has an older age structure with smaller proportions in the younger age groups and greater proportions in the older age groups.

In Arctic Canada the Inuit population has the highest percentage of people in the 0–14 age group (42%), and the non-Aboriginal population the lowest (22%).

Table 1.1.1
Aboriginal peoples: population size and proportion of the total population in each region of Arctic Canada, 1996

Region	Total population	% Aboriginal peoples[a]
Nunavut	24,665	84 (20,695)
Northwest Territories	39,455	48 (19,010)
Nunavik (Northern Quebec)	8700	89 (7765)
Labrador (arctic)	2435	88 (2145)
Yukon	30,650	20 (6170)
Total Canadian Arctic Regions	105,905	53 (55,785)

Source: Statistics Canada (2001).
[a] Data presented in this table are for those who identify with one or more Aboriginal groups (Metis, Inuit, or North American Indian).

Approximately 19% of the Inuit population in Arctic Canada are between ages 15 and 24, vs. roughly 13% of the non-Aboriginal population. Again, a similar pattern
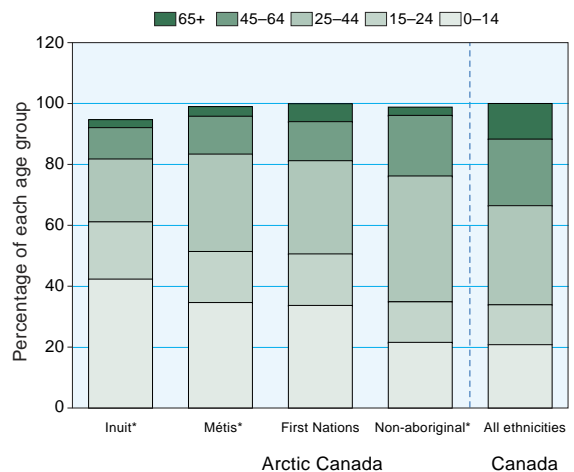

Fig. 1.1.2. Age distribution of Canadian Arctic population by ethnicity.

by ethnicity holds true in the rest of Canada. There are lower proportions of Inuit in the 25–44 and 45–64 age groups in Arctic Canada compared to the total Canadian population (33% and 22%, respectively).

In comparison to Arctic Canada, the total Canadian population shows an even distribution, with a smaller population of young people (21% aged 0–14) and a larger population aged 65 years and over (12%), accounted for by the large non-Aboriginal population. Both the Aboriginal and non-Aboriginal populations of Arctic Canada have a lower percentage of people in the 65-and-over age group (range of 3–6% for the four ethnic groups of interest).

1.2. Aboriginal perspectives on food and health

In Aboriginal populations, food is perceived as an integral component of being healthy. While this section does not discuss this issue in full detail, it attempts to illustrate how Aboriginal perspectives on food and health differ from those in most Western societies.

Aboriginal peoples describe their food quite specifically as Inuit food, or Dene food, as the case may be. The term "country food" refers to mammals, fish, plants, berries, and waterfowl/seabirds harvested from the local environment. Imported foods refer to all other foods which are brought mainly from the store and generally imported from other regions of the country/world. Country foods play a critical role in the social, cultural, spiritual, economic and nutritional well-being in many Aboriginal communities. Within many northern Aboriginal societies exchanging country food involves a complex set of social and cultural rules and procedures that relate to the structure and organization of these societies.

For Inuit, country food are directly associated with physical health and well-being. At Sanikiluaq, for example, people regard certain foods, such as seal, as being capable of generating bodily warmth and strength in a way that imported food cannot. Such foods are therefore essential in the diet of Inuit activities such as hunting (Usher et al., 1995). However, as Egede (1995) notes, country foods represent not only health in the physical sense but also form an essential basis of personal and community well-being for Inuit and Dene.

Among Inuit, individual life is itself seen as a synthesis of two elements that can be roughly trans-lated as: the body (the physical being and functionality of the human body) and the soul (spirit, mind, immediate emotional state, or even the expression of consciousness) (Borré, 1994). Country food is important in contributing to the way individuals frame their own well-being (Ridington, 1988). Among Inuit, this integration is accomplished through capturing, sharing and consuming country food. The cultural aspects and knowledge transfer related to the harvesting of country foods such as sharing and communal processing of food are important to individual and community health.

These cultural aspects have been examined in survey-type studies in Arctic Canada. For example, information collected in interviews in three major dietary surveys demonstrated a similar agreement of selected cultural attributes of the harvesting and use of country food. Data for the five Inuit areas ($n = 1721$ individual interviews) show that more than 80% of respondents agreed that harvesting and using country food by the family gives a wide range of social, cultural, spiritual, economic and nutritional benefits (Kuhnlein et al., 2000).

1.3. Factors that contribute to Aboriginal Northerners' exposure to country food contamination

Food is a significant vector for contaminant exposure in all populations. A substantial proportion of the Aboriginal diet consists of country food; therefore, Aboriginal peoples have a higher risk of contaminant exposure if contaminant levels are higher in traditional foods than the non-Aboriginal populations in the North specifically, or in the rest of Canada.

Aboriginal peoples are especially likely to be exposed to environmental contaminants such as mercury or polychlorinated biphenyls (PCBs) through the consumption of fish and mammalian organ meats or marine mammal fats, respectively (Kinloch et al., 1992; Kuhnlein et al., 1995c). Health impact assessments must consider both exposure to contaminants through country foods and the many benefits of these foods. Health impact assessments must also be considered in terms of the distinctive significance of country food to Aboriginal peoples. Vulnerability to a hazard is a function not only of the intrinsic nature of the hazard, but also of the geographical location and socio-economic conditions of people exposed to

it, as well their cultural perspective of the hazard (Hewitt, 1983; Douglas, 1992).

Dewailly et al. (2001c) conducted a study to better understand the socio-demographic factors that influence Nunavimmiut exposure to contaminants and the intake of certain nutrients found to be deficient among some sub-groups in this Nunavik population. These researchers re-analyzed 1992 Santé Québec data and identified a number of relationships between contaminant exposures, nutritional deficiencies, and various socio-demographic factors among residents in the region. Inuit couples appeared to have higher levels of country food consumption than those reporting to be divorced, widowed or single. Mean contaminant intake increased with age, with the geometric mean age-adjusted intake being higher among Inuit with fewer years of formal education completed, among those living in couples, and among those living in households of more than six individuals. For several nutrients, mean age-adjusted intake was higher among those residing in communities along the Hudson coast. Some nutritional deficiencies were more frequently associated with individuals less often employed in full-time work.

The results of the Dewailly et al. (2001a) study reflect the effects of some traditional socio-demographic factors (occupation, community of residence, marital status and household structure, age, gender, and level of education) on contaminant and nutrient intakes through country food consumption. These results identify sociological characteristics of individual and their potential effects on such things as their geographical, social, and economic access to both country and imported foods in Nunavik. The findings are helpful to health officials, as they support the identification of potential "at-risk" groups for some contaminant exposures and nutritional deficiencies based on existing community variables that are commonly available. Further, it provides information as to the potential "why" question relating to individuals' exposure or lack of access to these foodstuffs. In general, this information supports the development and design of more effective promotion strategies for country food and health.

Economic factors also affect exposure of Aboriginal peoples to contaminants in country food. Country food is an economic necessity for most Aboriginal peoples. In many northern communities, employment and incomes are low, and country food makes a sig-

nificant addition to effective household income. The cost of a standard basket of imported food to provide a nutritionally adequate diet is prohibitively high in Arctic communities. For example, previous calculations of the cost to purchase equivalent amounts of imported meats in local stores have resulted in estimated value of country food production in the NWT of about $55 million, or well over $10,000 per Aboriginal household per year (Usher and Wenzel, 1989). Although this estimate was published in 1989, and applied to the NWT when it still included Nunavut, the key message still holds today. Moreover such estimates apply only to the product itself, as a food commodity, and do not include any other values that Aboriginal peoples commonly attach to country foods such as the activity of hunting itself, or the collective cultural and social values of sharing and teaching.

Finally, there are health costs associated with not eating country food, which are borne both by Aboriginal peoples themselves and by public health programs. For example, reduced country food consumption in northern Aboriginal populations, coupled with decreased physical activity, has been associated with obesity, dental caries, anemia, lowered resistance to infection, and diabetes (Szathmary et al., 1987; Thouez et al., 1989).

1.4. Evaluation of research in CACAR and application to benefit and risk assessment/management

The Northern Contaminants Program (NCP) has generated a considerable body of knowledge on the human health implications of contaminants. This assessment report reviews this information and presents research that has been conducted in or is relevant to Arctic contaminants issues. As with any scientific review caution should be used when interpreting the results of any single study. In assessing causal associations between findings in any epidemiological or toxicological study the following factors must be considered: the strength and magnitude of the association, consistency of the association, dose–response relationship, temporally correct association, and biological plausibility of the association. Several studies are needed to draw any conclusions about factors such as consistency of the association. Many toxicological and epidemiological studies examining the issue from several perspectives may have to be reviewed to draw

causal associations between environmental contaminants and human health effects and may also point out new directions for research and evaluation.

The results from 5 to 10 years of NCP research have been gathered from a variety of studies. For example, these studies have ranged from animal experiments on toxaphene which found immune effects at low doses, to laboratory tests of components and metabolites of chlordane which indicate that levels of oxychlordane and *trans*-nonachlor in highly exposed individuals may approach levels where physiological changes are seen in rodents. Animal experiments based on the mixture of contaminants found in Arctic marine mammals demonstrated effects on immune systems. Epidemiological studies in the Canadian Arctic have documented higher exposures to environmental contaminants among a number of Arctic populations. Initial results from ongoing cohort study among the Inuit population of Nunavik have shown a decrease in birth size possibly related to increasing PCB concentrations. Ongoing studies related to this birth cohort study have also found a possible link between contaminants and immune deficits in Inuit infants. Similar findings have also been seen on birth size and immunological effects in the Michigan fish-eater studies and the Netherlands populations, respectively.

As discussed, these results need to be interpreted with caution. Some of the studies are the first analyses of data and have not yet been published and critiqued by the scientific community. Once published and subjected to full peer review, and available for comment in the scientific literature, the importance and validity of data and its interpretation will be confirmed. Other factors such as lifestyle (e.g., alcohol and cigarette consumption), diet, socio-economic status, and genetic predisposition are important determinants of health. In fact, contaminants may only play a modest role in determining many important health outcomes (e.g., birth size). All these factors need to be considered when evaluating the results described herein.

1.5. Research ethics

A number of considerations must be taken when undertaking research in the Arctic. Communities must consent to the research within their jurisdiction and, when seeking informed consent, researchers should explain the potential benefits or harmful effects the research may have on individuals, communities and/or the environment. No undo pressure should be applied to obtain this consent and greater emphasis should be placed on the risks to cultural values than on the potential contributions of the research to knowledge.

Communication and participation planning have become integral components of the research proposal development process for projects funded through the NCP. Methodologies and guidelines have been developed through the NCP to ensure an ethical and responsible approach to contaminants research in the Arctic. The purpose of these guidelines is to ensure researchers respect and appreciate their responsibilities to the communities in all aspects of their research from research needs assesment to project design and implementation to communication of the final results and conclusions.

2. Exposure assessment

Key aspects of exposure to environmental contaminants include evaluating sources of exposure and measuring human tissue levels of specific contaminants. In the context of Arctic Canada, consumption of contaminated traditional foods is a major vector of exposure to organochlorines, heavy metals, and radionuclides. Since Van Oostdam et al. (1999), documentation of the Canadian Arctic food systems has vastly improved. The importance of traditional food in the diet of Nunavik Inuit (Blanchet et al., 2000) and the diet of pregnant women in the Inuvik region (Tofflemire, 2000) have been better documented. The safety of traditional food has been the object of surveillance (Lawn and Hill, 1998; Lawn and Harvey, 2001), and three major studies of dietary intake in Arctic communities have been completed by the Centre for Indigenous Peoples' Nutrition and Environment (CINE) (Kuhnlein et al., 2001a,b).

Fig. 2.1.1 shows the communities included in the three CINE surveys, identified as Yukon First Nations, Dene and Métis, and Inuit. In Van Oostdam et al. (1999), partial results from the Dene and Métis survey were known, and they Yukon survey was underway. Data collection in Inuit communities ended in April 1999. Final reports from these three major dietary surveys are now available (Receveur et al., 1996, 1998; Kuhnlein et al., 2000), and additional peer-

Fig. 2.1.1. Communities participating in CINE dietary assessments.

reviewed publications are forthcoming. Data from the Dene and Métis communities have led to several publications developing the points already reported in Van Oostdam et al. (1999): how traditional food improves the nutritional quality of the diet (Receveur et al., 1997); what levels of exposure are associated with traditional food consumption for organochlorines and heavy metals (Berti et al., 1998a; Kim et al., 1998) and radioactivity (Berti et al., 1998b); and what are some of the social, cultural benefits (Receveur et al., 1998a,b) and determinants (Simoneau and Receveur, 2000) of traditional food use. Throughout this large research effort, the objectives were to understand the patterns of traditional food use as well as the benefits and risks of using this food in the context of the total diet. Comparable methods were used in all of three surveys whereby several types of interviews were conducted in two major seasons with individuals in randomly selected households. Food samples were collected for analysis of several contaminants and nutrients. In all, 24-h recall interviews were conducted with 1012 Dene

and Métis, 802 Yukon First Nation residents, and 1875 Inuit, and more than 700 food samples were contributed to the research during the study years.

2.1. Country food consumption in the Arctic

In Table 2.1.1, average weekly frequency of consumption of main traditional food items during late winter and fall in the major geographical areas is given. The most frequently mentioned traditional food items are caribou, moose, salmon, whitefish, grayling, trout, coney, scoter duck, cisco, walleye, spruce hen, pike, ptarmigan, Arctic char, Canada goose, muskox, eider duck, crowberry, beluga muktuk, ringed seal, narwhal muktuk, partridge, and cloudberry. More than 250 different species of wildlife, plants and animals were identified in workshops by community residents as forming the rich framework of the traditional food systems of Arctic peoples. Regional differences in species used most frequently are due to ecosystem variety and cultural preferences.

Table 2.1.1
Five country/traditional food items most often consumed (yearly average of days per week)

Region	Food item and yearly average of days per week consumed				
	1	2	3	4	5
Yukon	Moose 1.6	Caribou 0.7	Salmon 0.6	Grayling 0.4	Trout 0.1
Dene and Metis					
Gwich'in	Caribou 3.2	Whitefish 1.3	Coney 0.5	Moose 0.3	Scoter 0.2
Sahtu	Caribou 2.5	Moose 1.0	Trout 0.8	Whitefish 0.7	Cisco 0.3
Dogrib	Caribou 3.9	Whitefish 1.2	Trout 0.2	Moose 0.2	Walleye 0.2
Deh-cho	Moose 2.7	Whitefish 0.9	Caribou 0.8	Spruce Hen 0.4	Pike 0.3
South Slave	Moose 2.2	Caribou 1.9	Whitefish 1.8	Trout 0.4	Ptarmigan 0.2
Inuit					
Inuvialuit	Caribou 1.8	Char 0.5	Goose 0.2	Whitefish 0.2	Muskox 0.1
Kitikmeot	Caribou 1.2	Char 0.9	Muskox 0.3	Trout 0.3	Eider Duck 0.2
Kivalliq	Caribou 1.9	Char 0.4	Crowberry 0.2	Beluga Muktuk 0.2	Trout 0.1
Baffin	Caribou 1.3	Seal 1.0	Char 0.9	Narwal Muktuk 0.2	Beluga Muktuk 0.1
Labrador	Caribou 1.3	Trout 0.5	Partridge 0.3	Cloudberry 0.3	Char 0.2

Source: Kuhnlein (2002).

Results of 24-h recall dietary interviews in the three areas (Yukon, Dene and Métis, and Inuit) demonstrated the extent of traditional food use. Fig. 2.1.2 shows that country food use as a percent of total dietary energy in the three areas, varied from a low of 6% in communities close to urban centres, to a high of 40% in the more remote areas. In terms of grams per person per day (amount per capita calculated from averaging all 24-h recall data for fall and late winter combined), traditional food represents: for women 20–40 years of age, approximately 106 g in the Yukon, 144 g in Dene and Métis communities, and 194 g in Inuit communities; for men of the same age group the corresponding values were 169 g, 235 g, and 245 g for each region, respectively. Traditional food consumption increases with age so that in the age group 40 years and over, per capita daily consumption for women was: 193 g, 335 g, and 341 g in the Yukon, Dene and Métis, and Inuit communities, and 236 g, 343 g, 440 g, respectively, for the men in each region (Kuhnlein and Receveur, 2001).

2.2. Contaminant levels in people and their relationship to traditional food diets

A number of maternal/cord blood contaminant studies were done in the NWT, Nunavut and Nunavik between 1994 and 2000 (Fig. 2.2.1), and these studies have given an assessment of the spatial variation in contaminant levels. All of the studies in Nunavut took place before devolution and so all of these population groups are included in NWT/Nunavut. In the NWT and Nunavut there are four ethnic groups: Caucasians, Dene and Métis, Inuit, and Other (East Asian and African). Since Caucasians in the NWT consume mostly imported foods their contaminant patterns are very similar to southern Canadian values, they provide a good comparison for northern peoples who consume northern traditional foods. The number of mothers in each region and ethnic group varied due to number of mothers available and the time of sampling. Populations sampled ranged from 175 Inuit mothers in Nunavik to 145 Inuit, 134 Caucasian, 93 Dene and Métis and 13 Other mothers in the NWT/Nunavut (Tables 2.2.1–2.2.7). The Caucasian and

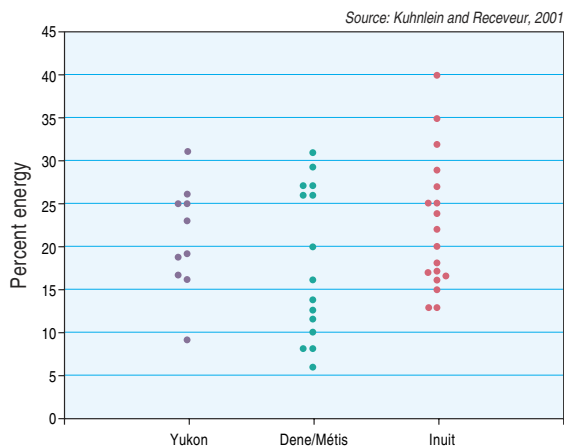

Source: Kuhnlein and Receveur, 2001

Fig. 2.1.2. Percentage of energy from traditional/country foods in the Yukon, Dene and Métis, and Inuit communities.

Fig. 2.2.1. Contaminant studies in the Northwest Territories, Nunavut, and Nunavik.

Dene and Métis mothers were from more than one region in the NWT/Nunavut but there were no significant differences in contaminant levels between these populations, so they were combined into their respective groups. Inuit came from four regions in NWT/Nunavut and there were significant differences between various groups, and so they are retained as separate groups. In Nunavik only 159 Inuit mothers were included in the population sampled.

2.2.1. Tissue levels of contaminant results

The results presented here for the NWT and Nunavut were supplied by Butler Walker et al. (2003, 2005), who are preparing the NWT/Nunavut Environmental Contaminants Exposure Baseline report. The results for Nunavik were supplied by Muckle et al. (2001a,b) in an upcoming paper and in some specific analyses for this report.

Residues of a number of organochlorine pesticides have been attributed to long-range transport to the Arctic, and approximately 11 of these pesticides were included in the maternal/cord blood monitoring programs. The levels of eight of the major pesticides found most commonly in Canadian Arctic maternal blood samples are presented in Table 2.2.1. Oxychlordane and *trans*-nonachlor are components/metabolites of technical chlordane, an older generation insecticide no longer used in most of the developed world. It can be seen that Inuit have levels that are six to ten times higher than those seen in other population groups such as Caucasians, Dene and Métis, or Other (Fig. 2.2.2). When the Inuit groups in NWT/Nunavut/Nunavik are examined, the Inuit from Baffin have the highest oxychlordane and *trans*-nonachlor levels. Similar patterns are seen for HCB, mirex and toxaphene, as the Inuit mothers have markedly higher levels of these pesticides than those seen in rest of the groups (see Figs. 2.2.3 and 2.2.4 for HCB and toxaphene levels, respectively).

Table 2.2.1
Mean levels of organochlorine pesticides in maternal blood, by region and ethnic group (geometric means, range, μg/L plasma)

OC contaminant	Ethnicity/Region							
	Caucasian[a] (n=134)	Metis/Dene[a] (n=93)	Other[a] (n=13)	Inuit				
				Baffin[a] (n=30)	Inuvik[a] (n=31)	Kitikmeot[a] (n=63)	Kivalliq[a] (n=17)	Nunavik[b] n=159
Years of study	1994–1999	1994–1999	1994–1995	1996	1998–1999	1994–1995	1996–1997	1995–2000
Oxychlordane	0.05 (nd–0.22)	0.04 (nd–0.23)	0.04 (nd–0.21)	0.58 (0.09–2.4)	0.15 (0.03–1.1)	0.29 (nd–2.9)	0.36 (nd–6.2)	0.30 (0.01–3.9)
Trans-Nonachlor	0.06 (0.02–0.26)	0.06 (nd–0.37)	0.07 (0.02–0.30)	0.64 (0.16–2.5)	0.28 (0.05–1.8)	0.31 (nd–3.0)	0.44 (0.03–3.7)	0.46 (0.01–4.6)
p,p′-DDT	0.05 (nd–0.19)	0.03 (nd–0.13)	0.22 (nd–3.2)	0.14 (0.04–0.47)	0.07 (nd–0.45)	0.08 (nd–0.33)	0.09 (nd–0.35)	0.09 (0.02–1.1)
p,p′-DDE	0.91 (0.22–11.2)	0.69 (0.15–5.3)	4.0 (0.51–34)	2.1 (0.55–6.0)	1.1 (0.40–3.8)	1.3 (0.12–7.8)	1.7 (0.21–7.2)	2.2 (0.14–18)
DDE:DDT	18 (nd–75)	18 (nd–89)	15 (nd–31)	15 (7.1–43)	13 (nd–51)	15 (nd–53)	19 (nd–52)	23 (2.8–209)
HCB	0.12 (0.04–0.61)	0.18 (0.02–1.7)	0.11 (0.02–0.40)	0.53 (0.14–1.5)	0.31 (0.06–1.2)	0.56 (0.05–4.5)	0.46 (0.07–1.8)	0.31 (0.05–2.8)
β-HCH	0.09 (nd–0.55)	0.04 (nd–0.13)	0.48 (0.04–39)	0.11 (nd–0.44)	0.08 (nd–0.25)	0.09 (nd–0.44)	0.09 (nd–0.30)	0.04 (0.02–0.25)
Mirex	0.02 (nd–0.14)	0.02 (nd–0.21)	0.01 (nd–0.07)	0.06 (nd–0.19)	0.03 (nd–0.11)	0.05 (nd–0.38)	0.06 (nd–0.80)	0.07 (0.01–0.60)
Toxaphene (total)	0.05[c] (nd–0.50)	0.07[d] (nd–0.81)	NA	0.59 (nd–6.4)	0.43 (nd–3.6)	0.686[e]	0.74 (nd–5.2)	NA
Parlar 26	0.01[c] (nd–0.04)	0.01[d] (nd–0.06)	NA	0.10 (0.02–0.57)	0.05 (nd–0.36)	0.096[e]	0.08 (nd–0.43)	NA
Parlar 50	0.01[c] (nd–0.05)	0.01[d] (nd–0.07)	NA	0.13 (0.03–0.66)	0.06 (nd–0.43)	0.146[e]	0.10 (nd–0.57)	NA

NA=Not available; nd=not detected.
[a] *Source:* Butler Walker et al. (2003).
[b] *Source:* Muckle (2000) and Muckle et al. (2001b).
[c] N=25.
[d] N=42.
[e] Four composites (n=12, 12, 12 and 14; Seddon, 1996).

Table 2.2.2
Mean levels of PCBs in maternal blood, by region and ethnic group (geometric means, range, µg/L plasma)

OC contaminant	Ethnicity/Region							
	Caucasian[a] (n=134)	Metis/Dene[a] (n=93)	Other[a] (n=13)	Inuit				
				Baffin[a] (n=30)	Inuvik[a] (n=31)	Kitikmeot[a] (n=63)	Kivalliq[a] (n=17)	Nunavik[b] (n=159)
Years of Study	1994–99	1994–99	1994–95	1996	1998–99	1994–95	1996–97	1995–2000
Aroclor 1260[c]	1.3 (0.24–5.7)	1.3 (0.26–14)	1.1 (0.31–3.7)	8.0 (2.0–27)	2.4 (0.62–7.9)	4.5 (0.20–27)	5.6 (0.41–60)	6.0 (0.10–48)
PCB 28	0.02 (nd–0.10)	0.01 (nd–0.06)	0.02 (nd–0.04)	0.02 (nd–0.05)	0.01 (nd–0.09)	0.01 (nd–0.06)	0.01 (nd–0.07)	NA
PCB 52	0.01 (nd–0.07)	0.01 (nd–0.04)	0.01 (nd–0.02)	0.03 (nd–0.08)	0.02 (nd–0.06)	0.02 (nd–0.11)	0.02 (nd–0.09)	NA
PCB 99	0.04 (nd–0.19)	0.03 (nd–0.28)	0.03 (nd–0.09)	0.19 (0.04–0.73)	0.08 (0.02–0.28)	0.12 (nd–0.81)	0.13 (nd–1.3)	NA
PCB 101	0.01 (nd–0.03)	0.01 (nd–0.04)	0.01 (nd–0.02)	0.02 (nd–0.06)	0.02 (nd–0.07)	0.02 (nd–0.07)	0.02 (nd–0.04)	NA
PCB 105	0.01 (nd–0.05)	0.01 (nd–0.06)	0.01 (nd–0.02)	0.04 (nd–0.15)	0.02 (nd–0.07)	0.02 (nd–0.09)	0.03 (nd–0.22)	NA
PCB 118	0.04 (nd–0.27)	0.04 (nd–0.26)	0.03 (nd–0.09)	0.14 (0.03–0.50)	0.07 (0.02–0.32)	0.09 (nd–0.40)	0.09 (nd–0.66)	0.10 (0.01–0.84)
PCB 128	nd	nd	nd	0.01 (nd–0.05)	0.01 (nd–0.03)	0.01 (nd–0.06)	0.01 (nd–0.02)	NA
PCB 138	0.11 (0.02–0.48)	0.10 (0.02–0.98)	0.10 (0.03–0.29)	0.51 (0.12–1.5)	0.19 (0.05–0.67)	0.30 (0.02–1.6)	0.37 (0.03–3.3)	0.42 (0.01–3.1)
PCB 153	0.14 (0.03–0.61)	0.16 (0.03–1.8)	0.12 (0.03–0.41)	1.0 (0.25–3.9)	0.26 (0.06–0.88)	0.56 (0.02–3.6)	0.70 (0.05–8.3)	0.75 (0.03–6.1)
PCB 156	0.02 (nd–0.11)	0.02 (nd–0.22)	0.02 (nd–0.07)	0.06 (0.02–0.30)	0.02 (nd–0.08)	0.05 (nd–0.31)	0.05 (nd–0.49)	NA
PCB 170	0.03 (nd–0.16)	0.03 (nd–0.39)	0.03 (nd–0.10)	0.18 (0.04–0.95)	0.04 (nd–0.13)	0.01 (nd–0.67)	0.11 (nd–2.3)	NA
PCB 180	0.09 (nd–0.50)	0.08 (nd–0.12)	0.07 (0.02–0.29)	0.40 (0.07–1.8)	0.08 (0.02–0.30)	0.27 (0.02–1.7)	0.28 (0.03–4.2)	0.32 (0.02–2.3)
PCB 183	0.01 (nd–0.05)	0.02 (nd–0.14)	0.01 (nd–0.03)	0.05 (nd–0.16)	0.02 (nd–0.07)	0.03 (nd–0.11)	0.05 (nd–0.44)	NA
PCB 187	0.03 (nd–0.13)	0.05 (nd–0.52)	0.03 (nd–0.13)	0.18 (0.05–0.53)	0.06 (0.02–0.25)	0.01 (0.01–0.54)	0.13 (0.02–1.1)	NA
Sum of 14 PCBs	0.52 (0.11–2.2)	0.52 (0.12–5.5)	0.43 (0.13–1.4)	2.7 (0.70–9.4)	0.82 (0.23–2.7)	1.6 (0.12–9.4)	1.9 (0.17–22)	2.3 (0.17–16)

NA=Not available; nd=not detected.

[a] *Source:* Butler Walker et al. (2003).

[b] *Source:* Muckle (2000) and Muckle et al. (2001a,b).

[c] Aroclor 1260=5.2 (PCB 153+138) (Weber, 2002).

Table 2.2.3

Dioxins and furans and PCBs in maternal blood

Ethnicity	2,3,7,8, TCDD–TEQs[a] (ND=0) (pg/L plasma)			
	PCBs	D+F[b]	D+F+PCBs	% PCBs
Inuit	117.8	29.8	147.7	80%
Caucasian	42.0	115.0	157.0	27%
Dene	54.0	67.0	121.0	45%

[a] TEQs=toxic equivalents.

[b] D+F=dioxins and furans.

In contrast to the above pattern, the patterns demonstrated by β-HCH (beta-hexachlorocyclohexane) and DDE (dichlorodiphenyl dichloroethylene), a metabolite of the pesticide DDT, are quite different. Levels of β-HCH are 5 to 12 times higher among individuals in the Other group than levels seen in Inuit, Caucasians, or Dene and Métis (Fig. 2.2.5). The levels of DDE in the Other group are also roughly three to six times higher than the levels observed in Inuit, Caucasian, or Dene and Métis (Fig. 2.2.6). The Other group is made up of people with African and East Asian ancestry, and their exposure to these contaminants may have taken place in Africa or East Asia, or in foods imported from these regions, where β-HCH and DDE are still widely used.

Polychlorinated biphenyls (PCBs) are a group of industrial compounds that were widely used in the 1950s, 1960s, and 1970s, and are now banned and being phased out but are still widespread in the environment. PCBs have been implicated in deleterious effects on the learning abilities of young children, and are a major contaminant of concern in the Arctic. Inuit mothers have the highest levels of PCBs measured as Aroclor 1260 compared to Caucasians, Dene

and Métis, and the Other mothers (Table 2.2.2 and Fig. 2.2.7). When the Inuit from all regions are compared, it can be seen the Baffin Inuit have the highest levels of PCBs (8.0 μg/L).

When PCBs are examined on a congener-specific basis, the more highly chlorinated congeners (PCBs 128–187) exhibit a similar pattern to that seen for PCBs as Aroclor 1260. Concentrations of PCB congeners are found in the following order: PCB 153 > 138 > 180 > 187, etc. There are no marked differences in congener patterns among the various ethnic groups. The Inuit have a slightly greater proportion of the most predominant PCB 153 when compared to the Caucasian and Dene and Métis groups, and also have slightly smaller proportions of PCBs 28, 52, 101 and 128 (see Table 2.2.2).

