

AMAP Report on Issues of Concern: Updated Information on Human Health, Persistent Organic Pollutants, Radioactivity, and Mercury in the Arctic

September 2000

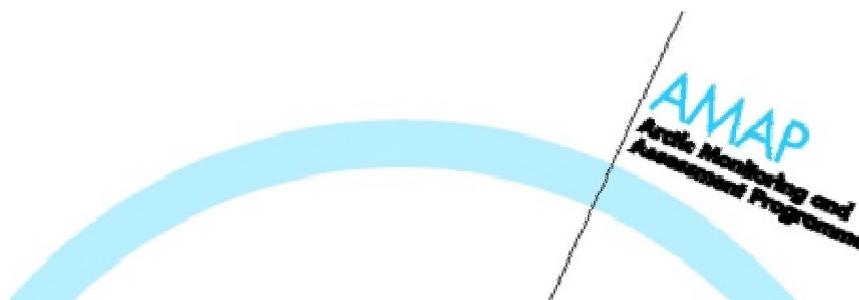


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AMAP Report on Issues of Concern: Updated Information on Human Health, Persistent Organic Pollutants, Radioactivity, and Mercury in the Arctic.

Preface

Work is currently underway to prepare a comprehensive update of the AMAP assessment of pollution in the Arctic, and its effects on Arctic environments and ecosystems, including humans. Four such update assessments, on Human Health, Persistent Organic Pollutants, Radioactivity, and Heavy Metals in the Arctic, are due to be published in 2002¹. Effects of Climate Change and UV Radiation will be addressed as part of the Arctic Climate Impact Assessment (ACIA), and additional assessments of Oil and PAHs and Acidification in the Arctic are planned for 2004 and 2006, respectively

The first AMAP assessment of the State of the Arctic Environment with respect to pollution, which included data up to 1996, was delivered in two reports published in 1997/1998^{2,3}. In the period since 1996, a considerable amount of new information and data have become available. Although this new information, together with that arising from still ongoing studies, will not be fully assessed by AMAP until 2002, preparatory work on the 2002 assessments made clear that it was appropriate to provide some of the initial findings of this work to Ministers at the Second Arctic Council Ministerial Meeting (Barrow, Alaska, October 12-13, 2000). These 'Key Scientific Findings', and associated recommendations, are intended to provide the Ministers with information that will help them to continue their efforts to develop and implement actions to protect the Arctic environment and its ecosystems, including human populations, during the period between the AMAP main assessments. It should be noted that all of the new findings further support the recommendations made by AMAP in its 1997 and 1998 assessment reports.

In order to document the 'Key Scientific Findings and Recommendations' reported to Ministers, this report has been prepared presenting interim updates of information on the following issues.

- Human Health in the Arctic
- Persistent Organic Pollutants in the Arctic
- Radioactivity in the Arctic
- Mercury in the Arctic

AMAP would like to express its appreciation to those involved in preparing the interim update reports, and also to those scientists who made their data and information available to this process.

Oslo September 2000

¹ *AMAP Strategic Plan: 1998-2003*. Arctic Monitoring and Assessment Programme (AMAP). AMAP Report 1999:6.

² *Arctic Pollution Issues: A State of the Arctic Environment Report*. Arctic Monitoring and Assessment Programme (AMAP). Oslo, Norway. 1997. 188 pp.

³ *AMAP Assessment Report: Arctic Pollution Issues*. Arctic Monitoring and Assessment Programme (AMAP). Oslo, Norway. 1998. xii + 859 pp.

Human Health in the Arctic: An Update

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1. Introduction

This interim report from the AMAP Human Health Expert Group (HHEG) is based on information available since the publication of the *AMAP Assessment Report: Arctic Pollution Issues* (AAR, Chapter 12 on *Pollution and Human Health*). The information comes from: new reports; discussions and agreements during the first three HHEG meetings of Phase II; status reports from each country on implementation plans for the AMAP Human Health Program; ongoing research programs of relevance to AMAP; and finally, presentations made at the Workshop on *POPs in the Arctic: Human Health and Environmental Concerns*, in Rovaniemi, Finland, 18-20 January 2000.

1.1 Development of the Monitoring Program

The Human Health Monitoring Program is, to a large extent, based on the program initiated during AMAP Phase I, with some modification introduced to take account of experiences gained in Phase I monitoring. For example, the clear correlation established for levels of persistent organic pollutants (POPs) and metals between maternal and cord blood led to a change in the status of cord blood sampling from essential (E) to recommended (R). The advantage of taking only maternal samples is that they can be collected during routine medical checks, whereas cord blood sampling must be carried out during delivery and thus under difficult conditions, and is consequently often omitted. Taking only maternal samples will be more reliable and provide a more representative sample collection.

As was the case during Phase I, the focus of the second phase program is mainly on well-described industrial compounds and by-products, pesticides and heavy metals. During the last few years, there has been an increasing interest in “new” POPs and metabolites. The list of new contaminants includes current-use pesticides and a wide range of industrial chemicals, for example, polybrominated flame retardants. However, the presence in the Arctic, and the potential hazard for human health posed by these compounds are far from well documented.

1.2 Development of the Effects Program

The new Human Health Effects Program is quite extensive and focuses on fertility studies, pregnancy outcomes, and immunological and neurological effects. A number of ways to gather data on effects are proposed, ranging from the collection of health statistics on mortality and morbidity to biochemical tests results at the molecular/cellular level. The collection of health statistics is indicated as essential (E) in all sampling regions, while other parameters are recommended (R). It is not intended that all measures of effects listed should be implemented in all Arctic countries, however, they should be the focus of sampling in the key AMAP monitoring areas. Furthermore, as several measures require highly developed laboratory facilities and are expensive, the implementation of the Human Health Effects Program will depend on mutual agreements between countries based on specific needs for effects monitoring by region, analytical capacity of the countries involved, and cost-sharing benefits. This will be a major issue for discussion within the HHEG.

2. Collaboration with other Programs

2.1 Health Status of Children and Youth in the Arctic

The Arctic Council decided in September 1998, to advance sustainable development in the Arctic through a project that would examine the current health status of children and youth in the circumpolar region. This initiative, *The Future of Children and Youth in the Arctic*, draws attention to a broad range of factors that can affect health. These range from socio-economic factors (such as social status, and poverty or income), to availability of health services, to biophysical factors (such as microbiological aspects of water quality, chemical and metal contaminant levels in air, food or water, ultraviolet light or radionuclides) and to psychosocial factors (such as family violence, social support networks, substance abuse and physical activity levels).

The Arctic Council decided to gather and evaluate the information available and to prepare an Action Plan on the Health and Well-Being of Children and Youth in the Arctic. They requested that Canada

and AMAP, under the direction of the Senior Arctic Officials, co-operate specifically in reviewing knowledge on the impacts of biophysical factors on the health and development of children and youth.

The Circumpolar Plan for the initiative was developed at a meeting in Toronto in March, 1999 and called for a concise scoping study to identify and bring together information and knowledge pertaining directly to the health and well-being of children and youth in the Arctic. AMAP accepted responsibility for the biophysical health component at the Toronto meeting.

A framework document developed by Canada and modified by the AMAP Human Health Expert Group in September 1999 in Ottawa, provided a mechanism for identifying and defining some biophysical measures of the health and well-being of children and youth of the Arctic. This framework document does not describe all the biophysical measures of health and well-being, but only those deemed most relevant and critical to the development of prescriptive guidelines for the purpose of public health and risk assessment in the Arctic region. The key measures proposed include but are not limited to:

Demographics:	Population ratios by gender (for 5 year age groups) Life expectancy
Birth Outcome:	Prenatal care Preterm birth incidence and low birth weight
Health Determinants:	Duration of breast feeding and immunisation status Infant/adolescent stunting and obesity Fetal alcohol exposure Blood contaminant levels (POPs, metals) Tobacco/drug/solvent /alcohol abuse Iron deficiency anaemia and vitamin status
Mortality/Morbidity:	Age of mother at birth of child Birth rate and infant mortality rate Age at death
Maternal/Neonatal Health:	Cause specific death rates (cancers and other causes) Incidence of notifiable diseases

Circumpolar partners in the AMAP Human Health Expert Group have agreed to first identify and characterise in their respective countries the data bases which are relevant to the basic measures proposed (March 2000). Following an evaluation of the availability and characteristics of the databases a final set of circumpolar measurements will be agreed upon by the Expert Group (September, 2000). Circumpolar partners will then provide the basic data or the information in final form for the time period, age, ethnic group and geographical region (March 2002). The Expert Group will then interpret the information and provide the secretariat (Canada) with a written report (June 2002) for inclusion in an integrated report to the Arctic Council on the entire initiative on children and youth (September 2002).

Sustainable development places goals such as economic growth or technical renewal within the context of an environment that must remain as robust and viable today as it will tomorrow. The ultimate objective of sustainable development is human capacity and security for successive generations. The first principle of the Rio Declaration, 1992, states: "Human beings are the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature." Sustainable development in the Arctic cannot be considered without attention to the health and well-being of its children and youth; they are the essence of our future. The nurturance and realisation of their human capacities and capabilities are at the very core of sustainable development. Cross comparisons of the health information provided through this initiative will allow the Arctic Council to develop and implement a realistic and effective Action Plan on the Health and Well-Being of Children and Youth in the Arctic.

2.2 IASC Co-operation

The International Arctic Science Committee (IASC) has established a sub-group focusing on contaminants and human health in the Arctic. The main objective is to define information gaps and research needs related to human health. This is an important supplement to the work of the AMAP Human Health Expert Group. The first official meeting was organised in conjunction with the AMAP *Workshop on POPs in the Arctic: Human Health and Environmental Concerns* in Rovaniemi, Finland. All Arctic countries, except Iceland and Sweden, were represented. The meeting was organised as an open hearing, with experts on all aspects of contaminants invited together with the established IASC Human Health Project Group. This led to a very wide discussion of research needs, from basic molecular biology to dietary research and ethics of human health research in the Arctic. A detailed report from the meeting will be sent to the IASC Secretariat, and pertinent aspects are summarised in this Interim Report.

3. New Data obtained since the AMAP Report

The following additional data have been obtained on POPs and toxic metals in human tissues for the circumpolar countries since the AMAP Phase I Report. These data augment the information on the spatial variation of contaminant levels in various countries and provide some information on possible trends of mercury in human tissues in one circumpolar country. Since this is the first tissue survey of POPs in many circumpolar countries and many of the POPs have long half lives it will be necessary to wait for several years before expecting any significant changes. It will likely also be necessary to have several data points to establish a trend.

3.1 Canada

Additional data has been collected on maternal levels of POPs and metals in the Canadian Arctic. This allows an assessment of the concentration of contaminants in maternal blood for Dene/Metis, Inuit (four regions) and non-aboriginal Canadians. The highest levels of POPs in the Canadian north are seen in Inuit from the eastern Arctic. This data also confirms that levels of POPs in maternal blood in Inuit from Canada are not as high as those reported in Greenland. Recent data on mercury in human tissues over a twenty years time span from one northern Canadian community does not indicate any major changes in human tissue mercury levels though the historical data is highly variable.

3.2 Greenland

Additional surveys have been implemented in Greenland to assess spatial variation of POPs. Levels of POPs were measured in the tissues of men from five communities of Greenland. The highest levels were seen in men from Scoresbysund on the east coast of Greenland while lower levels were seen in the men from the west (Upernavik, Ilulissat, Nuuk) and south (Nanortalik) coast. Women of reproductive age from Tassilaq on the east coast of Greenland had levels of POPs that were 1.5 to 2 times higher than mothers from Disko Bay on the west coast (lipid concentrations). Both of these observations are consistent with earlier environmental data, which show relatively higher levels of POP in marine mammals from the east-coast versus the west-coast of Greenland.

3.3 Norway

During 1999 a detailed dietary survey was performed in Vestvågøy, Nordland County, Norway, based on questionnaires and interviews, and combined with analyses of organic contaminants in blood from the same persons who participated in the dietary interviews. Vestvågøy is an area with a considerable consumption of fish, nevertheless, contaminant levels were low, and not correlated to fish consumption. These data can be useful for comparisons with blood sample results from more contaminated areas. An interesting observation was that the contaminant levels in maternal blood decreased during the breast -feeding period and was dependent on parity.

3.4 Russia

During the spring and autumn of 1999 a detailed survey was performed in both the non-Sami and Sami populations of Lowozero, Murmansk County, Russia. This information will provide a basis for comparison of the dietary survey planned for other areas of Russia in the next phase of AMAP. A project team has now been established in the survey area that can take local responsibility for ensuring the quality of sampling, storage and transportation of biological samples in this remote area. Sampling of local food items will also take place to identify contaminant levels.

New blood samples from Archangelsk have been analysed and will be statistically assessed soon. The preliminary results indicate elevated pesticide levels, especially from the DDT-group.

In the period 1994-96 blood and breast milk samples were collected from 94 women during delivery in Yamal and Tajmyr Autonomous Regions of Siberia. The analyses of concentrations of chlorinated pesticides and polychlorinated biphenyls (PCBs) were not finished in time to be included in the Phase I AMAP report. The POPs levels in maternal plasma among the non-indigenous women were higher than among the native population, especially in total PCBs, total HCHs (hexachlorocyclohexanes) and the total DDT-group. The dietary questionnaires showed that the non-indigenous populations consumed considerably fewer local food items such as reindeer meat and fresh water fish. There was no correlation between local food consumption and elevated levels of pollutants. Even though the indigenous groups had lower concentrations of the most important pollutants than the non-indigenous population, the levels were still higher than those reported in the Scandinavian countries under Phase I AMAP report and approached levels of medical concern. The most important sources of organic pollutants for the Russian Arctic populations of Yamal and Tajmyr seem to be imported food from other areas of Russia and local use of pesticides.

Detailed statistical analysis of the human health and exposure data collected in Phase I of AMAP have been completed, resulting in 6 publications in 1999. Significantly lower birth weights were observed in Russia compared to Norway. The difference in new-born body mass index (BMI) was also lower in Russia. In the Sami population examined in Russia, birth weight was comparable to non-indigenous Russian values; however, the mean BMI for Sami babies was close to the mean BMI for Norwegian babies. These data indicate that the Russian babies in the study area were thinner than both the Norwegian and the Sami babies. Explanations for this difference are not known, but both nutritional and environmental factors might be important. A number of essential elements (iron, selenium, and zinc) were positive predictors of birth weight, while lead was a significant negative factor. Lead was also found to be most elevated in children living in an isolated native community and the use of leaded ammunition in subsistence hunting was suspected as an important environmental source. Finally, a critical review of medical records in the Kola Peninsula of Russia revealed the availability of information suitable for reproductive and developmental health studies.

4. Thematic Data Centre

In the SAAO's report to Ministers for the Fourth Ministerial Meeting under the Arctic Environmental Protection Strategy, Alta, Norway June 12-13, 1997 development of a human health data centre was mentioned as a main issue. Denmark offered at the AMAP working group meeting in Aarhus in December 1997 to establish and run a Thematic Data Centre for Human Health to be placed at the Danish National Institute for Public Health.

The primary aim of the data centre for Human Health is to facilitate the AMAP assessment process. It will accordingly be the policy not to release data for other purposes unless the data owners (e.g., those scientists who submitted the original data) explicitly give their permission to do so. The database structure has been established.

