

Human Exposure Monitoring and Evaluation in the Arctic: The Importance of Understanding Exposures to the Development of Public Health Policy

William A. Suk,¹ Maureen D. Avakian,² David Carpenter,³ John D. Groopman,⁴ Madeleine Scammell,⁵ and Christopher P. Wild⁶

¹National Institute of Environmental Health Sciences, National Institutes of Health, Department of Health and Human Services, Research Triangle Park, North Carolina, USA; ²Michael D. Baker, Inc., Research Triangle Park, North Carolina, USA; ³Department of Environmental Health and Toxicology, School of Public Health, University at Albany, State University of New York, Albany, New York, USA; ⁴Department of Environmental Health Sciences, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland, USA; ⁵School of Public Health, Environmental Health, Boston University, Boston, Massachusetts, USA; ⁶Molecular Epidemiology Unit, Epidemiology and Health Services Research, School of Medicine, University of Leeds, Leeds, West Yorkshire, United Kingdom

Arctic indigenous peoples face significant challenges resulting from the contamination of Arctic air, water, and soil by persistent organic pollutants, heavy metals, and radionuclides. International cooperative efforts among governments and research institutions are under way to collect the information needed by environmental health scientists and public health officials to address environmental contamination in the Arctic. However, the climatic, political, and cultural conditions of the land and its native populations combine to present a unique set of scientific and logistic challenges to addressing this important public health issue. Public health officials have the responsibility to respect the cultural traditions of indigenous communities, while simultaneously designing strategies that will reduce their exposure to environmental contaminants and rates of disease and dysfunction. Researchers can better understand the link between environmental exposures and disease through monitoring programs for both the subsistence diets and health status of the indigenous populations. We suggest that the incorporation of community-based participatory research methods into programs designed to assess biomarkers of contaminant exposure in children and adults may be a valuable addition to ongoing and newly developed research programs. This approach could serve as a model for international environmental health initiatives, because it involves the participation of the local communities and seeks to build trust between all stakeholders. *Key words:* Arctic, biomarker, community-based participatory research. *Environ Health Perspect* 112:113–120 (2004). doi:10.1289/ehp.6383 available via <http://dx.doi.org/> [Online 31 October 2003]

The Arctic is home to many indigenous populations that face significant challenges to their health resulting from the contamination of Arctic air, water, and land. Unique obstacles introduced by climatic, political, and cultural aspects of the land and its native populations have made it difficult to assess the true extent of environmental contamination and exposure in the region and address them through the design and application of appropriate research programs and prevention strategies. However, this highly vulnerable population can be protected through the most modern research tools available and community participation.

In this article we frame the various problems and opportunities presented by the climate and culture of the Arctic and its peoples; briefly review research initiatives and international collaborations that address environmental contamination in the region; and recommend pathways to develop and implement a research-and-prevention strategy that considers both the needs of the research community and the desires and concerns of the native populations that the research seeks to observe and understand.

The approach recommended here focuses on the development of research programs designed to assess biomarkers of exposure and susceptibility and monitor the diet and health of native Arctic populations within the context

of carefully designed community-based participatory research programs. We discuss a specific process for developing and executing a region-wide monitoring program that could serve as a model for international environmental health initiatives worldwide.

Framing the Issue: Arctic Geography and Native Populations

There are many definitions of the Arctic, variously based on climatic, physical, geographic, or political criteria. For research purposes, the Arctic Monitoring and Assessment Programme (AMAP) describes the Arctic as the area north of 60° north latitude, including Alaska north of the panhandle, Canada north of the southern shore of Hudson Bay, all of Greenland and Iceland, and the northern reaches of Norway, Finland, Sweden, and Russia (AMAP 2002a). In addition to these land masses, the Arctic encompasses approximately 20 million km² of ocean. The perennial ice pack covers about 8 million km² of the Arctic Ocean; nearly 15 million km² are covered by sea ice from March to May.

The inhabitants of this region, particularly indigenous peoples such as the Inuit, Aleut, Saami, Yupik, Dene, Métis, and Yukon First Nations, face a unique set of challenges resulting from the vastness of the region and the

extremes of the climate. Moreover, all Arctic native cultures are in the midst of change as the indigenous peoples attempt to adapt to a wide variety of external influences, such as technologic advances, the introduction of nontraditional foods, and the appropriation of modern practices. We examine specifically the impacts of external environmental forces that have presented a new challenge for the native Arctic populations, who depend heavily on the natural resources and healthy functioning of ecosystems (Union of Concerned Scientists 2003): contamination of Arctic air, water, soil, tundra, and permafrost by persistent organic pollutants (POPs), mercury and other heavy metals, and radionuclides (Ayotte et al. 1995).