A number of studies have shown that some PCBs have dioxin-like activity. Twelve of the 209 PCBs share certain toxicological properties with dioxins and furans and have been assigned dioxin-like toxicity equivalency factors (TEFs) by the World Health Organization (Van den Berg et al., 1998). The concentration of these "dioxin-like" PCBs can be multiplied by their TEF to calculate a PCB toxic equivalency (TCDD–TEQ) which is then added to the dioxin/furan component for a total TCDD–TEQ. There have not been many dioxin, furan and dioxin-like PCB analyses conducted under the Canadian Northern Contaminants Program maternal blood contaminant monitoring program due to the expense and large sample volumes needed for these analyses. Recently some analyses of composite samples were undertaken to assess the relative contributions of dioxins, furans and dioxin-like PCBs in Arctic Cana-

Table 2.2.4

Cord and maternal contaminants (lipid weight basis)

Contaminant	N[a]	Cord[b]	Maternal[b]	Ratio[c]	Correlation[d]	p value[e]
B-HCH	116	68	59	1.4	0.87	0.0001
Hexachlorobenzene	335	37	40	1.1	0.95	0.0001
Oxychlordane	143	32	54	0.63	0.96	0.0001
PCBs (Aroclor 1260)	303	360	454	0.84	0.96	0.0001

Source: Van Oostdam (2001).

Abbreviations: B-HCH, beta-hexachlorocyclohexane; PCBs, polychlorinated biphenyls.

[a] Sample size: cord–maternal pairs.

[b] Concentration (μg/kg lipid, arithmetic mean).

[c] Cord/maternal blood (paired data only).

[d] Pearson's correlations.

[e] Statistical significance of cord/maternal Pearson's correlations.

Table 2.2.5
Worldwide comparisons of maternal blood levels of PCBs (Aroclor 1260) and β-HCH (geometric means, μg/L plasma)

Contaminant	NWT/Nunavut/Nunavik Inuit[a,b]	NWT other[a]	Greenland Inuit[c,d]	Arctic Russia (non-indigenous)[e,f,g]	India (indigenous)[h]
PCBs (Aroclor 1260)	2.4–8.0	1.1	6.4–36	3.3–4.3	
Beta-HCH	0.04–0.11	0.48	0.07–0.24	0.31–3.1	127

[a] *Source:* Butler Walker et al. (2003).
[b] *Source:* Muckle (2000) and Muckle et al. (2001a,b).
[c] *Source:* Deutch (2001).
[d] *Source:* Deutch and Hansen (2000).
[e] *Source:* Klopov et al. (1998).
[f] *Source:* Klopov (2000), Klopov and Shepovalnikov (2000), and Klopov and Tchachchine (2001).
[g] *Source:* Odland (2001).
[h] *Source:* Sharma and Bhatnagar (1996).

dian populations (Van Oostdam and Feeley, 2002). In Table 2.2.3 the results are outlined for the 11 composite analyses for maternal blood from some of the mothers in the same groups previously described for organochlorines and PCBs. The Caucasian mothers had slightly higher levels of total TCDD–TEQs (dioxins and furans and dioxin-like PCBs 2,3,7,8-TCDD–TEQs) than Inuit or Dene mothers (157 vs. 148 and 121 pg/L, respectively) but the relative contributions of dioxin-like PCBs are very different in the three groups. Among Inuit mothers 80% of the total TCDD–TEQs are accounted for by dioxin-like PCBs while Caucasian mothers have only 27% of the total TCDD–TEQs coming from PCBs. The Dene mothers have a more equal contribution of dioxins and furans and dioxin-like PCBs in the overall total TCDD–TEQs. The main source of exposure for dioxins and furans, PCBs and many other organochlorine contaminants is through diet. Due to the expense and more difficult analyses there are few data on levels of dioxins, furans and dioxin-like PCBs in Arctic traditional/country foods. In spite

of this, it seems reasonable to speculate that Caucasian mothers obtained their higher levels of dioxins and furans in their diet from imported foods while Inuit mothers likely obtained their higher levels of dioxin-like PCBs from traditional/country foods such as marine mammals which contain higher levels of PCBs (well documented).

Comparisons can be also made based on contaminant levels found in cord blood. A similar pattern to that seen in the maternal data emerges for various contaminants, although the magnitude does vary in maternal and cord blood for contaminant data from the NWT and Nunavut (Van Oostdam et al., 2001). Since lipid levels vary markedly between maternal and cord blood, cord-to-maternal comparisons are best made on a lipid weight (lw) basis. The strong correlation between cord and maternal blood levels can be seen in Table 2.2.4; correlations range from 0.87 to 0.96 and all are highly significant. These correlations indicate that either cord or maternal blood levels may be used in health impact studies of these contaminants. Some organochlorines (lipid

Table 2.2.6
Current and historic levels[a] of mercury in maternal hair (μg/g)

Community	Year(s) tested	Age group (years)	No. tested	Range Min	Max	Geometric mean	GSD[b]
Inuvik + region	1976–1979	15–45	70	0.5	41.4	4.16	2.91
Inuvik + region	1998–1999	15–45	85	<LOD	11.5	0.49	2.74
Tuktoyaktuk	1976–1979	15–45	48	0.5	41.2	4.62	2.76
Tuktoyakuk	1998–1999	15–45	7	<LOD	11.5	2.29	5.69

Source: Snider and Gill (2001).
LOD: below analytical method detection limits (0.4 μg/g).
[a] Peak exposure levels reported as parts per million (ppm) in hair.
[b] GSD: Geometric mean standard deviation.

Table 2.2.7
Mean concentrations of metals in maternal blood, by ethnicity and region (geometric mean (range), μg/L whole blood)

Metal	Ethnicity/region			Inuit				
	Caucasian[a] (n=134)	Metis/Dene[a] (n=92)	Other[a] (n=13)	Baffin[a] (n=31)	Inuvik[a] (n=31)	Kitikmeot[a] (n=63)	Kivalliq[a] (n=17)	Nunavik[b] (n=162)
Lead	21.2 (2.1–58)	31.1 (5.0–112)	22 (5.0–44)	42 (5.0–120)	19 (2.1–102)	36.1 (6.2–178)	29 (12–64)	50 (5.2–259)
Mercury (total)	0.9 (nd–4.2)	1.4 (nd–6.0)	1.3 (0.20–3.4)	6.7 (nd–34)	2.1 (0.60–24)	3.4 (nd–13)	3.7 (0.60–12)	10.4 (2.6–44)
Mercury (organic)	0.69 (0.0–3.6)	0.80 (0.0–4.0)	1.2 (0.0–3.0)	6.0 (0.0–29)	1.8 (0.0–21)	2.9 (0.0–11)	2.7 (0.40–9.7)	NA
Selenium	123 (80–184)	117 (67–160)	128 (97–156)	118 (99–152)	118 (88–151)	122 (86–171)	106 (77–156)	318 (150–1232)
Cadmium	0.43 (nd–8.5)	0.65 (nd–5.9)	0.36 (nd–3.2)	1.7 (0.03–6.2)	1.0 (nd–7.1)	1.9 (0.01–7.8)	1.4 (0.11–7.7)	NA

NA=Not available; nd=not detected.
[a] Source: Butler Walker et al. (2005).
[b] Source: Muckle et al. (2001a,b).

weight basis) such as PCBs, oxychlordane, and DDE/ DDT are found at lower levels in the cord blood than the maternal blood, thus resulting in cord-to-maternal blood ratios of 0.6 to 0.9. PCB congeners in cord blood were also 0.7 to 0.9 times the maternal concentration. Some organochlorines such as β-HCH, hexachlorobenzene, and heptachlorepoxide showed the opposite pattern, with 1.4 to 3.2 times higher levels being found in the cord blood compared to maternal blood. Similar patterns for a number of contaminants have been reported by Bjerregaard and Hansen (2000) for Greenland Inuit. Although many researchers have taken the ratio between the cord and maternal blood concentrations to be a static relationship, recent work by Van Oostdam et al. (2001) has indicated that this ratio does vary by contaminant concentration, with the highest cord-to-maternal ratios being found at the lowest concentrations.

Comparisons to other populations in the world can easily be made. No specific comparisons were made to the southern Canadian population, as the Caucasian population included in the NWT/Nunavut sampling has a similar diet and resulting similar contaminant levels as the southern Canadian population, which can serve as a useful benchmark for southern levels of contaminants. In comparison to Canadian Inuit mothers from Nunavik and Nunavut/ NWT, Inuit from Greenland have markedly higher levels of PCBs as Aroclor 1260, i.e., 2.4–8.0 μg/L vs. 6.4–36 μg/L, respectively (Table 2.2.5). This difference may result from consumption of more marine mammals in the traditional Greenland diet. Compared to Inuit mothers, lower levels of PCBs are seen in non-Indigenous people living in Arctic Russia. In contrast, levels of β-HCH are markedly higher in the mothers from India, followed by non-Indigenous mothers of Arctic Russia and then mothers in the Other group in the NWT/Nunavut (Table 2.2.5). This indicates that DDT must still be used in the Indian and Russian commercial food supply or used for insect control in the local environment. The markedly higher levels of β-HCH in mothers in India (127 μg/L) (Sharma and Bhatnagar, 1996) are likely due to the more extensive present-day use of β-HCH in the tropics to protect against insect vectors in the home and on crops.

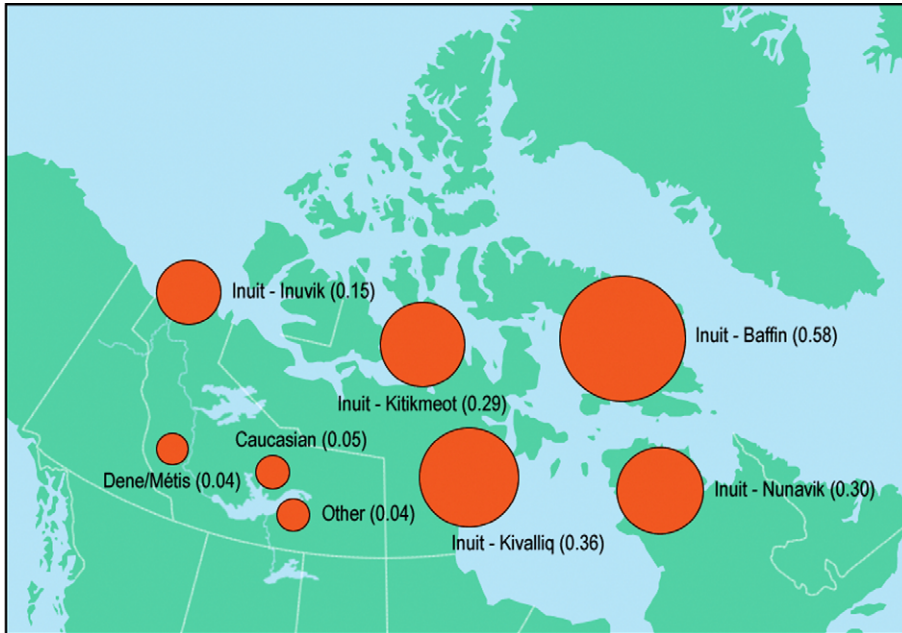Human environmental monitoring for organochlorines does not have a long history in the Cana-

Fig. 2.2.2. Maternal contaminant levels in Arctic Canada: oxychlordane (µg/L plasma).

dian Arctic. In most cases there are only one or a few data points to assess contaminant trends—the late 1980s to the mid-1990s. Methodological differences in sampling strategies, and sampling high consumers versus general maternal samples make it difficult to compare the specific results of these two time points.
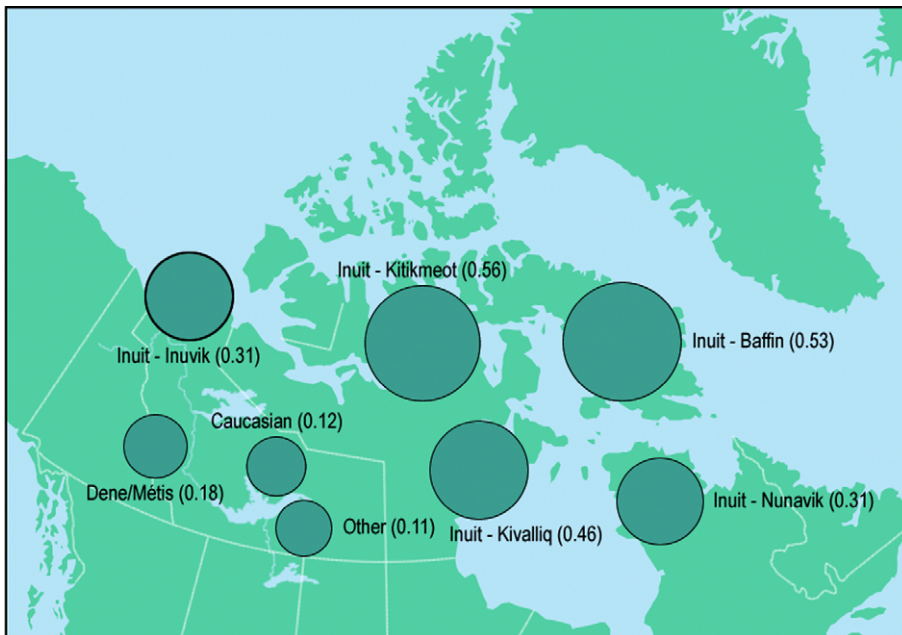

Fig. 2.2.3. Maternal contaminant levels in Arctic Canada: hexachlorobenzene (µg/L plasma).
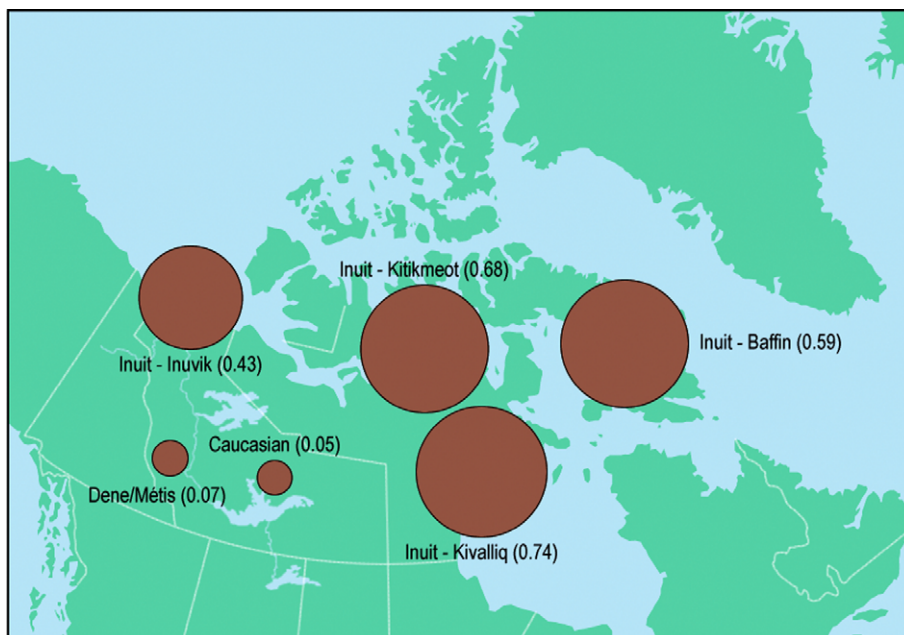
Fig. 2.2.4. Maternal contaminant levels in Arctic Canada: total toxaphene (μg/L plasma).

Recently Dallaire et al. (2003a) has analyzed the cord blood contaminant data by year collected by Muckle et al., (2001a,b) and has found that there is a sig- nificant downward trend in cord blood contaminant levels over 1996–2000 (Fig. 2.2.8). A decrease in traditional food consumption or a decrease in con-
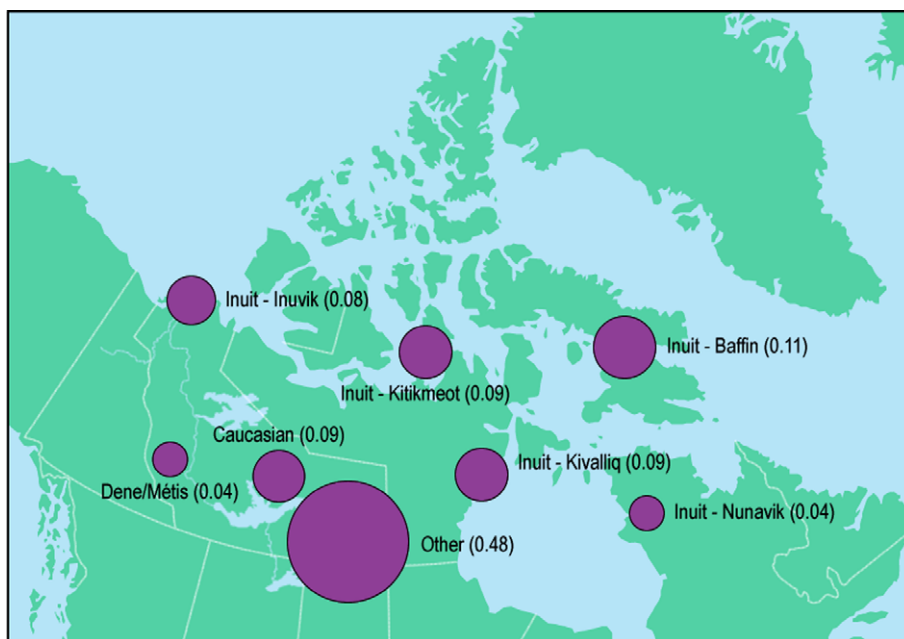

Fig. 2.2.5. Maternal contaminant levels in Arctic Canada: β-hexachlorocyclohexane (μg/L plasma).
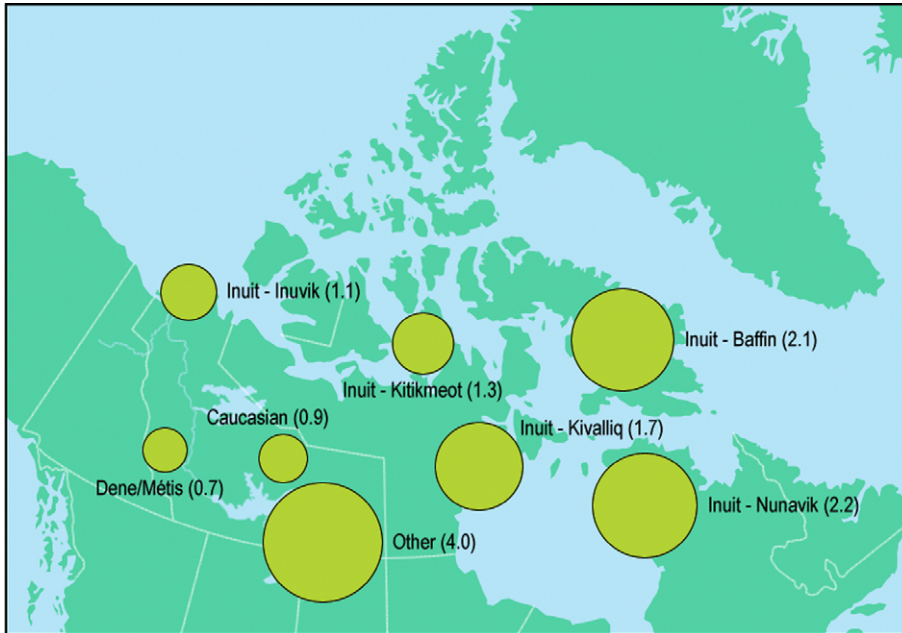
Fig. 2.2.6. Maternal contaminant levels in Arctic Canada: p,p'-DDE (μg/L plasma).

taminant levels in these traditional foods have been hypothesized as the cause of this decrease (Dallaire et al., 2003a).

2.2.2. Levels of mercury in hair and blood

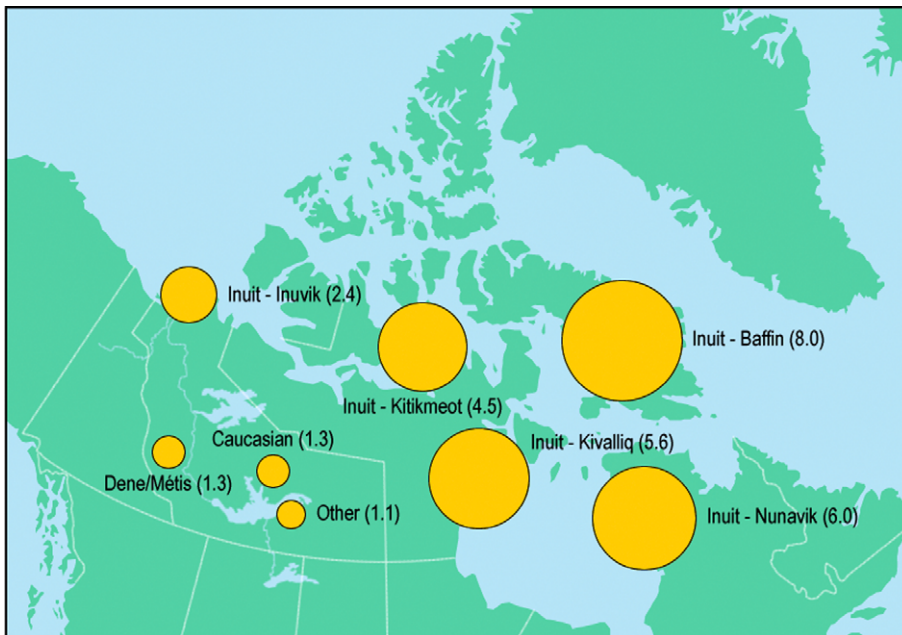Traditional/country foods, such as fish and sea mammals, are considered the primary environmental

Fig. 2.2.7. Maternal contaminant levels in Arctic Canada: PCBs (as Aroclor 1260) (μg/L plasma).
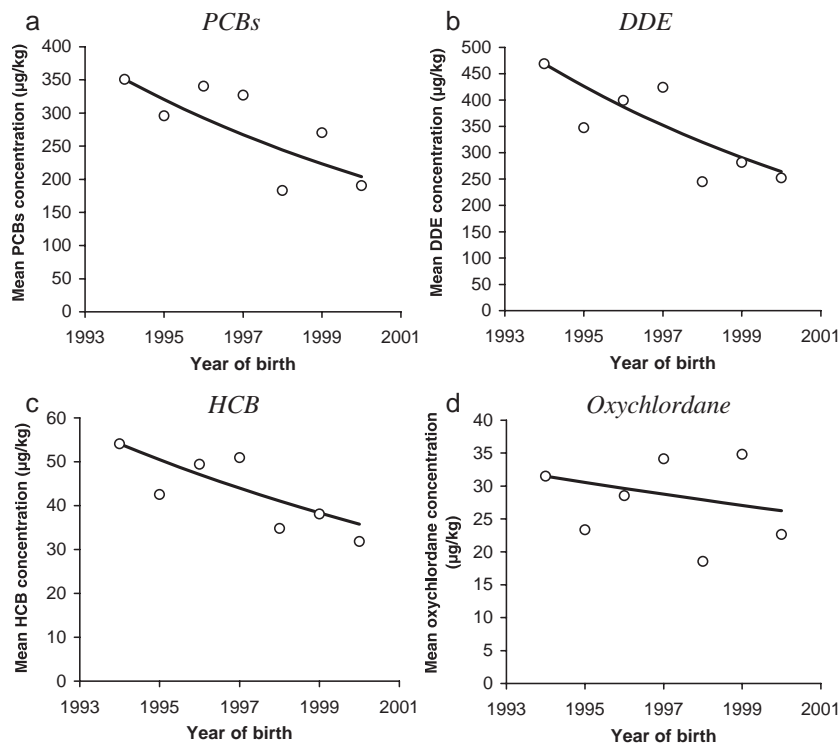
Fig. 2.2.8. Adjusted mean organochlorine (OC) concentrations according of the year of birth: (a) PCBs; (b) DDE; (c) HCB; (d) oxychlordane (Dallaire et al., 2003a).

pathway for mercury for Canadians living in the Arctic. Environmental and health concerns about mercury levels in human tissues in Canada were first identified in the early 1970s in two northern Ontario First Nations communities following contamination of fish due to effluents from chloralkali plants (Sherbin, 1979; Health Canada, 1979). Later on, these same concerns were raised in other Aboriginal communities across Canada (e.g., Nelson House, Manitoba; James Bay, Québec) affected by hydroelectric developments (McKeown-Eyssen and Ruedy, 1983).

Following these developments, the Medical Services Branch of Health Canada determined human tissue concentrations and regional distribution of mercury in Aboriginal peoples of Canada. These mercury determinations (total and organic mercury) have been done for adults, pregnant and reproductive-age women, and children including newborns. Up to 1998, the First Nations and Inuit Health Branch (FNIHB), formerly the Medical Services Branch of Health Canada, carried out community health risk

assessments by analyzing hair and blood samples obtained from more than 40,000 residents in more than 500 First Nations and Inuit communities across Canada (Van Oostdam et al., 1999). Since the mid-1980s, the mercury monitoring program among Cree First Nations of Québec has been continued by the Cree Board of Health and Social Services. A similar program has been undertaken by the Government of the Northwest Territories (GNWT) Department of Health and Social Services.

2.2.3. Population groups and studies

Specific population groups with exposure to mercury through consumption of traditional/country foods in NWT, Nunavut and northern Québec (Nunavik) include four ethnic groups: Caucasian, Dene and Métis, Inuit, and Other (East Asian, African). There are extensive data sets on patterns of exposure, including seasonal and temporal patterns, measured by hair and blood mercury levels as biomarkers and by eating pattern surveys, for First Nations and Inuit across

Table 2.2.8
Worldwide comparisons of maternal blood mercury levels (µg/L whole blood) for women living in arctic regions

Site	Year(s) collected	N	GM[a] (µg/L)	GSD[b]
Greenland				
Disko Bay	1994–1996[c]	180	12.8	
Iceland	1994–1996[d]	40	2.9	1.3
Norway				
Kirkenes	1994[d]	40	3.4	1.2
Bergen	1994[d]	50	3.4	1.1
Hammerfest	1994[d]	57	2.5	0.8
Sweden	1994–1996[d]	23	1.6	1.2

[a] GM: geometric mean.
[b] GSD: geometric standard deviation.
[c] Source: Bjerregaard and Hansen (2000).
[d] Source: AMAP (1998).

Canada covering a 30-year period (Wheatley and Paradis, 1998; Health Canada, 1999). These data sets are maintained at Health Canada, the Cree Board of Health and Social Services of James Bay (for the James Bay Cree since 1988) (Dumont et al., 1998), and the Department of Indian Affairs and Northern Development for data from the NCP over the past 10 years (Van Oostdam et al., 1999). The research and data on mercury from human tissue monitoring programs by the above-mentioned sources

have led to one of the largest environmental contaminant research projects in Canada.

It is being carried out in northern Canada by Dewailly and colleagues to examine detrimental effects on children exposed to dietary mercury and other contaminants. Recent maternal hair and maternal/cord blood contaminant studies in the NWT have given an assessment of the spatial and temporal variation in mercury levels (Tables 2.2.6, 2.2.7 and 2.2.8) (Snider and Gill, 2001; Dewailly et al., 1999; Butler Walker et al., 2005). The number of mothers in each region and ethnic group varied due to the number of mothers eligible to be included in the sampling procedure.

2.2.4. Maternal hair

The Inuvik region is located in the Mackenzie Delta and Sahtu regions of the NWT. The mercury exposure as measured in hair of women of reproductive age during 1976–1979 and 1999–1999 are summarized in Table 2.2.6. Clearly there are time trends and regional differences. Mercury levels in hair were lower in both Inuvik and region and Tuktoyatuk 1998–1999 than those seen in 1976–1979. Levels in 1998 were approximately four times higher in Tuk-
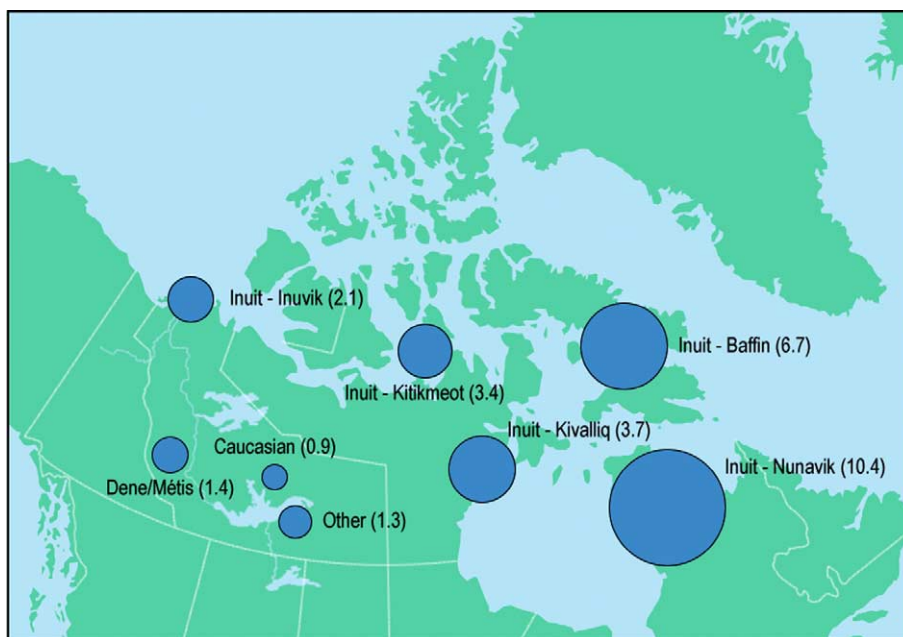

Fig. 2.2.9. Maternal contaminant levels in Arctic Canada: total mercury (µg/L plasma).

toyatuk women than Inuvik region women. Mercury levels may now be lower in hair of women from some NWT communities but differences in sampling strategies may effect any conclusion on time trend. Some of the results reported by Wheatley and Paradis (1998) may be effected by resampling communities/residents with previously high mercury values.

Similarly, Dewailly et al. (1999) in their studies in the Salluit region reported that the mean (geometric) mercury concentration in hair samples collected in 1999 was 5.7 μg/g, a value 2.5-fold lower than the 15.1 μg/g determined in a 1978 survey conducted by Health Canada. The mean mercury concentrations measured during 1999 in the 18- to 39- and the 40- to 59-year-old age groups were also five and four times lower ($p < 0.001$), respectively, than those documented during the 1978 survey. Dewailly et al. (2000a) has re-evaluated these data and reported that mercury levels in the Salluit residents' hair were five- to six-fold lower in 1979 and 1980 compared to 1978. It was pointed out that 1978 also had an exceptional harvest of beluga and other marine species. Higher consumption related to a large traditional/country food harvest could explain why high mercury concentrations were found in hair samples in the 1978. Dewailly et al. (2000a) concluded that mercury levels in Salluit vary markedly from year to year due to variation in availability of traditional/country foods, but recent tissue levels are similar to the levels found in the late 1970s.