5. Analytical Quality Assurance and Quality Control

To obtain reliable and comparable data, it is essential to assess and control analytical quality (QA/QC). This requires assessment of the accuracy of the analytical result, evaluation of various analytical methods in terms of accuracy and precision, and the implementation of a comprehensive

quality assurance programme. Sampling procedures, sample transportation and sample storage must also be harmonised.

Chemical analyses have to follow accepted analytical protocol or criteria, but not necessarily an identical method. Chemical trace analyses of contaminants in human samples are difficult. Low concentration, small sample volume, a large number of contaminants and the presence of interfering compounds dictates the need for well-designed analytical procedures. This means that parameters such as identification, detection and quantification limits, accuracy and precision as well as the methods robustness have to be evaluated. In addition data treatment, reporting format and data storage should be harmonised.

A key aspect of quality control can be assessed through the interlaboratory comparison programme for relevant reference material within the AMAP Human Health laboratory network. This laboratory network currently consists of a small group of qualified laboratories. The main reference laboratory is the Institut National de Santé Publique du Québec (le Centre de Toxicologie de Québec) in Canada (CTQ). The main responsibility for the reference laboratory will be to run intercomparison programmes on relevant reference samples based on human material. At the moment only reference samples for the heavy metals are commercially available, however, human samples containing organic contaminants (PCB, standard pesticides, lipids, new organic xenobiotics and metabolites) will be provided. In each country a limited number of laboratories will be involved, with one national reference laboratory in the core network. The laboratories in the core network will also participate in other relevant intercomparison programmes such as QUASIMEME. In addition to QA/QC-issues, the laboratories in the core network will collaborate on method development to meet future analytical needs. To be accepted by AMAP, laboratories have to participate in the AMAP Human Health intercalibration programme with acceptable results, and provide documentation for their quality control procedures.

The core network now consists of CTQ (Canada), NILU (Norwegian Institute for Air Research, Norway) and CDC (Centers for Disease Control and Prevention, US). The first intercalibration exercise among the core network has been carried out for PCBs and DDT/DDE. The data from the three laboratories are comparable and close to the theoretical values. Based on this study, a report with recommendations for future action is in preparation.

6. Implementation plans for Human Health in AMAP Phase II

6.1 Alaska

The Alaska Native cord blood monitoring programme has started enrolling pregnant women, and will sample 20-25% of the prenatal population yearly, in Arctic coast and Bering Sea populations. Regularly performed studies include dietary assessments, POPs and heavy metals. Outcome measures in infants and mothers are essentially those of the AMAP Phase II Effects Programme. Additional studies on the first year cohort include: maternal hair mercury, fatty acids, selenium, and maternal urine for radionuclides.

The Monitoring Programme has been offered to the Aleutian Islands, Alaska Natives and through the Aleutian International Association, to the Russian Aleutain Islands, but the outcome is as yet unknown.

6.2 Canada

Canada is implementing the AMAP Human Health Program by undertaking the following activities:

- Additional maternal blood contaminant monitoring has been completed or is underway in Baffin, Keewatin and Inuvik regions.
- Dietary surveys of 19 Inuit communities have been completed and analysis is underway.
- A variety of effects studies have been initiated (3 mixtures studies, 1 neurobehavioral study, 1 immunological study, 2 chemical specific studies).

- Evaluation of the implications for humans of exposure to mixtures as well as specific contaminants such as chlordane, toxaphene and mercury.
- The influence of biophysical factors on the health (such as morbidity and mortality) of children and youth is being evaluated under the Arctic Council Initiative Future of Children and Youth in the North.
- Pregnancy outcome information for Canadian Arctic women is being gathered and evaluated.
- Development of a new provisional tolerable daily intake (PTDI) of 0.2 ug mercury/Kg body weight/day has been completed and other TDIs may be revised based on the results of new toxicological information. The PTDI for mercury does not include an assessment of the benefits of traditional foods or the interactions with selenium.

Details on specific studies are provided in the country report. (See section 9.)

6.3 Denmark

6.3.1 Greenland

The AMAP Human Health Program in Greenland will continue according to the specifications of the core monitoring and effects program activities.

The objectives of the Human Health Program in Greenland are:

- To continue monitoring POPs and other pollutants and biomarkers in maternal and cord blood in Nuuk and Ilulissat at regular intervals for surveillance purposes, e.g. temporal trend studies.
- To monitor maternal blood and, in some places (Thule), cord blood in various districts in Greenland in order to make regional comparisons. Cord blood measurements are considered less necessary due to the consistently high correlation between POPs in maternal and cord blood.
- To study spatial trends in younger men (and women) from selected districts in Greenland for comparison with regional differences of POP concentrations in animals used for food.
- To study biomarkers of effect according to the AMAP Human Health Effects program.

Special attention will be given to the east-coast population where the highest POP concentrations have been found. During the year 2000 samples will be collected from 100 men and 100 women (pregnant and non-pregnant) for analyses of contaminant levels and biomarkers of effects.

6.3.2 The Faeroe Islands

Dietary exposure to marine pollutants in the last trimester of pregnancy of Faeroese women.

In the year 2000, 150 women will be interviewed with a food frequency questionnaire and a 24 hours respective telephone interview about diet. Blood samples will be taken for organochlorines. Analyses will be according to the core program in AMAP Phase II.

The proposed project is in agreement with the general objective for the Human Health Program of AMAP.

- It is evaluating human exposure.
- It is developing and implementing long-term strategies to reduce sources of environmental contaminants at the local and international level.
- It is developing and providing short-term advice at a local level to Faeroe people on ways of reducing contaminant intakes while preserving traditional ways of living.
- It is continuing monitoring of maternal blood to provide temporal trends.
- It is instituting tissue banking, especially cord blood, for retrospective studies.
- It is evaluating the significance of contaminant levels in blood to provide a basis for more consistent advice.

6.4 Finland

The general objective of the Finnish human health subprogramme is to protect and promote the health of Arctic peoples, especially children, with respect to exposure to environmental contaminants (anthropogenic contaminants and radionuclides). The subprogramme has the following objectives:

- To fill the monitoring gaps: The population of Sodnakylä (Saami area) and of the area surrounding the steel works at Tornio are also being taken as target population.
- To continue to monitor maternal blood at 5 year intervals in order to obtain temporal trends.
- To make better use of existing data bases for estimating the impacts of environmental contaminants on the population.
- To evaluate the utility of biomarkers as a tool for assessing the impact of contaminants.
- To harmonise the dietary and demographic survey instruments.
- To co-ordinate the activities of Phase 2 of AMAP within the public health administration.

6.5 Iceland

Blood samples will continue to be collected in different areas around the country, from expectant mothers at weeks 30-40 of pregnancy. These samples will be analysed for various POPs. Data on age, seafood and seabird consumption, life-style factors, fertility, birthweight and birthlength, etc., are being collected.

A small scale dietary study in an eastern coastal-village is planned to estimate the intake of POPs by specific Icelandic communities. Another study on the association of POPs and male fertility is underway.

6.6 Russia/Norway

The research objectives itemized below are to be conducted as part of AMAP Phase II:

- Blood samples (plasma and whole blood) are to be collected in strategic communities not previously surveyed, based on the 'Key areas-strategy' of AMAP. These samples will be analysed for methyl mercury, lead and selected organochlorines.
- In the selection of new study areas, the inclusion of indigenous communities will be emphasized.
- Blood samples are to be collected for the determination of organochlorines and toxic metals in support of and as part of the AMAP Human Health Effects Initiative (fertility, time to pregnancy and semen quality studies).
- To continue to investigate the relationship between the intake of toxic contaminants in traditional foods and observed concentrations in human blood and breast milk;
- To create a database to derive dietary advice and recommendations for regulatory guidelines;
- To strengthen and build the infrastructure established for the cooperation between the health groups of Norway and Russia under the umbrella of the AMAP Human Health Group.

6.7 Sweden

A new programme for “Human Health related Environmental Monitoring” has been proposed which, if implemented, will include some investigations in the Umeå region, south of the Arctic circle. The proposal incorporates measurements of airborne exposure for carcinogenic substances and contaminant measurements in blood and breast milk..

7. Knowledge Gaps and Recommendations for Research

The knowledge gaps and suggestions for research made in the Rovaniemi AMAP workshop on POPs were expanded during the IASC meeting. Some of these are related to basic analytical issues and the

abiotic/biotic environment. However, they are of importance for a better understanding of the human exposure situation with regard both to the priority contaminants already analysed and to new contaminants of possible concern. The following major research gaps or recommendations were identified:

- Establish tissue banks to facilitate identification of new contaminants and prospective epidemiological studies.
- Identify new POPs of concern including determination of toxaphene (as specific Parlar congeners), brominated flame retardants, coplanar- and hydroxy-PCBs, alkyltin compounds, polychlorinated paraffins as well as chlorinated naphthalenes.
- Perform laboratory risk assessment studies (no-adverse effect levels (NOAELs), no-adverse effect concentrations in diets (NOAECs), as well as *in vitro* effect studies of selected POPs individually and in combination).
- Assess the consumption of Arctic traditional food considering: dependence on region, community, season, age and gender; contaminant analysis; dichotomization into traditional and market foods; any associated social fabric and cultural heritage.
- Provide consumption advisories carefully balancing any perceived health risk with the substantial nutritional and sociocultural benefits of traditional foods.
- Identify gaps in knowledge of human health outcomes. A comprehensive review and critical appraisal is needed of published studies describing associations between POP exposure/body burden and the following disease states: breast and other cancers, endometriosis, fertility (female and male), impairment of neurodevelopment, pregnancy outcomes, and immune-system impairment (e.g., susceptibility to infection).
- Identify groups at special risk (genetic or acquired susceptibility).
- Design epidemiologic studies of health outcomes in the Arctic. The studies need to overcome the following limitations or include the indicated components: small population size; body burdens/exposure near or below NOAELs/LOAELs; synergy between POPs and toxic metals; mitigating dietary factors/status; and biological plausibility.
- Perform perceived risk research and management strategies.
- Design of intervention strategies.
- Develop quantitative models for human exposure and outcome.
- Selection of the timing of sample collection in biological monitoring studies need to consider the time frame involved in the movement of an agent/metabolite into, between or from body compartments (i.e. the length of the observation period must be compared to biological half times).
- Evaluate infant infection experience using uniform criteria for identifying hospitalised infections in infants.
- Evaluate data sets for pregnancy outcomes (complications) where contaminant monitoring data exist.

8. Conclusions and Recommendations

The Human Health Expert Group has reviewed the conclusions and recommendations contained in the first AMAP assessment report (AAR, Chapter 12: Pollution and Human Health) and considers them to be still valid. However, new data and significant progress on laboratory and population studies provided in this Interim Report and discussed at the *Workshop on POPs in the Arctic: Human Health and Environmental Concerns* have given rise to the following additional conclusions and recommendations.

8.1 HCH and DDT/DDE Levels in Russia

Extensive new data is now available for the western Russian Arctic and indicate that traditional supplies of country food do not appear to lead to a marked elevation of POPs or metals. Elevated levels of HCH and DDT/DDE were restricted to populations living in the highly industrialised region around Norilsk. It is recommended that data on exposure sources such as market foods, water supply, air, and industrial/agricultural workplaces be carefully examined in this region to identify the primary cause of elevated levels of these contaminants in human tissues.

8.2 Lead Shot

Recent determinations of moderately elevated levels of lead in maternal blood in Canada, Greenland and Russia in some communities appear to be associated with quantities of ingested lead shot, lead shot microfragments and dissolved lead all found in some subsistence game. It is recommended that more extensive evaluation of this problem be undertaken in regions where lead shot is used for subsistence hunting.

8.3 Co-planar PCBs

Little has been provided to date on the levels of dioxins, furans and co-planar PCBs, all of which exhibit to varying degrees toxic properties of 2,3,7,8-TCDD. It is recommended that all countries undertake an evaluation of their current data and determine the relative contribution of these chemicals to the total TCDD toxic equivalencies (TEQs).

8.4 “New” Xenobiotics and Metabolites

Additional data has been reported for toxaphene from Greenland and Norway. However in general, there is a paucity of data on levels of toxaphene in human tissues from the circumpolar region. It is recommended that toxaphene levels be determined in all circumpolar countries and reported utilising compound specific chemical nomenclature.

The presence of metabolites is recognised, but so far not implemented to today’s environmental monitoring. Reports have shown that the most abundant hydroxy-PCBs in human blood samples equals the presence of dominant PCB-congeners. Among the many “new” contaminants, especially polybrominated flame retardants and polychlorinated paraffins have recently received much attention. Exploratory data on human blood samples from the Arctic has shown levels of brominated flame retardants equal to the presence of dominant PCBs. These findings should be followed up.

8.5 Immune System Indicators

Recently published studies from Arctic Canada suggest an association between POPs exposure and risk of otitis media in young children. It is recommended that the relationship between immune system function and POPs exposure be more fully evaluated in Phase 2 activities.

8.6 Mercury

New findings from the Faeroe Islands on the effects of mercury on subtle infant neurodevelopment and blood pressure raise concerns that present exposures may pose risks of such effects on infants in several parts of the circumpolar region. It is recommended that existing studies and data sets be evaluated for these effects.

8.7 New Studies

Considerable progress has been made on dietary surveys of indigenous people in Canada, Greenland, Alaska and Russia. In addition, more extensive blood monitoring surveys have been completed in the following Arctic regions of Alaska, Canada, Finland, Greenland and Russia. Laboratory animal studies are also being completed for toxaphene and chlordane derivatives. These studies will provide a better basis for information and advice from health agencies.

8.8 Implementing the Human Health Program

A number of methodologies have been developed and validated since the last AMAP report and some have been used to provide more comparable results on food consumption, contaminant exposures and human health effects, including biomarkers of effect. It is recommended that the AMAP Human Health Program for Phase II with its emphasis on health effects and monitoring according to the core Program be implemented in all the key sampling areas in order to provide an improved scientific background for local advice to Arctic people.

8.9 Sustaining Breast Feeding

Evidence from the Arctic, and from other parts of the world, emphasises the benefits of breast-feeding for infant development, especially for the psycho-social development of children, and development of their immune systems. Nutritional studies also support the benefits of consuming traditional food. It is again the recommendation of the HHEG that traditional food consumption and breast-feeding be encouraged in the circumpolar region.

9. Appendix: National Status Reports

9.1 Alaska

The Alaska Native cord blood monitoring programme has started enrolling pregnant women, and will sample 20-25 % of the prenatal population yearly in Arctic coast and Bering Sea populations. Regularly performed studies include dietary assessments, POPs and heavy metals. Outcome measures in infants and mothers are essentially those of the AMAP Phase II Effects Programme. Additional studies on the first year cohort include: maternal hair mercury, fatty acids, selenium, and maternal urine for radionuclides.

The Monitoring Programme has been offered to the Aleutian Islands, Alaska Natives and through the Aleutian International Association, to the Russian Aleutain Islands, but the outcome is as yet unknown.

AMAP "Related Activities:"

1. An ongoing study of POPs levels in new breast cancer patients and a group of matched controls.
2. A group of elders residing on the Pribiloff Islands, in the Bering Sea, for POPs, heavy metals, and PCBs. Results are pending.

9.2 Canada

Monitoring Contaminants

Maternal Cord Blood Contaminants - POPs, Metals

Two further surveys of Inuit regions of Arctic Canada have been completed (Baffin, Keewatin Health Boards) and the data are available. The Inuvik region is the final area where a maternal/neonatal contaminant survey is being completed and data should be available in mid-2000 (Regional Health Boards, HC).