A prime example of the way in which these external environmental influences threaten Arctic communities is demonstrated by the impact of global climate changes. The Arctic is warming at a faster rate than the global average; the average annual temperature in the Arctic has increased by about 1°C over the last century (Dickson 1999; Wang and Key 2003). Scientists led by Maynard Miller have monitored the Lemon Creek Glacier in the Juneau Icefield since 1953 and have documented a terminal retreat of 800 m, with dramatic changes observed in the 1990s (Miller and Pelto 1999). The Arctic ice pack is not only shrinking in area, but rapidly thinning as well (Vinnikov et al. 1999). Overall, the Arctic ice has lost 40% of its volume in less than three decades (Kerr 1999; Rothrock et al. 1999). Coastal erosion has already forced native communities in Alaska to relocate, and

Address correspondence to W.A. Suk, Center for Risk and Integrated Sciences, NIEHS, P.O. Box 12233, Research Triangle Park, NC 27709 USA. Telephone: (919) 541-0797. Fax: (919) 541-2843. E-mail: suk@niehs.nih.gov

The authors extend their appreciation to S. Wilson of the NIEHS for his vision and guidance; to D.C. VanderMeer, Environmental Health Consultant, for his critical role in the early stages of this project and his insight on a wide range of topics. Special appreciation is extended to M.M. Miller, with whom W.A.S. spent time years ago as a part of a truly unique experience on the Juneau Icefield and learned the meaning of interdisciplinary research.

The authors declare they have no competing financial interests.

Received 8 April 2003; accepted 30 October 2003.

changes in temperature, ice pack, and snow cover are affecting the distribution and breeding of animals hunted for food and materials (AMAP 2002b). Arctic permafrost has acted as a sink for greenhouse gases, POPs, heavy metals, and radionuclides (BBC News 2001). Loss of this ice could trigger the release of these contaminants, allowing them to enter the food chain.

Arctic Environmental Contamination: Sources and Potential Impacts

Because the human population is relatively small and there is limited large-scale industry in the Arctic, there are few local anthropogenic sources of pollution. However, some contaminant sources do exist in the Arctic, including oil and gas installations, mining and metallurgy industries, military installations, and nuclear waste dumps and storage sites (SeaWeb 1999). The vast majority of Arctic contamination is the product of atmospheric or oceanic transport from industrialized and agricultural regions in the lower latitudes. In a typical global atmospheric circulation pattern, eastward-moving air masses in northern mid-latitudes can become polluted near the surface and then get carried at moderate or higher elevations to the Arctic regions, where the air masses descend and can deposit the contaminants (Pacyna 1995). The rapid transport of radioactive contaminants from the nuclear facility at Chernobyl to northern Scandinavia, with the incorporation of contaminants into all levels of the food chain, is a dramatic demonstration of the effectiveness of transport of pollutants from southern latitudes into the Arctic. By the marine route, pollutants reach the Arctic through the northeast Atlantic. Chemically stable or slow-reacting pollutants from industrialized eastern North America are carried by winds or rivers into the Atlantic Ocean and then northward by the Gulf Stream and North Atlantic Drift into the Arctic Ocean (Canadian Arctic Resources Committee 1990). Volatile organic compounds (VOCs) are transported on the wind as gases. VOCs can reach Arctic surfaces via direct deposition on the ground or ice, or in the oceans by adhering to particles or organic films. In addition, as the temperature drops, VOCs condense out of the gas phase onto particles or snowflakes in the air, which eventually land on the ground (AMAP 2002b).

The distribution and accumulation of environmental contaminants in Arctic regions have been well documented (AMAP 2002b; Barrie et al. 1992; Gubula et al. 1995; Ikononou et al. 2002; Pacyna 1995). POPs of concern include organochlorine pesticides, polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers (PBDEs). These synthetic organic chemicals break down slowly

in the environment and are fat-soluble. They have been shown to interfere with thyroid and sex hormones, limit cell-mediated immunity, and increase the risk of cancer (AMAP 2002b; Ayotte et al. 1995; Canadian Arctic Resources Committee 1990). Exposure to heavy metals produces a wide range of health impacts. Mercury is a nerve toxin; cadmium can damage the kidneys and disturb the metabolism of vitamin D and calcium; and lead interferes with the formation of red blood cells, leading to anemia (Kuhnlein 1995; U.S. National Library of Medicine 2001a; Van Oostdam et al. 1999). Lead is especially toxic to the growing brain and can affect the behavioral development of the young, even at low concentrations. Furthermore, exposure to lead can result in progressive declines in memory and learning long after exposure to lead has stopped (Schwartz et al. 2000). Radionuclide exposure can affect germ cells and may also increase risks of cancer (Frohberg et al. 2000; Environment Canada 1991).

Once deposited on land, ice, or water, environmental contaminants often persist in the Arctic as low temperatures and low levels of sunlight slow chemical degradation processes. Pollution reaching the Arctic is generally too dilute to present a substantial threat to humans—until bioaccumulation occurs. The same fat that allows indigenous peoples and animals to survive in the harsh climate also stores the many fat-soluble organic pollutants. Bioaccumulation begins when lichen or phytoplankton absorb pollutants. By the time these pollutants reach the top of the food chain, they are often greatly magnified. For example, AMAP reports (AMAP 2002b) that caribou in Canada's Northwest Territories had 10 times as much PCB as the lichen on which they grazed, and that wolves preying on the caribou had another 6-fold increase in PCB concentration. Figure 1 contains examples of complex Arctic food webs, illustrating the potential for biomagnification and bioaccumulation of environmental contaminants.