2.2.5. Maternal/cord blood

The Caucasian, and Dene and Métis mothers were from more than one region in the NWT/Nunavut, but there were no significant differences in contaminant levels between these populations, so they were combined into their respective groups. Inuit came from four regions in NWT/Nunavut, and there were significant differences among various groups, so they were retained as separate groups. In this data set, significantly higher levels of mercury were found in maternal blood from Inuit women compared to Caucasian, Dene and Métis, or mothers in the Other group (see Table 2.2.7 and Fig. 2.2.9). In terms of geographic representation, among individuals tested in the program Inuit in the Baffin region had higher levels of mercury in maternal/cord blood than those seen in the Kitikmeot, Kivalliq and Inuvik regions. Markedly higher levels of mercury were observed in Inuit from Nunavik. Mer-
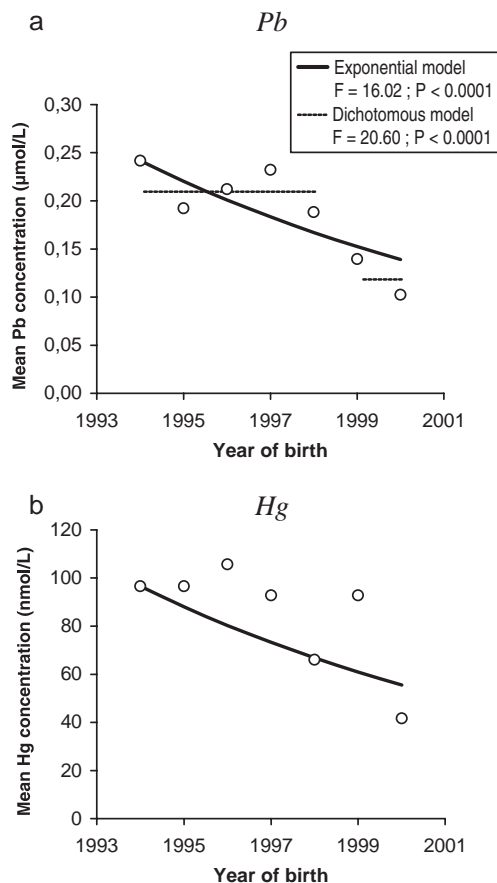

Fig. 2.2.10. Adjusted mean metal concentrations according to the year of birth for (a) lead and (b) mercury (Dallaire et al., 2003a).

cury has been noted to concentrate on the fetal side of the placental circulation, and cord blood mercury concentrations were 1.5 and 1.8 times greater than maternal concentrations in Nunavik and Nunavut, respectively. Similar patterns have been reported by Bjerregaard and Hansen (2000) for Greenland Inuit. Dallaire et al. (2003a) found that a significant reduction of lead and mercury concentrations in umbilical cord blood of Inuit infants born in Nunavik (Québec, Canada) between 1994 and 2001 (Fig. 2.2.10).

Some of the recent data from Arctic countries on mercury levels in maternal blood are shown in Table 2.2.8. No specific comparisons were made to the southern Canadian population, as the Caucasian population included in the NWT/Nunavut sampling has a similar diet and therefore will have similar contaminant levels as the southern Canadian population, which

serves as a useful benchmark for southern levels of contaminants. Maternal and cord blood mercury levels were low, were similar in Norway, Iceland and Sweden, and were similar to levels in Caucasians, and Dene and Métis mothers in the NWT (Table 2.2.7). Mercury levels in Greenland Inuit mothers were higher than those seen in Inuit mothers from Nunavik and Nunavut/NWT (Table 2.2.7). These higher levels are likely due to the consumption of more marine mammals in the traditional Greenland diet.

2.2.6. Levels of selenium in maternal blood

Selenium levels in maternal serum are very similar among Caucasian, Dene and Métis, Other, and Inuit (Baffin, Inuvik, Kitikmeot, and Kivalliq) peoples from the NWT/Nunavut (range of 117–128 μg/L) (see Table 2.2.7). Selenium levels were elevated (318 μg/L) only among Nunavik Inuit who had the highest levels of mercury. High concentrations of selenium are generally found in the traditional/country food diet of the Inuit of Canada (and Greenland), particularly marine mammals (e.g., whale skin). This element is a component of the glutathione peroxidases and it is believed that it may act as an antagonist to methylmercury, thereby offering some protection against potential adverse health effects due to methylmercury exposure; however, there is still much controversy over the role of selenium in methylmercury toxicity (AMAP, 1998).

2.2.7. Levels of lead in maternal blood

Table 2.2.7 shows that lead levels in maternal blood are moderately elevated among some of the Inuit groups (Baffin, Kitikmeot, Kivalliq, and Nunavik) and the Dene and Métis (range of 29–50 μg/L), while Caucasians, Other, and Inuvik Inuit have lower levels (range of 19–22 μg/L) (Butler Walker et al., 2005). Research on lead isotope signatures has indicated that these elevations of blood lead levels are likely due to the use of lead shot in the hunting of traditional/country foods, and thus its presence in the wild game consumed (Dewailly et al., 2000b).

In an international context, lead levels are moderately elevated among some of the Inuit mothers from Greenland (range of 31–50 μg/L), and less so among women from Siberian Russia (range of 21–32 μg/L) compared to other circumpolar countries or regions (AMAP, 1998).

2.2.8. Levels of cadmium in maternal blood

Table 2.2.7 shows that the Inuit have the highest mean levels of cadmium in maternal blood, ranging from 1.0 μg/L in Inuvik to 1.9 μg/L in Kitikmeot. Baffin and Kivalliq Inuit have levels of 1.7 μg/L and 1.4 μg/L, respectively. These values are roughly 1.5–5 times higher than blood cadmium levels of Dene and Métis (0.65), Caucasians (0.43), and Other (0.36). Note that of these three latter groups, blood cadmium levels were highest among the Dene and Métis, but still lower than any of the Inuit groups. This difference is likely due to the high rate of smoking among Inuit mothers and the high cadmium content in Canadian tobacco (Benedetti et al., 1994). It may also result from the consumption of marine and terrestrial mammal liver and kidney. Although liver and kidney can contain significant amounts of cadmium, Elinder (1992) has shown that cadmium absorption from food is only 3% to 7% while the absorption of inhaled cadmium is from 10% to 60%.

2.2.9. Radionuclide exposure

Van Oostdam et al. (1999) identified the lichen caribou human food chain as the most significant radiation exposure pathway for Arctic residents. Caribou are a major source of meat in many northern communities. These animals graze over wide areas on slowly growing lichens, which can accumulate deposited radionuclides and other contaminants over decades. Most of the radiation exposure received through this food chain resulted from anthropogenic radiocesium isotopes and from the naturally occurring lead-210 polonium-210 decay chain (Van Oostdam et al., 1999).

2.2.9.1. Radiocesium. The radiocesium isotopes—cesium-137 (^{137}Cs) and small traces of cesium-134 (^{134}Cs)—entered the environment as a result of atmospheric testing of nuclear weapons. The most intense period of testing occurred in the late 1950s and early 1960s. At that time ^{137}Cs was contributing a radiation dose as high as 5 mSv (millisieverts) per year to some northern residents (Tracy et al., 1997), in addition to a normal radiation background dose of about 2.4 mSv/year (UNSCEAR, 1993). After the cessation of atmospheric testing by the major powers in 1963, levels of ^{137}Cs in the northern environment decreased dramatically but have persisted at lower concentrations right up to the present. This is due to the long half-life (30

years) of ^{137}Cs and to its slow turnover rate in Arctic ecosystems. Also, until 1980, there were small injections of radiocesium into the atmosphere from continued testing by non-signatories of the 1963 Limited Test Ban Treaty. On September 10, 1996 the General Assembly of the United Nations adopted a Comprehensive Test Ban Treaty banning the testing of all nuclear weapons in all environments for all time (Preparatory Commission, 1996). A number of nations have yet to ratify this Treaty and in 1998 India and Pakistan conducted several underground nuclear tests, although none of these tests were observed to have released any measurable radioactivity to the environment.

Large quantities of radiocesium (^{137}Cs and [134]Cs in a ratio of about 2 to 1) were released from the Chernobyl nuclear reactor accident in 1986. Although fallout from this accident had a major impact on reindeer herds in Scandinavia (Xhman and Xhman, 1994), the effect on Canadian caribou herds was to increase radiocesium levels by about only 20% above residual fallout levels (Marshall and Tracy, 1989; MacDonald, 2002). Because of its shorter half-life (2 years), [134]Cs disappears from the environment much more quickly than [137]Cs.

Tracy et al. (1997) gave details on whole-body measurements of radiocesium carried out by Health Canada on northern peoples in 1989–1990. The average radiation doses for northern communities at that time were all less than 0.1 mSv/year and the highest single dose was 0.4 mSv/year. These are insignificant compared to normal background radiation doses of 2 to 3 mSv/year. Since that report, recent measurements of radiocesium levels in Canadian caribou herds have shown that levels are decreasing further, with an ecological halftime of about 10 years (MacDonald et al., 1996).

2.2.9.2. Lead-210 and polonium-210. Naturally occurring uranium in rocks and soils releases radon gas into the atmosphere. Van Oostdam et al. (1999) showed that radon gas itself is not a particular problem in the North. However, the decay of radon in air gives rise to the long-lived lead-210 (^{210}Pb; half-life=22.3 years), which in turn decays to the alpha-emitting radionuclide polonium-210 ([210]Po; half-life=138 days). These radionuclides eventually settle onto lichens and other vegetation in more or less equal concentrations. When the lichens are eaten by caribou, ^{210}Pb is concentrated in bone and [210]Po accumulates in the meat and organs of the animal, which are in turn eaten by northern peoples. Van Oostdam et al. (1999) indicated [210]Po doses as high as 10 mSv/year for some northern communities consuming large amounts of caribou. The report recommended that more research be carried out to better characterize this source of radiation exposure.

The radionuclides ^{210}Pb and [210]Po are naturally occurring and have been present in the Arctic environment for thousands of years at more or less the same concentrations as found today. Local enhancements may have resulted from uranium mining, milling, and ore transport operations, although there is no evidence that any such contamination is widespread.

Since the publication of Van Oostdam et al. (1999), extensive dietary surveys have been carried out by CINE (see Section 2.1) which more accurately reflect the amount of polonium-210 ingested through caribou meat and other traditional/country foods. For example, in a 24-h recall survey, Berti et al. (1998b) obtained a caribou consumption of 224 g/day for men and 178 g/day for women living in Gwich'in, NWT, who were over 40 years of age. These values have been corroborated independently by whole body surveys of ^{137}Cs in northern residents and in the meat they have been consuming (Tracy and Kramer, 2000). Concentrations of [210]Po in Canadian caribou meat are known to vary from 10 to 40 Bq/kg, with an average of about 20 Bq/kg (Thomas, 1994). Until recently, questions remained as to how much polonium is absorbed in the human intestine and how long it remains in the body. A study by Thomas et al. (2001) shows that intestinal absorption of polonium is indeed more than 50% and that the retention time in the human body is significantly longer than the previously accepted value of 50 days. All of these factors combined would give a radiation dose of 3 to 4 mSv/year to a high consumer of caribou meat, over and above normal background radiation.

2.2.9.3. Summary of radionuclide exposures. Information for the two most important radionuclides—[137]Cs and [210]Po—contributing to the radiation exposure of northern residents is summarized in Table 2.2.9. The table gives concentrations of the two radionuclides in caribou meat, concentrations in human

Table 2.2.9
Radionuclide levels in caribou meat and people in the Canadian Arctic, and resulting radiation doses to people

Levels/Doses	Radionuclide	
	Cesium-137	Polonium-210
Levels in caribou meat (Bq/kg)		
Mid-1960s	500–3000	10–40
Late 1980s	Up to 700	10–40
Late 1990s	Up to 300	10–40
Levels in northern residents (Bq/kg)		
Mid-1960s	Up to 1500	
Late 1980s	Up to 110	
Doses to northern residents (mSv/year)		
Mid-1960s	Up to 5[a]	9–12[b]
Late 1980s	Up to 0.4[a]	3–4[b]
Late 1990s	Up to 0.2[b]	3–4[b]

Source: Tracy and Kramer (2000).

[a] Doses based on measured whole-body concentrations of ^{137}Cs (Tracy et al., 1997).

[b] Doses based on estimated caribou consumption in a typical northern diet and on human metabolic parameters. The higher ^{210}Po doses in the 1960s is not based on any changes in environmental levels of ^{210}Po but on an estimated higher consumption of caribou meat at that time (Tracy and Kramer, 2000).

tissues where available, and the radiation doses to humans consuming a traditional diet of caribou and other traditional/country foods. All of these doses must be interpreted in the context of a worldwide average exposure to natural background radiation of 2.4 mSv/year (UNSCEAR, 1993). The radiocesium doses have decreased to insignificant levels. Barring future inputs from another nuclear reactor accident or from a resumption of nuclear weapons testing, the radiocesium levels in northern food chains should be completely undetectable in a few years. The ^{210}Po doses remain somewhat elevated over and above normal background radiation (2.4 mSv/year).

2.3. Trends in traditional/country food dietary intakes and contaminant exposures

Interview data from Inuit communities in 1999–2000 included questions about how individuals compared their intake of traditional/country food at that time to intake 5 years earlier. More than 50% of the entire sample from all Inuit communities reported that they were consuming the same or more than they did previously. When asked why more traditional/country food was not consumed by the family, most men-

tioned the expenses of hunting and other priorities for their time. Many individuals (42–68% of respondents in the five regions) expressed their wish to be able to purchase traditional/country food in the commercial food stores in their communities because they did not have time to harvest these foods themselves (Kuhnlein et al., 2000).

In addition to the studies conducted by CINE, a review of circumpolar Inuit dietary studies was conducted by Dewailly et al. (2000d). The study collected and reviewed all available dietary studies from the circumpolar Inuit regions to conduct an analysis of data coverage, and temporal and geographic trends in consumption, contaminant levels and nutrient status. Research conducted in Canada covered in this review included: the Santé Québec study in Nunavik (1995); Lawn and Langer (1994) survey in Labrador and the NWT; a survey in Broughton Island by Kuhnlein (1989); research conducted by Wein et al. (1998) in the Belcher Islands, NWT; and a study by Wein and Freeman (1992) in Aklavik, NWT.

Results obtained from recent studies for the Canadian North were compared to the Nutrition Canada Eskimo Survey conducted in 1971. The analysis shows that in 1971, daily traditional/country food consumption varied between 191 and 219 g/day among women, while amounts today vary between 164 and 448 g/day. Among men, traditional/country food intakes varied between 277 and 646 g/day in 1971 and are now between 171 and 615 g/day, as reported in the more recent studies. In Canada, intakes of traditional/country food (by weight) do not seem to have changed significantly in the last 20 years. Changes in the Inuit diet are primarily related to an increase in the amount of imported foods consumed. More cereals, meats, fruits, vegetables and sugars are included today than before. Mean energy intakes among Inuit were lower in 1971 than today, and the contribution of protein to total energy intake has decreased in the last 30 years while the total lipid intake has increased on average. According to the Santé Québec study this is attributable in Nunavik to a higher consumption of market meats and prepared meals. This increase is also related to the degree of urbanization of Inuit communities (Schaefer and Steckle, 1980). Despite the fact that higher nutrient intakes are observed today compared to the last 20–30 years, several recent studies still show low intakes of

vitamins A and C, and folic acid and calcium among Inuit populations (Dewailly et al., 2000d).

Similar dietary intake measurements in Qikiqtarjuaq (Broughton Island), Nunavut were taken in 1987–1988 and 1999. The earlier study, however, was more intensive in that data were collected bimonthly for the entire year, whereas in the latter study data were collected during two periods representing the estimated highest and lowest intake seasons. In both studies, measurements of mercury, chlordane, PCBs and toxaphene were made in foods eaten, for development of the food database. It was shown that mercury exposure data were similar in the two surveys, thus implying little change in dietary pattern or mercury concentration in food. However, reported intakes of the organochlorines were somewhat higher in the latter survey, particularly among the highest users (95th percentile). This was due to a higher reported consumption of narwhal muktuk and blubber in the community (Kuhnlein et al., 1995c).

3. Toxicology

3.1. Priority contaminants

3.1.1. Toxaphene

Toxaphene, or chlorinated bornane, was one of the most extensively applied insecticides in North America during the 1960s and 1970s. Encouraged as a replacement pesticide for DDT, total global use estimates for toxaphene are on the order of up to 1.2 billion kg (McDonald and Hites, 2003). Due to its environmental persistence (soil half-life of up to 14 years) and ability to be transported in the atmosphere, toxaphene continues to be a contaminant of concern for Arctic populations who consume country or traditional food items. A number of dietary surveys conducted in the Canadian Arctic have provided intake estimations which suggest high level consumers of marine mammal fatty tissues and organs (blubber, liver, brain, and kidneys) may exceed the current tolerable daily intake (TDI) guideline for toxaphene, in certain cases by over two orders of magnitude (Section 5.1.1). This higher intake of toxaphene from the diet can then result in increased concentrations of residues being detected in human tissue samples. For example, total toxaphene residues

detected in maternal blood samples from Caucasians living in the Arctic were found to be over 10-fold lower than Inuit (0.05 ppb vs. 0.74 ppb, respectively) (Section 2.2).

Toxicological issues related to toxaphene, which in part led to its deregistration as a pesticide, included it being classified as a suspected carcinogen and endocrine disruptor. To further address these aspects, with an ultimate goal of possibly revising the current Health Canada TDI of 0.2 µg/kg body weight (bw)/day, a number of experimental studies were devised.

Toxaphene's ability to interact with DNA, a critical event in the development of certain cancers, was tested in a series of in vitro studies. In a standard mutagenicity assay, technical toxaphene was tested in five strains of *Salmonella typhimurium* for its ability to induce point mutations (Schrader et al., 1998). This test is commonly employed as an initial screen for chemical genotoxic activity, with the premise being that DNA point mutations are implicated in many human genetic diseases, including tumour formation. Results indicated that while toxaphene was able to induce mutations in bacteria, the addition of a metabolic activation system significantly decreased its activity. In addition, toxaphene was tested for its ability to induce sister chromatid exchanges (SCE) in hamster lung fibroblasts (V79 cells). Although not related to mutation frequency, an increase in SCE beyond a background value indicates a chemical has caused genetic (DNA) damage, such as adducts, which is correlated to recombinational DNA repair. Even at cytotoxic concentrations, toxaphene was only able to induce nonsignificant increases in SCE.

Technical toxaphene is a complex mixture of chlorinated bornanes, theoretically comprised of up to 32,000 different congeners. As with PCBs, various abiotic and biotic processes results in selective decomposition of the technical formulation to the extent where only 100–200 congeners are detected in environmental samples (Gouteux et al., 2002; MacLeod et al., 2002). To address possibly toxicological differences that may exist between technical toxaphene and "environmental" toxaphene, technical toxaphene was fed to cod for 4 months and then toxpahene residues (biotransformed) were extracted and purified from cod liver (Besselink et al., 2000). Following an initial exposure to a known liver carcinogen, *N*-nitroso-

diethylamine, female rats were treated for 20 weeks with 0.46–12.5 mg cod liver-extracted toxaphene (biotransformed)/kg bw/week by subcutaneous injection. One week following the last dose, rat livers were removed and assessed histopathologically for altered hepatic foci, a preneoplastic lesion associated with the development of liver cancer. Unlike the positive control, TCDD, neither technical toxaphene or toxaphene extracted from cod liver significantly increased the mean foci area or percent area fraction of foci in the liver. Overall, these preliminary results would suggest that biotransformed toxaphene does not have strong tumour promoting activity.

Following a preliminary study where nonhuman primates were dosed with technical toxaphene for 52 weeks (1.0 mg/kg bw/day), an additional longer term study was initiated. Groups of 10 female cynomologus monkeys were given daily oral doses of 0, 0.1, 0.4 or 0.8 mg technical toxaphene/kg bw/day for at least 75 weeks. After 75 weeks, treated females were mated with control males, with continued toxaphene exposure for the additional 26-week mating and gestation period. Prior to the mating phase of the experiment, immunological assessment of the treated females was conducted between weeks 33 and 70 (Tryphonas et al., 2001).

No parameters related to fertility and gestation were affected by toxaphene dosing. One of the more prominent offspring observations was that male neonates from the toxaphene treated dams weighed less at birth and grew at a slower rate during lactation than the controls, whereas the opposite effect was seen with female offspring. At the highest dose, male newborns weighed about 10% less than controls while on average females from all treated dams weighed approximately 24% more than the controls.

During immunologic assessment of the treated females, effects related mainly to humoral immunity (antibody mediated) were observed. The primary and secondary response (IgM and IgG) to T-cell-dependent antigens (sheep erythrocytes and tetanus toxoid) was decreased in the animals dosed with 0.4 and/or 0.8 mg toxaphene/kg bw/day. These results suggest that the animals could possibly be more susceptible to bacterial infections.

3.1.1.1. Discussion. Although questions remain as to the significance from a human health perspective of the tumours induced in experimental animals by technical toxaphene, short term in vitro and in vivo studies suggest toxaphene would be classified as a weak mutagen and an equivocal tumour promoter. Associated with toxaphene-induced liver cancer in rodents were observations of hepatic toxicity (liver weight increase, fatty cell degeneration, focal necrosis). In a study designed to investigate a possible link between liver toxicity in humans and toxaphene, 104 autopsy samples from Greenland Inuit, collected from 1992 to 1994, were assessed for histopathological findings as well as concentrations of contaminants (Dewailly et al., 1995). The average sum (mean) of chlordane-related chemicals in a representative sample of omental fat ($n=41$) was 2.80 ppm (range of 0.57–9.61 ppm) while toxaphene (detected in 100% of samples) was found at lower levels (mean = 0.57 ppm; range of 0.09–1.85 ppm). No differences were seen in the levels of contaminants in samples for which liver pathologies (fatty degeneration, portal fibrosis, and inflammation) were or were not present. While not designed to provide conclusive evidence, the results are at least suggestive that the toxaphene concentrations found are not associated with detectable symptoms of liver toxicity in humans.

From the main reproductive study in non-human primates, ingestion of up to 0.8 mg toxaphene/kg bw/day had no immediate effect on fertility. In comparison, the 95th percentile estimated daily intake of toxaphene by Inuit in Qikiqtarjuaq from a 1998–99 dietary survey was 26 µg/kg bw/day, or approximately 30-fold lower (Section 5.1.1). A similar comparison can be made with respect to body residues accumulated through the diet. For example, body burdens (total bioaccumulated) as estimated from the non-human primate feeding study would be in the order of 2.9, 13.6 and 32.6 mg for the 0.1, 0.4 and 0.8 mg/kg bw/day doses, respectively (Arnold et al., 2001; Arnold, 2003). Average toxaphene body burdens found in Baffin and Kivalliq women who participated in a maternal blood study would be 1.1 and 9.1 mg, respectively based on total lipid, or within the same range where immunologic effects and infant weight changes were seen (Butler Walker et al., 2003). This would suggest that, for certain consumers of country or traditional food, exposure to toxaphene may be sufficiently high as to warrant concerns related to the immune system and infant physical development.

Table 3.1.1
Relative percent contribution to chlordane total

Isomer	Technical chlordane[a] (%)	"Biological" chlordane[b] (%)
cis-Chlordane	19	1.7
trans-Chlordane	24	1.4
cis-Nonachlor	2.7	8.3
trans-Nonachlor	9.7	54.9
Heptachlor	10	6.8[c]
Oxychlordane	0	27

[a] Buchert et al. (1989).
[b] Marine mammal blubber average, 1993–1994.
[c] As heptachlor epoxide.

3.1.2. Chlordane

North American production of chlordane began in 1947 and peaked at approximately 5000 tons/year by 1974. Chlordane was first registered in Canada as a pesticide in 1949 with subsequent sale and/or use prohibited after 1995. One of the major applications of chlordane was as a termiticide in the U.S. where its estimated there have been over 30 million houses treated (Kilburn and Thornton, 1995).

Technical chlordane actually consists of up to 120 similar compounds with 5–6 major isomers predominating (Table 3.1.1). Of interest is that up to 10% of chlordane can be the related insecticide heptachlor while up to 20% of commercial formulations of the latter can be chlordane.

As with other structurally-similar chlorinated insecticides, chlordane was identified as a contaminant of concern in certain Arctic communities based on estimated daily intakes exceeding recommended guidelines as established by various health agencies. Mean intake of chlordane by the Inuit community in Qikiqtarjuaq (Broughton Island) in 1998 was estimated at 0.62 μg/kg bw/day. High consumers of country foods (top 5%) were thought to be ingesting up to 5 μg/kg bw/day of chlordane residues. Consumption of marine mammal blubber (beluga, narwhal, walrus) was responsible for up to 84% of the total chlordane intake although these three food items contributed less than 4% of the traditional diet (Kuhnlein and Receveur, 2001). In contrast, a conservative estimation is that North Americans are only exposed from food to up to 0.01 μg/kg bw/day of chlordane (Dougherty et al., 2000). These intake figures are in comparison to "tolerable" guidelines, as established by Health Canada and US EPA, of 0.05–0.5 μg/kg bw/day.

Following an evaluation of chlordane residues in marine mammals by Health Canada, it became apparent that there were major differences between actual human exposure through consumption of these foods and the technical chlordane mixtures used in the safety assessments (Table 3.1.1). In particular, trans-nonachlor (TNC), a minor component of technical chlordane, and oxychlodane (OXY), a stable metabolite of chlordanes and nonachlors, can contribute over 75% to the chlordane-related residues found in marine mammal blubber (Muir et al., 2000). As important, trans-nonachlor and oxychlordane account for more than 90% of the chlordane residues found in human milk samples (Newsome and Ryan, 1999).

As the majority of toxicology data used to establish tolerable intake values was generated using technical chlordane, a major goal of NCP was to address the lack of information on chlordane-related residues commonly found in country foods and humans.

For the initial series of experiments, rats were orally dosed for 28 days with cis- and trans-nonachlor or oxychlordane and the results compared to technical chlordane. At the highest dose tested, 25 mg/kg bw/day, no animals treated with either cis-nonachlor or technical chlordane died while there was significant morbidity/mortality with trans-nonachlor and especially oxychlordane at lower doses (Table 3.1.2).

Residue analysis conducted at study termination and after the animals had been given an additional 28 or 56 days following dosing indicated that oxychlordane was approximately 2–3 times more bioaccumulative than trans-nonachlor and 19–26 times greater than trans-chlordane. While both male and female animals effectively cleared trans-chlordane

Table 3.1.2
Chlordane-induced mortality in sub-acute studies

Chemical	Dose (mg/kg bw/day)	Time to morbidity/mortality (days)	Mortality incidence (%)
Technical chlordane	25	>28	0
cis-Nonachlor	25	>28	0
trans-Nonachlor	2.5	>28	0
	25	17–20	43
Oxychlordane	10	1	100
	2.5	26	4
	1	>28	0

Bondy et al. (2000, 2003).

residues by 28 days after dosing, oxychlordane and *trans*-nonachlor were significantly more persistent especially in females, with up to 90% of oxychlordane still present after 56 days following dosing (Bondy et al., 2003). Histopathological indications of organ effects (mainly liver, kidney and thyroid) were apparent at the highest dose (25 mg/kg bw/day; 10 mg/kg bw/day OXY) for all chemicals, but also at lower doses for TNC and OXY (0.25 and 2.5 mg/kg bw/day, respectively) (Bondy et al., 2003). Residue analysis also supported the concept that there is a link between total amount of chlordane-related chemicals bioaccumulated and indications of toxicity.

Additional experimental investigations focused on endpoints related to immunology as previous studies had suggested prenatal exposure to various OC pesticides was associated with an increased risk of recurrent *otitis media* in Inuit children. Unlike toxaphene, treatment with certain of the chlordane compounds, mainly nonachlors, resulted in a stimulatory response in terms of Ig production. However, in female rats, there was a dose-related decreased resistance to *Listeria* infectivity with TNC, starting at doses as low as 0.25 mg/kg bw/day (Tryphonas et al., 2003). The sex-related difference, in terms of female animals being more susceptible to bacterial infections, was once again thought to be related to amount of accumulated chlordane residues (higher and more persistent in females).

3.1.2.1. Discussion. At sufficiently high levels of exposure, technical chlordane is capable of producing a variety of toxic effects in both experimental animals and humans. The lowest adverse effect dose in experimental animals was estimated to be approximately 50 μg/kg bw/day, based on histopathological lesions produced in liver. Long-term exposure to doses of technical chlordane as high as 250 μg/kg bw/day produced liver weight increases and hepatocellular swelling in rats. In comparison, high consumers of country foods are likely ingesting up to 5 μg/kg bw/day of chlordane-related chemicals.

Results from these series of experiments provided indications that the more persistent and bioaccumulative chlordane-related chemicals, nonachlors and oxychlordane, are also more toxic than the technical mixture. For example, exposure for short durations to *cis*- and *trans*-nonachlor produced significant effects in various immunology parameters, including

a decreased ability to mount an effective challenge against bacterial infection. A similar response was not observed with technical chlordane, even at doses 100-fold higher. As toxicity of chlordanes appears to be related to the extent of accumulated residues, comparison of tissue or organ concentrations between experimental animals and humans may be a reasonable approach to refining the risk assessment. At the lowest dose tested which caused effects, 0.25 mg/kg bw/day, total chlordane residues in experimental animals were approximately 0.8 mg/kg bw. In comparison, the average body burden of sum of chlordanes from a recent Arctic survey of maternal blood was approximately 319 μg/kg bw, or almost 25-fold lower (Muckle et al., 2001b). However, values from this survey ranged up to 212 μg/kg bw, or only 4-fold lower. This would imply that certain Arctic consumers of country foods might accumulate sufficient quantities of chlordane-related chemicals to be within the range where immunological effects are seen in experimental animals.

3.2. Toxicological effects induced by exposure to food-chain contaminant mixtures

While the majority of toxicology studies focus on individual chemicals, from the perspective of food-borne contaminants, exposure is almost always to complex mixtures. These mixtures are comprised of not only chemicals with different physicochemical properties but also possible metabolic/degradation products of the original chemicals, often more toxic than the original compounds. Methodologies have been suggested to address the issue of risk assessment for complex mixtures (US EPA, 2000; Groten et al., 2001). These can involve either reconstitution or extraction of the mixture from the matrix in question (soil, air, or water) or, in the case of certain foods, actual incorporation of the food commodity in question into experimental diets. Applicable for Arctic residents are studies by Lapierre and colleagues in which marine mammal fat was fed to rodents and immunological endpoints assessed (Lapierre et al., 1999).

To further address the issue of complex mixtures of environmental contaminants found in country foods, a contaminant mixture was reconstituted to approximate what is found in ringed seal blubber and fed to female pigs from 4 months of age until weaning of their first

Table 3.2.1
Composition of the organochlorine mixture

Chemical	Weight percent in mixture (wt.%)
PCB mixture[a]	32.6
Technical chlordane	21.3
p,*p*′-DDE	19.3
p,*p*′-DDT	6.8
Technical toxaphene	6.5
α-HCH	6.2
Aldrin	2.5
Dieldrin	2.1
1,2,4,5-Tetrachlorobenzene	0.9
p,*p*′-DDD	0.5
β-HCH	0.5
Hexachlorobenzene	0.4
Mirex	0.2
γ-HCH	0.2
Pentachlorobenzene	0.2

Source: Ayotte (2001).
[a] Mixture containing 2,4,4′-trichlorobiphenyl (320 mg), 2,2′,4,4′-tetrachlorobiphenyl (256 mg), 3,3′,4,4′-tetrachlorobiphenyl (1.4 mg), 3,3′,4,4′,5-pentachlorobiphenyl (6.7 mg), Aroclor 1254 (12.8 g), and Aroclor 1260 (19.2 g).

litter (Table 3.2.1) (Bilrha et al., 2004). Following weaning, the piglets were assessed for a variety of developmental and immunological parameters at intervals up to 8 months of age.

There were no signs of maternal toxicity although female pigs in the high dose group were exposed to contaminant levels that exceeded tolerable daily intakes by up to 2 orders of magnitude. There was, however, a dose-dependent decrease in the length at birth for female piglets (7% decrease at the highest contaminant intake). Following contaminant assessment in the piglets at 1 month of age, various immunologic tests were conducted up to the age of 8 months. Minimal effects were seen with respect to physical development, although there was a slight decrease in testis weight for all animals (not dose-dependent) and sperm motility for the high dose animals. For immunological endpoints, one of the more significant findings was a reduction in antibody response to *Mycoplasma hypopneumoniae* vaccination seen in the piglets exposed perinatally to the highest dose from the age of 5 months onwards. At 8 months of age, only 10% of piglets in the high dose group had what would be considered as a positive response to this antigen, compared to 50% in the controls (Bilrha et al., 2004). Additional findings

included slightly enhanced proliferative responses of lymphocytes and enhanced phagocytic activity of leukocytes, mainly evident in the mid and high dose animals. As the findings became more prevalent as the animals aged, it was suggested that innate or natural immune defense was less affected as compared to acquired immunity.