Metals

A 1999 survey of mercury in residents of Salluit, Quebec, has allowed an initial assessment of a time trend between 1978 and 1999. Large variability in the early data does not allow any conclusions to be drawn on possible trends of mercury in this population (CHUQ).

A survey of lead and its isotopes in the cord blood of Inuit new-borns in Nunavik indicates that lead shot is the likely source of this contamination. (CHUQ).

Dietary Surveys

A dietary survey of 19 Inuit communities in Inuvialuit, Kitikmeot, Kivalliq, Baffin and Labrador regions of Arctic Canada has been completed. Data evaluation is ongoing and reports to communities should be completed in 2000/2001. (CINE).

A large database on traditional food dietary intakes is available for the DeneMetis in Northwest Territories and Yukon First Nations Communities and is continuing to be evaluated. (CINE).

Effects Studies

Epidemiological Studies

Infant Cohorts - Ongoing Neurobehavioral Immunological studies in Nunavik, Quebec are presently assembling their respective cohorts and undertaking an initial evaluation. Data will not be available until 2002. (CHUQ).

Adult Uptake of Polonium 210 - A study of adults consuming caribou has provided data on the uptake of Polonium 210 from these traditional foods. (HC).

Animal Studies

Toxaphene - A study of the reproductive effects of technical grade Toxaphene in monkeys has been completed and initial data available. Further evaluation is being conducted. (HC).

Chlordane Derivatives - A toxicological study of studies of *cis*- and *trans*-nonaol in rats has also been completed and initial data are available. Further experimental work and evaluation are being undertaken. (HC).

Mixtures of Northern Contaminants - The adverse developmental effects of *in utero* and lactational exposure to mixtures of organochlorines is being tested in pigs. Some initial data are available and the study is to be completed by March 2000. (CHUQ).

The toxicology of Hg and Se found in ringed seal tissues is being evaluated in a rodent study. Some initial data are available and the study is to be completed by March 2000. (CINE).

A rodent study examining the effects of a mixture organochlorines in traditional food has been completed and the data are being used to validate a PBTK model for risk assessment of exposure to these contaminants. (CINE).

Evaluation

Future of Children and Youth in the North

Canada has agreed to lead the Arctic Council project on Children and Youth. AMAP has agreed to work with Canada on the biophysical component of this project. Canada is working with the territorial governments to assemble the data outlined in the biophysical component framework document which was finalised by the Human Health Expert Group in Rovaniemi, Finland.

Contacts:

CHUQ - Centre Hospitalier Universitaire de Quebec, Public Health Research Unit -
Drs. E. Dewailly, P. Ayotte.

CINE - Centre for Indigenous Peoples Nutrition and Environment, McGill University, Drs. O.
Receveur, H. Kuhnlein.

HC - Health Canada, Drs. A. Gilman, J. Van Oostdam.

9.3 Denmark

9.3.1 Greenland

The Human Health Program in Greenland in 1997-1999.

Research co-ordinator: Jens C Hansen.

Main researchers: Peter Bjerregaard, Bente Deutch, Eva Bonefeld-Jørgensen, Gert Mulvad.

Introduction

The Human Health programme in Greenland has the purpose to:

1. Continue monitoring POPs and other pollutants and biomarkers in maternal and cord blood in Nuuk and Ilulissat at regular intervals for surveillance purposes, e.g. temporal trend studies.
2. To monitor maternal blood and, in some places (Thule), cord blood in various districts in Greenland in order to make regional comparisons. Cord blood measurements are considered less necessary due to the consistently high correlation between POPs in maternal and cord blood.
3. To study spatial trends in younger men (and women) from selected districts in Greenland for comparison with regional differences of POP concentrations in animals used for food.

Additional studies (see below) are linked to the project.

Background

Statistical analysis of maternal and cord blood data collected during the AMAP Phase 1 (1994-96) has indicated that besides dietary habits (traditional food), other lifestyle factors (mainly smoking) are associated with high accumulation of organic pollutants. Thus, the purpose of this additional study has been to analyse the data, collected for surveillance purposes under the Human Health Program of AMAP in Greenland and to make possible exposure assessments regarding both the geographical differences, and various lifestyle factors versus pollution load from persistent organic pollutants (POPs). It is based upon the above mentioned data from a regional study of 6 districts and the ongoing study on pregnant women and infants mainly in Disko Bay.

Methodology

Biostatistical analyses of data collected in Greenland from 61 men and 10 women from 6 different districts (1997-98) and from 95 births in Disko Bay area (1996-97) and 175 births (1994-96). The data consisted of questionnaire answers and blood samples from men, women, and new-born infants (cord blood) analysed for fatty acids, selenium and 26 POPs including 14 PCB-congeners and 4 toxaphenes.

Results

Table 1 presents geometric mean, minimum and maximum values of POP-plasma concentrations in micrograms per litre and micrograms per kg lipid among 61 men (m) and 10 women (w) according to district. As comparison to the women from Tassiilaq, results are included from the study concerning pregnant women, namely 95 women from Disko Bay 1997-98, 175 women from 1994-96, and 7 pregnant women from Thule. Compared by Student's T-test the men from Scoresbysund show significant differences from men from all the other districts and the women from Tassiilaq show significant differences from the pregnant women from district 4, Disco Bay, $p < 0.05^*$, $p < 0.01^{**}$, $p < 0.001^{***}$.

Strong regional differences were found, with very high PCB-loads among men from the east coast. Besides PCB also beta-HCH, DDTs and mirex were significantly higher on the east coast. These differences were related to differences in intakes of marine food, seal in particular. The various POP-plasma levels were mutually correlated and strong positive correlations were found between POP-plasma concentrations from mothers and new-born, $R > 0.9$, $p < 0.0001$. Among the pregnant women, 95% exceeded the Canadian concern level for PCB, and 60 % of the men from Scoresbysund exceeded the action level. The association between reported monthly food frequency and POPs was relatively weak, but in general the POPs were strongly positively correlated with plasma and erythrocyte n-3/n-6 fatty acid ratios as biomarkers of marine food intake (standardised correlation coefficients 0.31-0.50, $p < 0.001$).

The levels of POPs were also strongly correlated with the age of the person, correlations coefficients 0.39-0.46 $p < 0.001$. In addition multiple regression analyses of the data from both the pregnant women (Disko Bay) and the regional study showed significant positive correlations between almost all measured POP-plasma levels and smoking status (standardised correlation coefficients 0.15-0.27)

after correction for age, alcohol intake, marine food, region, plasma lipids and n-3/n-6 fatty acid ratios.

Table 1. Geometric mean, minimum and maximum values of POP-plasma concentrations (micrograms per litre and micrograms per kg lipid).

District, N (m-men, w-women), descriptives	β -HCH	Chlor-dane	Σ DDT	HCB	Mirex	Σ PCB	Σ Toxa-phene	Lipid (g/l)
1. Scoresbysund, 15 m mean microgram/l	0.56***	7.65	11.1*	1.45	0.52**	41***	0.71	6.1
minimum	0.17	0.88	1.64	0.4	0.02	6.6	0.18	
maximum	1.8	60.7	33.0	3.9	2.2	127	2.1	
microgram/kg lipid	93	1270	2470	240	90	6750	120	
2. Tassiilaq, 10 w mean microgram/l	0.20	3.98*	7.23*	1.03	0.35**	12.4**	1.23**	6.6
minimum	0.04	1.1	2.86	0.3	0.06	4.9	0.48	
maximum	0.48	10.7	24.7	2.7	0.85	29.9	2.4	
microgram/kg lipid	32	630	1390	160	40	1960	190	
3. Upernavik, 11 m mean microgram/l	0.18	3.16	4.8	0.90	0.15	6.55	0.79	6.1
minimum	0.10	1.24	2.2	0.24	0.05	3.9	0.29	
maximum	0.42	15.0	17.2	2.7	1.0	26.9	3.1	
microgram/kg lipid	30	520	980	150	30	1080	130	
4. Ilulissat, 15 m mean microgram/l	0.34	7.44	8.8	2.62	0.33	13.6	1.87	7.2
minimum	0.07	0.80	2.0	0.38	0.07	2.8	0.19	
maximum	0.85	23.7	25.4	8.4	0.64	28.7	7.0	
microgram/kg lipid	50	1070	1610	380	40	1960	270	
5. Nuuk, 15 m mean microgram/l	0.17	2.48	5.0	1.01	0.15	7.56	0.78	6.7
minimum	0.06	0.4	1.3	0.22	0.06	2.38	0.07	
maximum	0.66	11.9	16.3	5.1	0.51	26.8	5.2	
microgram/kg lipid	26	380	920	160	20	1170	120	
6. Nanortalik, 5 m mean microgram/l	0.20	7.54	15.7	1.2	0.61	21.2	1.55	6.7
minimum	0.08	3.0	7.4	0.4	0.29	9.6	0.5	
maximum	0.30	14.5	29.2	2.6	1.4	40.4	3.7	
microgram/kg lipid	32	1210	890	190	100	3400	250	
Total 6 districts, 71 mean microgram/l	0.26	4.76	7.6	1.33	0.26	13.9	1.03	6.6
minimum	0.04	0.4	1.3	0.22	0.02	2.4	0.07	
maximum	1.8	60.7	33.0	8.4	2.2	127	7.0	
microgram/kg lipid	41	740	1610	210	40	2160	160	
4. Disko Bay, 95w mean microgram/l	0.15	1.89	3.79	0.80	0.12	5.50	0.81	9.14
minimum	0.03	0.05	0.59	0.14	0.00	1.05	0.00	
maximum	0.50	13.7	17.2	4.0	1.9	20.5	4.7	
microgram/kg lipid	16	206	415	88	14	580	90	
4. Disko Bay 175 w mean microgram/l	0.17	1.82	3.84	0.89	0.08	5.19		9.35
minimum	0.03	0.05	0.52	0.13	0.01	1.13		
maximum	0.81	19.1	30.8	7.0	0.66	34.0		
microgram/kg lipid	18	190	407	92	8	544		
7. Thule, 7 pregnant w mean microgram/l	0.27	4.07	7.38	1.21	0.19	8.72	0.97	8.72
minimum	0.11	1.91	4.36	0.52	0.06	4.02	0.47	
maximum	0.37	7.06	10.35	1.90	0.32	14.3	1.70	

Table 2 presents (arithmetic) mean values of POP plasma concentrations in micrograms per litre in cord blood from 75 infants from Disko Bay area 1996-97 and 5 infants from Thule 1997. In addition, whole blood and plasma selenium, and whole blood mercury was measured in infants from Thule. In the infants from Disko Bay mercury was not measured during 1997. For comparison, the mean mercury values is presented from the 160 infants studied in 1994-96 (a). After correction for plasma lipid contents the correlations between mother and infant POP levels are close to unity, $R > 0.90$ $p < 0.001$.

Table 2 Arithmetic mean values of POP plasma concentrations in cord blood (micrograms per litre).

	Disko Bay, n=75	Thule, n=5
Whole blood Se	127.2	240
Plasma Se	47.3	53
Whole blood Hg	35.7 a)	86
Beta-HCH (Plasma)	0.085	0.07
Chlordanes	0.45	1.04
DDT (sum)	1.2	2.21
Hexachlorobenzene (HCB)	0.25	0.31
Mirex	0.009	0.03
PCB (sum)	1.28	2.0
Toxaphenes (sum)	0.13	0.13

Conclusion

The most important determinants of high POP-plasma levels in Greenlanders were identified as: age, intake of marine food (indicated by high plasma n-3 fatty acids), east coast region, and smoking.

Additional studies:

Case-control study of POP-accumulation among smoking and non-smoking Inuit Hunters

Researchers: Bente Deutch, Henning Sloth Pedersen, Jens C. Hansen.

The purpose of the study is to further investigate the combined effects of diet, smoking and other lifestyle factors on the high human POP levels in Greenland through a case-control study among 48 Inuit hunters in Ummanaq district. Of these hunters, 16 non-smokers are compared with 8 previous and 24 present smokers. The data collection took place in August 1999 and the following parameters are being analysed:

plasma POP concentrations, plasma lipids, cholesterol and fatty acids, male hormones, mercury, selenium, anthropometric and demographic factors and serum cotinine as a tobacco marker. The study is supported by The Danish Health Foundation and Greenland HomeRule.

Exposure to Persistent organochlor pollutants and the risk of breast cancer

Project participants: Eva C. Bonefeld-Jørgensen, Unit of Environmental Biotechnology, University of Aarhus (project co-ordinator in Denmark). Jens C. Hansen, Center of Arctic Environmental Medicine, University of Aarhus. Gert Mulvad, Dronning Ingrid's Hospital, Nuuk, Greenland (project co-ordinator in Greenland). Henning Sloth Pedersen, and Michael Pedersen, Dronning Ingrid's Hospital, Nuuk, Greenland. Eric Dewailly, Professor, Université Laval, Québec, Canada.

Objectives

The aim of the study is to undertake an epidemiological examination of the risk of breast cancer in association to the increased burden and exposure to environmental contaminants with potential hormone disrupting effects. The study will be carried out in Greenland involving three groups of 10 - 20 Greenlandic women; i) cases in treatment, ii) new identified cases, iii) controls of comparable age, diet and smoking habits.

Methodology

At the Dronning Ingrid's Hospital, Nuuk, new cases and already identified cases of breast cancer in Greenland are currently registered and treated. At the hospital, there is a good basis for selecting matched controls.

In addition to dietary questionnaires, blood test and morning urine test materials will be collected from individuals in each of the three test groups, and Mamma fat biopsy test materials from the newly identified Mamma cancer study group.

The blood test and fat biopsy test materials will be analysed for POPs including pesticides, selenium and the profile of n-3 and n-6 fatty acids. The urine test materials will be analysed for the ratio of the estradiol metabolites 16 α -hydroxy estrone and 2-hydroxy estrone.

Determination of Dioxin-like Effects in Human Blood and Breast Milk

Project participants:

Project leader: Eva C. Bonefeld-Jørgensen, Unit of Environmental Biotechnology (UEB), University of Aarhus.

Co-researchers: Joan Lynggaard, University of Aarhus, Denmark. Anne Marie Vinggaard, Food Administration, Søborg, Denmark. Jens C. Hansen, Center of Arctic Environmental Medicine, University of Aarhus. Eric Dewailly, Université Laval, Quebec, Canada. Jon Øyvind Odland, University of Tromsø, Tromsø, Norway.

Objectives

The aim of the study is to determine the total activity of accumulated, dioxin-like contaminants in extracts of human blood and breast milk from highly exposed (Inuit) and lesser exposed (Danes) human populations. The study will be carried out using established methods for extraction of dioxin-like compound (dioxin and PCBs) from human samples. The dioxin-like activity will be measured in a human (TV101L) and a rat (CALUX) cell culture system carrying a Ah-receptor reporter gene. The study will involve samples with known concentrations of organochlorines collected in Greenland 1997, in Denmark 1999, and Canada and Norway/Russia in the 1990s.

Children Cohort Project

Principal investigator: Peter Bjerregaard, National Institute of Public Health.