Most of the traditionally harvested fish and land and marine animals that make up the subsistence diets of indigenous communities are long-lived and from the higher trophic levels of the food chain. Thus, these food sources may represent a significant source of contaminant exposure to Arctic populations (Van Oostdam et al. 1999), setting the stage for a complex web of scientific, cultural, and political dilemmas.

The Subsistence Diet of Arctic Communities: Benefits and Costs

Arctic indigenous communities depend on traditional subsistence foods, sometimes called "country foods," for physical, cultural, and spiritual health (Wheatley and Paradis 1996).

Although foods taken from their surrounding environment constitute the majority of the diet of rural indigenous Arctic peoples, their diets also include imported foods such as the staple items flour, sugar, and tea (Van Oostdam et al. 1999).

Analyses of traditional foods have shown that they provide adequate sources of many important nutrients. Traditional foods contribute 25–30% of total daily energy intake (Tenenbaum 1998; Wein EE. Unpublished data), and the type of lipids derived from marine fish and mammals is considered responsible for the low rate of heart disease among Arctic indigenous peoples (Dyerberg et al. 1975). Traditional animal foods provide most essential minerals, with the possible exception of calcium (Doolan et al. 1991; Kuhnlein 1995; Wein EE. Unpublished data). Traditionally harvested fish and game are also rich in many vitamins, particularly fat-soluble vitamins and the vitamin B-complex (Health and Welfare Canada. Unpublished data), and contribute adequate amounts of protein (Department of Indian Affairs and Northern Development. Unpublished data; Kuhnlein et al. 1995). Researchers have concluded that if Arctic peoples were to remove traditional food resources from their diets, the mineral nutrition of most Arctic populations would be compromised to such an extent that nutritional deficiencies would occur (Van Oostdam et al. 1999). In communities where traditional foods and the associated lifestyles have been replaced by food purchased from grocery stores, researchers have also documented decreases in physical activity, lowered resistance to infection, and increases in obesity, diabetes, dental problems, and anemia (Szathmary et al. 1987; Thouez et al. 1989; U.S. National Library of Medicine 2001a, 2001b).

Just as important as the contribution of traditional foods to the physical well-being of Arctic indigenous populations is the role these foods play in the cultural and spiritual lives of their communities. The harvesting, communal processing and sharing of these foods are essential to individual and community health. The harvest and exchange of traditional foods emphasize the relation of an individual to his or her family group and the ties of families to the community through a web of practices that ensures that food is available to all who are in need (Wenzel 1995). These traditions link individuals to their environment and to one another. They are viewed by Arctic peoples as a "social glue" that shapes minds, brings joy, and ties together families and communities (Egede 1995).

On a more practical level, members of Arctic communities often rely on a subsistence diet of traditional foods out of economic necessity; they face severe economic difficulties and often do not operate on a cash economy.

In many Arctic communities, opportunities for employment are limited and incomes are low (Van Oostdam et al. 1999). Food commodities, if available, are generally far beyond the budgets of families in indigenous communities (Usher and Wenzel 1989), and their populations typically suffer from poor health care delivery, inadequate housing and sewage disposal, and heavy use of alcohol and tobacco (Tenenbaum 1998). These economic realities pose numerous basic public health challenges to the native communities and local public health officials. Public health authorities must identify priorities that use their limited resources to obtain the maximum benefit.

In the Arctic, as in other parts of the world, food is the primary nonoccupational route of exposure to persistent environmental contaminants (Environment Canada 1991). Because traditional foods represent a substantial portion of the diet in indigenous Arctic communities, these populations have a higher risk of contaminant exposure than do non-Arctic populations (Van Oostdam et al. 1999). Table 1 presents environmental contaminants that have been detected in food items and in tissue samples from Arctic indigenous peoples. The potential for contaminant exposure via traditional food sources is not an isolated or local problem, as it

poses a public health challenge across the entire Arctic region. The situation is additionally complicated by the cultural and spiritual importance of the harvesting and consumption of traditional foods. The contamination of these food sources raises problems that transcend the usual confines of public health and that cannot be resolved simply by health advisories or food substitution (Van Oostdam et al. 1999).

Although the current assessment of data suggests that the health risks associated with exposure to contaminants are outweighed by the benefits of continued consumption of traditional food sources, the health risks do exist (Van Oostdam et al. 1999). Public health scientists must strive to develop and implement strategies to simultaneously reduce exposure and preserve cultural traditions. Public health officials must also compile the information necessary to weigh the benefits of traditional foods against the risks in order to formulate appropriate recommendations concerning the consumption of traditional foods. Reliable dietary information should then be provided to Arctic communities so that community members can make informed choices concerning the food they eat.

Challenges to the Design and Implementation of Monitoring Programs in the Arctic

The climatic, political, and cultural conditions described above combine to present a unique set of scientific and logistic challenges to addressing environmental contamination in the Arctic. The largest obstacles include the following (Ayotte et al. 1995; McCauley et al. 2001; National Academy of Sciences Institute

Table 1. Environmental contaminants detected in traditional food items and human tissue samples.