When assessed at delivery, the pigs showed a dose-dependent increase in plasma concentrations for most of the OCs found in the complex mixture. For example, low, mid and high dose group plasma concentrations of PCBs (sum of congeners) were 153, 1425 and 11,485 ppb, respectively (controls not detected). In comparison, the mean concentration of PCBs in maternal plasma samples from an Inuit cohort in Nunavik was 397 ppb lipid, with a range up to 1951 ppb lipid, or only 6-fold lower than the high dose group (Muckle et al., 2001b).

The same complex mixture of contaminants was tested in vitro for its ability to affect the maturation and embryonic development of porcine oocytes. While doses of contaminants almost 1000-times higher than those seen in plasma of Inuit women of reproductive age had no effect on the fertilization of oocytes, there was a significant decrease at the highest dose tested of polyspermy (Campagna et al., 2001). However, there were indications that the in vitro maturation process and subsequent developmental

Table 3.2.2
Composition of complex mixture based on human blood residues

Chemical	Amount in 5 mg/kg bw dose (mg)
PCB mixture[a]	1.100
Aldrin	0.005
β-HCH	0.075
cis-Nonachlor	0.052
p,*p*′-DDE	0.919
p,*p*′-DDT	0.057
Dieldrin	0.022
Hexachlorobenzene	0.296
Heptachlor epoxide	0.023
Mirex	0.029
Oxychlordane	0.136
Toxaphene	0.07
trans-Nonachlor	0.220
Σ OCs	1.900
Methylmercury chloride	2.000

Source: Bowers et al. (2003).
[a] Containing PCBs 28, 52, 99, 101, 105, 118, 128, 138, 153, 156, 170, 180, 183, 187.

competency of oocytes was negatively affected at lower doses. When similar endpoints were investigated with both oocytes and sperm being treated in vitro, an increase in polyspermic oocytes occurred at lower doses while a decrease was evident at higher doses (Campagna et al., 2002).

In a similar experimental design, pregnant rats were exposed from gestation day 1 to the end of lactation to a complex mixture of contaminants based on what has been found in blood from Arctic populations known to consume country/traditional food items (Table 3.2.2). Pregnant rats were treated orally (food supplement) with 0, 0.05, 0.5 or 5.0 mg/kg bw/day of the mixture from gestation day 1 to the end of lactation (postnatal day 23). Developmental landmarks were assessed in the pups as well as a number of neurobehaviour endpoints up to maturity (postnatal day 60). A 15 mg/kg bw/day dose of Aroclor 1254 served as a positive control (Bowers et al., 2003).

The contaminant mixture had no significant effect on maternal gestational weight gain, litter size, pup sex ratio or offspring mortality however maternal body weight in the high dose mixture group decreased by 6–10% during lactation compared to the controls. Pup weight gain was decreased throughout lactation in the high dose and positive control groups, with the difference in weight increasing as the pups matured (20% by PND 23). The decreased weight gain observed during lactation also persisted into adulthood (PND 80). Maternal blood samples collected at 5–7 days after the final dose exhibited mercury concentrations ranging from 0.5 to 46.4 ppm for the 3 complex mixture dose groups, compared to maximum values of 44 ppb in the previously mentioned Nunavik cohort (Muckle et al., 2001b). Offspring blood mercury values ranged from 13.0 to 250 ppb for the 3 mixture groups compared to an average cord blood concentration of 22.7 ppb from the Nunavik cohort. Various organ weights at PND 35 were also affected (liver and brain increased; spleen and thymus decreased) in mainly the same two dose groups. Certain organ weight effects also persisted when measured at PND 75 (brain and spleen).

In young rats (17 days old), the highest mixture dose produced time-dependent hyperactivity and decreased rearing in a novel open-field, both suggestive of altered reactivity to the environment. In contrast, 17-day-old pups from the Aroclor positive control group exhibited hypoactivity and decreased rearing, suggestive of reduced motor activity or decreased interaction with the novel environment. At 30 days of age, hypoactivity and decreased rearing was still evident in Aroclor-treated pups compared to the controls, but to a lesser extent. Acoustic startle and prepulse inhibition of acoustic startle were evaluated in the pups at PND 21 and 44. Acoustic startle is a basic defensive reflex response to sudden noise while prepulse inhibition (PPI) of acoustic startle is a measure of the integration of sensory information (i.e., information processing) in the brain and reflects basic neural functions. Offspring from the positive control group (Aroclor 1254) consistently exhibited a decrease in the startle response at PND 21 and 44 while the mixture had little impact on the startle response at PND 21. The lowest mixture dose however decreased PPI at PND 21 but not at PND 44. Gender differences in the effects of the mixture and the positive control treatment emerged as animals matured. For instance, at PND 44 the two highest mixture doses and the positive control decreased startle in males but produced small increases in startle responses in females. Similarly, while PPI was unaffected in females, Aroclor and the two highest mixture doses produced small increases in PPI. in males. When visual discrimination, a measure of learning, was tested in the offspring at PND 100, only females from the high dose mixture group showed a decreased response.

In a further attempt to define the relationship between exposure to complex mixtures of contaminants and potential adverse effects, physiological based toxicokinetics (PBTK) modeling was applied

Table 3.2.3
Comparison of PBTK-derived TDIs to estimated contaminant intakes

OC contaminant	Average Inuit intake ($\mu g/kg$ bw/day)	Current TDI ($\mu g/kg$ bw/day)	Estimated TDI from modeling rat data ($\mu g/kg$ bw/day)
Hexachlorobenzene	0.12	0.27	2.7
Chlordanes	0.43	0.05	0.02
HCHs (α, β, γ)	0.03	0.3	4.4
Total DDT	0.53	20	18
Mirex	0.01	0.07	0.21
PCBs (sum 14 congeners)	0.66	1	17
Dieldrin	ND	0.1	18.5

Source: Chan et al. (1997, 2000). ND—not determined.

to residue data obtained following a subacute dietary exposure period. Female rats were dosed (gavage) for 28 days with an organochlorine mixture based on average intakes from a Qikiqtarjuaq dietary survey conducted in 1988 (Chan et al., 1997). At the end of the dosing period, various tissues were collected for both toxicological assessment and residue analysis (Chan et al., 2000). Comparison of tissue residues found in the rats at the highest dose tested (observed adverse effect level) to estimated equivalent human residues from modeling suggested that the average dietary intake of chlordane by Inuit was approximately 20 times greater than a suggested safe dose. For all other OCs, except DDT, the tolerable intake from the modeling exercise suggested that actual dietary intakes would be less than doses capable of inducing toxic effects (Table 3.2.3).

Physiologically based toxicokinetic (PBTK) models have been shown to be useful tools in predicting the target tissue dose of chemicals in a mixture and in extrapolating effects between species (Haddad et al., 2000). In agreement with the chlordane toxicological studies, these results suggest that consumers of country foods may be accumulating chlordane residues at concentrations where adverse effects are observed in experimental animals.

3.2.1. Discussion

Toxicological studies with complex mixtures that mimic real life situations (exposure or body burdens) have the added advantage of identifying any potential interactions that may occur between the different contaminants. For example, preliminary experimental results suggest that PCBs and methylmercury could act synergistically to induce adverse neurological effects (Bemis and Seegal, 1999). Also, non-cytotoxic doses of toxaphene have been shown to significantly enhance the genotoxic response of a carcinogenic PAH in cultured human liver cells (Wu et al., 2003).

Two series of experiments with dosing based on slightly different complex mixtures has provided evidence that: 1) organochlorines can cause effects related to fetal development (decreased birth weight), immunosuppression (deceased antibody production) and possibly oocyte maturation; and 2) organochlorines combined with methylmercury produced behavioural alterations both similar and unique to those

seen with PCBs alone. Physical developmental delays of offspring from the combined in utero/lactational exposure also persist into adulthood. There were indications that certain effects from both experiments were occurring at contaminant concentrations seen in recent blood surveys from Arctic residents. This would imply that these endpoints would be relevant to assess in human studies investigating associations between adverse health outcomes and exposure to environmental contaminants.

3.3. Contaminant and dietary nutrient interactions

The ability of diet to affect the prevalence of various adverse health outcomes in humans has been clearly established. For example, its been estimated that 20–60% of all human cancers are related to diet (Doll, 1992). Diets rich in various antioxidants, including vitamins and essential trace elements, are hypothesized to have a beneficial influence on risks associated with other major human diseases, including diabetes, osteoporosis, kidney and cardiovascular diseases (IOM, 2000). Dietary long chain polyunsaturated fatty acids, such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), play an essential role in human growth and neurodevelopment while the same fatty acids have recently been associated with a reduced risk of impaired cognitive function in adults (Das, 2003; Kalmijn et al., 2002).

From an Arctic perspective, results from experimental research have suggested certain diet components can either protect against or attenuate adverse effects caused by contaminants of concern. For example, protein, fibre and trace elements (calcium, iron, and zinc) can all influence the extent of cadmium bioavailability and toxicity (WHO, 2000). Earlier studies have suggested replacing casein with fish protein can decrease the toxicity of methylmercury in mice (Ohi et al., 1976). Although the mechanism is unclear, selenium has been shown to be protective against mercury-induced toxicity, possibly through complexing reactions (Watanabe, 2002; Whanger, 2001). Developmental exposure to both a selenium deficient diet and methylmercury can result in synergistic effects on the neurobehavioural functions in mice (Watanabe et al., 1999).

To further define the benefits associated with consuming country foods, a series of experiments were

devised to investigate potential interactions between dietary components and contaminants. In a first experiment, rats were exposed to diets containing different types of protein (casein, fish or whey) for 4 weeks prior to dosing with methylmercury for 14 days. At the end of the methylmercury treatment period, various organs were analyzed for mercury content and the presence of thiobarbiturate reactive substances (TBARS), as an indication of oxidative stress (lipid peroxidation). No mercury pharmacokinetic differences were seen and the type of dietary protein had no effect on organ TBARS (Chan et al., 2004). In a similar experimental design, the lipid or fat component of diets was modified so rats ingested 20% by weight either seal oil, fish oil, DHA, soya oil or beef lard for the same 4-week period followed by 14 days of oral dosing with methylmercury. Only in rats consuming the soya-containing diet was there no increase in TBARS concentrations in brain tissue suggesting dietary oleic and linoleic acids (essential fatty acids) are important in preventing methylmercury-induced oxidation damage (Chan et al., 2004).

Related studies have shown that selenium did not prevent increases in mercuric chloride-induced TBARS in rat liver homogenates isolated from animals maintained on a soya oil-supplemented diet (Farina et al., 2003).

Selenium has been recognized as an essential trace element for both animals and humans. In particular, selenium is thought to be important for maintaining membrane integrity and reducing oxidative damage to cellular macromolecules, including lipids and DNA (Rayman, 2000). Experimental evidence to date indicates that selenium not only can decrease the extent of methylmercury neurotoxicity but if a selenium deficiency condition exists, mercury toxicity can be enhanced. The chemical form of selenium appears to be an important factor in its ability to influence methylmercury toxicity. For example, sodium selenite (Na_2SeO_3), an animal feed supplement, forms complexes with mercury to a greater extent than selenium isolated from liver (Magos et al., 1983). Both selenium and vitamin E are known to be capable of reducing the toxic effects induced by acute or chronic exposure to methylmercury (Ganther, 1978). Hamsters exposed to methylmercury concurrently with vitamin E exhibited no signs of intoxication whereas those exposed to methylmercury alone develop severe symptoms of poi-

soning (Chang et al., 1978). As with selenium, a diet enhanced with vitamin E is protective against mercury-induced oxidative damage while a deficient diet enhances methylmercury hepatic lipid peroxidation (Andersen and Andersen, 1993). In an experiment to further address the relationship between methylmercury and antioxidants, female rats were maintained on diets supplemented with selenium, vitamin E or both for 8 weeks prior to mating and during gestation. Beginning 4 weeks before mating, all rats were dosed with 1.25 mg methylmercury/kg bw/day and allowed to deliver their litters. Selenium alone did not prevent mercury-induced pup mortality while vitamin E alone and in combination with selenium did (Chan, 2002).

To further characterize the potential toxicity of mercury found in country foods, rats were fed diets in which seal liver, a major source of methylmercury exposure for Inuit, was added. The seal liver, containing either 20 ppm (low) or 110 ppm (high) mercury, comprised 20% of the diet and was fed to rats for 14 days before absorption; organ distribution rates for mercury were then determined. Whereas 16% of mercury from the low dose seal liver diet was absorbed, only 3% in the high dose diet bioaccumulated which indicates the chemical form of mercury in seal liver is substantially less bioavailable than methylmercury in fish tissue (usually 90%+) (Chan, 2000a,b). However, 2% of both the seal liver mercury doses was distributed to brain compared to 0% in rats fed the control diet (veal liver with 110 ppm inorganic $HgCl_2$). This supports analytical findings that on average only 2% of total mercury in ringed seal liver was in the form of methylmercury whereas up to 53% of mercury was estimated to be insoluble mercuric selenide (HgSe) (Wagemann et al., 2000). Previous experimental results have indicated a total mercury dose of 158 mg from seal liver did not induce toxic effects in cats (Eaton et al., 1980).

3.3.1. Discussion

A recent review has concluded there is a link between exposure to chemicals from the environment and over 200 different human diseases (Janssen et al., 2004). Certain essential dietary nutrients, including vitamins, minerals and fatty acids, found in traditional/country foods have been suggested as being capable of reducing or possibly preventing adverse effects caused by contaminants. Results from preliminary experiments have indicated that omega-6 fatty

acids in soya oil were more effective at preventing lipid peroxidation in brains of methylmercury treated mice than oils rich in omega-3 fatty acids (DHA and EPA). In addition, mercury in seal liver is less bioavailable when it occurs at high concentrations, possibly due to the insoluble complexes it forms with selenium. Selenium, an essential trace element for humans, did not prevent methylmercury-induced pup mortality while another antioxidant, vitamin E, alone or in combination with selenium did. From a human perspective, to date there has been little epidemiologic evidence that selenium supplementation has a therapeutic benefit with environmentally associated health disorders (Lacour et al., 2004). Further studies dealing with interactions between dietary components and contaminants will have to consider both the mechanistic implications as well as the relevance.

4. Epidemiology and human biomarkers

Over the past decade most research efforts in Arctic Canada were focussed on the characterization of exposure of northerners. Epidemiological studies are now in place or in preparation. In order to detect early biological changes preceding overt diseases, biological markers of effects were also validated and introduced in epidemiological studies.

Van Oostdam et al. (1999) identified areas with knowledge gaps where research programs should be oriented. Under epidemiology, the following priorities were listed:

1) Evaluate the developmental status (neurobehavioural, immunological, reproductive, etc.) of newborns in the Arctic;
2) Evaluate fetal effects of mercury; and
3) Evaluate kidney function among people exposed to cadmium (via liver and kidney consumption, or smoking).

In this section, the discussion is limited to methylmercury and POPs. Other contaminants such as cadmium and lead are now considered of low priority since major sources are local point sources (smoking for cadmium and lead shot for lead), and information on their toxicity is already available, validated, and widely used by regional/national/international health organizations. Furthermore, most health risk uncertainty related to the presence of contaminants in the Arctic food chain is due to methylmercury and POPs. Most of this section is devoted to prenatal exposure and adverse developmental effects resulting in altered immune and nervous system function early in life. In addition, since oxidation is one of the possible mechanisms of mercury toxicity, biomarkers of oxidative stress are being investigated as biomarkers of effect in the adult Inuit population.

Since Inuit people constitute the most exposed group in the Canadian Arctic, this assessment is focussed on this group.

Conducting epidemiological studies in the Arctic is difficult and should take into account the following specific considerations.

Mixtures of contaminants found in the Arctic. Multi-chemical interactions of ecologically relevant mixtures (at relevant concentrations) can have an effect different from the sum of the effects of each component of the mixture. Arctic seafood contains a mixture of contaminants which may differ from those found in other parts of the world. How important these differences are is not known. The PCB congener profile found in human tissues in the Arctic, however, is similar to that found in southern Canada. Effects of mixtures need to be better understood.

Population size. The small size of the populations living in the Arctic limits the use of epidemiology. The number of disease cases is small and case control studies are extremely difficult to conduct. Only cross-sectional and cohort designs are possible. Health outcomes most amenable to epidemiological research in the Arctic are those with a range of stages from normal to abnormal, and which can be measured in all individuals (e.g., neurodevelopment, immune parameters, bone density, and fertility parameters), and are not based on a stochastic distribution (having the disease or not; e.g., cancer). It is probably possible to avoid this limitation by implementing circumpolar studies.

Toxicant–nutrient interactions. The possibility that nutrients present in seafood could modify or counteract the toxicity of contaminants is highly probable and specific to fish-eating populations. These interactions need to be better understood.

Genetic factors. It is important to recognize that genetic variability may affect the susceptibility of individuals or populations to the effects of pollutants. Gene/environment interactions could also explain why some populations or individuals are more susceptible than others. Since few genetic studies have been conducted in the Arctic, and considering that Aboriginal peoples have their own genetic background, the impact of genetic polymorphisms that are involved in xenobiotics metabolism and toxicity in the Arctic should be evaluated.

Confounders. Many health endpoints have multifactorial causes and environmental stressors can contribute in varying degrees to the etiology of these diseases. Compared to the role that lifestyle and genetic factors play in the etiology of most diseases, contaminants likely play a modest role. However, this contribution is highly preventable.

4.1. Immune system function

In children and young adults accidentally exposed to large doses of PCBs and polychlorinated dibenzofurans (PCDFs) in Taiwan ("Yu-Cheng disease"), serum IgA and IgM concentrations as well as percentages of total T-cells, active T-cells and suppressor T-cells were decreased compared to values of age- and sex-matched controls (Chang et al., 1981). The investigation of delayed-type hypersensitivity responses further indicated that cell-mediated immune system dysfunction

was more frequent among patients than controls. Infants born to Yu-Cheng mothers had more episodes of bronchitis or pneumonia during their first 6 months of life than unexposed infants from the same neighborhoods (Rogan et al., 1988). The authors speculated that the increased frequency of pulmonary diseases could result from a generalized immune disorder induced by transplacental or breast milk exposure to dioxin-like compounds, more likely PCDFs (Rogan et al., 1988). 8- to 14-year-old children born to Yu-Cheng mothers were shown to be more prone to middle-ear diseases than were matched controls (Chao et al., 1997).

In Dutch preschool children the effects of perinatal background exposure to PCBs and dioxins persisted into childhood and was associated with a greater susceptibility to infectious diseases. Levels of PCB exposure, based on serum PCB congener 153 values, of this cohort from two Dutch cities were comparable with those found among Canadian, northern Québec Inuit (Fig. 4.1.1). Common infections acquired early in life may prevent the development of allergy, so PCB exposure might be associated with the lower prevalence of allergic diseases found in this study (Weisglas-Kuperus et al., 2000). It should be also be noted that Canadian Inuit from northern Québec have higher levels of PCB 153 than modern US populations (1990s) studied, but similar to historical levels in the US (1960s and 1970s) and lower levels than those seen in the Faroe Islands (Fig. 4.1.1).
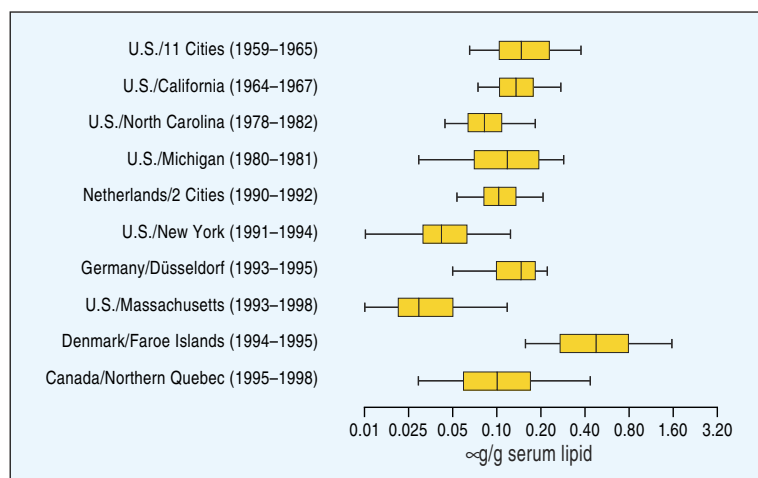

Fig. 4.1.1. Distribution of PCB 153 concentration in cord serum or plasma, 10 studies (Longnecker et al., 2003).

Some of the data presented in Section 2 on human exposure has relied on summary measures such as PCBs as Aroclor 1260. It should be noted that PCB 153 on average was found at the highest concentrations in all populations sampled (Table 2.2.2) and is one of the key PCBs that determines overall concentration of PCBs measured as Aroclor 1260.

Organic or inorganic mercury has cytotoxic activities for cellular components of the immune system in several species of rodents. Methylmercury, a form of organic mercury, can alter non-specific defense mechanisms, such as inhibition of natural killer (NK) cell's activity in rats and mice. It also decreases the expression of certain activation markers of T-cells (HLA-Dr and IL-2R) (NRC, 1992). Moreover, it has been well demonstrated that methylmercury can affect the function of B-cells and therefore reduce the humoral-mediated response (Daum, 1993).

4.1.1. Clinical outcomes

In Nunavik, an epidemiological study conducted during 1989–1991 investigated whether organochlorine exposure is associated with the incidence of infectious diseases and immune dysfunction in Inuit infants (Dewailly et al., 2000c). The number of infectious disease episodes during the first year of life of 98 breast-fed and 73 bottle-fed infants was determined. Concentrations of organochlorines (OCs) were measured in early breast milk samples and used as surrogates to prenatal exposure levels. *Otitis media* (middle-ear infection) was the most frequent disease, with 80% of breast-fed and 81% of bottle-fed infants experiencing at least one episode during the first year of life. During the second follow-up period, the risk of *otitis media* increased with prenatal exposure to p,p'-DDE, HCB and dieldrin. The relative risk (RR) for 4- to 7-month-old infants in the highest tertile of p,p'-DDE exposure compared to infants in the lowest was 1.87 [95% confidence interval (CI), 1.07–3.26]. The lowest tertile had a breast milk concentration of p,p'-DDE of <730 vs. >1320 μg/kg lipid in the third or highest tertile. The relative risk of *otitis media* over the entire first year of life also increased with prenatal exposure to p,p'-DDE (RR, 1.52; 95% CI, 1.05–2.22) and HCB (RR, 1.49; 95% CI, 1.10–2.03). Furthermore, the relative risk of recurrent *otitis media* (≥ 3 episodes) increased with prenatal exposure to these compounds. No clinically relevant differences were

noted between breast-fed and bottle-fed infants with regard to biomarkers of immune function, and prenatal OC exposure was not associated with these biomarkers. In this study, the potential confounders were not fully controlled i.e., omega-3 fatty acids, vitamin A and smoking. For this reason, studies were designed and initiated to address these issues.

In Nunavik, there are two ongoing studies on the effect of OCs on immune function and infectious disease incidence. The first one is a component of the cohort study, where infectious diseases are monitored during the first year of life (Dallaire et al., 2004). Results showed that that prenatal exposure to PCBs and DDE was associated with a higher incidence rate of acute infections during the first 6 months of life. Although the associations were not always statistically significant because of limited statistical power, infants in the highest quartiles of PCBs and DDE exposure had systematically more episodes of infections than their counterparts in the first quartile of exposure. This was mostly observed during the first 6 months of life, and the association was much weaker when infections during the first 12 months of life were considered.

The second study is a review of all the medical files of 350 preschool children who participated in the Nunavik umbilical cord blood monitoring program in 1993–1996 (Dallaire et al., in preparation(b)). Preliminary results showed that during the first 5 years of life, children in the higher quartiles of PCB prenatal exposure had a significantly higher incidence rate of outpatient visits for *otitis media* and LRTIs, but not for URTIs. The association between PCB exposure and otitis adopted a clear dose–response pattern. This study confirms the associations previously observed in the same population. Furthermore, it shows that the relation between OCs and respiratory infection seems to persist passed the first months of life.

It should also be noted, however, that some studies have not found a link between pre or post-natal PCB or dioxin exposure in infants and respiratory tract symptoms but did find shifts in various types of white blood cells related to contaminant levels (Weisglas-Kuperus et al., 1995). Other factors such as vitamin A and omega-3 fatty acids can also modulate immune function and vitamin A has been found to be deficient in some Canadian Inuit populations (Blanchet et al., 2000). It will be important to see the full results of the Nunavik studies when it will be possible

to address a number of the important determinants of immune status.

4.1.2. Biomarkers

In 1997, an international symposium was held in Bilthoven (Netherlands) to discuss the most appropriate biomarkers of effect that could be used in epidemiological studies investigating the effects of contaminants on immune function (Van Loveren et al., 1999). One of the stronger conclusions was to use antibody responses to vaccination with an antigen having no prior exposure.

4.1.2.1. Lymphocyte subsets and immunoglobulins. In the course of the 1990 cohort conducted in Nunavik, biomarkers of immune system function (lymphocyte subsets and plasma immunoglobulins) were determined in venous blood samples collected from breast-fed and bottle-fed infants at 3, 7 and 12 months of age. Results showed that at age 3 months, concentrations of white blood cells (lymphocytes and more specifically those of the CD4 subtype), were lower ($p \leq 0.05$) in blood samples from breast-fed babies when compared to those in the bottle-fed group. At 7 and 12 months of age, IgA concentrations were lower ($p \leq 0.05$) in breast-fed infants than in bottle-fed infants. This also appeared to be the case for CD4/CD8 ratios, although differences were not statistically significant. None of the immunological parameters was associated with prenatal OC exposure (Dewailly et al., 2000c).

In the scope of the ongoing cohort study on neurodevelopmental effects of Arctic contaminants (Muckle et al., 2001a), an immune component was added in 1998. The following immune function biomarkers have been selected: antibody response following vaccination; complement system; cytokine production by Th1/Th2 cells; and vitamin A status.

4.1.2.2. Antibody response following vaccination. Antibody response to vaccination is an intermediate marker of the competence of the adaptive immunity to infections. Vaccination programs include essentially three types of products: 1) killed vaccine (influenza, whole-cell pertussis, inactivated polio); 2) protein-conjugated or protein-based vaccine (*Haemophilus influenzae* type b, diphtheria, tetanus, acellular pertussis vaccine, hepatitis B); and 3) attenuated live virus (measles–mumps–rubella, varicella, BCG). Antibody response to conjugated *Haemophilus influenzae* type b (Hib) is of great interest. This vaccine is important in Inuit children because, prior to immunization, Hib was the most frequent cause of bacterial meningitis in Inuit children, which was 5–10 times more frequent than in caucasian children (Ward et al., 1986).

4.1.2.3. Complement system. The complement (C′) system plays an important role in natural immunity against infectious agents. It is particularly essential in young children for whom the acquired immune system is not yet fully developed. Deficiency of many of the C′ components is associated with increased susceptibility to infections, generally of the upper respiratory tract. In a murine model, exposure to OC compounds increased the susceptibility to *Streptococcus pneumoniae* infections, decreased C3 levels, and lowered total C′ hemolytic activity (White et al., 1986).

4.1.2.4. Cytokine production by Th1/Th2 Cells. Organochlorines and heavy metals could modulate the production of Th1/Th2-type cytokines. Along with their effects on Th1/Th2-type cytokines, OCs and metal ions are known to alter B-cell activity and to impair host resistance to several bacterial and viral infections (Heo et al., 1996). High levels of OCs and metal ions in blood and tissues are frequently related to fish consumption. Fish oil-supplemented diets (rich in omega-3 fatty acids) have generally been shown to reduce plasma levels of some cytokines. Most human studies have shown decreased plasma levels or diminished production of IL-1 and TNF. Both contaminants and omega-3 fatty acids alter the balance between Th1- and Th2-type cytokines, and could impair host resistance to infections. One of the principal limitations of using cytokines is their high variability due to minor infections (usually non-detected). The extremely high incidence of minor infections in the Arctic strongly limits the use of cytokines in epidemiological studies.

4.1.2.5. Vitamin A status. Vitamin A influences the expression of over 300 genes and thus plays a major role in cellular differentiation, including that of cells related to immune response (Sommer and West, 1996; Semba, 1994). Results from different animal and human studies vary; however, almost all studies revealed that lymphopoiesis and/or maturation of lym-

phocytes are altered (generally reduced) with vitamin A deficiency (Sommer and West, 1996; Olson, 1994; Semba, 1994). Vitamin A deficiency could increase the frequency, severity, and duration of infections. Lower respiratory disease was associated with vitamin A deficiency in many cross-sectional clinical and population-based studies. Also, *otitis media* was among the first infections to be associated with vitamin A deficiency in humans (Sommer and West, 1996; Bloem et al., 1990; Semba, 1994).

Vitamin A clinical deficiency has never been documented in Canadian Arctic populations. However, numerous studies have documented inadequate intakes of vitamin A (Receveur et al., 1998a). A more recent report suggests that the daily vitamin A intake in Nunavik falls below the recommended intake (Blanchet et al., 2000). Furthermore, persistent organic pollutants such as OCs have been shown to alter vitamin A homeostasis in many species, including primates (reviewed by Zile, 1992). It is important, therefore, to gain a better understanding of the relationships between vitamin A, OC levels, and infectious disease incidence in Arctic populations.

In a recent pilot study, plasma concentrations of retinol were measured in cord blood samples to assess the vitamin A status of 135 Inuit newborns from Arctic Québec and 22 newborns from the general population of southern Québec. Mean retinol concentrations were 148.2 ng/mL and 242.8 ng/mL, respectively (Dallaire et al., 2003b). Vitamin A levels of more than 200 ng/mL have been considered as normal vitamin A status, those between 100 and 200 ng/mL as low, and those lower than 100 ng/mL as deficient (Sommer and West, 1996). The difficulty of using vitamin A as an effect biomarker of PCB exposure is related to 1) the variability of vitamin A intake among individuals and 2) non-systematic supplementation programs in infants. Vitamin A status is being measured in the preschool and the newborn studies currently underway in Nunavik.

4.2. Neurodevelopment

4.2.1. Clinical outcomes

4.2.1.1. Polychlorinated biphenyls (PCBs). Effects of prenatal exposure to background levels of PCBs and other OCs from environmental sources have been stu-

died since the 1980s in prospective longitudinal studies in Michigan, North Carolina, the Netherlands and Oswego, New York. The principal source of PCB exposure was Great Lakes fish consumption in both the Michigan (Schwartz et al., 1983) and the Oswego (Stewart et al., 1999) studies, and consumption of dairy products in the Netherlands (Koopman-Esseboom et al., 1994a). Newborns from the North Carolina cohort were exposed to background levels of PCBs, and there was no specific source of exposure (Rogan et al., 1986b). Comparison of exposure levels between these different cohort studies is presented in Fig. 4.1.1.