In 1999, data collection started for the Nuuk child cohort study. It is the aim of the study to collect information on prenatal exposure to POPs and mercury among 500 newborns from Nuuk, Greenland. In addition to the exposure data, information is obtained for confounding factors such as use of alcohol and tobacco, infections, and sociocultural factors. The children will eventually be followed for several years with regard to infections and immunological as well as neurobehavioural development, a similar protocol on neurobehavioural development will be used as that applied to 200 children from Nunavik, Canada. A subcohort of 100 children will be followed.

9.3.2 The Faeroe Islands

Prenatal Methyl Mercury Exposure and Neurobehavioral Development

A cohort was established in 1986/1987 comprising 1023 children. 90 % of them were examined for neurobehavioural status at 7 years of age. Samples taken so far include: umbilical cord blood, umbilical cord tissue, mothers hair, mothers milk, hair of the child at 12 months, blood and hair of child at age 7 years.

This cohort is intended to be re-examined in 2000 and 2001. Blood samples, hair samples and urine samples will be collected.

Prenatal Exposure to PCB and Neurobehavioral Development

A cohort was established in 1994/95 comprising 128 newborn. Samples collected include: blood in third trimester, umbilical cord blood, cord tissue, mothers milk, blood from child at 56 months of age.

The children have been examined annually since birth and detailed neuropsychological examination is planned to start in the fall of 2000. Blood and hair will be collected.

Significance of Seafood for Neurobehavioral Development of Children in the Faroe Islands

A cohort was established in 1998/99 comprising 600 newborn. Samples collected include: blood in third trimester, umbilical cord blood, cord tissue, placental tissue, mothers milk, blood from child at 3 months of age.

In 2000, blood samples will be examined for xenohormon activity. Organochlorines and mercury will be measured in milk and blood. New blood samples are intended to be collected from a subgroup of 400, to be analysed for antibody response to vaccinations.

Dietary Intervention Study in the Faroe Islands

In the spring of 1999, 400 women answered a questionnaire and sent in hair samples, which have been analysed in segments to estimate the effect of the dietary recommendation given in August, 1998. In 2000 new hair samples will be collected.

Dietary Exposure to Marine Pollutants in the last Trimester of Pregnancy from Faeroe Women

In 2000, 150 women will be interviewed with a food frequency questionnaire and a 24-hours respective telephone interview about diet. Blood samples will be taken for organochlorine analyses according to the core program in AMAP Phase II.

9.4 Finland

Human Health Sub-programme

Information on the concentrations of pollutants in local food stuffs are needed (and still missing) in order to calculate the external dose of pollutants (Hg, Cd, Pb, Se, Cu, Zn, PCBs, HCH, HCB, DDT/DDE, toxaphene, dioxins) from, e.g., water, milk, berries, potatoes and other vegetables, mushrooms, elk and reindeer meat, birds and fish.

1. Monitoring and Effects Studies

Target media	Parameters	Frequency	Location of sampling/ examination	Programme and/or responsible institute
Maternal blood	Cd, Hg, Pb, Se, Toxaphene PCB, DDTgroup HCH, HCB, Chlordan Dieldrin, Toxaphene (PCC) Dioxins/ (PCDD)	at 5-year intervals 50 mothers	Enontekiö, Inari, Utsjoki, Savukoski, Salla, Kemijärvi, Pelkosenniemi, Sodankylä,	State Provincial Office of Lapland

Target media	Parameters	Frequency	Location of sampling/ examination	Programme and/or responsible institute
	Dibenzofuran (PCDF)		Tornio	
Mothers/ food	Calculating external dose: Hg, Cd, Pb, Se, Cu, Zn, PCBs, HCH, HCB, DDT/DDE, toxaphene, dioxins in food Food questionnaire	at 5-year intervals 100 mothers	9 communes above	State Provincial Office of Lapland
Human breast milk	PCB, dioxins	10 mothers	Enontekiö, Salla, Inari	National Institute of Health
Placentas	Enzymes indicating xenobiotic and steroid metabolism in human placenta	at 5-year intervals 40 mothers	The whole target population of 9 communes	University of Oulu Department of Pharmacology and Toxicology
Human eyes	Effect of UV radiation		Northern population	University of Oulu, Department of Eye Diseases
Human skin	Effect of UV radiation		Northern population	University of Oulu Department of Skin Diseases

Bio-physical indicators	Epidemiological Effect Markers	Frequency	Target Population	Programme and/or responsible institute
Health statistics	Morbidity/ Mortality data		Lapland/ Finland	State Provincial Office of Lapland
Pregnancy outcome	Abortion Gestational age Sex (single/multiple) Placenta weight, metabolism		Lapland/ Finland 9 communes	State Provincial Office of Lapland
Develop- mental anomalities	Maldescent testis Hypospadias Epispadias Cancer incidence		Lapland/ Finland	State Provincial Office of Lapland
Immunologic al effects	Hospitalisation Vaccination response		The whole population of nine communes in Lapland	State Provincial Office of Lapland

2. Supporting Studies

Human tissues are being analysed for Hg, Cu, Pb, Cd, Ni, PCBs and dioxins at 5-year intervals in nine communes by the State Provincial Office of Lapland.

The effect of cold on hormone metabolism in the northern human population is being studied at the Department of Physiology and Institute of Occupational Health, University of Oulu.

The concentrations of heavy metals (Hg, Zn, Cd, Pb) in human blood are being analysed and correlated with human health status within the "Cohort 66" project conducted by the Department of Public Health and General Practice, University of Oulu. Samples collected in 1996 were taken from the whole population of Lapland born in 1966.

9.5 Iceland

Monitoring

The levels of persistent organochlorines in breastmilk of 22 mothers from the Reykjavík area were analysed in 1993 (Ólafsdóttir, 1997). The study was repeated in 1998 by sampling breastmilk in 5 different rural areas. These were: Snæfellsnes, Ísafjörður, Húsavík, Neskaupstaður and Höfn. The results indicated no significant differences in organochlorine burden in these areas, with the highest levels encountered being 37 ng/g milk for sum PCBs and 33 ng/g milk for DDE.

Blood samples have been collected in different areas around the country in 1999 to allow regional comparison, and hopefully temporal comparisons in the future. These were: Reykjavík, Ólafsvík, Sauðárkrúkur, Vestmannaeyjar, and Reyðarfjörður. Samples are collected by midwives during maternal check-ups in weeks 30-40 of pregnancy. The plasma is analysed for about 25 different POPs and the expectant mothers fill out a questionnaire on various lifestyle factors. Again, the result indicate no significant differences in organochlorine burden in these areas, the greatest source of variability seems to be age, rather than parity or the duration of breastfeeding, although some trend was seen with increased consumption of seabirds. The levels found in Reykjavík were very similar to those found in the circumpolar research conducted in 1993.

Main investigator: Kristín Ólafsdóttir, University of Iceland, stinaola@hi.is

Supporting effect studies

The association between the levels of persistent organochlorines and male fertility is being investigated. Although the neonatal period is most probably the most sensitive to the hormonal effects of organochlorines, their effects during spermatogenesis can not be ruled out. Plasma and seminal fluid from three different groups of men seeking the help of the Icelandic infertility clinic are analysed for about 25 different organochlorines. The first group of men have low quality semen according to WHO standards, the second group consists of men with good quality semen and a spouse with a known reason for infertility. The third group consists of men with idiopathic infertility.

Main investigator: Elín V. Magnúsdóttir, University of Iceland (elinmag@hi.is).

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9.6 Norway/Russia

Coordinator and investigator:

Jon Øyvind Odland, Institute of Community Medicine, University of Tromsø, Norway.

Main investigators:

Valeri Klopov, Regional Centre "Monitoring of the Arctic", St.Petersburg, Russia. Valeri Tchachtchine, Kola Laboratory of Occupational Health, Kirovsk, Russia. Anatoly Tkachev, Institute

of Physiology, Ural Division, Russian Academy of Science, Arkhangelsk, Russia and Institute of Community Medicine, University of Tromsø, Norway. Ivan Burkow, Norwegian Institute for Air Research, Tromsø, Norway. Eiliv Lund, Institute of Community Medicine, University of Tromsø, Norway. Evert Nieboer, Institute of Community Medicine, University of Tromsø, Norway and McMaster University, Hamilton, ON, Canada.

Preface

The program is fully integrated with the activities of the AMAP Human Health Group.

In 1999 financial support was received from the Barents Secretariat, the University of Tromsø, the Nordic Council, the Norwegian Pollution Control Authority, the Norwegian Research Council, and the Russian Federation Ministry of Health.

Goal

The main purpose of the project is to fulfil the Norwegian and Russian obligations under the umbrella of AMAP concerning health effects in relation to environmental pollution. (Note that radioactivity issues are dealt with by the AMAP Radioactivity group).

The work has concentrated on organic contaminants, toxic metals, and essential trace elements in relation to selected pregnancy outcomes.

Completed Work

Detailed statistical analysis of the human health and exposure data collected in Phase I of AMAP has been completed, resulting in 7 publications in 1998-1999 (see below). Significantly lower birth weights were observed in Russia compared to Norway. The difference in newborn body mass index (BMI) was also lower in Russia. In the Sami population examined in Russia, birth weight was comparable to non-indigenous Russian values; however, the mean BMI for Sami babies was close to the mean BMI for Norwegian babies. These data indicate that the Russian babies in the study area were thinner than both the Norwegian and the Sami babies. Explanations for this difference are not known, but both nutritional and environmental factors might be important. A number of essential elements (iron, selenium, and zinc) were positive predictors of birth weight, while lead was a significant negative factor. Lead was also found to be most elevated in children living in an isolated native community and the use of leaded ammunition in subsistence hunting was suspected as an important environmental source. Finally, a critical review of medical records in the Kola Peninsula of Russia revealed the availability of information suitable for reproductive and developmental health studies.

In the period 1994-96, blood and breast milk samples were collected from 94 women during delivery in Yamal and Tajmyr Autonomous Regions of Siberia. The analyses of concentrations of chlorinated pesticides and polychlorinated biphenyls (PCBs) were not finished in time to be included in the Phase I AMAP report. The POPs levels in maternal plasma among the non-indigenous women were higher than among the native population, especially in total PCBs, total HCHs (hexachlorocyclohexanes) and the total DDT-group. The dietary questionnaires showed that the non-indigenous populations consumed considerably less amounts of local food items such as reindeer meat and freshwater fish. There was no correlation between local food consumption and elevated levels of pollutants. Even though the indigenous groups had lower concentrations of the most important pollutants than the non-indigenous population, the levels were still higher than those reported in the Scandinavian countries in the AMAP Phase I report and approached levels of medical concern. The most important sources of organic pollutants for the Russian Arctic populations of Yamal and Tajmyr seem to be imported food from other areas of Russia and local use of pesticides.

Ongoing Work

During 1999 a detailed dietary survey has been performed in Vestvågøy, Nordland County, based on questionnaires and interviews, conducted in parallel with analyses of organic contaminants in blood from the same persons. This is an area with a considerable consumption of fish. Despite this, the contaminant levels are low, and not correlated to fish consumption. These data will be very useful as

reference data to compare with data for more contaminated areas. An interesting observation is that the contaminant levels decrease during the breast-feeding period and depend on parity.

During the spring and autumn 1999, a pilot dietary questionnaire survey was conducted in both the non-Sami and Sami populations of Lowozero, Murmansk County, Russia. This questionnaire will be modified for future surveys in eastern Russia. A group of Kola Peninsula health professionals were involved in the pilot study and now have suitable experience to participate in upcoming surveys. Sampling of some local food items for the determination of contaminant concentrations has been completed.

Blood samples from Archangelsk collected in the autumn 1998 have been analysed for organochlorines. The preliminary impression (rigorous statistical analysis have not yet been applied) is that DDT-group pesticides appear to be elevated.

Future Work

The following activities/objectives will be included under Phase II of AMAP:

- Blood samples (plasma and whole blood) are to be collected in strategic communities not previously surveyed, based on the AMAP 'Key areas-strategy', for the determination of methyl mercury, lead and selected organochlorines.
- In the selection of new study areas, the inclusion of indigenous communities will be emphasized.
- Blood samples are to be collected for the determination of organochlorines and persistent metals in support of and part of the AMAP Health Health Effects Initiative (fertility, time to pregnancy, and semen quality studies).
- To continue to investigate the relationship between the intake of toxic contaminants in traditional foods and observed concentrations in human blood and breast milk.
- To create a database to derive dietary advice and recommendations for regulatory guidelines.
- To strengthen and build the infrastructure established for the cooperation between the health groups of Norway and Russia under the umbrella of the AMAP Human Health Group.

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9.7 Sweden

A new programme for “Human Health related Environmental Monitoring” has been proposed. In the event that this programme is implemented, some investigations will be carried out in the Umeå region, south of the Arctic circle. The proposal includes measurements of airborne exposure for carcinogenic substances and contaminant measurements in blood and breast milk.

POPs in the Arctic: An Update

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1. Introduction

The Persistent Organic Pollutants (POPs) chapter of the AMAP Assessment Report (AAR) (AMAP 1998, Chapter 6) presented the data available on POPs in Arctic air, seawater, sediments, and terrestrial, freshwater and marine biota that was available as of 1996. Since then, new data has emerged on spatial and temporal trends as well as biological effects, which address some of the knowledge gaps identified in the assessment. Here we present a brief overview of major new findings and updates of information on previously reported studies. As such, it constitutes an intermediate report prior to the next full assessment by AMAP of POPs in the Arctic which is due to be completed in 2002.

2. Sources and Pathways

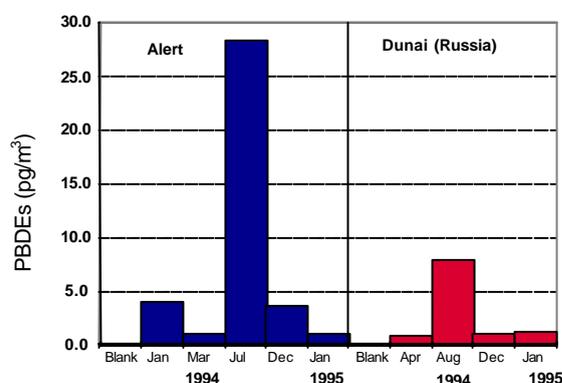
2.1 Air Monitoring

The air monitoring station at Dunai in the Lena River delta, that was operated from 1994-96, has been closed and relocated to a newly established monitoring site at Amderma in western Russia (69 deg. 44 min. N, 61 deg. 35 min. E; near the southern Kara Sea) in 1999. An air monitoring site for POPs has also been in place at Pallas in northern Finland since 1996 (Brorström-Lundén and Juntto 2000). Under the first phase of AMAP (1991-96), measurements of POPs in air were made continuously at four sites (Svalbard (Ny Ålesund), northern Ellesmere Is. (Alert), southern Yukon (Tagish), and the Lena River delta (Dunai Island)) and, with lower frequency in Iceland and continental Norway from about 1992 to 1995. Those initial results were reported in the AAR and in other publications (AMAP 1998; Oehme et al. 1996; Fellin et al. 1996; Stern et al. 1997; Halstall et al. 1997; 1998). The results for air demonstrate that current and past use of persistent organochlorines (OCs) in the mid-latitudes of the northern hemisphere is the most likely source of these contaminants to the Arctic environment while mid-latitude combustion sources, especially in winter, are important for PAHs. From 1995 to the present, air monitoring has continued at Alert, Ny Ålesund and Pallas, however, additional results are being compiled at to the AMAP atmospheric thematic data centre. Measurements of fog water have been initiated on Bear Island (halfway between mainland Norway and Svalbard) as part of studies on pathways of POPs to Arctic char in lakes on the island (Skotvold et al. 2000). Precipitation (rain) monitoring for POPs is also underway in northern Finland (Brorström-Lundén and Juntto 2000). Snow collections for POPs are underway in northern Norway (Heimstad 2000).