Industrial chemicals and by-products
Polychlorinated biphenyls
Polybrominated diphenyl ethers
Dioxins (PCDDs) and furans (PCDFs)
Hexachlorobenzene
Brominated flame retardants
Organochlorine pesticides
Dichlorodiphenyl-trichloroethane (DDT) and DDT metabolites
Toxaphene
Chlordane
Hexachlorocyclohexane
Dieldrin
Mirex
Polycyclic aromatic hydrocarbons
Heavy metals
Mercury
Cadmium
Lead
Selenium
Radionuclides
Potassium-40
Members of the uranium and thorium decay series

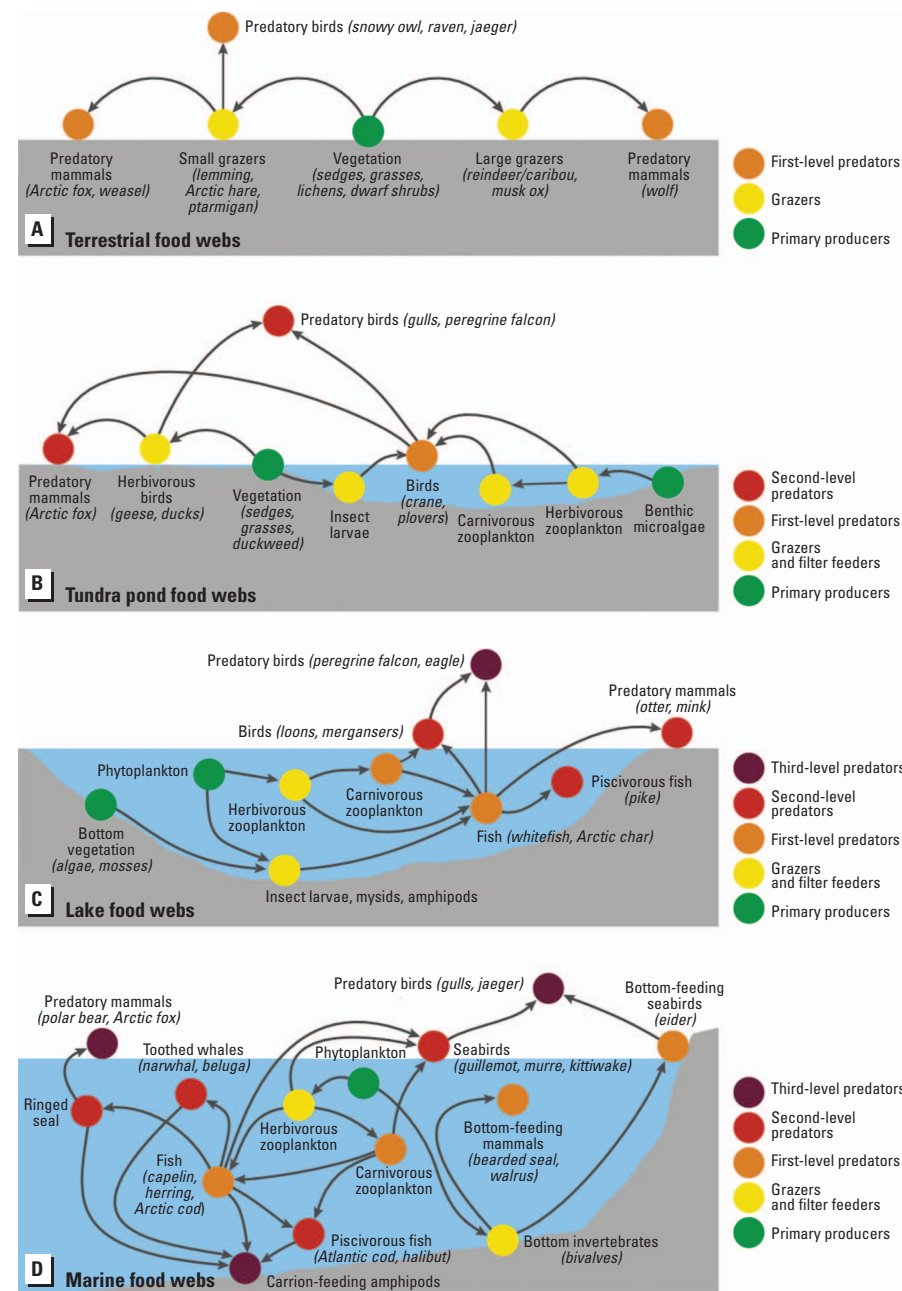


Figure 1. Examples of Arctic food webs: (A) terrestrial, (B) tundra pond, (C) lake, and (D) marine. Data from AMAP (2002a).