Growth effects. The effects of prenatal exposure to PCBs and other OC compounds from environmental sources on birth size and duration of pregnancy have been investigated in the Michigan, North Carolina and Netherlands studies In Michigan, higher cord serum PCB concentrations were associated at birth with lower weight, smaller head circumference, and shorter gestation (Fein et al., 1984; Jacobson et al., 1990b). Similar effects were observed in the Netherlands study up to 3 months of age (Patandin et al., 1999). Prenatal PCB exposure was not associated with birth size or growth at 1 year of age in North Carolina, the cohort with the lowest PCB exposure (Rogan et al., 1986a).

A recent study on infant development was conducted in northern Québec. Prenatal PCB exposure in this cohort is 2–3 times higher than that observed in general populations in southern Québec and in Massachusetts (USA); is similar to that found in Michigan and the Netherlands; and is about 2–3 times lower than found in Greenland and the Faroe Islands. After controlling for potential confounders with the studied outcomes, higher cord plasma PCB 153 concentrations were associated with lower weight and height at birth, and to shorter gestation (Muckle et al., in preparation). These findings are consistent with the results of previous epidemiological studies conducted in populations exposed to PCBs through consumption of PCB-contaminated food. The hypothesis of protective effects of omega-3 fatty acids against the negative effects of PCB exposure on birth outcomes was examined for the first time in this study. The results indicate that the negative effects of prenatal PCB exposure on human growth and gestation remained significant despite the significant beneficial effects of omega-3 fatty acids on these same endpoints (Muckle et al., 2004).

Neurobehavioural effects. Exposure to PCBs was associated with less optimal newborn behavioural function (e.g., reflexes, tonicity and activity levels) in three of the four studies previously described (Huisman et al., 1995a; Rogan et al., 1986a; Stewart et al., 2000). Adverse neurological effects of exposure to PCBs have been found in infants up to 18 months of age in the Netherlands study (Huisman et al., 1995b). In Michigan, prenatal PCB exposure was associated with poorer visual recognition memory in infancy (Jacobson et al., 1985, 1990a, 1992), an effect that was recently confirmed in the Oswego study (Darvill et al., 2000). In North Carolina, deficits in psychomotor development up to 24 months were seen in the most highly exposed children (Gladen et al., 1988; Rogan and Gladen, 1991). In Michigan, the Netherlands, Oswego and Germany, prenatal PCB exposure was linked to poorer intellectual function during childhood (Jacobson et al., 1990a; Jacobson and Jacobson, 1996; Patandin et al., 1999; Stewart et al., 2003; Vreugdenbil et al., 2001; Walkowiak et al., 2001). Virtually all the adverse neurobehavioural effects reported to date were linked to prenatal exposure, indicating that the embryo and fetus are particularly vulnerable to these substances. Moreover, recent analyses from the Michigan and the Netherlands cohorts underline the greater vulnerability to prenatal PCB exposure in non breast fed infants (Jacobson and Jacobson, 2004; Vreudenhil et al, in press, cited in Jacobson and Jacobson, 2004).

One prospective, longitudinal study, performed in the Faroe Islands, examined the effects of prenatal exposure to low doses of methylmercury resulting from fish and pilot whale consumption (Grandjean et al., 1992, 1997). Because pilot whale tissues contain other neurotoxicants, this cohort was also exposed to PCBs and, as such, is the only cohort studied to date where the main source of PCB exposure was consumption of marine mammals, as is the case for the Inuit. Further analysis provides some evidence that the effects of methylmercury identified in this study are not the consequence of exposure to PCBs. Again, PCB concentrations in cord serum in these different studies are presented in Fig. 4.1.1.

4.2.1.2. Methylmercury. Three well-designed, prospective, longitudinal studies that examined the neu-robehavioural effects of prenatal exposure to low doses of methylmercury were performed in New Zealand, the Faroe Islands, and the Seychelles Islands. High methylmercury exposure in the Faroese population results from fish and pilot whale consumption (Grandjean et al., 1992); deep-sea and reef fish consumption is the source of exposure for the Seychelles population (Myers et al., 1995); and fish consumption is the source of exposure for the New Zealand population (Kjellström et al., 1986).

Comparisons of mercury concentrations in Inuit populations with those cohorts are shown in Table 4.2.1. Greenlandic Inuits have the highest levels of maternal and cord blood mercury. High and quite similar levels of mercury are also seen in the Faroe Islands, Seychelles and New Zealand and Nunavik studies and lower levels are found in the southern Québec and US populations cited (Muckle et al., 2001b).

The Faroe Islands study reported associations between maternal hair mercury concentrations corresponding to the pregnancy period and children's performance on neurobehavioural tests, particularly in the domains of fine motor function, attention, language, visual–spatial abilities, and verbal memory (Grandjean et al., 1997). Those effects were also found to be associated with cord blood mercury concentration (Grandjean et al., 1999). In the New Zealand study, higher hair mercury levels were associated with poorer neurodevelopmental test scores in similar domains to those observed in the Faroe study (Crump et al., 1998; Kjellström et al., 1986). In contrast, prenatal methylmercury exposure was not related to neurobehavioural effects in the Seychelles Islands study (Davidson et al., 1995, 1998; Myers et al., 1995). Recently, the authors of the Seychelles Islands study reported that two of the 21 neurobehavioural end points assessed at 9 years of age were associated with prenatal methylmercury exposure, but their conclusion was that these associations were probably due to chance as a result of multiple analyses (Myers et al., 2003).

Differences in the marker of mercury exposure, the end points assessed, age at testing, source and pattern (stable vs. episodic) of exposure between the Faroe and the Seychelles Islands studies have been suggested to account for the differences in the find-

Table 4.2.1

Comparison of mercury (total) concentrations in Nunavik with those observed in other cohorts

Cohort (reference)	Medium	Years	N	Geometric mean	Range	Interquartile range
Canada						
Nunavik Inuit	Cord blood (μg/L)	1996–2000	95	18.5	2.8–97.0	12.0–27.2
	Maternal blood (μg/L)	1993–1995	130	10.4	2.6–44.2	6.6–17.0
	Maternal hair (μg/g)	1992	123	3.7	0.3–14.0	2.5–6.2
Southern Quebec	Cord blood (μg/L)[a]	1977–1978	1108	1.0	0.9–1.0[b]	
James Bay Cree	Women hair, not pregnant (μg/g)[c]	1981	70	2.5	Max = 19.0	
Northern Quebec Cree	Maternal hair (μg/g)		215	6.0[d]	5.2[e]	
USA	Women hair, not pregnant (μg/g)	1981	1274	0.36[f]	0.14–0.90	
			1546	0.24[g]	0.09–0.62	
Faroe Islands						
First cohort	Cord blood (μg/L)	1986–1987	894	22.9		13.4–41.3
	Maternal hair (μg/g)	1994–1995	914	4.3		2.6–7.7
Second cohort	Cord blood (μg/L)		163	20.4	1.9–102.0	11.8–40.0
	Maternal hair (μg/g)		144	4.1	0.4–16.3	2.5–7.4
Seychelles Island						
Main study	Maternal hair (μg/g)	1989–1990	740	5.9	0–25	6.0
Pilot study	Maternal hair (μg/g)		789	6.6	0.6–36.4	6.1
New Zealand	Maternal hair (μg/g)	1978–1984	935	8.3[d]	6.0–86.0	
Greenland, Disko Bay	Cord blood (μg/L)	1994–1996	178	25.3	2.4–181.0	
	Maternal blood (μg/L)	1994–1996	180	12.8	1.9–75.6	

Source: Muckle et al. (2001b).

[a] The average Hg concentration was reported in nmol/L, this concentrations was divided by 5 to transform to μg/L.

[b] 95% confidence interval.

[c] Women aged between 15 and 39 years old.

[d] Arithmetic mean.

[e] Standard deviation.

[f] Among seafood consumers.

[g] Among non-seafood consumers.

ings (NRC, 2000). The New Zealand study, in which the exposure and research design were similar to the Seychelles Islands study, also found neurobehavioural effects, as did the pilot study conducted in the Seychelles Islands population.

Since 1997, Nunavik mothers and infants have been observed in a prospective longitudinal study. Exposure data were published (Muckle et al., 2001a,b). Statistical analysis of the data is ongoing and results on growth and neurobehavioural effects of perinatal exposure to PCBs, other OC compounds, and methylmercury will be published soon.

In addition, a sub-sample of the newborns who participated in the Nunavik cord blood monitoring program in 1993–1996 were evaluated at preschool age in 2000 and 2001 using a battery of sensitive tests designed to assess fine motor, gross motor, neurological, and neurophysiological functions. Results will be available in the near future.

4.2.2. Biomarkers of developmental effects

4.2.2.1. Cytochrome P4501A1 induction and DNA adduct formation. Overexpression and increased activity of cytochrome *P*4501A1 (CYP1A1) in placenta have been linked to reduced birth weight (Pelkonen et al., 1979; Lucier et al., 1987). This enzyme can bioactivate several xenobiotics to reactive intermediates that can bind DNA.

CYP1A1 induction and DNA adducts were tested as possible markers of early developmental effects related to OC exposure in Inuit women from Nunavik (Lagueux et al., 1999). CYP1A1-dependent ethoxyresorufin-*O*-diethylase activity (EROD) and DNA adducts were measured in placenta samples obtained from 22 Inuit women from Nunavik. These biomarkers were also assessed in 30 women from a Québec urban centre (Sept-Îles) who served as a reference group. Prenatal OC exposure was determined by mea-

suring these compounds in umbilical cord plasma. Placental EROD activity and the amount of DNA adducts thought to be induced by OC exposure were significantly higher in the Nunavik group than in the reference group. For both biomarkers, smoking was found to be an important confounding factor, but OC exposure was significantly associated with EROD activity and DNA-adduct levels when controlling for self-declared smoking status. It was then concluded that CYP1A1 induction and DNA adducts in placental tissue could constitute useful biomarkers of early effects induced by environmental exposure to OCs (Lagueux et al., 1999). In the latter study, however, there were very few Inuit women who did not smoke during pregnancy, the smoker and non-smoker groups were not balanced, and the smoking status was not ascertained with a biomarker. Therefore, a second study was conducted to determine if environmental exposure to PCBs induces placental CYP1A1 in Inuit women. This more recent study was designed to control the confounding effects of smoking better. The use of cotinine concentration in meconium and of cadmium concentrations in placenta as markers of prenatal exposure to tobacco smoke was previously validated (Pereg et al., 2001). Placenta, cord blood and meconium samples were obtained from 35 Inuit women in Nunavik and 30 women in Sept-Îles (reference population). Efforts were made to sample more smokers in the Sept-Îles population and more non-smokers in the Nunavik population in order to balance the smokers and non-smokers groups. Smoking status was ascertained with the use of cotinine concentration in the meconium and, when necessary, individuals were reassigned to the proper smoking category based on this marker.

PCB concentrations were measured in cord plasma and CYP1A1 activity (EROD) was assessed in placental tissue. Despite the higher PCB exposure of the Inuit population, both groups showed similar EROD activities when data were stratified according to the smoking status ascertained by the cotinine concentration. In the Nunavik population, EROD activity was correlated with 2,2′,4,4′,5,5′-hexachlorobiphenyl (PCB 153) plasma concentration (a marker of exposure to the environmental PCB mixture). However, cotinine concentrations in meconium were also significantly correlated to PCB 153 plasma concentrations, and multivariate analyses failed to demonstrate a signifi-

cant contribution of PCB exposure to placental CYP1A1 activity when tobacco smoking (as estimated with cotinine concentration in the meconium) was included in the analysis. Results from this study, therefore, showed that low-level environmental PCB exposure does not induce any increase in CYP1A1 activity in the placenta, leaving tobacco smoking as the major modulating factor (Pereg et al., 2002). Exposure of Inuit from Nunavik to PCBs was much lower than the PCBs/PCDFs exposure in Taiwanese children. This could explain these contradictory results.

4.2.2.2. Thyroid hormones. Although many theories exist on how PCBs affect neurodevelopment, the main hypothesis involves the effect of PCBs on thyroid hormone homeostasis (Porterfield and Hendry, 1998). Thyroid hormones regulate neuronal proliferation, cell migration and differentiation, including control of when differentiation begins and when cell proliferation ends (Hamburgh, 1969).

One hundred and eighty-two singleton term births were evaluated in the Faroe Islands, where marine food includes pilot whale (Steuerwald et al., 2000). Maternal serum, hair, milk and umbilical cord blood were analyzed for contaminants. Levels of essential fatty acids, selenium, and thyroid hormones were determined in cord blood. Each infant's neurologic optimality score was determined at two weeks of age, adjusted for gestational age, and predictors were assessed by regression analysis. Thyroid function was normal and not associated with PCB exposure.

In the Netherlands study, 418 mother–infant pairs were enrolled. Thyroid hormone levels were in the normal range, but higher dioxin and PCB–TEQ levels in human milk were significantly correlated with lower thyroid T3 (triiodothyronine) and T4 (thyroxine) levels and with higher levels of thyroid-stimulating hormone (TSH) in the infants' plasma at the age of 2 weeks and 3 months. Thyroid hormone level alterations detected in this study, however, were not directly associated with neurological dysfunction (Koopman-Esseboom et al., 1994b).

In Nunavik, 466 measurements were taken of thyroid hormones in Inuit newborns' umbilical cord blood samples in the cord blood monitoring program that took place between 1993 and 1996. Free T4 (thyroxine), total T3 (triiodothyronine), TBG (thyroxin-binding globulin) and TSH were measured. Hydroxylated

metabolites of PCBs (OH-PCBs) and other phenolic compounds were also measured in a subsample ($n = 10$). As expected, birth weight was positively associated with thyroid hormones (thyroxine, TBG). For this reason, further analyses were adjusted for birth weight. After adjustment, TBG and TSH levels were significantly and negatively associated with PCB congener levels (Dewailly et al., 1998)

The main transport mechanism of thyroid hormones to the brain requires passing through the blood/brain barrier via a thyroid hormone transport protein called transthyretin (TTR) (Chanoine and Braverman, 1992). Although PCBs show some binding affinity for TTR (Chauhan et al., 2000), OH-PCBs have much higher in vitro binding affinities—as high as 12 times the binding affinity of the natural ligand, thyroxine (T4) (Lans et al., 1994; Cheek et al., 1999; Brouwer, 1991). Binding to TTR is not limited to OH-PCBs—other chlorinated phenolic compounds such as pentachlorophenol (PCP), halogenated phenols, and brominated flame retardants also have strong affinities for TTR (Van den Berg et al., 1991; Van den Berg, 1990; Meerts et al., 2001). Recently, PCP was found to be the dominant phenolic compound determined in Inuit whole blood (Sandau et al., 2000). Other halogenated phenolic compounds may also be important contaminants in plasma, as they have been found to exhibit toxicological properties similar to those of OH-PCBs (Van den Berg et al., 1991; Schuur et al., 1998).

PCBs have been previously measured in umbilical cord plasma; however, few studies have examined levels of hydroxylated metabolites in blood, especially in humans. OH-PCBs have been quantified recently in Canadian Inuit whole blood (Sandau et al., 2000) and in Swedish and Latvian fish-eaters (Sjödin et al., 2000). Sandau et al. (2000) examined chlorinated phenolic compounds in umbilical cord plasma of newborns in three populations with different PCB exposures, including the Inuit population. Retinol and thyroid hormone status [triiodothyronine (T3), free thyroxine (T4), thyroid-stimulating hormone (TSH), and thyroxin-binding globulin (TBG)] were determined in most samples. The authors found an inverse association ($r = -0.47$; $p = 0.01$) between log-normalized free thyroxine and log-normalized total phenolic compounds (sum PCP and OH-PCBs). Total chlorinated phenolic compounds were also negatively asso-

ciated with T3 ($r = -0.48$, $p = 0.03$) (Sandau et al., 2002).

4.3. Sex hormone disruption

The development and maintenance of reproductive tissues are to a large extent controlled by steroid hormones. Some environmental chemicals mimic, while others antagonize natural hormone activity when tested with in vitro assays or in whole animal models. Studies dating back to the late sixties identified o,p'-DDT, a minor constituent of technical DDT, as a weak estrogenic compound capable of causing an increase in rat uterine weight in the classic immature female rat model (Bitman and Cecil, 1970). This compound and a few others sharing estrogenic properties have been implicated in abnormal sexual development in birds (Fry and Toone, 1981), and in feminized responses in male fish (Jobling et al., 1995).

Certain male reproductive tract disorders (cryptorchidism, hypospadiasis, and testicular cancer) have been reported to be increasing in parallel with the introduction of xenoestrogens such as DDT into the environment. Reduced semen quality was also reported in certain regions of the world during the last half of the 20th century (Carlsen et al., 1992; Auger et al., 1995). Although these alterations are thought to be mediated by the estrogen receptor, they are also consistent with inhibition of androgen receptor-mediated events. Kelce et al. (1995) identified the major and persistent DDT metabolite, p,p'-DDE, as a potent anti-androgenic agent in male rats. In addition to inhibiting androgen binding to the androgen receptor, this compound, when administered to pregnant dams, also induced characteristic anti-androgenic effects in male pups (reduced ano-genital distance; presence of thoracic nipples). Treatment with p,p'-DDE at weaning delayed the onset of puberty, while treatment of adult rats resulted in reduced seminal vesicle and ventral prostate weights.

2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) is yet another OC which has been shown to alter sexual development in male rats (Mably et al., 1992). Decreases in epididymis and caudal epididymis weights, and in daily sperm production and caudal epididymal sperm number were observed at day 120 and at most earlier times, when a dose as little as 64 ng/kg was administered to dams on day 15 of gesta-

tion. A number of compounds structurally related to TCDD, including other 2,3,7,8-chloro-substituted dibenzo-*p*-dioxins, dibenzofurans, as well as non-*ortho* and mono-*ortho* substituted PCB congeners, bind to the Ah receptor and display similar toxicological properties.

Typical OC mixtures found in highly exposed human populations contain a large variety of OC compounds, including substances with estrogenic, anti-estrogenic, or anti-androgenic capacities. It may therefore be anticipated that complex real life mixtures, composed of numerous compounds that can interact with different receptors involved in cell differentiation and growth, could affect reproduction and development, and be involved in the pathogenesis of hormonally responsive cancers.

4.3.1. Clinical outcomes

4.3.1.1. Sexual maturation of newborn males. DDE was recently found to inhibit binding of androgen to its receptor and to block androgen action in rodents. Normal development of male genitalia in mammals depends on androgen action. Recently, Longnecker et al. (2002) used stored serum samples to examine the relationship between maternal DDE levels during pregnancy and adjusted odds of cryptorchidism ($n=219$), hypospadias ($n=199$), and polythelia (extra nipples) ($n=167$) among male offspring, using a nested case-control design with one control group ($n=552$). Subjects were selected from a United States birth cohort study begun in 1959–1966, when DDE levels were much higher than they are at present. Compared with boys whose mother's recovery-adjusted serum DDE level was less than 21.4 μg/L, boys with maternal levels greater than or equal to 85.6 μg/L had adjusted odds ratios of 1.3 (95% confidence interval (CI): 0.7, 2.4) for crypt-orchidism, 1.2 (95% CI: 0.6, 2.4) for hypospadias, and 1.9 (95% CI: 0.9, 4.0) for polythelia. For cryptorchidism and polythelia, the results were consistent with a modest-to-moderate association, but in no instance was the estimate very precise. The results were inconclusive. In this cohort, DDE concentrations in umbilical cord serum were much higher than in Nunavik (geometric mean -2.2, range of 0.14 to 18 μg/L, Table 2.2.1).

Sexual maturation of newborn males is examined within the on-going cohort study conducted in

Nunavik, and ano-genital distance and penis length are recorded. In adults, no study on hormone-associated diseases (breast cancer, endometriosis, and male fertility) has been conducted in the Canadian Arctic.

4.3.1.2. Environmental risk factors for osteoporosis. POPs have recently been associated with an increased risk of osteoporosis in humans. The relationship between DDE and bone mineral density was recently examined in 68 sedentary Australian women who reported adequate dietary intake of calcium (Beard et al., 2000). Reduced bone mineral density was correlated significantly with age ($r=-0.36$, $p=0.004$), as well as with increases in the log of DDE levels in serum ($r=-0.27$, $p=0.03$). The authors also used multiple-regression analysis to examine the influence of other predictor variables on the relationship between log DDE and bone mineral density. The strongest model ($p=0.002$) included log DDE ($p=0.018$), age ($p=0.002$), and years on hormone replacement therapy ($p=0.10$) as predictor variables, and this model afforded a prediction of 21% of bone mineral density variation. These results suggest that past community exposures to DDT may be associated with reduced bone mineral density in women. As a potent androgen receptor antagonist, DDE may reduce the inhibitory effect on cytokines and result in the inappropriate turnover of osteoclasts or inadequate production of osteoblasts within bone marrow, thus leading to reduced bone density (Beard et al., 2000). These are interesting results, but they must not be over-interpreted as this was a small study and the menopausal status and time since menopause, two important determinants of osteoporosis, were not included in the analyses.

A study was conducted in Nuuk, Greenland, in September 2000 to evaluate the prevalence of risk factors for osteoporosis fracture and more particularly environmental factors and their association with bone mass in menopausal women (Côté et al., 2005). The risk of osteoporosis fracture was assessed using an ultrasound bone densitometer. All three ultrasound parameters adjusted for age were lower in this Inuit population compared with the women of Québec (Côté et al., 2005).

The study found that 19% of the Inuit women had a high risk of osteoporosis fracture compared to 7.2% for the women of southern of Québec. To identify which risk factors were associated with ultrasound parameters, a multiple linear regression model involving the stepwise removal of non-significant independent variables was used. The independent predictors of the bone density were age ($p=0.018$), BMI ($p=0.018$), former users of oral contraceptives ($p=0.003$), current hormone replacement therapy users ($p=0.005$), and the sum of log of mono-*ortho* PCB TEQs ($p=0.004$). These variables accounted for 36% of the variance of the bone density ($r^2=0.359$) (Côté et al., 2005). Mono-*ortho* substituted congeners (IUPAC numbers 105, 118 and 156) share some structural similarities with TCDD and can bind to the aryl hydrocarbon receptor (AhR). The consequences of activation of the AhR pathway on osteoporosis, however, are not clear. One possible explanation is that dioxin-like compounds elicit a broad spectrum of anti-estrogenic activities and may reduce bone density through this mechanism. In summary, mono-*ortho* PCB concentrations were associated with a low bone density, and this association remained significant after controlling for potential confounding factors (Côté et al., 2005).

4.3.2. Hormonal biomarkers

4.3.2.1. Hormone profiles. To obtain a steroid profile of androgens for both precursors and metabolites of dihydrotestosterone (DHT), a series of steroids, including DHT, could be measured: dehydroepiandrosterone (DHEA), androst-5-ene-3 eta,17-diol, androstenedione, testosterone, DHT, estrone, estradiol, DHEA sulfate, androstane-3,17-diol glucuronide, and androsterone glucuronide. These steroid levels help explain alteration in steroidogenic enzymes in classical steroidogenic tissues such as adrenals and the testis, and for steroidogenic transforming enzymes localized in peripheral tissues (prostate and skin).

In the Arctic, no study has been conducted to determine hormone profiles. A pilot study was recently performed in Greenland ($n=48$ males) and the following male hormones were measured: DHEA, delta5-diol, delta4, testosterone, DHT, E1 and E2. A study on male fertility is also on going in Greenland (Toft et al., 2003).

4.4. Oxidative stress

Although oxidative stress has been associated with many chronic diseases (e.g., cancer, cardiovascular disease (CVD), neuro-degenerative disorders, etc.), no specific epidemiological study of these outcomes has been conducted in the Arctic to assess the role of oxidants and antioxidants. Results reported by Salonen et al. (1995) suggest that the high CVD mortality observed among fish-eaters from Finland could be explained by the high mercury content of the fish (mainly non-fatty freshwater species), which could counteract the beneficial effect of fish consumption. This group noted a significant association between mercury concentration in the hair of eastern Finnish men and the risk of coronary heart disease (CHD). Mercury can promote the peroxidation of lipids, resulting in more oxidized low-density lipoprotein (LDL), which has been implicated as an initiator of atherosclerosis. In the same population, Salonen et al. (1982) previously observed an enhanced risk of CHD death in subjects with low serum selenium concentrations, an antioxidant which may possibly block the mercury-induced lipid peroxidation.

That both mercury and selenium can modulate CHD risk is also suggested by observations in fish-eating coastal populations such as Inuit living in Arctic regions. Inuit consume large amounts of fish and marine mammals, and consequently receive large doses of mercury. Contrary to the situation in eastern Finland, however, the mortality rate from CHD in Inuit is low. Although, it was reported that omega-3 fatty acids are strong protective factors for cardiovascular diseases among Inuit (Dewailly et al., 2001a), the protection could also result from a high intake of selenium, (Bélanger et al., 2003), through the consumption of traditional/country foods such as muktuk (beluga and narwhal skin) and sea mammal liver which are rich in selenium.

Methylmercury is a highly toxic environmental neurotoxin that can cause irreparable damage to the central nervous system (Choi, 1989; Clarkson, 1993, 1997). Although the underlying biochemical and molecular mechanisms that lead to impaired cell function and nerve cell degeneration are not well understood, there is abundant evidence supporting the hypothesis that a major mechanism of methyl-

mercury neurotoxicity involves oxidative stress (Sarafian and Verity, 1991; Yee and Choi, 1996). Mercury increases production of reactive oxygen species (ROS) via deregulation of mitochondrial electron transport, as well as through glutathione (GSH) depletion (Lund et al., 1993). The oxidative stress hypothesis is clearly supported by the finding that methylmercury neurotoxicity can be inhibited by various antioxidants, including selenium (Park et al., 1996) and *N*-acetyl-L-cysteine, a precursor of GSH (Ornaghi et al., 1993).

Glutathione peroxidase (GSHPx) and glutathione reductase (GSHRd) activities were measured in blood samples from 142 residents of Salluit, Nunavik (Dewailly et al., 2001b). Activities of enzymes involved in detoxication of free radicals were measured to investigate the relationships between mercury, selenium and oxidative stress. Mercury was found to be negatively correlated with GSHRd activity, an NADPH-dependent enzyme that regenerates glutathione from glutathione disulfide. In contrast, plasma selenium concentration was positively correlated to GSHPx activity, a selenoenzyme that catalyzes the conversion of hydrogen peroxide to water. Mercury exposure may, therefore, diminish defense mechanisms against oxidative stress by limiting the availability of glutathione, while selenium may afford protection by favouring the destruction of hydrogen peroxide.

A biochemical assessment of the oxidative stress in adult residents of Nunavik is underway using the following three other indices:

1) The first is the ratio of coenzyme Q10-reduced form (ubiquinol-10) to oxidized coenzyme Q10 (ubiquinone-10) in plasma, which is now considered one of the most reliable and sensitive indices of an oxidative stress in vivo (Yamashita, 1977). In contrast to the total level of coenzyme Q10, which is reported to be associated with multiple factors including gender, age, cholesterol and triglycerides levels (Kaikkonen et al., 1999), the ubiquinol-10/ubiquinone-10 ratio index is apparently independent of these variables and thus represents an oxidative stress index of choice.
2) Increased levels of specific F2-isoprostanes (direct oxidation metabolites of arachidonic acid) in plasma and/or urine are another index recently used to demonstrate oxidative stress in several pathological conditions involving oxygen free radical formation (Pratico, 1999; Patrono and FitzGerald, 1997). The most easily measurable and frequently used F2-isoprostane species as a marker of oxidative stress in vivo is 8-isoprostaglandin F2-alpha (Pratico, 1999; Patrono and FitzGerald, 1997).
3) The level of plasmatic LDL oxidation could also be assessed as a potential marker of oxidative stress. Preliminary results indicate that oxidized LDL was significantly lower in Inuit subjects than normal Caucasian population ($1.6\times$, $p < 0.0001$), supporting the previous observation that omega-3 fatty acids and selenium could be strong protective factors for cardiovascular diseases among Inuit (Bélanger et al., 2003).

These results will become available in 2006. This study also includes a neurological assessment and should produce some interesting results on another measure of oxidative stress and its possible relationship to neurological outcomes.

5. Risk-benefit characterization, assessment and advice

The contamination of wildlife in the Arctic ecosystem poses a complex problem. Weighing the benefits of country food consumption against the risk of contaminant exposure is very difficult, and cuts across the disciplines of nutrition, toxicology, environmental policy, sociology, and public health practice; and each discipline has its unique perspective. A comprehensive risk-benefit assessment/management framework is needed to coordinate the various perspectives and to respond to the challenging task of weighing the risks and benefits of country food consumption in northern Canada.

The NCP has adopted such a framework for risk assessment and management, one which involves a cooperative multi-agency approach, where the problem is considered in its ecological and public health context, and those who are affected by the risk management decisions are involved in the decision-making process. This collaborative approach is required under the NCP as territories and provinces are responsible for delivering health advice to their

residents but the broad range of issues requires input from all NCP partners (federal and territorial departments, Aboriginal groups, local communities and other interested parties).

This section explains the process of risk-benefit characterization. It focuses on risk-benefit characterization in Arctic communities and the special considerations that are required. An important consideration in Arctic communities is the role that risk perception plays in communication. Finally, an evaluation of current risks is provided.

5.1. Contaminant exposure risks

5.1.1. Contaminant intakes

5.1.1.1. Persistent organic pollutants. The contaminants having the greatest exceedances of dietary guidelines were chlordane and toxaphene. Fig. 5.1.1 shows the overall mean intakes of chlordane, toxaphene and mercury for various Aboriginal groups, based on data collected in the mid to the late 1990s. Mean intakes of Dene and Métis of the NWT and Yukon First Nations were below the provisional Tolerable Daily Intakes (pTDIs) for these contaminants, whereas the mean intakes in Inuit communities exceeded the pTDIs for chlordane and toxaphene (Chan, 2002).
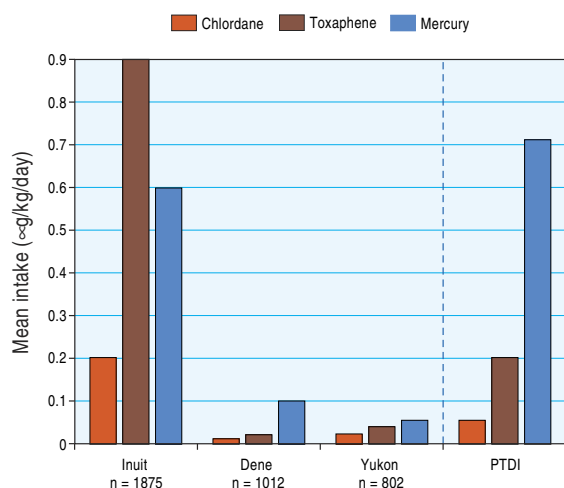
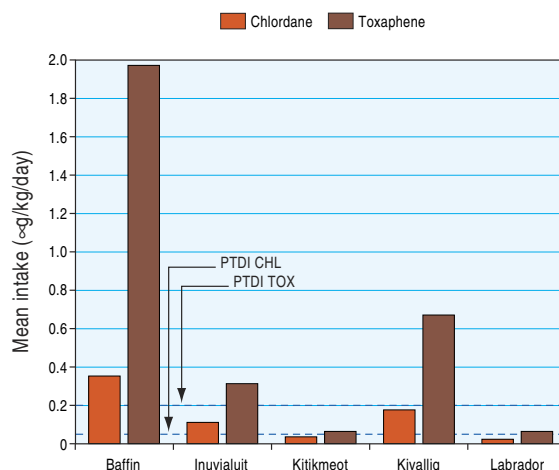

Fig. 5.1.2. Mean intakes of toxaphene and chlordane in different regions (ages 20–40 years) (Chan et al., in preparation(a)).