2.2 'New' POPs in Air

One of the knowledge gaps identified in the AAR concerned information on 'new' POPs, including current use pesticides and other chemicals that are being introduced as replacements for banned substances. Archived air sample extracts from Alert (1994-95) were analysed for brominated diphenyl ethers (PBDEs) and polychlorinated naphthalenes (PCNs) (Bidleman et al. 1999). PBDEs (Br₂-Br₇) were detected at low pg/m³ levels in pooled monthly air samples.

Figure 1. Brominated diphenyl ethers in air samples from Northern Ellesmere Is (Alert, Canada) and the Lena River Delta (Dunai, Russia) in 1994-95 (Bidleman et al. 1999).



PBDE levels observed in Alert were higher than Dunai (Figure 1); this may be attributable to the higher usage of these compounds in North America than in Russia. The peak concentration of PBDEs

was observed during July and August, indicating enhanced volatilization and transport from mid-latitude source regions during the summer months. The Σ PBDEs was dominated by tetrabromo followed by pentabromo-homologue groups, especially BDE 47 (2,2',4,4'-tetra BDE) and BDE-99 (2,2',4,4',5-penta BDE) which together accounted for 80% of Σ PBDEs.

The Σ PCN concentrations in air in 1994/95 ranged from 0.01 to 0.99 pg/m^3 at Alert, NT, Canada and from 0.03 to 2.33 pg/m^3 at Dunai Island, Russia (Figure 2) and were comparable to levels reported for these sites in 1993 by Harner et al. (1998). Σ PCN concentrations at the high arctic sites were lower

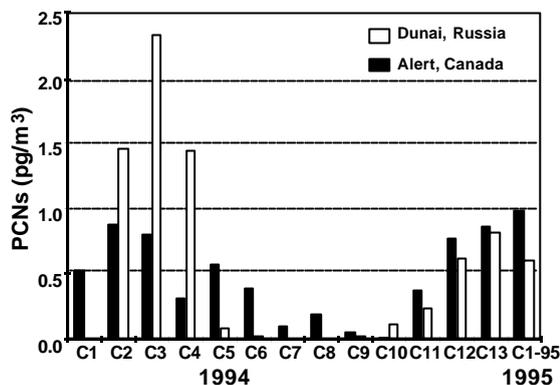


Figure 2. Concentrations of polychlorinated naphthalenes in air from Northern Ellesmere Is (Alert Canada) and the Lena River delta (Dunai, Russia) in 1994 and 1995. Each bar is a composite of 4 weekly samples.

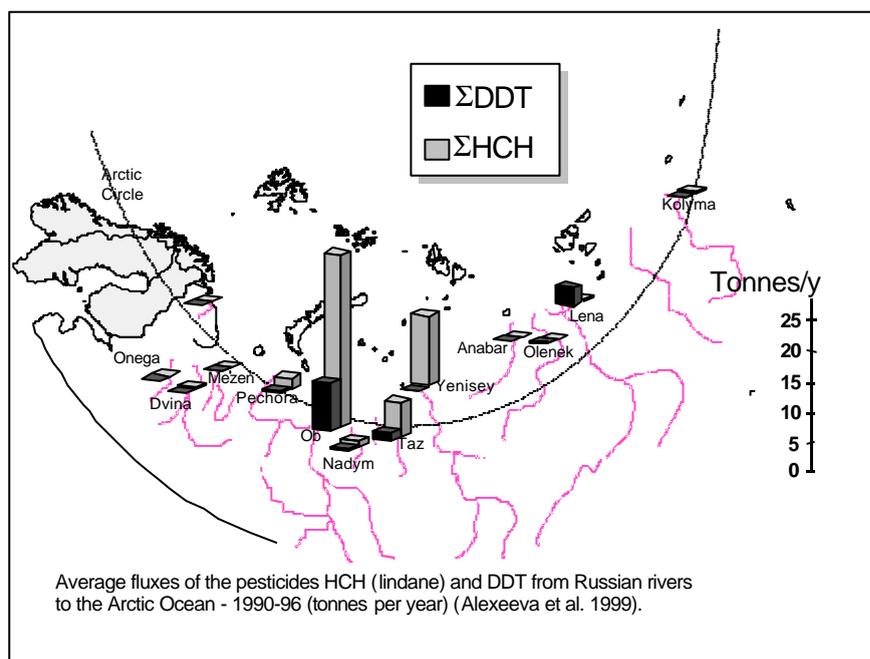
than those observed at lower arctic latitudes over the Eastern Arctic Ocean, Norwegian Sea, and Barents Sea (Harner et al. 1998). A small number of air extracts from 1992 were also analysed for short chain chlorinated paraffins (SCCPs) (Muir et al. 1999a). Results showed a wide range of concentrations ($<1\text{-}667 \text{ pg}/\text{m}^3$) in the gas phase. Further analyses are underway to confirm the SCCP levels.

A global use and emission inventory has recently been completed for HCH (Li et al. 1998a, 1998b). It demonstrates that China was the major world producer accounting for about 4.5 million tonnes between 1945 and 1983 (Li et al. 1998b). New work is underway concerning development of emission inventories for DDT and toxaphene (Li 2000; Li et al. 1999), and an emissions inventory of PCBs for Europe is also in preparation (Breivik and Pacyna 1999). Refinements of global transport and distribution models for POPs, to incorporate revolatilization process, are contributing to improvements in emission inventory work (Scholtz 1999).

2.3 River Waters

Monitoring of river waters for POPs continues in Russia (Roshydromet) and in Norway (under the OSPARCOM program). Additional river water sampling in Russia is planned under the RAIPON/AMAP GEF funded project "Persistent

Figure 3. Average fluxes of the pesticides HCH and DDT from Russian rivers to the Arctic Ocean, 1990-96 (tonnes per year) (Alexeeva et al. 1999).



toxic substances, food security and indigenous peoples of the Russian North'. No new monitoring of POPs in Arctic rivers of Canada or Alaska is underway. A re-evaluation of the results for HCH isomers, p,p'-DDT and p,p'-DDE reported in surveys of Russian rivers (Zhulidov et al. 1998; 2000; Alexeeva et al. 2000) has supported the preliminary findings reported under AMAP phase 1 (AMAP 1998) of high levels of these pesticides (10 to 100 times higher than found in Canadian or Norwegian rivers) in the Ob and Yenisey rivers. A decrease in DDT and HCH fluxes from 1986 to 1996 in several rivers was reported by Zhulidov et al. (2000). The south Kara Sea receives the largest fraction of OC discharges into the Arctic seas (Figure 3). For example, about 95% of Σ HCH = 65 tonnes/year of all Σ HCH inputs from Russian rivers (averaged over 1990-96), is discharged to the S. Kara Sea (Alexeeva et al. 2000).

2.4 Ocean Waters

Measurements of POPs, especially persistent OCs, has continued on an expedition basis in the Barents and Kara Seas (Swedish Oden cruise 1996), in the Canada Basin (SHEBA study 1998), as well as in the Canadian archipelago (JOIS 1997, North Water Polyna project 1998, Swedish Tundra Northwest cruise 1999). Monitoring also continues in nearshore waters in the Russian arctic under the Russian AMAP plan. Strachan et al. (2000) have summarized results from large volume samples taken between 1993-97. HCH (α - and γ -isomers) levels remain elevated in the Chukchi Sea, Canada Basin and Canadian archipelago. Lowest HCH was found in northern parts of Barents and Kara Seas with intermediate levels in Baffin Bay. PCB concentrations followed a geographic pattern that was qualitatively similar to HCHs. Average levels of total PCBs (113 congeners; not blank corrected) ranged from 0.27 ng/L in the northern Barents/Kara to 1.06 ng/L in the western Canadian archipelago. Most PCBs were in the dissolved phase not on particles. This reflects the predominance of lower chlorinated, more water soluble, congeners in the water column. These are the first set of PCB data over a large spatial scale for the Arctic Ocean. Results suggest higher levels of PCBs than previously assumed, although further interpretation of the data is needed to consider effects of blanks and particle phases.

The mass balance model of HCH in the Arctic Ocean that was discussed in the AAR (AMAP 1998) has been revised to take into account new knowledge of emissions from Russian rivers and recent results using enantiomer ratios of α -HCH showing that microbial degradation of HCH is very significant (Jantunen and Bidleman 1998). New calculations show that 53% of Σ HCH input to the Arctic Ocean is due to ocean advection, 23% is atmospheric (gas absorption and precipitation) and 24% is from rivers. Losses are estimated as 50% ocean advection and 36% microbial degradation (Bidleman et al. 2000). It may now be possible to model how long it will take to clear HCHs from the Arctic Ocean given this new information on inputs and degradation rates. Mass balances for other POPs remain much more difficult than for HCH due to lack of measurements with which to estimate advection as well as degradation.

3. Spatial Trends

3.1 Sediments

Additional marine sediment samples (grabs and cores) have been collected in the Canadian arctic as part of the cruises described previously but results for POPs are not yet available. Lake sediment cores have been along a north south transect in the Canadian Arctic to examine latitudinal trends of 'traditional' and 'new' POPs (Muir et al. 1999b) and results will be available for the next AMAP assessment. Sediment cores have been collected on Bear Island for analysis of POPs inputs to lakes (Skotvold et al. 2000).

PCBs have been determined in surface sediments from harbours in northern Norway (Harstad, Hammerfest, Tromsø, Honningsvåg) and Russia (Kola Bay, Guba Pechenga) (Dahle et al. 2000). Relatively high (10-100 ng/g dw) levels were found in comparison with background sites reported

previously in the AAR. PCB levels and congener composition among harbours was similar (higher chlorinated PCBs predominated) except for Guba Pechenga where lower chlorinated PCBs predominated for unknown reasons. No large differences in OC concentrations were found between Norwegian and Russian harbours. Because of much (up to 10 times) higher concentrations relative to non-harbour areas, harbours probably constitute hotspots for PCBs in the arctic marine environment.

3.2 Soils

An ongoing EU project is investigating levels of POPs in soils on a global basis. The project, called GLOBALSOC, has a limited number of samples from the Arctic (mainly Scandinavia and Canada) (Ockenden et al. 1999). The project leaders are looking for collaborators in Russia with which to extend their collections east and north. The information generated on POPs levels in soils will be important for construction of reliable (global) emission inventories.

3.3 Freshwater Biota

A follow up to a 1994 study, which found high levels of PCBs in a single arctic char from Lake Ellasjøen on Bear Island, has begun (Skotvold et al. 2000). This island is in a unique location, halfway between mainland Norway and Svalbard, with the only source for POPs being via long range transport. Zooplankton, chironomidae, Arctic char, and sediment were collected from two lakes (Ellasjøen and Øyangen). Because seabirds were hypothesized to be a major biotic pathway for contaminants to Ellasjøen, bird guano and intestines of seabirds were also studied. The lake with guano input had the highest levels of PCBs in sediment, all OCs in zooplankton, and most OCs in chironomids. ΣPCBs for Arctic char averaged 710 ng/g ww in Ellasjøen and 133 ng/g in Øyangen. The PCB levels in Ellasjøen are among the highest ever measured in Arctic freshwater fishes and may reflect the unusual biotic pathway.

Studies on POPs in landlocked Arctic char are underway in Resolute and Char lakes near Resolute in the central Canadian archipelago (Muir et al. 2000). The objective is to obtain annual samples from these lakes to follow temporal trends of POPs and mercury in freshwater systems of the high arctic, comparable to continuing studies that have been ongoing in the subarctic in Sweden since the late-1960s (AMAP 1998).

3.4 Marine Biota

3.4.1 Invertebrates

Sampling of zooplankton and amphipods has been conducted as part of detailed food chain studies in the Northwater polyna project (NOW) (Fisk et al. 2000) and in a project examining food chain accumulation in the marginal ice zone in the Fram Strait and the Barents Sea near Svalbard (Borgå 2000) (see discussion of results for seabirds). There has been limited sampling in the western Canadian arctic and the Alaskan north slope for invertebrate samples as part of ongoing studies of contaminants in the marine food chain (Hoekstra et al. 1999) and results should be available for the next AMAP assessment.

Preliminary studies of POPs in amphipods from Fram Strait and from the Svalbard area have also shown geographic differences, with higher PCB in samples from the Svalbard area which is influenced by Atlantic water and higher HCH in samples from the Fram Strait area which may be influenced more by polar water (Borgå 2000; Borgå et al. In prep.). Measurements of POPs in seawater at the same locations are underway in a collaboration between Norwegian Polar Institute and Stockholm University (Olsson 2000).

There have only been only modest studies on tributyltin (TBT) and its effects on gastropods in arctic or subarctic waters in recent years. During the AMAP meeting in Girdwood, Alaska, in April 1998, suggestions were made to focus on studies of imposex in species of the genus *Nucella* (dogwhelks),

however, to date, only limited information has emerged of studies in most of the countries of the AMAP area.

In Norway TBT has been measured and imposex, the induction of male sex characters in females, has been evaluated in dogwhelks (*Nucella lapillus*) in 41 populations sampled in 1993-1995 along the Norwegian coast (Foelsvik et al. 1999). Organotin species were quantified using gas chromatography and atomic emission detection (GC-AED). Some degree of imposex occurred in almost all populations of dogwhelks studied, except in four from Northern Norway. The concentration of organotin compounds in the gastropods from the unaffected populations was below the detection limit (7 ng Sn/g dw). The concentration of TBT in dogwhelks from affected populations was in the range 48-1096 ng Sn/g dw. A positive relationship between the concentration of TBT in dogwhelks and the degree of imposex was found.

In Canada, TBT was detected at low ng/g ww concentrations in mussels (*Mytilus edulis*) from Labrador and Northern Quebec (Muir et al. 1999c). TBT concentrations ranged from 5.2 to 38 ng/g ww in mussel samples from Labrador and 10 ng/g ww, in samples from Deception Bay near Salluit in Northern Quebec. These concentrations are at the low end of the range found in *Mytilus edulis* in the US east coast (TBT = 10-1200 ng/g ww; Uhler et al. 1993).

3.4.2 Seabirds

Levels of POPs are being determined in seabird muscle and liver samples from northern Baffin Bay as part of the Northwater polyna project (NOW) (Fisk et al. 2000). The Northwater in northern Baffin Bay is the largest and most productive polynya in the Canadian Arctic, supporting a highly productive food chain and large populations of seabirds and marine mammals. An extensive multi-disciplinary study on the NOW afforded the opportunity to collect a large range of species to form a comprehensive food chain study of POP concentrations and stable isotopes of nitrogen. The use of nitrogen isotope ratios is an excellent method for identifying trophic status since it represents what is assimilated into an organism from its diet and integrates signals from food consumed over the time period of tissue turnover. Samples include 7 zooplankton species, arctic cod, ringed seal and 7 species of seabird. Strong POP- $\delta^{15}\text{N}$ relationships were found for non-metabolized POPs (e.g., PCB 153, Figure 4). Slopes of these relationships give a relative rate of bioaccumulation or food chain transfer and provide information on biotransformation and behavior of POPs in arctic marine ecosystems. These relationships also provide insight on trophic level and feeding behavior of biota. Similar data have recently been published for the Barents Sea (Borgå et al. 2000).