Data from AMAP (2002b), Ikonomou et al. (2002), and Van Oostdam et al. (1999).

of Medicine et al. 1988; Van Oostdam et al. 1999):

- The harsh climate and poor infrastructure make travel and communication difficult during most of the year and nearly impossible during the deep winter months.
- The Arctic is comprised of land controlled by eight different countries. Scientists and environmental health professionals must therefore comply with eight sets of regulations.
- Indigenous peoples may consider themselves citizens of tribal nations, with no allegiance to any of the eight Arctic nations.
- Many indigenous populations are migratory. It is difficult for scientists and environmental health professionals to ensure that all populations are served, and it can be complicated to conduct follow-up research.
- The Arctic is a vast geographic area. Communities are widespread and remote, and the populations of most Arctic communities are very small. As a result, scientists and environmental health professionals must travel great distances to reach low numbers of people.
- Communities across the Arctic are ethnically diverse. Scientists and environmental health professionals are challenged by the difficulty of communicating effectively with community members.
- Ethnic diversity can add to the complexity of design and interpretation of research studies. Different communities have very different food intake habits. The unusual level of diversity among indigenous Arctic peoples makes it difficult to match study groups with populations that have similar levels of background contaminants or with control groups that have similar exposure routes.
- Arctic communities have limited technical infrastructure such as expertise in environmental public health program development and service, and state-of-the-art research and analytic laboratory sciences.
- The general environmental health community lacks appropriate knowledge and training with respect to the unique needs of Arctic peoples.

Despite these obstacles, international cooperative efforts among governments and research institutions are under way to collect the information needed by environmental health scientists and public health officials to address the issue of environmental contamination in the Arctic. A significant example of such cooperative international efforts is the work of AMAP. Eight nations established AMAP in 1991

to provide reliable and sufficient information on the status of, and threats to, the Arctic environment, and to provide scientific advice on actions to be taken in order to support Arctic governments in their efforts to take remedial and preventive actions relating to contaminants. (AMAP 2002a)

Research is being directed to improve our understanding of exposures, to learn more about the environmental contaminants known to be of concern in the Arctic, and to identify factors that affect the susceptibilities of communities of Arctic peoples.

However, the success of cooperative research programs depends on the willingness and capacity of participants to share information. Large relational databases, containing the results of many different studies, accessible to and used by many groups can increase the value of existing data and save research dollars and time (Suk and Wilson 2002). This issue was discussed at the International Conference on Arctic Development, Pollution and Biomarkers of Human Health, held in Anchorage, Alaska, in 2000. Participants agreed that AMAP should lead in establishing, coordinating, and maintaining such databases. Conference participants also agreed that to be valuable, database structures must be compatible, quality control measures must be in place, data accepted into the database must meet essential criteria, and research design standards should be established [National Institute of Environmental Health Sciences (NIEHS). Unpublished data].

Although information sharing between and within the research community is certainly an important component of the Arctic environmental health research agenda, the links between environmental exposure(s) and disease within native communities remain elusive. Below, we examine the importance of identifying markers of exposure and susceptibility within Arctic native communities to better understand disease causation and improve the development of effective disease prevention strategies.

Better Understanding of Exposures

Timing, duration, and dose as well as total lifetime exposures are critical factors in determining health outcomes for native Arctic populations. Furthermore, the transgenerational effects of exposure are largely unknown. While we attempt to understand the effect of exposure on an individual or a population, we must also recognize that this exposure may have implications for future generations (Anderson et al. 2002). A first step in evaluating the impact of Arctic environmental contamination on the indigenous populations is to increase our knowledge of the potential for human exposure. This research has two components: subsistence diet monitoring and health status monitoring. Diet monitoring is generally conducted via analyses of harvest data and dietary surveys concerning the quantity of traditional foods consumed and the proportional contribution of traditional foods to the total diet. Because actual consumption

will vary from what is harvested or brought into the kitchen, analysis of harvest data generally overestimates daily consumption (Ayotte et al. 1995). Dietary surveys are used to collect 24-hr data on food consumption and food preference. These surveys generally underestimate intakes (Gibson 1990). In addition, aggregation of dietary intake data has masked sources of variation (Van Oostdam et al. 1999). The following sources of variation in food use must be considered when evaluating dietary survey data (Ayotte et al. 1995; Tenenbaum 1998; Van Oostdam et al. 1999):

- Geography: Communities near the sea have diets centered around marine animals whereas inland communities depend on large terrestrial mammals and/or fish.
- Seasons: Diets vary through the course of the year due to availability of food items. Some food items are consumed at high daily rates for short time periods.
- Sex and age: Different subgroups within a community may have different diets.
- Access to urban centers and economic status: Such access influences the amount of purchased foods in the diet.

It is essential that data be gathered concerning timing and duration of exposures because contaminant impacts may be greater on children and women of childbearing age (Ayotte et al. 1995). To use dietary information appropriately, we must also understand in depth the levels of contaminants in the food supply throughout the Arctic. Participants at the International Conference on Arctic Development, Pollution and Biomarkers of Human Health recommended the establishment of monitoring programs that include both the primary environmental compounds of concern and their metabolic by-products in terrestrial and aquatic species and plants that make up the subsistence diet (NIEHS. Unpublished data). The analyses should take into account the consumption patterns, specifically including testing of the parts of fish and mammals that are consumed (NIEHS. Unpublished data).