Among the five major Inuit regions, Baffin, Kivalliq and Inuvialuit communities mean intakes of 20- to 40-year-old adults exceeded the pTDIs for chlordane and toxaphene while the intakes for Kitikmeot and Labrador did not exceed the pTDIs (Fig. 5.1.2). When intake data in the Baffin region were separated by age group, it is seen in Fig. 5.1.3 that mean intakes of all age groups exceeded the pTDI for toxaphene, and that the three adult age-groups exceeded the pTDI for chlordane. The intake of both contaminants increases
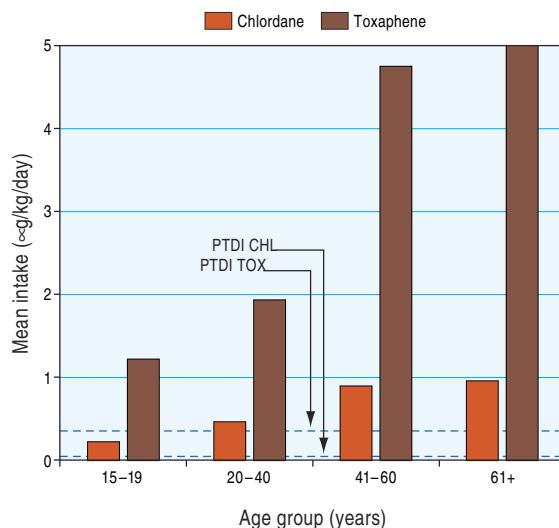

Fig. 5.1.1. Mean intakes of chlordane, toxaphene, and mercury in northern Canada (μg/kg/day) (Kuhnlein et al., 2001b).

Fig. 5.1.3. Mean intakes of toxaphene and chlordane among different age groups in Baffin (Chan et al., in preparation(a)).

with each age group. This increasing level of exposure with age is associated with the corresponding age-related increased intake of country food as was documented in Van Oostdam et al. (1999).

Individual intake of contaminants depends primarily on the amount of each country food consumed by the individual and the concentration of contaminants in that food. In this research contaminants contained in purchased market foods were not considered. Table 5.1.1 shows the sources of chlordane, toxaphene, and PCBs in the dietary intake profiles of the Baffin region ($n = 522$ interviews). It can be seen that the three most important food species, by their proportional contribution to total weight of food consumed, are caribou, ringed seal and Arctic char. However, the three species representing the largest proportions of chlordane and PCB exposure were the blubbers of narwhal, walrus, and beluga. For toxaphene, the greatest proportional contributions were made by walrus blubber, ringed seal flesh, and beluga blubber. Species which only make up a small proportion of the diet but high proportions of the contaminant exposure have markedly higher concentrations of these contaminants (Kuhnlein et al., 2000). Proportionate contributions to chlordane and toxaphene exposures are also shown in Table 5.1.2 for all five Inuit regions. In regions such as Baffin and Kivalliq

Table 5.1.2
Proportionate contributions of three main food sources of chlordane and toxaphene, in five Inuit regions, by food item

Inuit Region	Food item and proportionate contribution of chlordane (%)	Food item and proportionate contribution of toxaphene (%)
Inuvialuit	Beluga blubber (84%)	Beluga blubber (81%)
	Caribou meat (5%)	Beluga muktuk (4%)
	Beluga muktuk (5%)	Arctic char flesh (3%)
Kitikmeot	Beluga blubber (59%)	Beluga blubber (52%)
	Arctic char flesh (13%)	Arctic char flesh (26%)
	Caribou meat (7%)	Ringed seal flesh (9%)
Kivalliq	Beluga blubber (62%)	Beluga blubber (53%)
	Beluga muktuk (15%)	Walrus blubber (15%)
	Walrus blubber (8%)	Arctic char flesh (10%)
Baffin	Narwhal blubber (38%)	Walrus blubber (43%)
	Walrus blubber (35%)	Narwhal blubber (36%)
	Beluga blubber (11%)	Ringed seal flesh (9%)
Labrador	Caribou meat (30%)	Salmon flesh (41%)
	Lake trout flesh (20%)	Lake trout flesh (29%)
	Salmon flesh (12%)	Arctic char flesh (9%)

Source: Kuhnlein and Receveur (2001).

which had intakes higher than the pTDI for chlordane and toxaphene (Fig. 5.1.2) it can be seen that the major sources of exposure are marine mammal blubber (beluga, walrus or narwhal). In regions such as Labrador where the mean intakes did not exceed the pTDI, caribou meat and various fish species were the

Table 5.1.1
Sources of organochlorines in the Baffin Region (percent contribution)

Species	Part	Weight percent contribution[a] (wt.%)	Chlordane percent contribution[b] (%)	PCBs percent contribution[b] (%)	Toxaphene percent contribution[b] (%)
Caribou	Flesh	38.2	0.9	1.3	0.1
Ringed seal	Flesh	18.7	0.8	2.4	8.9
Arctic char	Flesh	15.6	2.2	1.5	3
Narwhal	Muktuk	5	1.8	7	0.1
Walrus	Flesh	3.2	1.7	0.6	0.1
Ringed seal	Broth	2.9	0.2	1.1	0.1
Polar bear	Flesh	2.8	1.5	3.1	0.1
Narwhal	Blubber	1.9	37.9	44.5	35.6
Ptarmigan	Flesh	1.3	0	0	0
Beluga	Muktuk	1.2	1.7	1.7	0.9
Walrus	Blubber	1.2	34.9	22.2	43.1
Beluga	Blubber	0.4	11.1	8.5	6.3
Ringed seal	Blubber	0.3	1.9	1.3	0.3
Polar bear	Fat	0.1	2.3	1.6	0.5
Total %		92.8	98.9	96.8	99.1

Source: Kuhnlein and Receveur (2001).
[a] Percent by weight of each species contributing to the traditional diet.
[b] Percent of each contaminant contributed by each food.

major source of exposure, indicating lower concentration in these species.

The population distributions of seven organochlorines are shown in Table 5.1.3 for Qikiqtarjuaq—a community selected because of high country food use. Mean intakes exceeded the organochlorine pTDIs for chlordane, PCBs and toxaphene, while median intakes exceeded the pTDI only for toxaphene. The 95th percentile indicates the level of intake by the highest 5% of consumers. When the 95th percentile/pTDI was computed it was noted that high consumers are exceeding the pTDIs by more than 100-fold for toxaphene and chlordane, and 15-fold for PCBs (Kuhnlein et al., 2000, 2001a,b; Batal, 2001). It is understood from dietary survey results that any one individual will not likely eat the same amount of high contaminant food items on several consecutive days. If more days of intake data from individuals were available, a tighter distribution and therefore a lower prevalence of high levels of exposure would result. The risk associated with usual levels of exposure (that is, levels, lower than the ones characterized by the 95th percentile/pTDI but higher than the pTDI) need to be characterized, since they appear prevalent in the Baffin region. These results (Kuhnlein et al., 2001a,b, 2003; Batal, 2001) confirm the earlier studies indicating higher exposures to various POPs in Inuit communities and those that were reviewed in Van Oostdam et al. (1999).

Possible changes in dietary intake of contaminants are a significant concern in the Canadian Arctic. Insight into the change in contaminant intake over the past 12 years in Qikiqtarjuaq (Broughton Island), Nunavut, a community known to have high country food consumption levels, can be achieved by compar-

Table 5.1.4
Comparison of daily intake of selected contaminants in Qikiqtarjuaq in 1987–1988 and 1998–1999

Contaminant	Daily intake (µg/kg bw/day) in 1987–1988[a]		Daily intake (µg/kg bw/day) in 1998–1999[b]	
	Median	95th percentile	Median	95th percentile
Mercury (total)	1	7	0.6	6.4
PCBs	0.3	3.6	0.05	15
Chlordane	0.06	2.1	0.02	5.2
Toxaphene	0.05	8.1	0.26	26

[a] *Source:* Kuhnlein et al. (1995a) and Chan et al. (1997).
[b] *Source:* Kuhnlein et al. (2000).

ing data collected in 1987–1988 (Kuhnlein et al., 1995a; Chan et al., 1997) to data collected in 1998–1999 (Kuhnlein et al., 2000). Intakes of organochlorines, including PCBs, chlordane, and toxaphene (Table 5.1.4), were higher in the more recent study, particularly among the high-end consumers (95th percentile). While the organochlorine concentrations used for the estimation of the two surveys were similar (data not shown), the amount of narwhal muktuk and blubber consumed was significantly higher in 1998–1999. The major sources of organochlorines were narwhal blubber and muktuk, walrus blubber, and ringed seal blubber reported in 1987–1988 compared to narwhal blubber and muktuk in 1998–1999 (Kuhnlein et al., 1995c, 2000).

PCB tissue levels and guidelines. While chlordane and toxaphene are of significant concern due to exceedances of dietary guidelines, there are only limited human or animal toxicology data available for these contaminants and no human tissue guidelines have been developed. More information is available on human tissue levels and on the animal and human

Table 5.1.3
Population distribution of organochlorine intake in Qikiqtarjuaq (µg/kg bw/day)

Organochlorine	N	PTDI (µg/kg/day)	N > PTDI	Mean	Median	95th percentile	95th/PTDI
Chlordane	110	0.05	34	0.62	0.02	5.18	104
HCB	110	0.27	14	0.23	0.02	1.7	6
DDT	110	20	9	1.58	0.04	13.1	0.7
HCH	110	0.3	11	0.06	0	0.36	1
Mirex	110	0.07	5	0.01	0	0.04	0.6
PCBs	110	1	16	1.9	0.05	15.3	15
Toxaphene	110	0.2	52	3.34	0.26	26.2	131

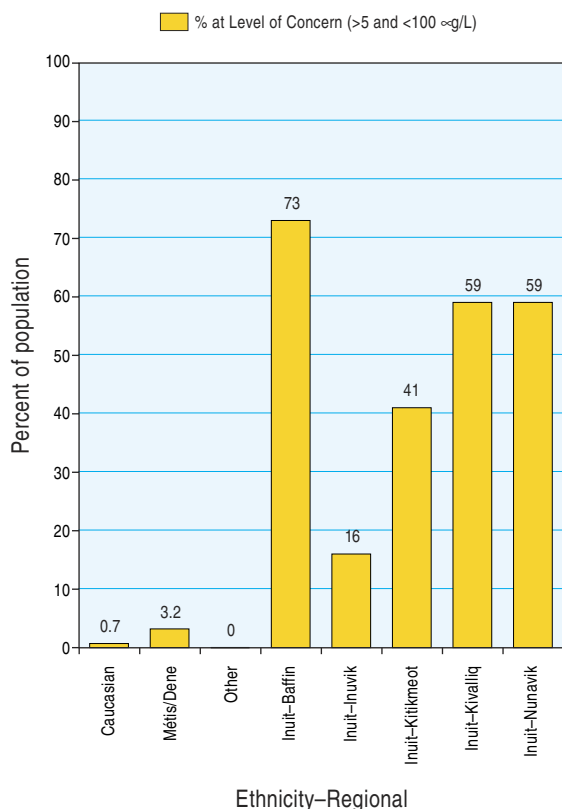*Source:* Kuhnlein and Receveur (2001).

Fig. 5.1.4. Maternal blood guideline exceedances for PCBs as Aroclor 1260 in Arctic Canada, by region and ethnicity (Van Oostdam, 2001).

toxicity of PCBs, which has allowed the development of human tissue PCB guidelines. This section compares PCB tissue levels in various ethnic groups to the PCB guidelines developed by Health Canada.

Blood contaminant levels in the NWT, Nunavut and Nunavik, are presented and compared in Section 2.2.1. For PCBs (as Aroclor 1260), Health Canada's maternal blood guidelines have a level of concern where concentrations are >5 μg/L, and an action level where concentrations are ≥100 μg/L. The most recent findings (Fig. 5.1.4) indicate that, on average, 43% of the blood samples from Inuit mothers in NWT/Nunavut exceeded the level of concern; of these, 87% were <20 μg/L, and none exceeded the Action level of 100 μg/L (Butler Walker et al., 2003). The corresponding values for Dene and Métis, and Caucasians exceeding the level of concern were 3.2% and 0.7%, respectively (Butler Walker et al., 2003). Fig. 5.1.4 also shows that exceedances of 5 μg/L

PCB blood guideline vary markedly among five Inuit regions, with greater exceedances in Baffin (73%), Kivalliq (59%), and Nunavik (59%), where the greater levels of PCBs were observed (Butler Walker et al., 2003; Ayotte, 2001). Inuvik had the lowest percentage exceedance (16%) among the Inuit regions. This information on blood guideline exceedances supports the previous assessment of dietary intakes, as it is the Inuit groups that exceed the TDIs for dietary contaminants intakes as well as the tissue guidelines.

5.1.1.2. Metals—mercury, cadmium, and lead. Toxic metals such as mercury, cadmium, and lead can bioaccumulate and this was well documented by Van Oostdam et al. (1999). Concentrations of these metals vary markedly between tissues and species of animals. Metals accumulate mostly markedly in organs such as liver and kidney (Chan et al., 1995). The dietary surveys outlined in Section 3.1 measured both dietary intakes for all country foods as well as contaminant levels and allowed estimates of exposures to be calculated for specific population groups. Fig. 5.1.1 shows that the Inuit have the highest intakes of mercury and their mean intakes approach the provisional tolerable daily intake (pTDI) for mercury of 0.71 μg/kg/day (WHO, 1978) while the mean intakes of mercury among First Nations peoples in the Yukon and NWT are well below the pTDI. The pTDI of 0.71 μg/kg/day is based on total mercury; the pTDI for methylmercury is 0.47 μg/kg/day. Much of the present data on dietary levels of mercury in food are only available for total mercury so the comparisons made in Fig. 5.1.1 are reasonable. Certain species, such as marine mammals, contain mostly inorganic mercury while other species such as fish contain mostly organic mercury (Wagemann et al., 1997), so more accurate risk assessments could be undertaken if methylmercury was specifically measured in country foods. Recently Health Canada has developed a new pTDI for methylmercury for children and women of childbearing age of 0.2 μg/kg/day (Health Canada, 1998). It would not be reasonable to use this pTDI in Fig. 5.1.1 illustrates the results for all men and women sampled in these communities, but it does indicate that children and women of childbearing age could be exceeding the pTDI.

Table 5.1.5 shows that for the Inuit regions some food items with low concentrations of mercury, such as caribou meat, contribute a small amount but significant proportion of mercury exposure due to the high intake of this country food. Other country foods only rarely eaten, such as ringed seal kidney, contribute a significant proportion of the contaminant exposure due to the high concentration of mercury therein. There is also marked regional variability in the country foods contributing to exposure. In the Baffin region, where the highest levels of mercury in human tissues were found, the most significant sources of exposure were marine mammals, ringed seals and walrus. This necessitates dietary recommendations that are specific to local populations and that reflect the particular species contributing the most significant exposure.

Exposure to mercury also varies markedly among the various Inuit groups as was the case for the various organochlorines. Fig. 5.1.5 indicates that the Inuit from Baffin have the highest exposure to mercury and that the older age groups have higher exposures to mercury. As was noted for the intake of POPs, Section 5.1.1, this increased exposure with increasing age is associated with the corresponding age-related increased intake of country food.

Fig. 5.1.5. Mean intake of total mercury in different regions (μg/kg/day) (Chan et al., in preparation(b)).

Table 5.1.5
Proportionate contributions of three main food sources of total mercury, and total mercury concentrations by food item in five Inuit regions

Inuit region	Food item	Proportionate contribution of Hg (%)	Hg concentration (mg/kg)
Inuvialuit	Caribou meat	52	0.06
	Beluga muktuk	11	0.73
	Lake trout	11	0.85
Kitikmeot	Caribou meat	27	0.06
	Arctic char flesh	15	0.10
	Caribou ribs	7	0.14
Kivalliq	Caribou meat	38	0.06
	Beluga muktuk	24	0.73
	Lake trout flesh	12	0.85
Baffin	Ringed seal meat	36	0.40
	Narwhal muktuk	14	0.56
	Caribou meat	12	0.06
Labrador	Caribou meat	37	0.06
	Lake trout flesh	36	0.85
	Ringed seal kidney	6	2.84

Source: Kuhnlein and Receveur (2001).

To further examine metal exposures, data are presented for Qikiqtarjuaq (Broughton Island), Nunavut, as these data exemplify a wide range of exposures to toxic metals (arsenic, cadmium, mercury and lead). Table 5.1.6 shows that mean intakes exceed the pTDIs only for mercury. The 95th percentile indicates the level of intake by the highest 5% of consumers. In computing the 95th percentile/pTDI ratio, it was noted that high consumers are exceeding the pTDIs by nine-fold for mercury and ratios for all other metals are less than three. This indicates that mercury is of greatest concern. As noted earlier in the case of organochlorines, it is understood from dietary survey results that an individual will not likely eat the same level of high contaminant food items on several consecutive days. If more days of intake data from individuals were available, a tighter distribution and therefore a lower prevalence of high levels of exposure would likely result. Nevertheless, it is advisable to discourage high intakes by individuals whenever possible and, since regular levels of exposure (i.e.,

Table 5.1.6
Population distribution of heavy metal intake in Qikiqtarjuaq (µg/kg bw/day)

Metal	N	PTDI (µg/kg/day)	N>PTDI	N>0	Mean	Median	95th percentile	95th/PTDI
Arsenic	110	2	30	110	1.3	0.3	5.6	2.8
Cadmium	110	1	27	110	0.6	0.2	2.3	2.3
Total mercury	110	0.71	47	110	1.6	0.6	6.4	9
Lead	110	3.57	49	110	3.6	2.7	10.4	2.9

Source: Kuhnlein and Receveur (2001).

levels lower than the ones characterized by the 95th percentile/pTDI but higher than the pTDI) appear widespread in the Baffin region, the risk associated with this exposure needs to be characterized. These results (Kuhnlein et al., 2000, 2001a,b; Batal, 2001) confirm the earlier studies reviewed by Van Oostdam et al. (1999).

To see whether there was a temporal change in mercury intake in Qikiqtarjuaq (Broughton Island), data on the daily intakes of mercury collected in 1998–1999 (Kuhnlein et al., 2000) were compared to those collected in 1987–1988 (Kuhnlein et al., 1995c; Chan et al., 1997). Intakes of mercury were similar in the two surveys (Table 5.1.4), indicating there has been little change in dietary pattern and/or mercury concentrations in the foods. The major sources of mercury in 1998–1999 (Kuhnlein et al., 2000) compared to those collected in 1998–1999 are

ringed seal meat, narwhal muktuk and polar bear flesh. In 1987–1988, the major sources were also ringed seal meat, narwhal muktuk and polar bear (Chan et al., 1995).

5.1.1.3. Contaminant tissue levels and guidelines.
Mercury. In the 1970s Health Canada developed blood guidelines for methylmercury. Blood levels below 20 µg/L are classified as being in the acceptable range, between 20 and 100 µg/L as "increasing risk" and levels greater than 100 µg/L in blood as "at-risk" (Health Canada, 1979). The United States undertook a re-evaluation of methylmercury and developed a benchmark dose level of 58 µg/L for this metal (NRC, 2000). Applying the United States' suggested 10-fold safety factor to the benchmark dose level allows the development of a maternal blood guideline of 5.8 µg/L.

Table 5.1.7
Blood guideline exceedances for methyl mercury, lead, and cadmium in Arctic Canada, by region and ethnicity

Region/Ethnic group Country/Ethnic Group/Region	N	Methyl mercury		Lead	Cadmium
		Percent of samples exceeding 5.8 µg/L[a] (%)	Percent of samples exceeding or equal to 20 µg/L[b] (%)	Percent of samples exceeding 100 µg/L (%)	Percent of samples exceeding 5 µg/L[c] (%)
NWT/Nunavut					
Caucasian[d] (1994–1999)	134	0	0	0	6
Metis/Dene[d] (1994–1999)	92	1	0	2	3
Other[d] (1995)	13	0	0	0	0
Inuit[d] (1994–2000)					
Baffin[d] (1996)	31	68	10	10	13
Inuvik[d] (1998–1999)	31	16	3	3	7
Kitikmeot[d] (1994–1995)	63	27	0	2	10
Kivalliq[d] (1996–1997)	17	35	0	0	18
Nunavik[e] (1995–2000)	162	79[f]	16	12	NA

NA=Not available.
[a] Based on US EPA 1999 re-evaluation of methyl mercury.
[b] Increasing risk range is 20–100 µg/L, Health Canada.
[c] Guideline value of 5 µg/L is for occupational exposure.
[d] *Source:* Butler Walker et al. (2005).
[e] *Source:* Ayotte (2001).
[f] ≥5.8 µg/L value.

Butler Walker et al. (2005) and Ayotte (2002) show that among the mothers from NWT/Nunavut and Nunavik, only Inuit exceeded the Canadian level of concern of 20 µg/L and almost no Caucasian or Dene/Métis mothers exceeded the lower guideline of 5.8 µg/L based on the United States evaluation. These differences among the three ethnic groups are almost certainly due to eating patterns. Among five Inuit regions, percentage exceedances of the Canadian guideline level of concern of 20 µg/L for organic mercury were highest in Nunavik (16%) and Baffin (10%) (Table 5.1.7 and Fig. 5.1.6). The percentage exceedance of the 5.8 µg/L United States blood guideline for organic mercury among Canadian Inuit women ranged from a low of 16% in Inuvik to highs of 79% in Nunavik and 68% in Baffin. No mothers were in the "at-risk" range of >100 µg/L. The groups that have the greatest exceedance of these blood guidelines are also the same groups that

Fig. 5.1.6. Maternal blood guideline exceedances for organic mercury in Arctic Canada, by region and ethnicity (Van Oostdam, 2001).

most often exceed the tolerable daily dietary intakes discussed previously.

The proportion of Inuit mothers who are in the "increasing risk" range for mercury has decreased quite markedly over the years. Wheatley and Paradis (1996) reported that 56% of mothers included in their 1972–1989 monitoring study were in the "increasing risk" range compared to 3–16% of Inuit mothers in the 1990s (Table 5.1.7). However care must be taken in concluding trends based on some of the historical mercury data as this data set may be biased due to re-sampling communities and individuals with high mercury values (Van Oostdam et al., 1999). Based on the new United States evaluation, a much greater proportion of Inuit women exceed the guideline indicated that although levels of exposure may have decreased, concerns for health associated with exposure still exist.

Lead. Canada and the United States use 100 µg/L as the action level for lead. In NWT/Nunavut, all average lead levels in women's blood samples were markedly lower than the 100 µg/L action level, but 3.4% and 2.2% of the blood samples from the Inuit, and Dene and Métis women, respectively, exceeded the action level (Butler Walker et al., 2005) (see Table 5.1.7). Among Inuit women, percentage exceedances ranged from a low of 0% in Kivalliq to a high of 12% in Nunavik. Historical data have shown that levels among many populations have decreased in parallel to the phase out of lead in gasoline around the world (AMAP, 1998), indicating that the lead issue in the Arctic may be due to local use of lead. Recent research by Dewailly et al. (2000b) using lead isotope tracers has indicated that most of the current lead exposure among Nunavik Inuit results from the use of lead shot.

Cadmium. The guideline of 5 µg/L for cadmium is an occupational level, and, in the absence of any other guideline, is offered as a general guidance. In NWT/Nunavut, cadmium levels in women's blood exceeded this guideline in 10% of Inuit, 6% of Caucasians, 3% of Dene and Métis, and 0% of women in the Other group. Among Inuit, the percentage exceedances ranged from a low of 7% in the Inuvik region to a high of 18% in the Kivalliq region (Butler Walker et al., 2005) (see Table 5.1.7). A number of studies have shown that there are markedly higher smoking rates among northern Aborigi-
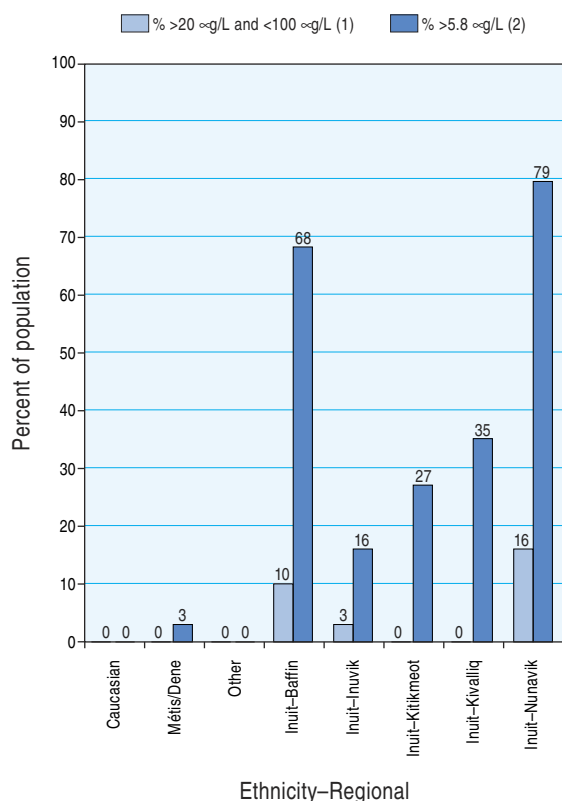
nal peoples (Benedetti et al., 1994), and other studies have found that smoking and not country food consumption contributes most cadmium exposure (Butler Walker et al., 2005).

Radionuclides. The debate continues in international scientific circles as to whether there is a dose threshold for radiation-induced cancer. Radiation protection authorities have always assumed a linear, no-threshold hypothesis in setting exposure limits. This means that all radiation exposures, no matter how small, carry a risk of producing cancer which is proportional to the dose received. However there is mounting evidence that a threshold may exist for radiation. The US-based Health Physics Society has recommended against quantitative estimation of health risk below an individual dose of 50 mSv (millisieverts) in 1 year or a lifetime dose of 100 mSv over and above normal background radiation (Health Physics Society, 1996). The issue is of significance to northerners, who were exposed in the past to nuclear fallout, or who have slightly higher exposures from caribou meat consumption.

Even if one assumes that the linear no-threshold hypotheses are correct, the risk of continued consumption of caribou meat is very small. Table 2.2.9 indicates a maximum dose rate (at present) of about 3 to 4 mSv/year. The International Commission on Radiological Protection (ICRP) gives a lifetime risk coefficient of $7.5. \times 10^{-5}$ per mSv of exposure for cancer and other serious illnesses (ICRP, 1991). If a person were to receive a lifetime radiation dose of:

$$3.5 \text{ mSv/year} \times 70 \text{ years} = 245 \text{ mSv}$$

$$245 \text{ mSv} \times 7.5 \times 10^{-5}/\text{mSv}$$

= lifetime risk of 1.8% from average caribou

meat consumption.

A normal background radiation of 2.4 mSv/year would give a lifetime risk of 1.3%. The normal incidence of cancer in the general population is approximately 25%. The only way to reduce these doses further would be to restrict caribou meat consumption, which would deny northerners the many benefits of a diet of fish and wildlife. Other lifestyle choices such as smoking and alcohol consumption have a much greater influence on rates of cancer.

Recent evidence from A-bomb survivors (Shimizu et al., 1999) and Chernobyl emergency workers (Ivanov et al., 2001) indicates that high dose radiation may be a factor in increased mortality from cardiovascular disease. This link needs to be studied further in groups exposed to high levels of radiation. The relevancy of this to northerners who have lower exposures is uncertain at this time.

5.2. Special considerations for risk management in Arctic communities

5.2.1. Nutritional benefits

The nutritional benefits of country food and its contribution to the total diet are substantial, although only 6–40% of total dietary energy may be derived from this food source. These foods are important sources of lipids, vitamins, minerals and protein and in many cases are the primary source of many important nutrients (Van Oostdam et al., 1999). Research has found that days "with" traditional/country food have significantly less fat, saturated fat, protein, sucrose and total carbohydrate than do days "without" country food (Table 5.2.1). These findings are consistent across the Canadian Arctic

Table 5.2.1
Percent energy from macronutrients on days with or without traditional/country food (least square means $\pm$ S.E.M.)

Nutrient	Region	With TF (%)	Without TF (%)
Carbohydrate	Yukon	37.2 ± 0.7 ($n=410$)	41.3 ± 0.8 ($n=387$)
	Dene/Métis	34.5 ± 0.6 ($n=661$)	41.3 ± 0.8* ($n=346$)
	Inuit	35.2 ± 0.5 ($n=968$)	46.6 ± 0.7* ($n=632$)
Sucrose	Yukon	9.1 ± 0.4	11.2 ± 0.5*
	Dene/Métis	9.1 ± 0.4	11.8 ± 0.5*
	Inuit	12.3 ± 0.4	16.7 ± 0.5*
Protein	Yukon	31.1 ± 0.5	19.0 ± 0.5*
	Dene/Métis	30.7 ± 0.4	20.1 ± 0.6*
	Inuit	34.2 ± 0.4	17.9 ± 0.6*
Fat	Yukon	31.6 ± 0.6	40.3 ± 0.6*
	Dene/Métis	34.2 ± 0.5	38.8 ± 0.7*
	Inuit	30.1 ± 0.4	35.9 ± 0.6*
Saturated fatty acids	Yukon	10.6 ± 0.3	14.4 ± 0.3*
	Dene/Métis	11.6 ± 0.2	13.6 ± 0.3*
	Inuit	9.1 ± 0.2	12.1 ± 0.2*

Source: Kuhnlein et al. (2004).
 * Different from with TF, $p < 0.01$.

and confirm that decreasing country food in the diet is likely to have negative health consequences in part through the corresponding increase in total fat, saturated fat and sucrose consumption above recommended levels, a lower intake of the vitamins A, D, and E, riboflavin and B6, as well as a decreased use of the important minerals iron, zinc, copper, magnesium, manganese, phosphorus, potassium, and selenium (Kuhnlein et al., 2004). Although some nutrients, such as vitamin C, were provided mainly by fortified market foods, one should not undermine the great potential that some traditional foods could contribute to the diets of indigenous peoples, if they were better utilized. Fediuk et al. (2002) listed a variety of rich sources of vitamin C from animal and plant traditional food such as raw fish eggs, raw whale skin, the livers of caribou and ringed seal, and blueberries. With the contemporary higher levels of fat intake, an increasing number of cardiovascular deaths can be expected (NRC, 1989); similarly, high saturated fat intake and high sucrose intake have been associated with increased risk of colorectal cancers (World Cancer Research Fund, 1997). The rising levels of excess weight and obesity documented in Yukon (Receveur et al., 1998a) and Inuit communities (Kuhnlein et al., 2004) need to be

further considered when the balance between traditional/country foods and imported foods is evaluated: 18% of women 20–40 years of age, and 33% of women 40–60 years of age in the five Inuit regions surveyed by CINE in 1998–1999 had a body mass index (BMI) over 30. An increase in mean BMI over a 5-year period (1992–1997) has also been reported for women in the Inuit communities of Repulse Bay and Pond Inlet (Lawn and Harvey, 2001). This increase in the proportion of energy derived from fat observed on days when no country food is consumed could be associated with the growing prevalence of excess weight observed in Yukon and Inuit communities. Although usually providing smaller proportions of daily energy and total dry weight in diets than imported food, country food was shown to contribute significantly more protein, iron and zinc to the diets of Baffin Inuit children (Berti et al., 1999).