The Greenland human diet study (Johansen et al. 2000) includes analyses of seabird muscle and liver

samples (thickbilled murre, king eider, common eider, and ptarmigan). Low levels of ΣPCBs (20-30 ng/g ww; 100 congeners) were found in liver and muscle of murre and eiders. Ptarmigan, a resident species, had lower PCB levels (13 ng/g ww in muscle). This study also illustrated the importance of toxaphene as a contaminant in seabirds. Toxaphene levels

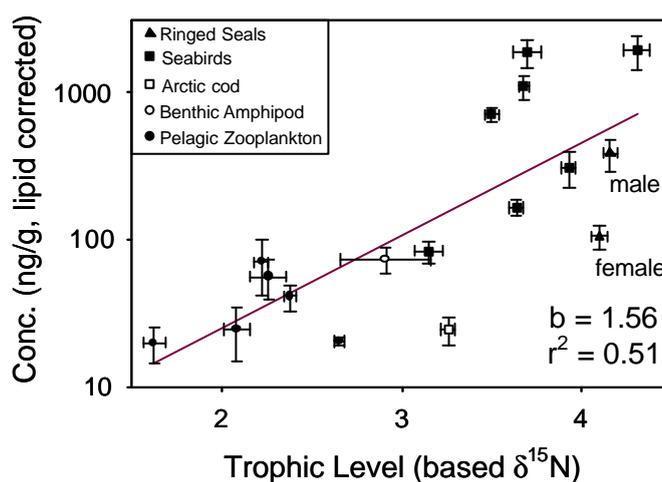


Figure 4. PCB 153 – trophic level relationship in the Northwater polynya. Trophic levels are based on $\delta^{15}\text{N}$ values (Fisk et al. 2000).

in murre liver and muscle (53 ng/g ww) were higher than PCBs. Similar dietary studies in selected areas of northern Russia form part of the planned work under the RAIPON/AMAP GEF funded project.

Glaucous gull and black guillemot eggs have been collected recently on Prince Leopold Is in the central Canadian archipelago which will allow interspecies differences to be compared and also comparisons made with the European arctic (Braune and Donaldson 2000). A food chain study in the Barents Sea (Borgå et al. 1999) includes measurements of POPs in biota from the marginal ice zone and use of stable isotopes to infer trophic position.

3.4.3 Marine Mammals including Polar Bears

Work is continuing in Canada, Alaska north slope, Greenland, Svalbard and northwest Russia on measurements of POPs in blubber of marine mammals collected in the traditional hunt or in scientific studies.

3.4.4 Seals and Whales

A study of harp and ringed seals in the White Sea has demonstrated that levels of POPs including toxaphene are higher there than in Svalbard or Greenland (Savinova et al. 2000a). Studies by Wolkers et al. (1998; 2000) have shown that toxaphene is elevated in harp seals collected off the east coast of Svalbard but not in ringed seals from the west coast of Svalbard. These results imply that there is a source of toxaphene in the Barents Sea area although there may be species specific differences. Studies of sediments in the Kola Bay area have demonstrated that elevated toxaphene is present in sediments in Polamy, a harbour north of Murmansk (Savinova et al. 2000b) possibly associated with past use for insect control on ships.

Measurements have also been made of PCBs and OC pesticides in beluga from the Svalbard area. Blubber biopsy samples were taken from live trapped beluga. Levels were, in general, similar or slightly lower than those in beluga from the Canadian arctic (Andersen et al. 2000a).

Results of analyses of beluga blubber from Alaska for PCBs and persistent organochlorine pesticides were reported by Krahn et al. (1999). Sampling and archival of marine mammal tissues in Alaska, especially at Barrow continues. The geographical gap identified in AMAP phase I is likely to be filled with the new results expected over the next 2 years (O'Hara et al. 2000).

A study of minke whale stocks in the North Atlantic included a comparison of levels of PCBs and OC pesticides in blubber of animals captured in West Greenland with those from the Svalbard area, the east Barents Sea, and northeast Greenland and the North Sea (Hobbs et al. 2000). Mean concentrations (sex-adjusted by ANCOVA) of Σ PCB, Σ DDT, and Σ CHL did not differ significantly among animals from Arctic locations. Σ HCH levels in minke whales from West Greenland were significantly higher than those from Svalbard or Jan Mayen. Levels of endosulfan were highest in minke whales from the east Barents Sea and the North Sea and lowest in animals from West Greenland and Jan Mayen.

Preliminary measurements have been made of TBT in ringed seals and beluga from the Canadian arctic. TBT and its metabolites DBT and MBT were present in ringed seal blubber and liver from Labrador and Northern Quebec at low ng/g concentrations (Muir et al. 1999c). TBT and its metabolites were not detected in beluga blubber or liver samples from Northern Quebec (de Mora 1999).

Steller sea lions from along the Alaskan coast and Dall's porpoise from the Aleutian Islands have lower butyltin concentrations than marine mammals (cetaceans and pinnipeds) from locations further south (Tanabe et al. 1998, Kim et al. 1996a).

Recent results show that DBT and MBT are present in high concentrations in plastics where they

have been used as stabilizers in PVC and as industrial catalysts for polyurethane foam and silicones (Takahashi et al. 1999a). New studies have also found butyltins in a range of invertebrates, fish, birds and marine mammals from the Pacific Ocean (Japan, Australia, Taiwan and Alaska, U.S.A. India, Bangladesh, Thailand, Vietnam, Indonesia, open ocean areas) (Takahashi et al. 1997, 1999b, Kannan et al. 1995a, 1995b, Tanabe et al. 1998, Guruge et al. 1996, 1997, Iwata et al. 1995, Kim et al. 1996a, 1996b, 1996c), in the Baltic Sea (Kannan and Falandysz 1997), on the U.S. Atlantic and Gulf coasts (Kannan et al. 1997), a freshwater lake in the Netherlands (Stäb et al. 1996) and the coast of Italy (Kannan et al. 1996). The coastal areas are more impacted by previous and current use of TBT on boats and fishing equipment near harbors and marinas. Open ocean areas are exposed to TBT from large vessels that are still allowed to use TBT on the ship's hulls.

Highest butyltin concentrations (wet weight basis) are found in the liver for all species studied. No correlations are found between concentrations and lipid contents in tissues. Higher concentrations are found in comparable matrices collected near coasts than in those collected from the open ocean. Higher relative amounts of MBT and DBT are found in birds and mammals as compared to fish, possibly due to metabolism of TBT.

These studies indicate that butyltins are widespread, global contaminants in aquatic environments and that they are present in the Arctic, including higher trophic levels.

3.4.5 Arctic Fox

Studies are planned on POPs in arctic fox from the Canadian arctic and the Alaska north slope (Braune et al. 2000). These will complement an ongoing study by Norwegian Polar Institute on contaminants in Arctic Fox at West Greenland, Svalbard and in the Pechora area of northwest Russia (Fuglei 2000). Results are expected to be available for the AMAP assessment in 2002.

3.4.6 Polar Bears

PCBs have been determined in blood from 90 adult female polar bears (5 years of age or older) from the Svalbard area eastward to Chukchi Sea. Blood sampling was carried out from live captured bears during late March to mid May in 1987-1995. Concentration of sum PCBs (sum of concentrations of PCB congeners -99, -118, -153, -156, -180 and -194) was determined in samples of whole blood or plasma and blood cells combined, and expressed as ng/g lipid weight. Significant differences between areas were found in PCB levels and congener patterns. Bears from Franz Josef Land (n=17) and the Kara Sea (n=12) had similar sum PCB levels and were higher than all other populations (Svalbard, (n=32), Siberian Sea (n=8) and Chukchi Sea (n=21)). PCB levels in bears from Svalbard were higher than those from the Chukchi Sea. The results indicate that polar bear from Franz Josef Land and the Kara Sea may have the highest circumpolar PCB levels and that decreasing trends are seen eastwards and westwards from this region (Andersen et al. 2000b). For HCHs there was a significant increasing trend eastwards, with the highest concentrations found in the Chukchi Sea. The levels of p,p-DDE increased significantly eastwards to Novaja Zemlja/Kara Sea and then decreased further eastwards. No significant spatial trends were found for HCB and oxychlorane (Lie et al. in prep). These results extend the work by Norstrom et al (1998) which was presented in AAR (AMAP, 1998). That study did not include samples from the Russian arctic, except for the Chukchi Sea.

The PCB levels in Svalbard polar bear are more than eight times higher than the corresponding level found in ringed seal at Svalbard (Severinsen et al. 1999). Furthermore, higher levels of PCB are found in male polar bear, increasing with age, as compared to the corresponding levels in females. The sex difference in OC levels reflects the fact that in females milk is an important excretory pathway for lipophilic compounds resistant to metabolic degradation. Considerable amounts of PCBs are transferred to the offspring via milk. In polar bear the PCB pattern in suckling yearlings reflects a low transfer of the higher chlorinated (hepta- and octachloro) PCBs into maternal milk. The levels of most other PCBs were higher in depot lipid of yearlings than in depot lipid in their mothers. This means that

young cubs are exposed to PCBs at a period of growth and development when they are most sensitive.

4. Temporal Trends

A critical question in the assessment of POPs in the Arctic is whether concentrations are increasing or decreasing. AMAP will be in a much better position to address this issue as part of Phase II. With a few important exceptions, assessment of temporal trends of OCs in the Arctic with the information available to 1996 was difficult because most measurements were recent.

Airborne concentrations of POPs have been determined in Arctic air since 1992 at Alert and Ny Ålesund. There are also easier measurements from the 1980's during cruises in the Bering-Chukchi seas, in the Canadian Arctic archipelago and at Ny Ålesund. At present only results from the 1993-95 period have been reported but there is a much longer term dataset (1992-2000) potentially available. These data are currently being compiled in the AMAP atmospheric thematic datacentre.

Temporal trend studies continue on fish and reindeer in northern Sweden. These studies by the Swedish national monitoring program represent the longest and most detailed temporal trend story (annual sampling). Additional results from this ongoing program will be reported in the assessment in 2002.

Organochlorine residues have been monitored in eggs and livers of several species of seabirds at Prince Leopold Island in the Canadian high Arctic since the mid-1970s (Braune and Donaldson 2000). Levels of PCBs and DDTs in the eggs of black-legged kittiwake, northern fulmar, and thick-billed murre have declined significantly during the period between 1975 and 1998. α -HCH and γ -HCH also declined over this period while β -HCH levels increased as a proportion of total HCH.

A long term data set for POPs in seabirds from northern Norway and Svalbard is also available from which temporal trends may be inferred (Gabrielsen 2000).

There are relatively few long term (multi-decade) studies of OCs in Arctic marine mammals. The longest running study of temporal trends in marine mammals is at Holman (NWT) in the western Canadian Arctic (Addison et al. 1986; Addison and Smith 1998) Further analysis of the Holman ringed seal population was carried out in 1996. These results have been compared with the 1981 and 1972 analyses (Addison and Smith 1998; Stern et al. 2000). The authors concluded that between 1972 and 1991, PCB concentrations in blubber declined about 5-fold to about 20 % of their initial value with major decline occurring in the 1970s. The DDT-group concentrations also declined slightly over the same interval; most of the decline occurred during the 1980s rather than the 1970s.

Stern et al. (2000) have studied temporal trends of PCBs as well as brominated and chlorinated diphenyl ethers and chlorinated paraffins in beluga blubber samples from the southeast Baffin Island stock. No significant decline in Σ PCBs, toxaphene or Σ DDT was observed over the period 1982-1996. A significant increase was observed in short chain chlorinated paraffins and brominated diphenyl ethers from 1982 to 1996 while chlorinated diphenyl ethers declined significantly. Figure 5 illustrates the increase in concentration of the brominated diphenyl ether 2,2',4,4'-TeBDE in beluga blubber.

Similar to the data for the Canadian arctic, there was little temporal trend information on

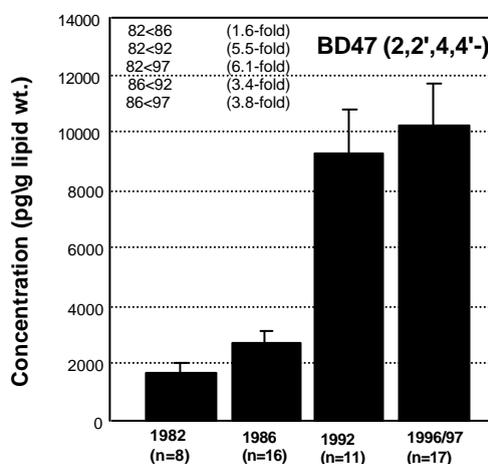


Figure 5. Increasing concentrations of PBDE congener 47 in beluga blubber (SE Baffin Is., 1982-96) (Stern et al. 2000).

POPs for marine mammals in the Greenland and Svalbard areas available as of 1996, but more will be available for the next POPs assessment because of continuing long term studies, e.g. on ringed seal. Wang-Andersen et al. (1993) examined concentrations of PCBs in Svalbard Arctic fox fat and liver samples collected in 1983-84, and compared these with earlier samples collected in 1973-74. Σ PCB, based on 7 selected congeners measured on both dates, did not differ significantly between sampling periods. Recent temporal trend work on arctic fox has been conducted by Fuglei (2000), who have also found no decline in PCBs between the 1970's and 1990's.

Results for Σ DDT in adult female minke whales from Svalbard and the east Barents Sea (mean 890 ng/g lipid wt.) taken in 1998 were lower than reported by Kleivane and Skaare (1998) for minke samples taken in 1992 (1510 ng/g lipid wt.) suggesting that DDT levels are declining (Hobbs et al. 2000). Σ PCB levels in samples from female minkes from the North East Atlantic reported by Kleivane and Skaare (1998) (2270 ng/g lipid wt.) were similar to those collected in 1998 (3030 ng/g lipid wt.) suggesting little change over the 6 year period (Hobbs et al. 2000).

In Iceland, the status of imposex has been evaluated in the dogwhelks (*Nucella lapillus*) in 1998 and compared to the levels of imposex evaluated in 1992/1993 (Svavarsson 2000). The level of imposex has decreased considerably since 1992/1993, two years after implementation of restrictions on the use of TBT-based anti-fouling paint. VDSI (vas deferens sequence index) and RPSI (Relative Penis Size Index) levels have declined considerably, both near large and small harbours. The impact area of a large harbour complex has decreased considerably, while lesser changes were seen in the impact areas near smaller harbours. This study shows that, in Icelandic waters at least, the situation has improved considerably.

5. Biological Effects

In the first phase of AMAP, a few studies had been performed which used subtle indicators of biological responses to contaminants (biomarkers) and correlated these to tissue concentrations of specific organochlorines. Mostly these studies concentrated on only one type of biomarker, such as cytochrome P450 enzymes, plasma concentrations of retinol, thyroid hormones, or reproductive effects. A preliminary ecotoxicological exposure assessment based on current concentrations of some POPs (DDT, PCBs, PCDD/PCDFs) compared to thresholds for effects in other species indicated that a range of marine mammals and predatory birds were at risk for reproductive, immunosuppressive and neurobehavioral effects.

5.1 Birds of Prey

Monitoring of egg-shell thinning and DDT levels in the eggs of peregrine falcon is continuing in some countries.