The vital statistics and health status data currently available from national, regional, and targeted community assessments indicate that the health of indigenous peoples varies considerably across the Arctic region. In general, the life expectancy of native Arctic populations is lower than that of nonnative groups, whereas chronic disease rates are higher than in non-natives. The reasons for these disparities are complex. It is certain that poverty, unemployment, and limited access to medical and dental care along with harsh climate, poor transportation, and inadequate housing are important contributors. In addition, lifestyle and behavioral factors—including high consumption of alcohol and tobacco and high rates of accidental injuries—are inimical

to good health (Tenenbaum 1998). Added risks to human health from environmental contaminants and climate change have been hypothesized, but the magnitude of this contribution, if any, has not been determined from the studies conducted so far. At the Anchorage conference, participants recommended that improvements be made to health status surveillance systems across the Arctic region, suggesting that systems focus on reproductive, neurobehavioral, and certain acute conditions (NIEHS. Unpublished data).

Better Understanding of Susceptibilities

Most diseases are the consequence of both environmental exposures and genetic factors (Suk and Wilson 2002). Consequently, the increased risk associated with a specific exposure may be detected only by studying exposure in different subgroups within the population. This integration of markers of exposure and susceptibility can thus both reveal environmental risk factors and identify specific individuals or groups within the population who are susceptible to that factor. This information is important for understanding disease causation and for developing effective disease prevention strategies. To understand the relationship between exposure and adverse health effects, scientists are working to develop biomarkers—key molecular or cellular events that link a specific environmental exposure to a health outcome (Bennett and Waters 2000). Molecular biomarkers play a central role in addressing the relationships between exposure to toxic environmental chemicals and development of chronic human diseases and in identifying those individuals at high risk for disease. The challenge is to use biomarkers to establish associations between exposure and human disease in epidemiologic studies and then to use the knowledge to design and conduct appropriate preventative interventions in high-risk individuals or populations.

There are three broad types of molecular biomarkers in the field of environmental health (Committee on Biological Markers of National Research Council 1987; Suk and Wilson 2002). Biomarkers of exposure quantify the body burden of chemicals or metabolites and are usually applied early in the exposure–disease pathway. These markers are powerful tools for epidemiologists, allowing relatively accurate measurement of external and/or internal dose of an environmental agent. However, the applicability of biomarkers of exposure is often limited by their relatively short half-life, providing information on exposure over a period of days to months compared to the natural history of the disease, which spans years or decades. An example of the application of biomarkers of exposure is epidemiologic research being conducted in

Arctic Québec to investigate the impact of PCB and mercury exposure on child development (AMAP 2002b; Dewailly et al. 2002). These studies are applying validated biomarkers of exposure including contaminant levels in breast milk, cord blood, and maternal and newborn plasma.

Biomarkers of effect detect functional change in the biologic system under study, and allow investigators to predict the outcome of exposure. DNA damage (e.g., adducts, chromosomal aberrations) are frequently used as biomarkers of effect although there is often no clear delineation from biomarkers of exposure. For example, DNA adducts can be interpreted as biomarkers both of exposure and biologic effect.

Biomarkers of susceptibility are indicators of the interindividual variation in mechanistic processes on the continuum between exposure and effect. An individual's susceptibility to environmentally mediated disease may arise from genetic causes or from nongenetic factors such as age, sex, disease state, or dietary intake. Genetic polymorphisms may function as biomarkers of susceptibility; but it is actually the phenotype that is of importance for the final response to the hazardous insult (Groopman and Kensler 1999).

Our ability to examine how genetic characteristics affect response to environmental exposure offers exciting possibilities for the prevention and control of environmentally induced diseases. As new high-throughput technologies are developed for simultaneous analysis of multiple genes, many additional disease-related polymorphisms will be discovered. Nanotechnology has the potential to influence future developments in the field of molecular biomarkers. These new technologies, such as DNA microarrays and automated workstations capable of extracting, amplifying, hybridizing, and detecting DNA sequences, will allow large-scale, low-cost genotyping of both individuals and populations. However, most genetic polymorphisms will modulate disease risk only in the presence of an environmental exposure. Consequently, it is essential that the genetic studies are conducted in parallel with increased efforts to characterize the prevalence and level of exposure to suspected environmental health hazards in the Arctic environment.

Ethical, Legal, and Social Issues

The conduct of research into the impact of environmental contamination on Arctic populations and the implementation of public health strategies to reduce exposure poses a number of ethical, legal, and social challenges. For example, advising against the consumption of traditional foods is akin to advising against an entire way of life for many Arctic

indigenous communities. Traditional foods are an integral component of good health among these communities, providing for both physical and social well-being. Further, there is no immediate, tangible evidence of the hazards potentially associated with the consumption of traditional foods. The effects may be delayed for many years and then it is difficult, if not impossible, to prove causality. Accordingly, residents of indigenous Arctic communities have only the word of outside “experts” whose language and culture may be difficult to understand (Van Oostdam et al. 1999). All these factors make it difficult to convince Arctic native populations of the potential health hazards associated with the consumption of traditional foods.

Research is needed as long as there are unanswered questions related to the future health of indigenous peoples and culture; the problem lies in how this research in indigenous communities is conducted. Many indigenous communities have become wary of research and researchers, which they consider irrelevant to their needs, paternalistic, colonial, and overly inquisitive. Perceived and actual cases of unethical experimentation, breach of confidentiality, cultural arrogance, and lack of consultation and feedback are not uncommon (Young 1994). Environmental health scientists must consider their ethical, legal, and social responsibilities at each step of research design and conduct—not simply in reaction to public or community concern. Researchers must include community members in decision making at every phase of a research program: defining the problem, setting the goals, selecting methods, interpreting data, and recommending policy (Riley et al. 2001). To have the support of affected individuals, research or public health programs must include and respect the preferences and beliefs of the communities (Van Oostdam et al. 1999).