In Table 5.2.2, the top three sources of several nutrients in the total daily diet as reported consumed in the five Inuit regions show that at least one country food is mentioned for each nutrient with the exception of calcium. It is also clear that iron and zinc are almost entirely contributed by country food, whereas the top three calcium sources are

Table 5.2.2

Top three sources of selected nutrients from 24-h recalls (fall and late winter combined) in five Inuit regions

Nutrient	Inuit region				
	Inuvialuit ($n=387$)	Kitikmeot ($n=300$)	Kivalliq ($n=341$)	Baffin ($n=522$)	Labrador ($n=417$)
Vitamin A	Caribou liver	Caribou liver	Carrots	Walrus liver	Carrots
	Carrots	Carrots	Beluga blubber	Ringed seal liver	Margarine
	Beef liver	Mixed frozen vegetables	Caribou meat	Narwhal blubber	Ringed seal kidney
Omega-3 fatty acids	Margarine	Arctic char flesh	Arctic char flesh	Arctic char flesh	Margarine
	Arctic char flesh	Caribou meat	Caribou meat	Walrus blubber	Salmon flesh
	Beluga blubber	Margarine	Beluga blubber	Ringed seal broth	Salad dressing
Vitamin E	Margarine	Caribou meat	Caribou meat	Caribou meat	Margarine
	Potato chips	Bannock	Potato chips	Bannock	Potato chips
	Caribou meat	Margarine	Bannock	Narwhal blubber	Caribou meat
Calcium	White bread	Bannock	Bannock	Bannock	Evaporated milk
	2% milk	Pizza	Pizza	2% milk	2% milk
	Pizza	White bread	White bread	Pizza	White bread
Zinc	Caribou meat	Caribou meat	Caribou meat	Caribou meat	Caribou meat
	Ground beef	Ground beef	Ground beef	Ringed seal meat	Ground beef
	Caribou dried meat	Caribou dried meat	Beluga muktuk	Narwhal muktuk	Chicken
Iron	Caribou meat	Caribou meat	Caribou meat	Ringed seal meat	Caribou meat
	White bread	Ringed seal meat	Beard. seal meat	Caribou meat	Partridge meat
	Ground beef	Caribou dried meat	Ringed seal meat	Walrus meat	White bread

Source: Kuhnlein and Receveur (2001).

entirely from imported food (Kuhnlein et al., 2001b,c; Blanchet et al., 2000).

Since CACAR-I, new analytical results for nutrients in country foods have shown some remarkable nutrient properties. For example, exceptional sources of vitamin C (>20 mg/100 g fresh weight) in Inuit country foods have been shown to be beluga muktuk, narwhal muktuk, seal liver, caribou liver, cisco eggs and blueberries. Excellent sources of omega fatty acids, vitamin A, vitamin D and vitamin E have been shown to be beluga blubber and oil, narwhal blubber, Arctic char, burbot eggs, beluga muktuk and narwhal muktuk. As well, several nutritionally essential minerals have recently been reported in high levels in Arctic foods, including iron, zinc, selenium, copper, magnesium and manganese (Blanchet et al., 2000; Kuhnlein et al., 2001a).

Fish are an important part of the country food diet across the Canadian North. The health benefits of consuming 1–2 servings of fish per week (17–34 g/day) have been well documented (Simopoulos, 1991; Kromhout et al., 1995; Weisburger, 2000) and some studies support recommendations for greater amounts, up to 69 g/day (Kris-Etherton et al., 2000). Health benefits would accrue most likely for preventing heart disease (Shmidt et al., 2000), but also possibly for certain cancers (World Cancer Research Fund, 1997) and type-2 diabetes (Feskens et al., 1991, 1995; Ekblond et al., 2000). Fish intake by Aboriginal peoples is summarized in Table 5.2.3 and suggests that they are likely to fully benefit at the current levels of consumption.

Limiting fish consumption in any way based on levels of organic mercury exposure would be further unwarranted in Inuit communities, given that the main source of exposure in these communities was caribou, representing 52%, 27%, 38% and 27% of total exposure in Inuvialuit, Kitikmeot, Kivallik, and Labrador, respectively (Kuhnlein et al., 2000). In Baffin, seal meat was the single main contributor of organic mercury (36% of the total exposure level). Seal meat and caribou are not highly contaminated with organic mercury, but their frequent consumption makes them the main sources of organic mercury intake in Baffin. In contrast to fish, the health benefits of consuming seal and caribou, above and beyond what can be inferred from their specific nutritional values, have not been studied and remain unknown.

Table 5.2.3

Reported daily fish consumption by gender and age group in three recent dietary surveys among Canadian Arctic indigenous peoples[a]

Indigenous peoples region (main fish species)	Women (age 20–40) g/person/day (no. of 24-h recalls)	Women (age 41+) g/person/day (no. of 24-h recalls)	Men (age 20–40) g/person/day (no. of 24-h recalls)	Men (age 41+) g/person/day (no. of 24-h recalls)
Yukon first nations (salmon, trout, grayling, whitefish)	48 ($n=253$)	76 ($n=169$)	69 ($n=221$)	91 ($n=159$)
Dene and Metis				
Gwichin (whitefish, loche, inconnu, arctic char, lake trout)	65 ($n=47$)	66 ($n=54$)	35 ($n=51$)	158 ($n=43$)
Sahtu (whitefish, lake trout, cisco, loche)	13 ($n=49$)	154 ($n=42$)	37 ($n=46$)	105 ($n=43$)
Dogrib (whitefish, pike, trout, loche)	8 ($n=28$)	82 ($n=29$)	32 ($n=21$)	120 ($n=31$)
Deh-Cho (whitefish, lake trout, loche)	10 ($n=72$)	39($n=38$)	37 ($n=51$)	13 ($n=56$)
Akaitcho (whitefish, lake trout, loche)	21 ($n=85$)	34 ($n=67$)	44 ($n=79$)	30 ($n=80$)
Inuit				
Inuvialuit (arctic char, whitefish, cisco, herring, lake trout)	54 ($n=121$)	111 ($n=74$)	12 ($n=100$)	124 ($n=45$)
Kitikmeot (arctic char, lake trout, whitefish)	34 ($n=113$)	137 ($n=49$)	36 ($n=76$)	136 ($n=41$)
Kivallik (arctic char, lake trout)	21 ($n=112$)	109 ($n=68$)	65 ($n=87$)	169 ($n=48$)
Baffin (arctic char, arctic cod, cisco)	39 ($n=160$)	72 ($n=105$)	47 ($n=112$)	73 ($n=102$)
Labrador (lake trout, salmon, rock cod, arctic char)	24 ($n=112$)	50 ($n=97$)	29 ($n=80$)	60 ($n=89$)

Data adapted from Receveur et al. (1996, 1998) and Kuhnlein et al. (2000).

[a] Estimates obtained by averaging food intake over all 24-h recalls collected in two seasons (Sep–Nov and Feb–Apr).

Other researchers have also noted that the shift away from country food diets may also be linked to the rise in obesity, diabetes and cardiovascular disease among Aboriginal peoples in the United States and Canada (Young, 1993; Young et al., 1993). Increased saturated fat, sucrose, and alcohol in diets has led to higher incidences of gall bladder disease, tooth decay, alcoholism and its complications, and fetal alcohol syndrome. Poor diet quality has also been associated with higher incidences of *anemia*, *otitis media*, a variety of infections, and to some kinds of cancer (Kuhnlein and Receveur, 1996).

5.3. Social, cultural, spiritual and economic benefits of country food

Historically, circumpolar northern Indigenous populations have relied on a variety of Arctic flora and fauna for survival. The way of life for Aboriginal peoples in Arctic Canada has been and still is very much defined by their relationship with the environment. Today country foods are still central to cultural, social and spiritual well-being in many regions. They are essential to the social and cultural health of individuals and communities (e.g., Van Oostdam et al., 1999; Receveur et al., 1996; Santé Québec, 1995; Condon et al., 1995). Country foods, and related activities (hunting, fishing, collecting, distribution, preparation, and consumption), still play critical roles in everyday life in many northern communities for reasons that include their social and cultural importance, formal and informal economic value, and contributions to physical, mental and spiritual well-being (Dewailly et al., 2000d).

Each food, and its related activities, provide specific benefits which must be considered when balancing the benefits and risks of exposure to environmental contaminants through country food consumption. Arctic Canada is undergoing significant economic, political, social, cultural and environmental change as a result of influences and pressures both from within and outside of the region. The maintenance of the link between the people and the land is therefore important, further stressing the importance of the collection, sharing, and consumption of wild foods in the North. Aboriginal peoples report that country foods define, maintain and increase aspects of the cultural, social and spiritual

identity and well-being (Dewailly et al., 2000d; Kuhnlein et al., 2000; Bjerregaard and Young, 1998; Egeland et al., 1998). Culture is strongly tied to language and participation in traditional activities and hunting and gathering various traditional resources provide the opportunity for these aspects of culture to be expressed. As the Inuit Circumpolar Conference stated, hunting is an integral social activity to Inuit communities.

"Hunting . . . is crucial to sustaining, reproducing, and expressing Inuit social relations. Where disruptions in primary cooperative subsistence activities occur, social relations at the community level suffer. Sealing . . . is . . . '. . . the patterned acquisition and use of (an animal) in such a way as to enhance the social relationships existing in a community.' . . . Inuit have always depended [sic] animals and other Inuit to maintain their culture and perpetuate their society. . . .sealing continues to establish and reaffirm productive and cooperative social relationships that are so crucial to Inuit survival through the hunting and sharing of seals. For many Inuit sealing is . . . a 'set of culturally established responsibilities, rights, and obligations.'" (Inuit Circumpolar Conference, 1996)

Hunting, fishing and gathering of wild resources and the subsequent sharing of those items with individuals throughout the community are social activities bringing together individuals, families and generations, and are often the focus of celebrations and festivities. In this way, they form and maintain an important social fabric among individuals which supports community health and well-being. For example, not only is muktuk nutritionally and psychologically beneficial, but its widespread sharing among relatives and between communities creates and sustains the bonds that remain the basis of Inuit social, cultural and economic relationships today (Freeman et al., 1998). Further, these activities are opportunities for the transfer of knowledge between generations and the maintenance of language, as they necessitate and use traditional knowledge and components of Aboriginal language, thus passing on information about hunting techniques, places and local history while on the land. Similarly, the preparation of country foods provides opportunities for coming together, learning and sharing

among individuals in communities. The link between Aboriginal people and the land, seas and waterways they travel and use is also regarded in a spiritual sense as an offering or gift. This spiritual relationship with the environment is expressed, maintained and strengthened by the ongoing practices of hunting, fishing and gathering of resources in a respectful way. Specifically, in regards to social and mental health, country foods and related activities are reported to define and maintain aspects of identity and Aboriginal culture.

"Inuit foods may have contaminants, they also have much more. They have sustained us, nourished us, brought us together, and given us the sense of who we are" (Egede, 1995).

To the people who have traditionally hunted on particular traplines, these areas are their primary world. Their roots and their ideas of who they are, are tied to their lands. The ties of particular people to the land are strongest to their own traplines since much of their own personal history and their family history is knit into the cultural and spiritual landscape of the North (Weinstein, 1976). Berkes and Farkas (1978) state that the retention and rejuvenation of Aboriginal practices (traditional food habits, such as eating of fish and game) depend to some extent on maintaining a sense of identity and pride.

Northerners state:

"Inuit foods give us health, well-being and identity. Inuit foods are our way of life... Total health includes spiritual well-being. For us to be fully healthy, we must have our foods, recognising the benefits they bring. Contaminants do not affect our souls. Avoiding food from fear does." (Egede, 1995).

"For the old people, the food for them is real food— strong food like igunaq, seal and all kinds of country food, and when they do not have it for a long time, they start to crave it...it's their way of life." (Quaqtaq resident, Nunavik; as in O'neil et al., 1997)

"They are so important to me because they are who we are. They are part of being Inuit. I have always eaten them and always will." (Labrador Inuk; as in Furgal 1999)

There are also economic realities which influence how much Aboriginal peoples rely on traditional/ country food. Employment and income are often low or uncertain compared to southern Canada, fluctuating with development projects and seasonal opportunities. In many cases and for many people, the costs of nutritious imported food are prohibitively high in northern communities. For example, in 1989 the cost to purchase equivalent amounts of imported meat in local stores was estimated to be over $10 000 per Aboriginal household per year (Usher and Wenzel, 1989). Country food, therefore, is an economic necessity for many Aboriginal northerners.

In a recent study, Kuhnlein et al. (2000) documented the cultural, social and economic benefits of country food among adult Inuit in five regions of the Canadian Arctic. Results indicated that ≥90% of 1721 respondents believed that harvesting and using country food by the family:

1. contributes to physical fitness and good health
2. provides people with healthy food
3. favours sharing in the community
4. is an essential part of the culture
5. is an occasion for adults to display responsibility for their children
6. provides education on the natural environment
7. contributes to children's education
8. provides skills in survival
9. provides skills in food preparation at home

In addition, the survey reported that interviewees recognize country food as being significantly more healthy for children, healthy for pregnant/breast feeding women, tasty and more important to community life compared to market food. It is clear from the research initiative by Kuhnlein et al. (2000) that country food provides multiple social and cultural benefits to Inuit. The effects of losing these benefits as a result of decreasing use of country food are of concern in several ways, including increased incidences of diabetes and heart disease, and effects on mental health (Van Oostdam et al., 1999).

When country food is compromised by contaminants, more than Aboriginal peoples' health is affected; their economy, culture, spiritual well-being and way of life are also threatened. The importance of country food is further stressed by the lack of healthy, accessible and economically viable nutrition

alternatives in many communities and for many individuals. Many market foods are expensive, of lower nutritional value and deprive Aboriginal people of the cultural and social significance and other benefits of hunting and consuming country food. Consequently, the contamination of country food raises problems which go far beyond the usual confines of public health and cannot be resolved simply by risk-based health advisories or food substitutions alone.

5.4. Assessment of perceptions of risks, benefits and safety of country foods

It is widely understood that the public does not see risk in the same way as technical "experts" (Kasperson, 1986; Erikson, 1990; Douglas, 1992) and that even among experts there are differences in their judgments of certain risks (Kraus et al., 1992). Individual factors such as age, gender, education, occupation, language, world view, and culture may all influence the individuals' perceptions and concerns about certain hazards (Flynn et al., 1994; Slovic and Peters, 1995). Also, certain attributes of hazards have been identified as being strongly influential on the perception and acceptance of risks among the public. These factors include: involuntary exposures, uncertainty about probabilities or consequences of exposure, lack of personal experience with the risk (fear of the unknown), effects of exposure delayed in time, genetic effects (effects on the next generation), accidents related to anthropogenic activity, unequal distributed risks and benefits, and the ease of perception of the associated benefits (Slovic, 1987; Douglas, 1986; Pidgeon et al., 1992).

For the individual, perception is a combination of personal and collective (i.e., social) factors that influence the way in which one understands issues, and to which one reacts and takes action at the individual level (i.e., personal behaviours). It is recognized that the individuals' basic conceptualizations for risk are much richer than that of experts and reflect legitimate concerns that are often omitted from formal risk assessments (Slovic, 1987). It is for these reasons that the perceptions of those involved and affected by a hazard must be considered as they directly influence the effectiveness of any risk management decision and action (including communications) taken

to minimize risks and to maximize the benefits of, in this case, consuming country foods in the North. It is critical to assess and understand the northern public's perception of food-chain contamination and the way in which this issue is being addressed in order for decision-makers and risk communicators to design successful activities to support the reduction of risks. Better and more effective risk management processes, decisions and communications help minimize anxiety, build trust, and avoid negative repercussions (e.g., confusion misperception, rejection of advice, mistrust, and introduction of exposure to indirect risks).

Consideration of public perception in these activities supports the development of more effective risk reduction strategies.

5.4.1. Perceptions of risks in the north

With the issue of food-chain contamination by various organochlorines, heavy metals and radionuclides, through primarily long-range transport, northern people are faced with involuntary exposure to a different type of hazard, as it is not easily observed or detected by conventional means. Furthermore, because of the central importance of country foods in Aboriginal communities in the North, even today, understanding and considering this context is critical to effectively communicating and managing these issues. Due to the significant qualitative and symbolic benefits attributed to country foods in Aboriginal cultures, the perceptions and concerns related to food contamination are not simply proportional to the level of harvesting and consumption activities in communities. Reports of contamination undermine confidence in the environment as well as in harvesting activities as sources of individual and collective well-being. These and other characteristics complicate the management of this issue, further emphasizing the need to understand public perceptions of this issue and how they are addressed.

5.4.2. Research on the perceptions of food-chain contamination in the north

Van Oostdam et al. (1999) detailed efforts made in assessing and collecting both qualitative and quantitative data on the perceptions of environmental contaminants among northern residents, and related

activities during Phase I of the NCP. The discussion of results presented here summarizes this information and presents any further knowledge gained in this area to date.

The Santé Québec (1994) survey assessed perceptions of Nunavik residents towards contaminants in country foods and revealed the high level of awareness (62%) and the desire to know more (87%) about this issue. Overall, 55% of Nunavik residents considered country foods to be more healthful and nutritious than commercial foods, and 21% believed that commercial foods were of higher quality either because they were better, more modern, or because country goods were contaminated. These perceptions varied with age, with the most favourable attitudes towards country foods being among individuals in the 25- to 45-year-old age group, and the least favourable attitudes among the younger participants. The survey also indicated that 14% of people reported having changed their habits upon becoming aware of food-chain contamination. About 11% reduced country food, while 3% discontinued consumption altogether (Dewailly et al., 1994). The survey, however, did not assess the duration of these changes. Work done by O'Neil et al. (1997) and Poirier and Brooke (1997) in Nunavik communities further documented these positive perceptions of country foods. More recent work by Dewailly et al. (1999) in Salluit found that most individuals in this community (71%) believe country food to be "very good for their health", as was found by Furgal et al. (1999) among most (91%) of the Labrador Inuit surveyed in the community of Nain, who reported their belief in the safety of country foods. As Nunavik residents state:

"Country food is preventing you from diseases. Therefore it is a medicine. When you are sick and you are trying to gain back your strength, you eat country food, it's your medicine." (Quaqtaq resident; O'Neil et al., 1997)

"In the winter we feel that wild meat is better to keep warm and for the body to feel good. We even bring frozen meat with us to eat while we are out because it is better for maintaining warmth and vitality out on the land. It is different in this way from Qallunat food, like chicken and other fry-pan type foods, because when we eat this we get cold more easily and become hungry again rather

quickly." (Inuit health official; Poirier and Brooke, 1997)

Despite the strong belief in the health and safety of country foods, concern is raised in some regions about the presence of and potential effects of contaminants on animal and human health, as well as the activities used to investigate these issues in wildlife (Furgal et al., 1999; O'Neil et al., 1997). Northerners are concerned about the health and well-being of wildlife (Usher et al., 1995; O'Neil et al., 1997; LIA, 1997; Poirier and Brooke, 1999; Furgal et al., 1999). As one Nunavimmiut hunter stated:

"I even discarded a beluga, a fine health, young adult male at his best because I thought it had mercury in him. He had this noticeable but tiny hole in his skin. I'd hear somewhere that there were people who injected mercury into beluga and I was afraid that this one had been contaminated." (Nunavimmiut hunter; Poirier and Brooke, 1997)

In a review of 13 contaminant cases in Aboriginal communities from Alaska to Nunavik, Usher et al. (1995) found that a lack of attention and understanding of the perception of contaminants among Aboriginal peoples in communication efforts had significant impacts on the receptiveness and effect of messages that were delivered to address public concerns. In most cases, communities were alerted to the possibility of food-chain contamination only from reports of animal tissues laboratory results, which were sometimes obtained for purposes not even directly related to local food safety concerns. With the exception of cases where there were visible pollution events (e.g., Exxon Valdez oil spill in Alaska) it was only after the reports of the presence of the contaminant(s) and the possible toxic effects that residents started to suspect that previously unexplained events, particularly abnormalities in animals, fish or humans, might be related to contaminants (Van Oostdam et al., 1999).

Almost all cases reviewed gave rise to local uncertainty and anxiety, potentially related to the balance of clear and credible information on toxicity (especially in cases of chronic but low-level exposure) or "safe" levels. Such concepts, standards, safety factors, and chronic exposures are all aspects of risk messages that are difficult and confusing, yet critical to explain in risk communication exercises. In cases where there

has been fairly strong evidence of low risk (e.g., cadmium in caribou liver and kidneys) or of benefits outweighing the risks (e.g., organochlorines in marine mammal fat), and this is clearly communicated, the problem of uncertainty and anxiety appears to have been minimized (Usher et al., 1995).

The connection between anxiety about potential health effects from country food consumption and actual consumption behaviours is complex. Significant reductions in country food consumption can occur when people are informed of "invisible contaminants" in the local food supply. Yet, invisibility alone is not the problem, as Aboriginal people have for years dealt with problems of trichinosis, botulism, and hypervitaminosis using their experience and traditional knowledge.

Northerners also regularly report knowing when an animal is unfit for consumption. These statements are often based on knowledge of visible abnormalities in wildlife such as parasitic or other infections. Confusion among these concepts has been reported by residents in some communities. Participants in a study conducted in Salluit, Nunavik stated a belief that organic mercury was caused by a bug, bacteria, germ or worm (Dewailly et al., 1999). The association could be made here with a significant amount of work done in this and other Nunavik communities on trichinosis in walrus. The combination of factors on this issue means that community residents have only scientists to trust in confirming the presence of contaminants in country food. There is often uncertainty as to how much to respond to the hazard. They must rely on individuals using different modes of understanding, communication and inquiry, and there are often competing messages about the nature and extent of the risks by different experts (Elias and O'Neil, 1995). Works by Usher et al. (1995), O'Neil et al. (1997) and Poirier and Brooke (1999) show the potential distrust resulting from this confusion, and the effects they have on reception of later explanation or clarification of the situation.

5.4.3. Impacts of these perceptions

Regardless of the knowledge of pollution or contaminants, many northerners report that they would continue to eat country foods despite the advice given by health officials, because country foods are part of their culture, lifestyle and health (O'Neil et al., 1997;

Furgal et al., 1999). Nunavik residents participating in recent work investigating the factors influencing individuals' intent to eat country foods (Furgal et al., 2001) report various advantages to eating country foods, including: the health and nutritional benefits; the economic/cost advantages; as well as aspects of taste and freshness. These participants and women in the western Canadian Arctic (Kuhnlein and Dickson, 2001), did not identify the concern of contaminants or food safety issues as a factor strongly influencing their choice of whether or not to eat country foods.

Further work on the potential effects of differing perceptions and on the public understanding of contaminants on individuals' behaviours conducted in one Baffin Island community (Clyde River), shows that some adjustment in hunting activities has occurred as a result of concern for contaminant in the local area (Wenzel and Qillaq, 2000). Ongoing research in Nunavik will shed light on the social processes involved in risk perception and the effects of perception on individual health-related behaviours (Bruneau et al., 2001).

5.5. Risk-benefit characterization

The need for a collaborative, multi-agency approach in risk assessment and management was identified in the late 1980s, and has now evolved into a broad comprehensive framework that is detailed in this section.

5.5.1. Risk management frameworks

The main objective of the NCP is: to reduce and, whenever possible, eliminate contaminants in country foods while providing information that assists informed decision-making by individuals and communities in their food use (Van Oostdam et al., 1999). This could be considered the overriding risk management goal for all activities under NCP.

The Presidential/Congressional commission on Risk Assessment and Management presented a very useful *Framework for Environmental Risk Management* (Fig. 5.5.1) in its final report in 1997. In this report, principles for risk management decision-making were outlined. Among them were:

1. Identifying and clearly characterising the problem in its public health and ecological context;
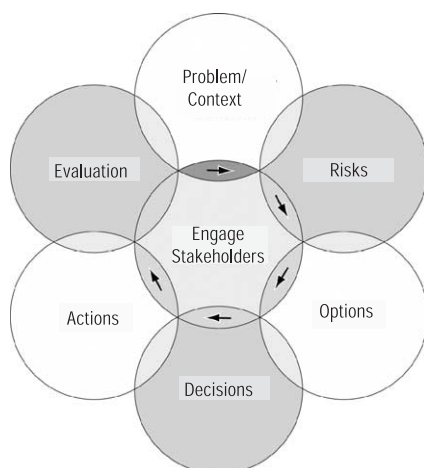
Fig. 5.5.1. Framework for environmental health risk management (Presidential/Congressional Commission on Risk Assessment and Risk Management, 1997a,b).

2. Establishing a process that elicits the views of those affected by the decision, so that different values and perceptions are considered;
3. Careful analysis of the weight of scientific evidence concerning potential effects to human health and to the environment; and
4. Considering a range of risk management options.

Health Canada's updated (1997) risk management framework described in the document Health Canada Decision-making Framework for Identifying, Assessing and Managing Risks (Health Canada, 2000), is similar to the Framework for Environmental Health Risk Management developed by the Presidential/Congressional Commission on Risk Assessment and Risk Management. Guiding principals for risk management presented in Health Canada's framework included:

1. maintaining and improving health as a primary objective;
2. involving interested and affected parties;
3. taking a broad perspective;
4. using a collaborative and integrated approach;
5. tailoring the process to the issue and its context;
6. using the precautionary approach;
7. clearly defining roles, responsibilities and accountabilities; and
8. striving to make the process transparent.

Common to both risk management frameworks are the importance of engaging stakeholders and affected parties during each phase of the process; the importance of appropriate and timely risk communication; and ensuring that the health risks are considered within the appropriate ecological and public health context.

5.5.2. Problem identification and context

The problem identification and context stage of the environmental health risk management framework is extremely important in identifying, assessing and managing health risks. In this stage the problem is identified, put into its ecological and public health context, risk management goals are determined and stakeholders are identified and engaged. The NCP has extensive processes in place to ensure that project proposals are reviewed by all stakeholders and that goals and objectives are relevant for the NCP and follow principles set out by the NCP and its partners.

Project proposals are reviewed by Territorial Contaminant Committees (TCCs) in the Yukon, NWT, Nunavut and Nunavik/Labrador. These committees have representation from local, territorial and federal governments, community representatives and Aboriginal groups. Committee members rank the proposal in terms of relevance, communication and capacity building, among other criteria. Proposals then go to review committees for human health, socio-cultural relevance, education and communication, and biological monitoring, where more detailed technical reviews occur. The proposals undergo a final review at the level of the NCP Management Committee. Stakeholders have the opportunity at several levels to be engaged in the problem/context stage of the NCP risk management framework.

A small amount of funding is also available for locally identified contaminant concerns, such as a potential contaminated site or wildlife species that may pose a risk to the health and well-being of local community members. This is one example under NCP where those who are affected by the risk management decisions are directly involved in identifying and characterizing the problem, and in each subsequent step of the risk management process.

5.5.3. Risk and benefit assessment

Benefit and risk assessment provides the scientific foundation for risk management decision-making. It

involves the careful objective analysis of the weight of evidence and scientific information on risks and benefits, and thorough consideration of the qualitative values associated with risk perception, and social, cultural and spiritual identity.

Benefit and risk assessment includes the identification and development of options to manage the health risk. Under the NCP framework, the assessment of risks and benefits is undertaken in a multi-disciplinary fashion with participation from researchers, several levels of government, and community representatives. This process evolves as new scientific information on health outcomes, nutritional, socio-cultural and economic benefits, and risk perception becomes available.

Under the NCP, benefit and risk assessment is undertaken on a case-by-case basis and involves both scientific evidence and good judgement. Risks are assessed by Health Canada using their risk assessment process (Health Canada, 1993, 1994, 2000), and in recent years also by the Centre for Indigenous Peoples' Nutrition and Environment (CINE). The risk assessment process used for assessing the human health implications of country food consumption in Arctic communities was described in detail in the CACAR-I (Van Oostdam et al., 1999), and is summarized in the following text.

5.5.3.1. Risk assessment. There is no universal definition of health risk. It has been defined as: the probability that a substance or event will produce harm under specific conditions (US EPA, 1997). Risk arises from exposure to a harmful substance or event and depends on whether that substance or situation can cause harm. Risk is determined by the careful consideration of the nature, likelihood, and severity of adverse effects on human health and the environment. What must be understood is that risk is complex and multifaceted. It does not mean the same thing to all people, and perceptions of risk are important in both risk assessment and management, and in related decision-making.

Risk assessment is the process wherein information is gathered and analyzed to determine the likelihood that a specific adverse health effect will occur in an individual or population following exposure to a hazardous agent. This process often establishes a best estimate of the risk as there are often gaps in information.

The Health Canada risk assessment process consists of four steps: 1) hazard identification; 2) hazard characterization; 3) exposure assessment; and 4) risk characterization.

Hazard identification and characterization are based on toxicological studies conducted in laboratories and/or epidemiological studies to establish dose–response relationships for contaminants. This involves gathering information on what type of adverse health effects might be expected as a result of exposure to the agent, and how quickly these effects might be experienced. The no-observed-adverse effect-level or NOAEL, is the dose at which no biologically adverse effects are observed in the study population as compared to the control population.

After the identification of the appropriate NOAELs and uncertainty factors, exposure guidelines (acceptable or tolerable daily intakes, provisional tolerable daily or weekly intakes: ADI/TDI/pTDI/pTWI) can be calculated by dividing the NOAEL by the uncertainty factor. The uncertainty factors adjust for the inter- and intra-species variation between and within animal and human populations. These intakes when averaged over the course of the entire human life span are thought to represent the exposure for humans that is without appreciable risk of adverse health effects, based on the available information (Van Oostdam et al., 1999). These guidelines are reviewed when new toxicological and epidemiological information becomes available, as was the case for mercury and for the pTDI for women of childbearing age and for children established in 1998 (Health Canada, 1998).

To estimate risk, contaminant levels in country foods are used to estimate the probable daily intake (PDI). The PDI is calculated by multiplying the average contaminant concentration in a food by the estimated daily intake of the food and this number is then divided by the average body weight of the consumer. The PDI is then compared to the exposure guideline value for the particular contaminant in question to estimate risk. If the PDI exceeds the TDI, then advice to limit consumption may be issued, and risk management decisions need to be considered. Risk characterization, benefit assessment, and the identification and evaluation of risk management options are completed by the Territorial Health agencies and their partners. These processes often involve the multi-stakeholder contaminant committees established under NCP in

each territory and in the northern provincial regions of Nunavik (Québec) and Labrador.

Different risk assessment procedures are used for substances determined to be genotoxic carcinogens. A more conservative approach is taken where no exposure level is considered to be free of risk. Animal and/or human study data are used to mathematically predict the exposure effect on various cancer risks, with risks usually assessed as one additional cancer per 100,000 population (10^{-5} risk) or one additional cancer per million (10^{-6} risk) (Van Oostdam et al., 1999).

In recent years, the Centre for Indigenous Peoples' Nutrition and Environment (CINE) at McGill University has been active in assessing risks and benefits associated with country food consumption. For example, a risk characterization of arsenic in berries in the Akaitcho Territory, as was toxaphene in fish from Fort McPherson, NWT (Stephens and Chan, 2001) was completed. CINE assesses risks using a process similar to that previously described, but with a significant difference, in that they use information from dietary studies they have conducted under the NCP across northern Canada. These dietary studies (Receveur et al., 1996, 1998; Kuhnlein et al., 2000) provide consumption information by community, by sex and age group, and by season. In addition, these studies present information on the nutritional benefits of country foods being consumed, on the cultural and social significance of country foods and on risk perceptions.

5.5.3.2. Benefit assessment. Comparing the quantitative risks with primarily qualitative benefits associated with country food is very challenging. Attempts have been made to assess the nutritional benefits of country food and to qualify the social/cultural benefits. However, a formal quantitative methodology to weigh and compare the many benefits associated with the health risks of a diet of fish and wildlife has not been established. For example, it has been well demonstrated that fish consumption has significant health benefits in reducing cardiovascular disease among northern populations. Benefits are assessed and relative risks related to the benefits are considered, as are perceptions of risk.