5.2 Seabirds

New data for glaucous gulls from Svalbard and Bear Island show correlations between number of intestinal nematodes (immunosuppression), liver enzyme activities and plasma retinol with PCB levels (Sagerup et al. 2000; Skaare et al. 2000a).

5.3 Polar Bear

The elevated levels of PCBs in polar bear from the Svalbard area (ranging from 4790 - 80300 ng/g in adipose tissue (Bernhoft et al. 1997) reported in the last POPs assessment have prompted further biological effects studies. CYP1A1 has been determined in white blood cells of polar bears and the preliminary results (n=10) show a significant positive correlation between sum PCB (the sum of PCBs 99, 118, 153, 156, 180 194) and CYP1A1 area in western blots (P=0.026). The strongest correlation was found with PCB 156 (P=0.011). These results are promising with regard to the potential for CYP1A1 in blood cells as a biomarker for PCB exposure in polar bears (Goksøyr et al. in prep).

Normal regulation of vitamin A and thyroid hormones is important for a wide range of biological functions, such as growth, cell differentiation, reproduction, behaviour and the immune system. In polar bear at Svalbard retinol and thyroid hormones (T3 and T4) have been determined in blood plasma of 114 individuals. The results of determination of multivariate associations between retinol, thyroid hormones, the ratio of total and free thyroid hormones and cortisol, respectively, and the concentrations of various OC components (PCBs, DDE, HCB, HCHs) revealed significant OC associations for retinol and the ratio total/free T4. Significant negative correlations between retinol and sum PCBs, HCB, HCHs and between total/free T4 and sum PCBs, HCB were found (Skaare et al. 2000b,c).

The production of antibodies plays an important role in the protection against infections. Antibodies are divided into different immunoglobulin classes, where IgG is the major one in blood. IgG and OC concentrations were determined in blood sampled from 56 free-living polar bears of different age and sex between 1991 and 1994. Total IgG concentration increased with age and was significantly higher in males than in females. A significant decrease of IgG with increased sum PCB level was found ($R = -0.29$, $P = 0.03$). IgG was standardized for sex and age, since both sex and age may influence the levels. Three individual PCB congeners showed significant inverse correlations to IgG: IUPAC nos. 99, 194 and 206. In addition, HCB was also inversely correlated to IgG. The OCs were found responsible for 11% of the variation of IgG levels. These results demonstrate a possible contaminant associated suppression of antibody-mediated immunity in polar bears at Svalbard (Bernhoft et al. 2000; Skaare et al. 2000c).

A larger scale study of immunosuppression in polar bear from Canada and Norway, representing low and high PCB exposure, is underway where animals have been captured, vaccinated and then recaptured after several weeks for sampling. The blood samples will be measured for a suite of immunological parameters (lymphocyte proliferation, IgG, IgA, IgM, antibody production after vaccination, T and B cell proliferation) as well as for contaminants analyses, which will provide a better picture of the effects of contaminant exposure on the immune system. Studies of reproductive success on Svalbard and in Canada are also being carried out. Alaska also has immune effects studies ongoing. A study on craniometrical changes in polar bears from the East Greenland population from 1850 to present is underway. Initial results show that the skull is correlated with bones such as the femur and lumbar segments usually analysed for Bone Mineral Density (BMD) in humans. Preliminary results from these studies are likely to be available for the 2002 assessment.

Pseudohermaphroditism (presence of a penis in otherwise normal females) has been observed in 1.5% of the polar bears from Svalbard that have been investigated (Wiig et al. 1998; A. Derocher and Ø. Wiig unpublished data). No similar animals have been found in the American or Canadian arctic although fewer detailed studies have been carried out there to examine this pathology. The results could be the result of endocrine disruption from environmental pollutants although the authors could not rule out excessive androgen excretion caused by a tumour.

In conclusion, the biological effect studies on polar bear in the Norwegian Arctic, show that in polar bears there is some evidence of reduced cub survival, suppressed immune function and disturbance of the thyroid hormone and retinol homeostasis as well as pseudo-hermaphroditism. The significance of these findings on the individual and population levels has to be further investigated.

5.4 Seals

Previously, correlations were seen for liver enzyme activities and PCB and dieldrin concentrations in ringed seals from Arviat (western Hudson Bay) and for PCB concentrations in hooded seal from the West Ice (Greenland Sea). A new study in Alaskan northern fur seals is determining mother-pup exchange of several OCs including DDTs, PCBs, TEQs from PCDD/Fs, and correlating these to changes in immune response, retinol levels and thyroid hormone levels. Results so far indicate correlations between reduced antibody levels, lack of response to vaccination, reduced retinol and thyroid hormones with higher PCB levels in the pups (O'Hara et al. 2000; Beckman et al. 1999;

Beckman 1999). Another recent study is looking at liver enzyme induction in ringed and harp seals around Svalbard correlated to levels of OCs such as PCB and toxaphene. Harp seals from east of Svalbard have higher enzyme activities than ringed seal from west of Svalbard, which seems to be correlated to high toxaphene levels in the harp seals, but high PCB levels in the ringed seals (Wolkers and Burkow 2000).

5.5 Arctic Char

In the previously mentioned study that is being carried out on Bear Island, Norway, studying two lakes, one highly contaminated by bird guano from nearby colonies, for organochlorine contamination and biomagnification, Arctic char have also been studied for liver enzyme activity including testosterone hydroxylation enzymes. Correlations were seen between cytochrome P450 enzyme activities and PCB levels. Levels of testosterone hydroxylation enzymes were similar at both lakes and not correlated to PCB levels (Evenset et al. 2000).

5.6 Other Studies

In addition to the above, studies of endocrine disruption in seals from the Barents Sea and population studies of Norwegian polar bear and glaucous gulls are ongoing or being initiated. Gross pathology and histopathology is planned in ringed seals, some whales and beluga in Alaska. Pathology is also planned in Arctic fox and wolverines in Canada and Alaska.

5.7 Data Gaps

The importance of the Ob and Yenisey rivers as a source for the Kara Sea has been demonstrated for DDT and HCH, however, there are currently no measurements available for PCB levels in these or other Russian rivers.

Although progress has been made with polar bears circumpolar coverage of POPs measurements in other key species, such as ringed seals and glaucous gulls, remain limited.

Studies of biological effects on seals (e.g. ringed seal), whales (e.g. beluga) and seabirds (e.g. glaucous gull) remain an important gap in knowledge. Such studies are difficult logistically but recent work by Wolkers et al (1998; 2000) and preliminary results cited in AAR (AMAP 1998) suggest that responses, e.g. CYP450 IA and other biochemical indicators, can be seen at present levels of exposure to POPs.

Acknowledgments

We are grateful to all the scientists whose work is cited here and who agreed to contribute their recent, mainly unpublished, data and graphics to this preliminary report. We particularly thank the participants in the POPs and Human Health workshop in Rovaniemi for their contributions many of which are summarized in this report.

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Radioactivity in the Arctic: An Update

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1. Introduction

Nuclear operations and activities in, and close to, the Arctic give rise to concern, especially in relation to the potential for accidental releases of radionuclides, because of the comparatively greater vulnerability of Arctic populations than those in temperate areas due to the dependence on natural and semi-natural foodstuffs (*e.g.*, wild foods and the consumption of reindeer) and higher radionuclide transfer factors to these foodstuffs. The first AMAP assessment concluded that the major risks of radiological exposures were associated with potential accidents at nuclear power plants, during the handling, transport and storage of nuclear weapons, during the maintenance and decommissioning of nuclear-powered vessels and the handling, storage and disposal of spent nuclear fuel. In addition, there are concerns about the potential for the transport of radionuclides into the Arctic following releases from nuclear installations.

This progress report deals with new information regarding activities in, and threats to, the Arctic that has become available since the completion of the first AMAP assessment published in 1998 (AMAP, 1998). It must be stressed that only those issues that pertain directly to conditions in the Arctic or pose threats to the Arctic environment have been included in this report.

The work to be carried out during the second phase of AMAP includes an assessment of the possible consequences of potential major accidents and the associated releases of radionuclides to terrestrial and aquatic environments of the Arctic. There remain gaps in contemporary knowledge relating to: the long-term migration of radionuclides in the terrestrial and aquatic systems of the Arctic; changes in the characteristics of the diets of different Arctic population groups with time; and the reasons for the high variability of radionuclide accumulation in natural and semi-natural foodstuffs. Further experimental, survey and modelling investigations on these topics are also included within the AMAP II radioactivity programme. High priority has been assigned to determining the vulnerability of Arctic regions and communities as a means of predicting the radiological consequences of potential releases of radionuclides. Moreover, monitoring of the Arctic environment needs to be maintained and improved in order to acquire greater insights into the basis for spatial and temporal variability which, in turn, can be used to improve further assessments. Some progress has been made in formulating a new AMAP monitoring programme although a full circumpolar programme of monitoring has yet to be implemented.

The first AMAP assessment concluded that there was a limited ability to assess radiation effects on flora and fauna. The current system of radiological protection is based solely on the protection of human health. During the second phase of AMAP, the development of a framework for including the protection of flora and fauna in the basis for radiological protection has been given considerable priority. This is warranted because of the low density of human habitation of the Arctic and the need to ensure that flora and fauna are adequately protected from the effects of radionuclides in the environment.

Finally, the topic of risk management has also been assigned a high priority within the AMAP II radioactivity programme. This is because risk management is essential for determining relative priorities among sources and potential sources for intervention and also for ensuring that risk reduction measures (*i.e.*, human actions to reduce risks) are properly designed and take account of all the beneficial and detrimental effects of possible interventions. The application of environmental impact assessments (EIAs) of potential interventions included in action programmes, as well as proposed developments, is valuable to ensuring net benefits to society and as a basis for subsequent compliance and surveillance monitoring.

2. Sources

2.1 Nuclear Power Plants

Several Arctic countries have implemented individually or in cooperation with other countries action plans to increase the safety of nuclear power plants potentially affecting the Arctic. This includes work carried out at the Kola and Bilibino nuclear power plants, among others, to improve nuclear

operations and systems safety. Information regarding improved nuclear power plant safety measures in Arctic states is expected to be included in the final report to Ministers in 2002.

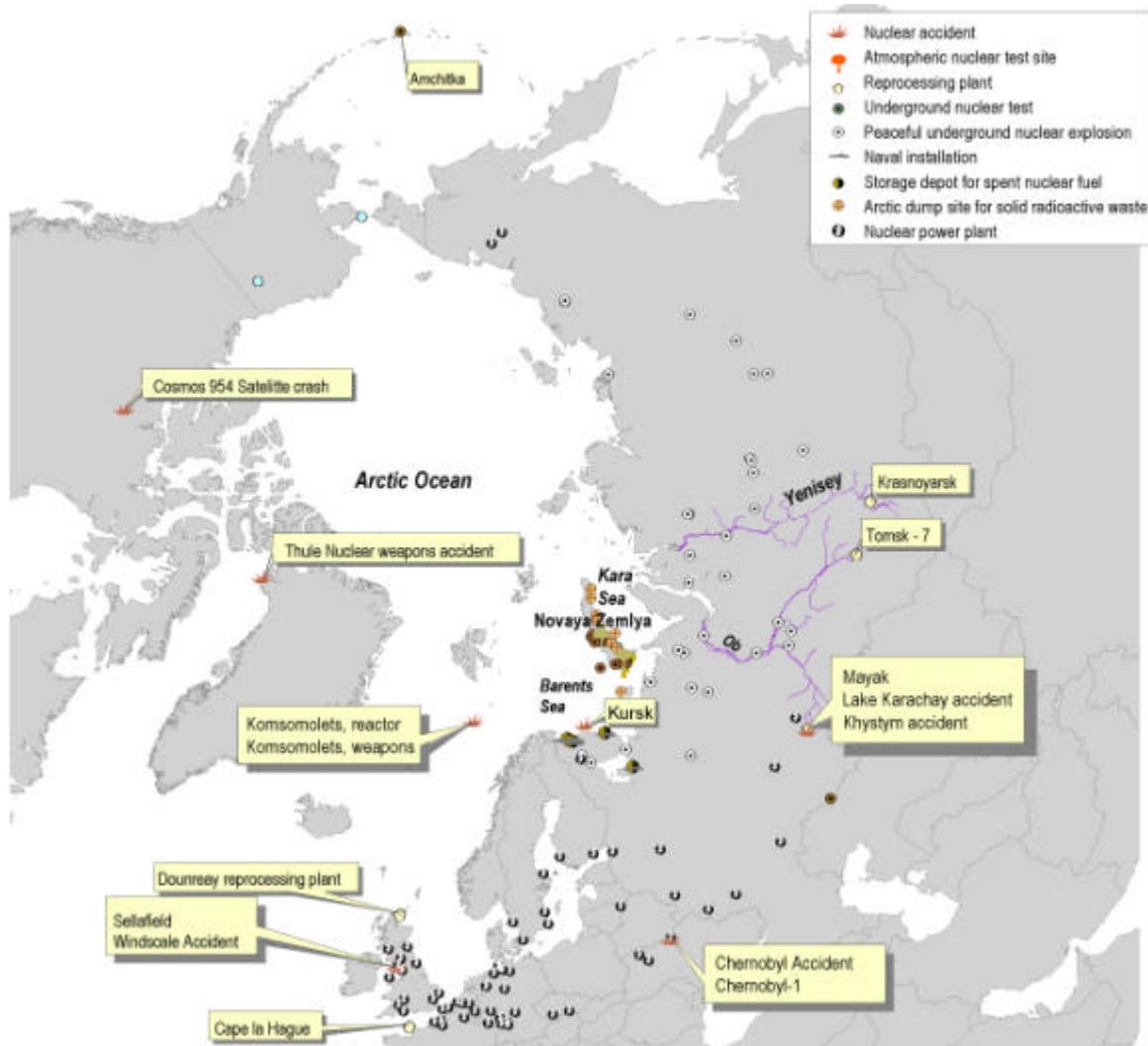


Figure 1. Overview of selected sources, actual and potential, of radionuclides in the Arctic.

Feasibility studies for the construction of floating nuclear power plants are being carried out within the Russian Federation. At present, no further detailed information is available, but should such information be released, it will be presented in the report to Ministers in 2002.

2.2 Nuclear Vessel Decommissioning and Associated Spent Fuel Storage

The decommissioning of nuclear submarines of the Russian Northern Fleet is continuing. A total of 110 decommissioned submarines lie moored in northern harbours with 70 of these submarines containing spent nuclear fuel. Since the beginning of 1998, 12 submarines have been decommissioned and it is expected that during the year 2000 a further 18-20 submarines will be decommissioned.

The handling and storage of spent nuclear fuel is of major importance in terms of threats to the Arctic environment while the long-term disposal option is still unresolved. Current practice is not up to international standards largely because of the difficulty of transporting spent fuel to reprocessing facilities or long-term spent fuel disposal sites. This problem is being addressed under a number of

multilateral programmes but this still remains a crucial unresolved issue. The primary location for the storage of spent fuel (approximately 80% of the spent nuclear fuel inventory) from the Russian Northern Fleet is at Andrejeva bay on the Kola Peninsula. There has been some leakage of radionuclides from these storage sites although the overriding threat derives from deficiencies in the entire spent fuel management process.

In addition to spent fuel derived from military vessel operations and decommissioning, there is also spent fuel from civilian nuclear vessel maintenance stored at the Atomflot facilities at Murmansk.