The most important asset that the public health system can have is the public's trust that work is being done on its own behalf (Kass 2001). To earn and maintain the trust of the community, good communication, which emphasizes two-way or multidirectional flow of information, is critical (Suk and Anderson 1999). Community members may have only some of the information they need concerning environmental contamination, and may or may not have the educational foundation to process and apply the information. They want information on the sources and potential impacts of the contamination explained to them in direct and simple ways by credible sources (Van Oostdam et al. 1999). Communication must therefore be a continuous process. In working with indigenous Arctic communities, it is critical that researchers address unique communication issues that may arise from differences in language and culture, and respect the traditional

knowledge systems, behaviors, and beliefs of the communities.

Ethical, legal, and social issues also exist with respect to the use of the data collected. Disease surveillance and vital statistics, designed to monitor health and population trends, can raise privacy concerns because data often are individually identifiable and may be publicly available. Although researchers may not consider such collected data to be personal or sensitive, they must respect the boundaries of privacy set by community members (Kass 2001). Biomarkers of susceptibility are of a particularly sensitive nature (Christiani et al. 2001). Discovery that a polymorphism of a specific gene is linked to an environmental disease could lead to discrimination or stigmatization of individuals, communities, or ethnic groups (Sharp and Barrett 2001). Therefore, serious attention must be paid to quality assurance so that data integrity can be even more highly assured than in most other types of studies. In addition, guidelines that protect confidentiality and ensure the participants' "right to know" must be carefully designed and implemented in light of the potential consequences of susceptibility studies.

Environmental health researchers must also be aware of and sensitive to a variety of cultural and legal concerns that indigenous communities may have concerning genetic testing (Harry et al. 2000). Most native peoples do not want their status defined by genetics. They believe that one is a member of a tribe not necessarily just because of ancestry, but because one is recognized by a tribe as being a member. Indigenous communities may resist genetic testing on the basis of their belief that their bodies, hair, and blood are sacred elements. Thus they consider scientific research on these materials a violation of their cultural and ethical mandates.

Finally, indigenous communities recognize that their populations represent a significant percentage of the world's human diversity, and fear that their knowledge systems and biologic resources are threatened by appropriation (Harry et al. 2000). Some indigenous communities view molecular biology as a threat to their way of lives, referring to genetic testing programs as "biocolonialism." For example, the United States Patent Office grants patents to people who claim to uncover genetic sequences. In numerous cases, indigenous peoples have not been informed that their DNA can be commercialized through patents and used in the development of new products. Some indigenous groups have come to believe that the potential commercialization of unique human DNA may be a significant motivation behind many research projects. These communities may feel that the typical human genetic research paradigm treats indigenous peoples as objects of curiosity rather than partners in

research. The National Bioethics Advisory Commission recently proposed that regulatory oversight for research with human subjects be extended beyond the protection of individual research participants to include the protection of social groups (Sharp and Foster 2002).

Developing a Community-Based Public Health Model for an Arctic Health Program

Policy makers in the nations that govern the circumpolar region must develop and implement strategies to manage and protect the Arctic environment, its inhabitants, wildlife, and plant life. By refining exposure assessment and identifying susceptible groups within the population, biomarkers could provide a valuable addition to the establishment of disease etiology. In this way, the biomarker technologies will contribute to public health intervention strategy. Biomarkers could also be used as outcome variables to measure the success of intervention strategies. If public health strategies can be designed and implemented to reduce toxic exposure to levels that are safe for most vulnerable subgroups in a population, the entire population will be protected. Molecular epidemiology has not yet led to broad policy changes to prevent or reduce exposures to environmental contaminants, but it has pointed the way (Perera 2000).

The creation of sound policy requires a foundation of sound data. It is through fundamental, mechanistically based research that environmental and public health officials can improve their understanding of risk and translate this knowledge into prevention strategies. AMAP has been given the mandate to collect and interpret information about the environmental and genetic susceptibility factors currently affecting human health in the Arctic. With these data, policy makers can begin to fashion public health modalities to prevent disease and dysfunction rather than focusing solely on the pursuit of ways to treat illnesses already affecting people. AMAP has made substantial progress, and the inclusion of community-based participatory research (CBPR) methods may be a valuable addition to the AMAP research program.

CBPR in public health is a collaborative approach to research that involves community members, organizational and/or political representatives, and researchers in a partnership in which all parties participate as equal members and share control over all phases of the research process (Israel et al. 1998). Community members gain a better understanding of health effects and risks of exposure, the complexity and limitations of the science, and the research process. Researchers gain knowledge regarding exposure pathways, as they are able to glean important information about community member habits and exposures through their

interactive partnership. The participation of affected communities in developing public health intervention research improves project sustainability and effectiveness by making projects more relevant and acceptable to the communities (Arcury et al. 1999). The result is culturally appropriate and sustainable public health interventions that will reduce health risks among community members. CBPR aims to improve the health and well-being of the communities involved, both directly through examining and addressing the issues identified, and indirectly through increasing power and control over the research process (deKoning and Martin 1996). The basic public health goal in the Arctic—to prevent or reduce exposure to environmental contaminants—is truly a global public health goal. The approach recommended here, focused on biomarker technologies in CBPR programs, could serve as a model for international environmental health initiatives worldwide.