Benefits are often assessed at the territorial or local level. Territorial Health Departments and TCCs (or sub-committees of these groups) come together to

discuss benefits, and the other determinants involved in the risk characterization. Information on the benefits of country food consumption gained from research activities is considered, and local Aboriginal representatives are included in the meeting to ensure that their knowledge and perspectives are included. Local representatives are best positioned to consider the socio-cultural and economic importance of specific country food items in the region of concern.

5.5.4. Risk characterization

Risk characterization provides a key source of information for risk management decision-making. It is a process where the uncertainty and assumptions that were used in the risk analysis are evaluated and the strength of scientific evidence for health effects associated with the contaminant is considered. Risk characterization involves the use of reliable scientific information from a range of disciplines (e.g., biology, physiology, economics, and social sciences) and should provide opportunities for discussion and deliberation. Scientific uncertainties, related assumptions, potential impacts on decision-making and health-related needs are carefully considered. The success of the risk characterization process depends on the participation of interested and affected parties in discussions, so that they may understand and participate effectively in the risk management process.

Within the NCP risk management framework, risk characterization is discussed by risk assessors, risk managers, health authorities, Aboriginal groups, community or regional representatives, territorial and federal governments and researchers. Risks are characterized and discussed within the same forum in which health benefits and risk management options are discussed. Risk assessors and scientists provide information on the uncertainties and assumptions that are associated with the TDIs and ADIs for various contaminants and on the strength of evidence for health effects associated with a particular contaminant. Researchers provide information on covariables for studies to assess all factors that may have had an influence on outcomes of a study. Territorial government and community representatives, local health authorities, Aboriginal groups and other interested parties help to ensure that all health-related questions of concern are answered and

that the risk characterization has put the risk in the proper perspective.

5.5.5. Assumptions/uncertainties of concern

The effects of chronic low-dose exposure in human populations remain controversial because of the inconsistency of findings among different studies and populations. Moreover, multiple factors such as smoking, substance abuse, nutrition and pre-existing health status can potentially affect the development of health effects associated with a particular contaminant. Additional considerations must include the fact that most country foods contain many toxic metal or organochlorine contaminants (Chan et al., 1995, 1997; Kuhnlein et al., 1995c; Berti et al., 1998a). Risk characterization of multiple chemical exposures poses a major challenge for risk managers, as most risk assessments address only single chemicals. Information on toxicologic interactions of environmental contaminants is limited. However, there is ample evidence suggestive of supra-additive and infra-additive interactions among environmental contaminants (Krishnan and Brodeur, 1994). Research is being conducted under the NCP to gain a better understanding of toxicologic interactions between contaminants and between nutrients and contaminants. However, research has not progressed far enough to allow this to be included in the present risk characterizations.

5.5.6. Weighing benefits and risks—challenges in practice

After the risks are characterized and the nature and extent of uncertainty and assumptions are understood, the characterized risk must be weighed and compared with the known and potential benefits. Risks and benefits are discussed and weighed in a multi-agency forum, with participation from risk assessors, risk managers, health authorities, Aboriginal governments, and community or regional representatives, territorial and federal governments and researchers. It is important to have as much technical and non-technical information as possible on which to base the comparison of risks and benefits, and to consider the perspectives and interests of all affected parties. These working groups or committees must take on the challenging task of considering the uncertainty associated with the health risks, the difficulty in comparing

quantitative risks with qualitative benefits, and the consideration of other associated health risks and issues in the region.

5.5.7. Option analysis/evaluation

Once risks have been characterized, risk management options can then be identified and evaluated. At this stage, the specific nature of regional issues must be considered, and public perceptions, uncertainties, and the social, economic and cultural consequences of the options are to be taken into careful consideration. Under the NCP, the identification and evaluation of risk management options occur at the level of the Territorial Contaminants Committees, or a sub-set of these in the form of a Health Advisory Working Group. Those involved in identifying and analyzing risk management options include: territorial or provincial health authorities, Aboriginal groups, scientists, risk assessors (Health Canada or CINE) community or regional representatives, environmental health officers, nutritionists and local and/or federal government representatives. It is within these groups that benefits are identified, assessed and compared to risks; assumptions and uncertainties associated with the risks are discussed; and local perceptions of risks are considered.

It is important that options are identified with the wide rage of interested and affected parties, because the responsibility for managing the risk is often shared, and various organizations may be involved in implementing the selected strategy. Interested and affected parties can help to identify criteria for analyzing options by providing required information, participating in the analyses, and providing advice as to whether the results of the analysis are acceptable and help to redefine risk management goals as required.

When analyzing potential risk management strategies, the following are considered: risks vs. benefits; expected costs of implementing the plan; available resources; unintended consequences (creation of new risks, or unwanted social, cultural, ethical, environmental and other indirect health impacts); and the perceptions, concerns and values of interested and affected parties. Risk management options relevant to the issue of contaminants in country food can include: regulatory measures (at local or international level); the release of consumption advice or identification of alter-

native food sources; education and communication strategies to help people make informed decisions; or not taking action when action is not required.

5.5.8. Selecting a risk management option

The results of the option analysis are used to select the most appropriate risk management option or options. Selecting an appropriate risk management strategy is always a challenge because complete information is often not available. Uncertainty factors relating to the intake values (TDI/ADI) may be large, making it difficult to accurately characterize the risk for particular contaminants. Data on dietary exposures may be limited and actual exposures may be lower than estimated. Good information on risk perceptions may also not be available.

There have been several cases for the Canadian Arctic where recommendations to continue consuming country foods have been made despite the potential risk of adverse effects from exposure to contaminants. The benefits of continued consumption are great, and there is uncertainty associated with the assessment of risk. All individuals are exposed to mixtures of contaminants, not sole contaminants as health risk assessments assume; there is evidence of interaction between nutrients and contaminants. In addition, the assessments are based on daily consumption levels over a lifetime, which are not consistent with the largely seasonal diet of northern Aboriginal peoples.

5.5.9. Implementation

Once the preferred risk management option is selected, a strategy for its implementation is developed. All affected parties need to participate in developing the management strategy. A protocol is established for the release of information related to contaminants in a prompt and understandable way. The communication of information must take into consideration cultural differences, language differences, and other potential barriers to comprehension such as individual perception of risk. Personal perception of risk can have a significant impact on personal and community reaction to the information presented (Van Oostdam et al., 1999).

5.5.10. Monitoring and evaluating the decision

Once a risk management decision has been made, its implementation is carefully monitored and evaluated to see if it is appropriate and effective. If implementation problems occur, or if knowledge of the hazard or the risk changes, the decision should be reviewed. This step is extremely important and illustrates how the process of risk management is an evolving process and is subject to change as new information about the situation is learned and assessed. This approach must be continually modified to suit each situation and each community (Van Oostdam et al., 1999).

5.6. Risk and benefit communication

Effective communication is fundamental to the aims of the NCP. Northerners must have appropriate information on the contaminant risks, and nutritional benefits to make informed decisions about the harvesting and consumption of country food. Communicating risk and benefit information in a balanced, clear, accessible and meaningful way to northern communities requires sound and accurate technical information as well as respect for and understanding of the knowledge, perceptions, concerns and priorities of northerners. Thus, benefit and risk communication of the potentially sensitive environmental health information generated under the NCP presents its own unique set of considerations and challenges, and has been a focus of resources, efforts and research during NCP-II.

Communicating about contaminants is typically a challenging process in the North, due to part nature of the subject matter. Stiles and Usher (1998) acknowledge that messages describing risk are the most difficult ones to generate. There is a fundamental difference between the quantitative way in which risk assessment results are characterized and the qualitative terms with which the general public thinks about risks. While health professionals are accustomed to risk calculations given as probabilities with built-in uncertainty factors, people receiving the message generally want definitive, clear-cut answers to the question of "What does it mean to me?" or "Is my food safe to eat?". This requires that technical terminology be put into plain language, whether be it English, French or the Aboriginal language understood by the audience; that visual representations of risk avoid the use of complex data graphs and figures; and that the messages be developed and delivered with consideration for the cultures and knowledge systems of Aboriginal peoples.

The contextual, technical, social and procedural challenges for communicators associated with these differences were reported in detail in CACAR-I (Van Oostdam et al., 1999) and by Usher et al. (1995), and reiterated in more recent work by Lampe et al. (2000) and Furgal et al. (2005). These reports emphasize the fact that within the cultures of northern Aboriginal peoples, the environment, including the foods that it offers, is a defining element of identity and overall well-being. Country foods are more than a source of nutrition. It is an important source of economic, cultural, social and spiritual well-being. Practical alternatives to country food are also not readily accessible to many northerners due to the associated costs and availability. Communicators must thus be sensitive and aware that any information that leads to a disruption of country food production, sharing and consumption patterns of northern communities has the potential to affect the northern way of life and the social fabric that keeps communities healthy, active and sustainable.

Effective risk and benefit communication is a process, not simply a product (Usher et al., 1995). Ideally, it is a dialogue: an ongoing two-way or multi-directional exchange of information, perspectives, ideas and feelings among individuals that creates and fosters opportunities for feedback and mutual learning. Effective risk and benefit communication use various media (e.g., reports, pamphlets, posters and audio–video materials), not to substitute face-to-face discussion, but to complement, enhance and facilitate dialogue and exchange. Ideally, too, it will portray a situation accurately such that recipients of the information will have a sound and shared appreciation of the issue at hand and its solutions, and will feel empowered to take action or make informed choices (Van Oostdam et al., 1999). Practical guidelines for developing communications materials specific to various media and delivering presentations to northern audiences have been developed by Stiles and Usher (1998) and Lampe et al. (2000), and in-depth assessment of NCP communications materials and methods can be found in the Knowledge in Action publication (see Furgal et al., 2003 for more details).

An appreciation of the profound importance of effective communication was gained through the experiences of early communications efforts that fell short of the ideal. These instances made it evident that misguided communications efforts, however well-intended, can and have led to significant impacts, both direct and indirect, intentional and unintentional, among the affected populations. The implications of poor risk communication of contaminants in country food and recommendations for improving communication efforts are becoming well documented (Wheatley and Wheatley, 1981; Usher et al., 1995; Powell and Leiss, 1997; Van Oostdam et al., 1999; Lampe et al., 2000; Furgal et al., 2005). In their review of 13 instances since the 1970s of dealing with contaminant issues in Aboriginal communities, Usher et al. (1995) reported that deficient communications efforts on environmental contaminant had left communities feeling anxious, angry and confused and disrupted social and cultural aspects of life related to harvesting and consumption of country food.

Usher et al. (1995) reported that 3 years following the completion of follow-up studies, residents were still anxious about the health risk posed by PCBs, and attributed many of their health problems, including cancer, suicides and premature births, to these contaminants. Hunters in one community had also shifted their seal hunting areas more distant from a perceived area of contamination (Wenzel and Qillaq, 2000). In this case, the communication process had begun in earnest by the researchers, through seeking appropriate permission to conduct the study and informing residents by community radio. Several factors, however, compounded to create the communication crisis. This may have been averted through a more careful consideration of the particular risk and benefit trade-offs of country food consumption, and by a thorough communication plan developed in cooperation with the community using funds allocated for communication activities (Usher et al., 1995; Powell and Leiss, 1997).

The practice of risk communication related to contaminants in northern country food has changed over the past two decades, building upon lessons learned along the way. This parallels loosely what Powell and Leiss (1997) describe as three distinct stages in the evolution of risk communication:

1. The early days focussed on the quantitative and comparative expressions of risk estimates;
2. The next phase adopted additional aspects of enhancing the credibility of the source and mes-

sage by building trust through public discussion and developing messages based on understanding the information needs, perceptions and concerns of the audience;

3. The current efforts further emphasized the social context of risk management by building effective stakeholder relationships through long-term organizational commitments to practising responsible risk communication.

In terms of the NCP, this has meant a transition from risk communication to risk-benefit communication; that is, from delivery of risk assessment results to ongoing two-way dialogue on the benefits and risks associated with the issue. Risks are placed within the context of the nutritional, social, cultural, economic and spiritual benefits of consuming country food, and within a greater public health context relating to general health and well-being. In place of one-way models of message dissemination, NCP-II strove toward shared decision-making through partnerships involving territorial and regional contaminants/health communities and representatives of Aboriginal organisations at all stages of the risk management and risk communication process. As a result of these changes, there has also been a shift away from health authorities issuing advisories to providing general advice which is discussed and delivered by individuals who are trusted in the community, using various formats and materials.

To support the shared decision-making process for benefit and risk communication, the NCP established various protocols and supports networks in all northern regions. In the Yukon, NWT and Nunavut, the Territorial Contaminants Committees, whose members included representatives of Aboriginal organizations and Territorial Health Departments, determine the applicability of Health Canada recommendations to northerners and devise an appropriate communication plan for the release of the information. Depending on the significance of the risk assessment results, the information may be released through a number of methods, including a press release, radio phone-in shows, and various forms of print media. The Territorial Health Departments, in association with the regional Aboriginal organizations, take the lead in ensuring that people receive the appropriate information. Similar processes are in place in Nunavik and Labrador, involving, respectively, the Nunavik Re-

gional Board of Health and Social Services in consultation with the Nunavik Nutrition and Health Committee, and the Labrador Inuit Association and Labrador Inuit Health Commission in consultation with the relevant health authority.

6. Conclusions

The key objectives of this paper are to assess the impact of exposure to current levels of environmental contaminants in the Canadian Arctic on human health, and to identify the data and knowledge gaps that need to be filled by future human health research and monitoring.

6.1. Aboriginal perspectives on food and health and interpretation of research results

Traditional/country foods are an integral component of good health among Aboriginal peoples, and their social, cultural, spiritual, nutritional and economic benefits must be considered in concert with the risks of exposure to environmental contaminants via consumption of traditional/country foods.

Persistent environmental contaminants such as PCBs, toxaphene, DDT and mercury biomagnify and bioaccumulate in the food chain. Because a substantial proportion of the Aboriginal diet consists of traditional/country food, Aboriginal peoples have a greater contaminant exposure than non-Aboriginal peoples or people in southern Canada. Traditional/country food is an economic necessity for many Aboriginal peoples, and provides additional benefits beyond the activity of hunting itself, as it is the tie that binds Aboriginal peoples together and allows the sharing and teaching of their traditional social and cultural values.

In assessing causal associations between findings in any epidemiological or toxicological study the following factors must be considered: strength and magnitude of the association, consistency of the association, dose–response relationship, temporally correct association, and biological plausibility of the association. Determining the adverse human health effects due to the presence of contaminants in traditional/country foods is very difficult as many factors contribute to the health of an individual and in fact contaminants may only play a modest role in deter-

mining an individual's health status. Factors such as lifestyle (e.g., alcohol consumption, smoking, and substance abuse), diet, socioeconomic status and genetic predisposition need to be considered when evaluating the results in this report.

6.2. Exposure assessment

A recent assessment of the average weekly frequency of consumption of main traditional/country food items in Dene and Métis, Yukon, and Inuit communities has shown a very wide range of these foods, including more than 250 different species of wildlife, plants and animals. Regional differences in species used most frequently are due to ecosystem variety and cultural preferences Traditional/country food use for women and men 20–40 years of age is highest in Inuit communities, followed by Dene and Métis of the NWT and then First Nations people of the Yukon. It was also noted that for Canadian Inuit, intakes of traditional/country food do not seem to have significantly changed in the last 20 years.

Inuit mothers have oxychlordane and *trans*-nonachlor levels that are 6–12 times higher than those in Caucasians, Dene and Métis or Other mothers, with Baffin Inuit mothers having the highest levels. Similar patterns were observed for PCBs, HCB, mirex and toxaphene. Levels of β-HCH are 5–12 times higher among the Other mothers than in Inuit, Caucasians or Dene and Métis mothers, while DDE levels in the Other mothers are also roughly 3–6 times higher. This higher exposure may be due to the fact that the Other mothers consists of people whose exposure may be related to their possible African or East Asian country of origin or foods imported from these regions. PCBs are a major contaminant of concern in the Arctic. Inuit mothers have the highest levels of PCBs compared to Caucasians, Dene and Métis and the Other mothers, with Baffin Inuit having the highest levels. Caucasians mothers from the NWT have slightly higher levels of total TCDD–TEQs (dioxins and furans and dioxin-like PCBs) than Inuit or Dene mothers. The relative contributions of dioxins and furans and dioxin-like PCBs to the total TCDD–TEQs are very different in the three groups. Among Inuit mothers dioxin-like PCBs account for 80% of the total TCDD–TEQs,

while for Caucasian mothers its only 27%; Dene mothers have a relatively equal contribution from both sources.

Recent research has revealed significantly higher levels of organic mercury in maternal blood of Inuit women compared to Caucasian, Dene and Métis, or the Other group. Nunavik and Baffin Inuit have higher levels in maternal/cord blood than those seen in the Kitikmeot, Kivalliq and Inuvik regions. Mercury levels in Salluit resident's vary markedly from year to year due to variation in availability of traditional/country foods, but recent tissue levels are similar to the levels found in the late 1970s.

Research on lead isotope signatures has shown that the slightly elevated blood lead levels among some of the Inuit groups and the Dene and Métis are likely due to the use of lead shot in hunting of traditional/country foods, and thus its presence in consumed wild game. Blood cadmium levels are roughly 1.5 to 5 times higher among Inuit than in Dene and Métis, Caucasians, and Other. This difference is likely due to the high rate of smoking among Inuit mothers and the high cadmium content in Canadian tobacco.

Radiocesium entered the atmosphere as a result of atmospheric testing of nuclear weapons. Since the CACAR-I (Van Oostdam et al., 1999), measurements of radiocesium levels in Canadian caribou herds have shown that levels are now considered insignificant and are continuing to decrease, with an ecological half-life of about 10 years. The radionuclides lead-210 and polonium-210 are naturally occurring and supply most of the radiation dose to consumers of traditional food. These radionuclides have been present in the Arctic environment for thousands of years at more or less the same concentrations as today and accumulate in the lichen–caribou–human food chain. Current estimates of polonium exposure would give a radiation dose of 3 to 4 mSv/year to a high consumer of caribou meat over and above normal background radiation exposure of 2 to 3 mSv/year.

6.3. Toxicology

In experimental studies, to clarify the potential toxicity of toxaphene, a no-observed-effect-level (NOEL) of 0.1 mg toxaphene/kg bw/day was found for non-human primates regarding immunological

effects. These findings support those seen in rodents where doses were 10 times higher (no NOEL was found in these studies). In certain Arctic populations, toxaphene residues are within the same range as the experimental studies where effects on immune function and infant size have been observed. While more information is needed on the carcinogenic and endocrine-disruptive capacity of toxaphene, new and forthcoming information will be useful in a re-assessment of the toxicity and provisional tolerable daily intake (pTDI) of this chemical.

The pattern of chlordane-related residue accumulation in humans parallels that seen in the highest levels of the Arctic marine food chain. Estimated chlordane intake values for Arctic residents vary from levels below the Health Canada pTDI to levels approaching or exceeding the higher US EPA TDI, depending on marine mammal fat consumption. More research is required on to clarify the risk that chlordane poses to human health. Based on the latest rodent studies at Health Canada, a thorough risk assessment with the goal of re-assessing the TDI should take into account that the major chlordane metabolite oxychlordane is almost 10-fold more toxic than the parent chlordanes and nonachlors, and that *trans*-nonachlor and oxychlordane are among the more bioaccumulative chlordane contaminants.

There is some evidence that dietary nutrients such as polyunsaturated fatty acids, fish protein, and selenium may interact with methylmercury toxicity at least on the mechanistic level. The two former nutrients may be protective against methylmercury neurotoxicity; however, there is no conclusive evidence of such an effect. Selenium has been the main nutritional factor considered by epidemiological and clinical studies to date. No epidemiological studies, however, have ever shown a correlation between selenium intake and the occurrence or absence of symptoms for methylmercury intoxication. There are also inconsistencies in the protective effects seen in animal studies, and the role of selenium remains to be confirmed. In animal studies, selenium alone did not provide protection against fetal mortality caused by in utero methylmercury treatment, while vitamin E alone and the combination of vitamin E and selenium treatments did.

6.4. Epidemiology and biomarkers

Neurobehavioural effects of perinatal exposure to environmental contaminants are best studied in prospective longitudinal cohort studies starting during pregnancy because there are numerous other determinants of infant and child development that need to be documented and are best assessed during pregnancy or at birth. Examples of these determinants are prenatal exposure to alcohol, drugs and tobacco; exposure to other environmental contaminants such as lead; and intake of nutrients such as selenium and omega-3 polyunsaturated fatty acids (PUFA) during pregnancy.

For methylmercury, the Faroe Islands study appears to be the most useful to extrapolate results to the Canadian Arctic [exposure to PCBs and mercury, similar sources (e.g., marine mammals), intake of omega-3 polyunsaturated fatty acids]. Differences remain, such as the genetic profile, a higher intake of selenium among Inuit, and a different pattern of exposure (peaks). Detailed analyses provide some evidence that the neurobehavioural deficits identified are the effects of methylmercury and not the consequence of exposure to PCBs.

In Nunavik, *otitis media* (middle ear infection) during the first year of life was associated with prenatal exposure to *p,p′*-DDE, HCB and dieldrin. Furthermore, the relative risk of recurrent *otitis media* increased with prenatal exposure to these compounds. To date, the ongoing Nunavik study supports the hypothesis that the high incidence of infections observed in Inuit children (mostly respiratory infections) maybe due in part to high prenatal exposure to POPs, although definitive conclusions need to await final adjustment for important possible confounders (e.g., parental smoking, and vitamin A).

The strength of the negative association of PCBs on birth weight for newborns in northern Québec was comparable to the associations with prenatal exposure to alcohol and smoking during pregnancy. The negative effects of prenatal PCB exposure on birth weight and duration of pregnancy could still be demonstrated despite the beneficial effects of omega-3 fatty acids from the traditional/country diet. The ongoing Nunavik cohort study should help to shed more light on contaminant exposure and potential related health effects in the areas of neurodevelopment and immune function.

6.5. Risk and benefit characterization, assessment and advice

The primary contaminants of concern in the context of traditional/country food consumption in Arctic Canada are the persistent organic pollutants PCBs, chlordane and toxaphene, the toxic metal mercury and naturally occurring radionuclides.

In recent dietary surveys among five Inuit regions (Baffin, Inuvialuit, Kitikmeot, Kivalliq and Labrador), mean intakes by 20- to 40-year-old adults in Baffin, Kivalliq and Inuvialuit communities exceeded the pTDIs for chlordane and toxaphene. High consumers (95th percentile) of traditional/country foods are exceeding the pTDIs by many-fold for toxaphene, chlordane, and PCBs. The Inuit populations that had the greatest exceedance of the pTDIs also had the greatest exceedance of the PCB maternal blood guideline.

In one Inuit community, Qikiqtarjuaq (Broughton Island), Nunavut intakes of organochlorines including PCBs, chlordane, and toxaphene were higher in 1998–1999 than in 1987–1988, particularly among the high-end consumers (95th percentile). While the organochlorine concentrations used for the estimations were similar, variations in the amounts of certain traditional/country foods consumed likely account for this difference.

Mercury is the toxic metal of greatest concern in the Canadian Arctic. Dietary intakes of mercury were similar in the two surveys conducted in 1987–1988 and 1998–1999, indicating that there has been little change in dietary pattern and/or mercury concentrations in traditional/country foods. Based on the exceedances of the provisional tolerable daily intake (pTDI) and of various blood guidelines, mercury, and to a lesser extent lead (from use of lead shot in hunting of game), may be a significant concern among Arctic peoples. It may be easier to change peoples' use of lead shot, as the users of the shot are also the consumers of the wild game. For mercury, the connection between those affected in the North and sources of pollution in the south is not as direct and it may be more difficult to institute appropriate pollution abatement measures.

There is mounting evidence that a threshold may exist for radiation-induced cancer and this threshold may be equal to or greater than 100 mSv. The issue is of significance to northerners, who were exposed in the past to nuclear weapons fallout, or who have slightly higher exposures due to caribou meat consumption. Even if one assumes that the linear no-threshold hypothesis is correct, the risk of continued consumption of caribou meat is very small. A maximum radiation dose rate at present is estimated to be about 3 to 4 mSv/year. The only way to reduce these radiation doses further would be to restrict caribou meat consumption, which would deny northerners the nutritional, social and cultural benefits of this important traditional/country food.

The nutritional benefits of traditional/country food and its contribution to the total diet are substantial, although only 6–40% of total dietary energy may be from this food source. Research findings are consistent across the Canadian Arctic and confirm that decreasing traditional/country food in the diet is likely to have negative health consequences, in part through the corresponding increase in total fat, saturated fat and sucrose above recommended levels. Traditional/country food also contributes significantly more protein, iron and zinc to the diets of Inuit children than imported foods.

Effective communication is fundamental to the aims of the NCP. Communication efforts incorporate Aboriginal knowledge on the nutritional benefits and risks associated with the consumption of traditional/country foods and of imported foods, and on the importance of a traditional lifestyle to overall health and well-being. These efforts provide northerners with the appropriate information to make more informed decisions about harvesting and consumption of both traditional/country and imported foods, and also to avoid some of the mistakes of earlier communication efforts related to environmental contaminants.

No one method of communication is best, but what is needed is a variety of methods and materials appropriate to communities in different regions and specific to groups within each community, all aimed at providing opportunities for two-way exchanges of information and allowing an understanding of the issue to develop. This builds a collective comprehension of benefits and risks, as well as the limitations of the scientific assessment.

The practice of risk communication has changed over the past two decades, building upon lessons learned along the way. In place of one-way models of

message dissemination, NCP-II strove toward shared decision-making through partnerships involving Territorial Health Departments and regional contaminants/health committees, community representatives and representatives of Aboriginal organizations at all stages of the risk management and risk communication process.

7. Knowledge gaps

7.1. Exposure assessment

Continued monitoring and assessment of the frequency of consumption of traditional/country foods in a limited number Dene and Métis, First Nations, and Inuit communities is needed to identify any significant changes in consumption patterns. Focus needs to be placed on communities with the highest exposure but must include an assessment of regional variations.

The monitoring of organochlorines in human tissues does not have a long history in the Canadian Arctic, and continued monitoring of tissue levels is needed to determine contaminant trends. Special attention should be given to oxychlordane, *trans*-nonachlor, HCB, mirex, toxaphene, PCBs, and mercury, especially among the Inuit of Nunavut and Nunavik. There may be systematic differences among subgroups in these regions, and more data are needed.

Although there is a longer history of Arctic environmental monitoring of mercury, than of organochlorines differences in sampling strategies have made any conclusions on trends very tenuous. Regular monitoring of tissue levels among communities with a range of exposures for mercury and selenium is advisable.

Ongoing concern about the effects of naturally occurring polonium-210 in northern food chains has led to a research project looking at the evidence of damage from this radionuclide in cultured human and animal cells using advanced techniques in molecular biology. This work needs to be completed, as the detection of these effects could serve as an early warning, long before any overt health effects occur or alleviate unfounded concerns.

Focussed monitoring of traditional/country food consumption in specific Arctic communities through surveys of dietary intakes of environmental contaminants, particularly of organochlorines (e.g., PCBs, chlordane, toxaphene) will help to provide more spatial and temporal data on changes in dietary patterns or contaminant concentrations in food. Communities with high traditional/country food consumption and a range of contaminant exposures need to be included.

Surveys of dietary intake in one Inuit community have shown that mercury exposures were similar in 1987–1988 and 1999, thus implying little change in dietary pattern or mercury concentration in food. However, monitoring in a range of communities would provide additional data points on which to base firmer conclusions.

7.2. Toxicology

More research is needed on the bioaccumulation and/or metabolism of toxaphene congeners by aquatic and terrestrial organisms, including human, in order to ascertain the number of congeners present in "toxaphene" and in the environment; to clarify their specific toxicity (e.g., immunological effects, infant size, mutagenicity and genotoxicity, and endocrine effects); and the appropriate TDI for these congeners.

The most relevant toxicological issues to be addressed in future research on chlordane contaminants are the relationship between tissue levels in humans and in experimental animals, and the occurrence of specific functional changes, including but not limited to immune suppression. Since *trans*-nonachlor and oxychlordane appear to be present at higher levels in marine mammal tissues than are other chlordane-related contaminants, it would be useful if future human exposure assessments focussed on *trans*-nonachlor and oxychlordane tissue levels.

Additional experimental animal and in vitro studies on the toxicological effects of complex organochlorine mixtures should also include assessment of the interactions between substances that may result in antagonism, additivity, or synergism and identification of compounds responsible for toxic effects. Particular attention needs to be paid to in utero and lactational exposure and developmental, reproductive effects, and immunological effects.

It is clear that there is a need for more studies designed specifically to address the role of nutrition in the metabolism and detoxification of methylmercury. It is also important to collect more detailed dietary information in future epidemiological studies of methylmercury exposure. A controlled human study on effects of various nutrients such as omega-6 fatty acids, selenium and vitamin E on methylmercury toxicokinetics will be useful to confirm the results obtained from the animal experiments.

7.3. Epidemiology

The Nunavik cohort study should allow differentiation of the specific deficits attributable to PCBs and those associated with mercury, since the cord blood PCB-mercury intercorrelation is low. With the establishment of a prospective Arctic birth-cohort, there will be opportunities to look at other contaminants which may have neurodevelopmental effects, as well as to study long-term effects that can only be documented at school age or later in the course of development.

The only recent epidemiological study of contaminant effects conducted in the Canadian Arctic is the one in Nunavik. This study suggested an association between in utero exposure to POPs and susceptibility to infections during the first year of life. Although efforts have been made to also use effect biomarkers (vitamin A and cytokines), as noted earlier, the low predictivity of these markers limits their use. The usefulness of new markers (antibodies post-immunization and complement system) needs to be assessed within the cohort study in Nunavik and elsewhere in the Arctic.

Epidemiological studies on stochastic diseases (e.g., breast cancer and other hormonal cancers) are extremely difficult to conduct in the Arctic because the number of cases is low. This is due to 1) the size of the population and 2) the fact that many chronic diseases (cancer) have a low incidence. To assess these health endpoints, long-term circumpolar studies need to be used to increase the sample size and increase the likelihood of detection of any real effects. Epidemiological studies in the Canadian Arctic should be restricted to diseases or conditions that: 1) have high-incidence rates; 2) have gradients of severity (from normality to overt abnormalities); and 3) are easy to diagnose.

7.4. Risk and benefit characterization, assessment and advice

Focussed monitoring and assessment of organochlorine intake, especially by high-end consumers of traditional/country foods in specific Inuit communities, are strongly warranted. The risks associated with usual levels of exposure to organic mercury via consumption of contaminated traditional/country foods also need to be characterized since they too appear prevalent in the Baffin and Nunavik regions.

The substantial nutritional benefits of traditional/country food and its contribution to the total diet have been documented; however, further research is needed on the negative health consequences of not consuming traditional/country food.

Few projects have been conducted under the NCP to specifically investigate public perceptions of contaminants in traditional/country foods and related risks, understandings and misunderstandings of the issue, and the potential impacts they may have on individual behaviour and activities. There is a continuing need to document and understand public perceptions of contaminants and how the issue is being addressed in the North.

There is a need to further clarify messages for Aboriginal peoples, taking into account different community-of-origin dialects that can significantly affect the reading comprehension of printed material, and improving the effectiveness of some of the methods used to convey environmental health information. Research is also needed on ways that women of childbearing age use information to make informed decisions regarding consumption of PCB- and mercury-contaminated traditional/country food items.

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