For CBPR to be successful, community members must understand and trust that participating government representatives and researchers are explicitly committed to conducting research that will benefit the participants (Israel et al. 1998). Indigenous communities are aware of the long history of research from which there was no direct benefit to the community studied—and sometimes actual harm (Young 1994). In addition to their technical skills, researchers must bring to CBPR projects an appropriate level of sensitivity to and competence in working within diverse cultures. They must be committed to communicating in a language that is understandable and respectful. Researchers must be willing to invest the time required to establish trusting relationships. Once established, trust cannot be taken for granted; researchers must continually prove their trustworthiness. This process and outcome should be the subject of ongoing evaluation by all partners.

CBPR is a co-learning and empowering process that facilitates the reciprocal transfer of knowledge, skills, capacity, and power. An atmosphere of mutual respect is absolutely critical. Community members, particularly indigenous peoples, possess a wealth of traditional ecologic knowledge that can be valuable in the design and interpretation of research (Frohberg et al. 2000; Tenenbaum 1998). However, this knowledge is often treated with skepticism by members of the scientific community (Sallenave 1994). Community members, who often possess less information, time, formal education, and income than officials and researchers, may be legitimately concerned about whether the concept of being "equal partners" can become a reality (Israel et al. 1992). Government representatives and researchers must demonstrate clearly their respect for community members

and their willingness to listen to and act on the ideas and concerns of the community. The establishment of trust enriches the value of the data for the researchers and maximizes the potential for change in knowledge, attitudes, and behavior within the community (Israel et al. 1998).

A region-wide monitoring program to determine the extent and effects of human exposure to contamination in the Arctic environment presents enormous logistic, fiscal, and technical problems. Appropriate, specific biomarkers could represent the technology needed to monitor impacts of contamination of the Arctic environment, providing Arctic residents and public health professionals with the critical data required to design and implement effective and preventative interventions in high-risk populations (Groopman and Kensler 1999). It should be possible to implement a program of human health as well as contaminant monitoring in selected villages across the Arctic. The villages would provide a network of sites where villagers, health care personnel, and scientists can work together to establish local models for surveillance, prevention, and evaluation of the contribution of environmental pollution to the health status. Community members must benefit from improvements in basic public health services supported by AMAP and participating governmental and nongovernmental agencies. It is important that a centralized data center is established to collect, analyze, and distribute information from the project.

Once the villages are selected and the centralized technical and organizational resources are identified, all efforts would be made to determine the nature of partnership. Several activities could be carried as part of this process. For example, a decision-making structure could be created for each village, with representation by local persons, health providers, relevant regulatory agencies, and environmental health science advisors to plan and implement the monitoring programs. Stakeholders could work together to jointly establish and document research goals and a schedule that satisfies all partners. In doing so, it would be prudent to ensure that the scientific goals address both long- and short-term community priorities. Another important activity would be to establish a process for hiring and involving community people as staff in the research. Launching a culturally appropriate orientation program in each community that is overseen by community members to help outsiders appreciate cultural ways and differences (i.e., history, tradition, language) could also be an activity for consideration, and one that would introduce an important educational element. Finally, stakeholders could design and implement an appropriate evaluation process whereby goals can be continually

revisited and assessed and the CBPR process openly critiqued. This allows those involved in the effort to continually assess the process and make changes as appropriate.

Once the mechanisms of partnership are in place, additional activities may be conducted in an effort to further define and implement the CBPR process. For instance, partners may wish to identify community health concerns and health care needs, including prenatal and maternal and child health services, primary care, dental care, basic environmental sanitation services, and environmental assessment and monitoring; identify and remediate confounding variables for environmental exposures such as indoor air quality; identify opportunities for the use of emerging biomarkers of exposure, effects, and susceptibility and include them in the human surveillance and monitoring program; and determine pathways for exposure to environmental contamination by POPs, heavy metals and radionuclides. Once these concerns/opportunities have been recognized and priorities have been set, prevention/intervention models may be implemented and evaluated to improve public health, including smoking cessation, alcohol abuse intervention, cancer and heart disease screening, and injury control. One specific example could be implementing a rigorous evaluation of the nutritional and spiritual benefits of subsistence diets to provide data required to conduct risk assessments in order to formulate recommendations concerning diet change.

Although specific activities carried out by each CBPR program should be unique to the particular native Arctic community that it serves, for any program of research and any resultant translation of findings into prevention strategies to be successful in the Arctic, two components must be included. Members of the communities affected must be involved in every phase—their input and support is critical to the design and implementation of appropriate, effective public health programs. And researchers and policy makers must recognize that in order to compile, interpret, and act on the wide range of information required to address the complex issue of contamination of the traditional food sources in the Arctic, a multidisciplinary approach using the most modern research tools available is essential.

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