2.3 Loss of the Russian nuclear submarine Kursk in the Barents Sea

On the morning of August 12th 2000, a Russian submarine sunk in international waters east of Rybatschi Peninsula in the Barents Sea. The submarine, a Russian Oscar class II attack submarine, sunk to 108 meters depth about 190 km from Murmansk. Kursk is 154 meters long and weighs 14 000 tons. The submarine was commissioned in 1995, and is powered by two pressurised water reactors. This is the most common reactor type. Each reactor has a thermal effect of 190 megawatt, or less than 10 % of a typical nuclear power plant (Russian sources and Jane's Fighting Ships). The reactors are according to official Russian information shut down. Measurements on sea water samples taken near the submarine and in the surrounding area have been carried out. Analyses of air filters, sea water and sediment carried out up to now, show no traces of radioactivity from the reactors on board Kursk. According to official Russian information, there are no nuclear weapons on board Kursk.

2.4 Accidents - Accident on Nuclear Submarine in Chazhma Bay, Vladivostok, August 1985

On the 10th of August 1985 a severe criticality accident took place on a nuclear submarine docked for repair in Chazhma Bay. The results of subsequent on-site observations and radioecological investigations showed that this accident did not have a measurable radiation impact on Vladivostok, or the nearby Shkotovo-22 village. Residual long-lived radioactive contamination in Chazhma bay region is localised and will not give rise to serious radioecological consequences. The measurements made during several years of follow-up investigations offer a unique opportunity to test various mathematical (numerical) models of radionuclide propagation in water, bottom sediments and beaches (Sarkisov, 1999).

2.5 Major Western European Sources

The first AMAP assessment discussed the importance of western European nuclear fuel reprocessing plants as sources of a proportion of the radionuclides, especially radiocaesium, found in the Arctic environment (AMAP, 1998). New aspects of the radionuclide releases from these sources not discussed in detail in the earlier assessment involve ⁹⁹Tc and ¹²⁹I.

Technetium-99

Technetium-99 is a long-lived fission product nuclide whose release from the Sellafield reprocessing plant has increased substantially in recent years. This combined with the conservative properties of this nuclide (i.e., it is a less particle-reactive nuclide than many) means that it is detectable over large distance scales. The major increases in the release of ⁹⁹Tc from Sellafield occurred during 1994 and 1995. This had led by 1997 to increased concentrations in the waters of the Norwegian Sea coast as shown in Figure 2 and later to increased concentrations in the Barents Sea (Figure 3). These increases are also reflected in water and seaweeds derived from the Norwegian coast at Hillesøy during the period July 1997 to November 1998 (Figures 4 and 5). During this period the concentration of ⁹⁹Tc in seaweed has increased fourfold from 50 Bq/kg to 200 Bq/kg. The present levels probably result in insignificant doses to humans. However, an assessment of the doses to Arctic populations associated with ⁹⁹Tc releases from European reprocessing plants taking account of all relevant exposure pathways will be conducted during AMAP Phase II. The exposures to flora and fauna will also be evaluated.

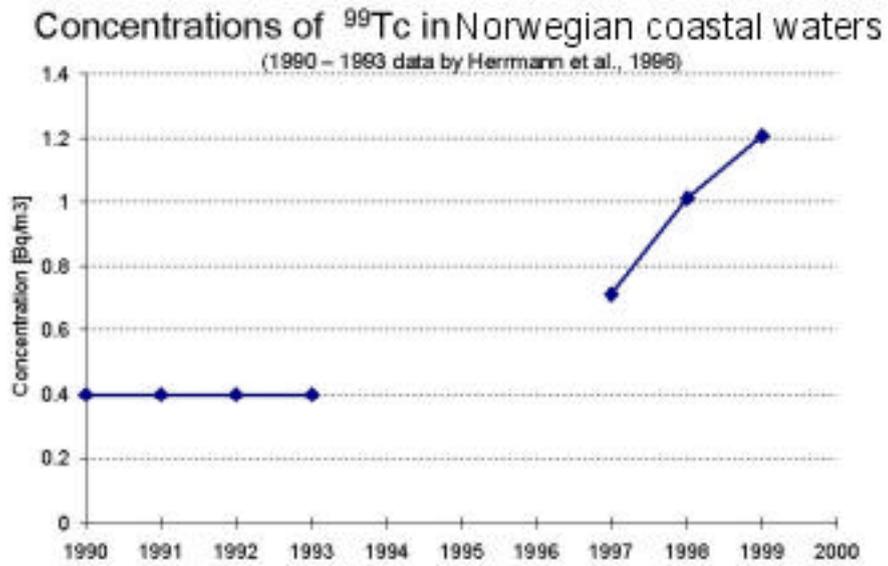


Figure 2. Increasing concentrations of Technetium-99 in Norwegian coastal waters

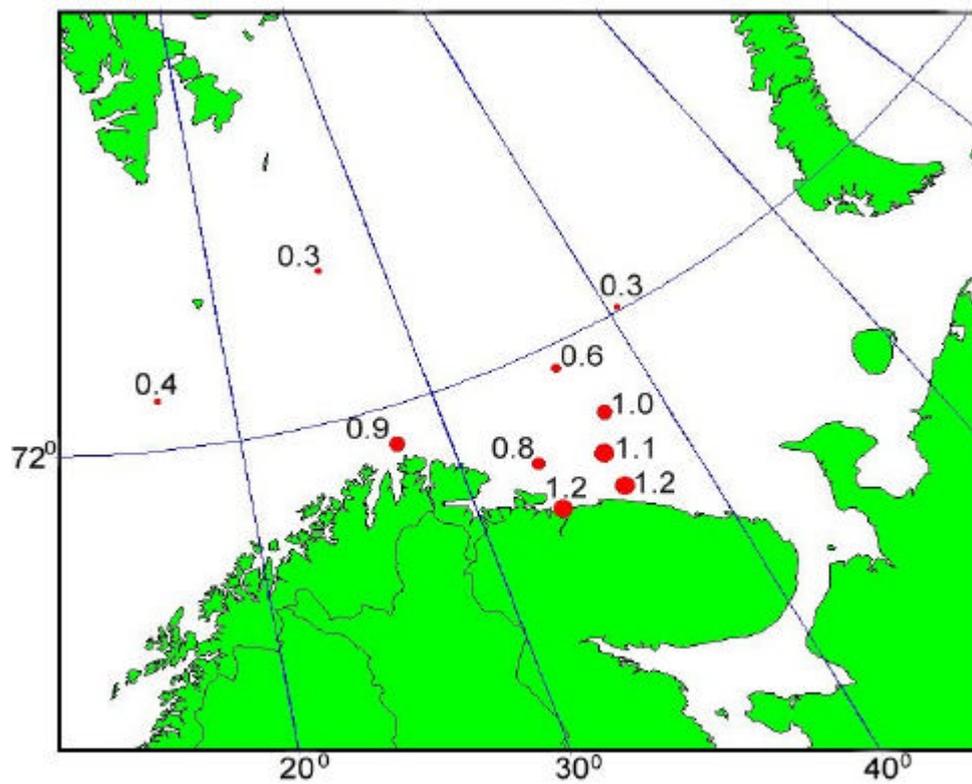


Figure 3. Concentrations of Tc-99 in the Barents Sea during 1999.

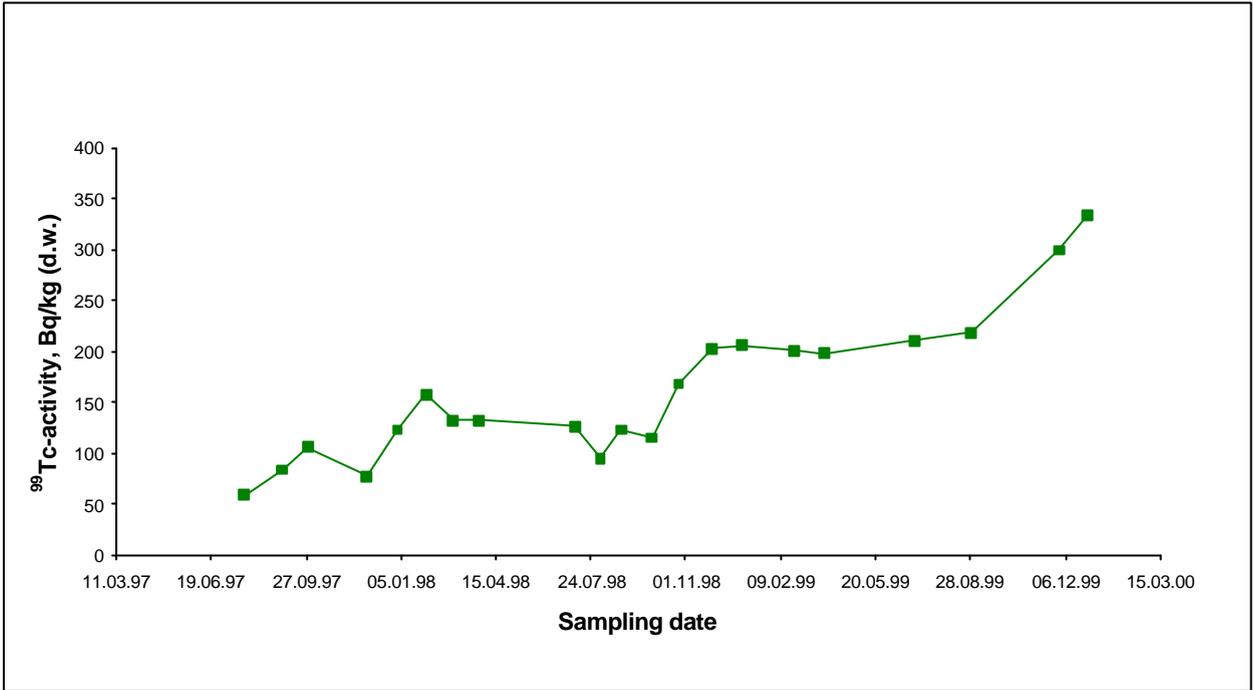


Figure 4. Temporal changes in the concentrations of Technetium-99 in seaweed at Hillesøy, Norway

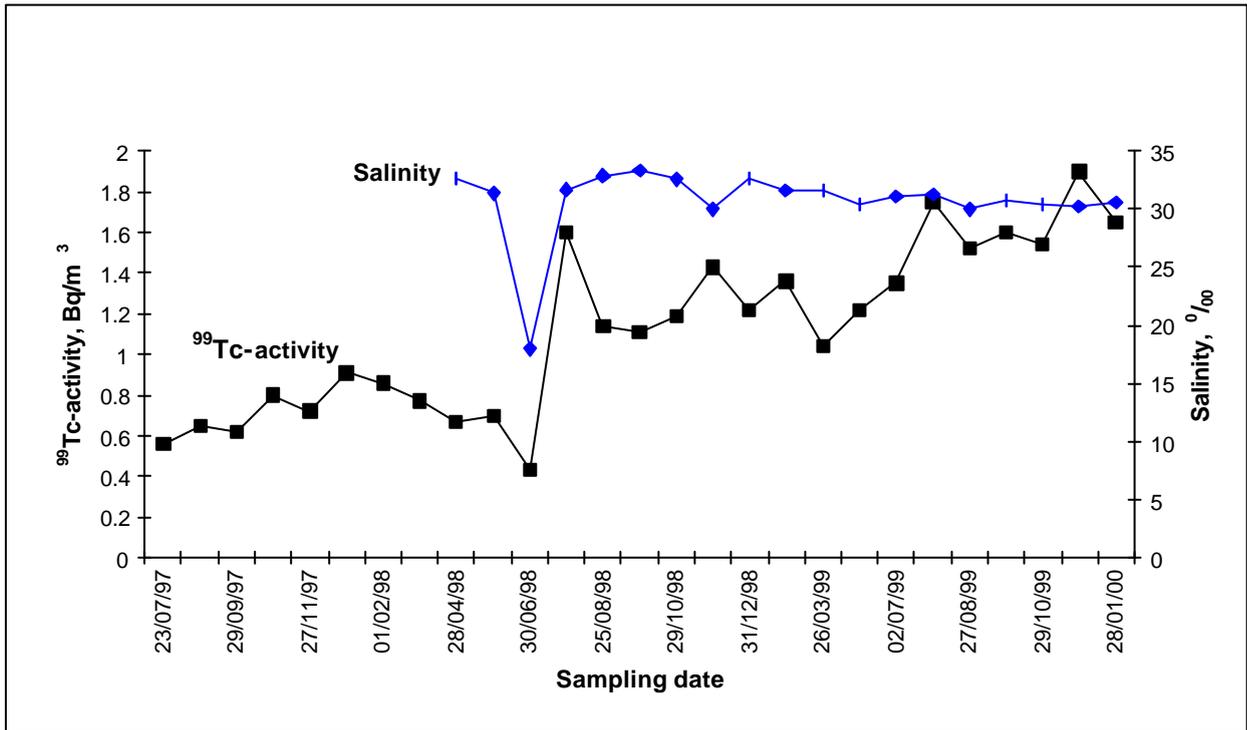


Figure 5. Temporal changes in the concentrations of Technetium-99 in seawater at Hillesøy, Norway

Iodine-129

Iodine-129 is another very long-lived (1.6 10⁷ year half-life) fission product whose release from European sources, in this case primarily Cap de la Hague, has increased substantially in recent years. It is also a conservative nuclide and is therefore potentially traceable in water over global scales.

During the last 25 years some 7.8 TBq of ^{129}I has been released from Sellafield and Cap de la Hague combined. In 1990 when a new plant at Cap de la Hague was put into operation, the release of this nuclide was increased substantially and La Hague became the dominant of the two sources (Raisbeck and Yiou, 1999). Since 1995, increased ^{129}I concentrations have been measured in the Arctic. Because of the ability of this radionuclide to accumulate in certain marine flora, it can give rise to significant collective doses although the question of truncation remains a problem in obtaining a true perspective on its radiological significance. As the case with ^{99}Tc , ^{129}I constitutes a valuable tracer of circulation because of its conservatism and the recent systematic variations in its release rate to the marine environment in western Europe.

2.6 Remobilization of Plutonium from Marine Sediments in Western Europe

Plutonium has accumulated in the marine environment from fallout and other sources. In general, plutonium is strongly particle-reactive in the marine environment and has therefore accumulated in marine sediments. About half a tonne of plutonium has accumulated in the sediments of the Irish Sea and North Sea from fallout and as a result of releases from the Sellafield reprocessing plant in the west of England. The $^{239,240}\text{Pu}$ activity concentration in surface waters of northern seas in 1995 ranged from 2 - 66 mBq/m^3 as depicted in Figure 6. As this figure shows, the highest $^{239,240}\text{Pu}$ activity concentrations in surface seawater occur off the north and northeastern coast of Scotland, with values of between 46.0 ± 2.3 and 65.7 ± 2.6 mBq/m^3 . Furthermore, the ^{238}Pu to $^{239,240}\text{Pu}$ isotope ratios in the surface waters of the Norwegian Sea, the Barents Sea, the Greenland Sea, Icelandic Waters and the North Atlantic (only one sample was measured here) lie in the range 0.04 and 0.2. These ratios indicate, together with available release data, that Sellafield has been a major contributor to the plutonium observed while the primary source remains fallout. The plutonium isotope ratios also imply

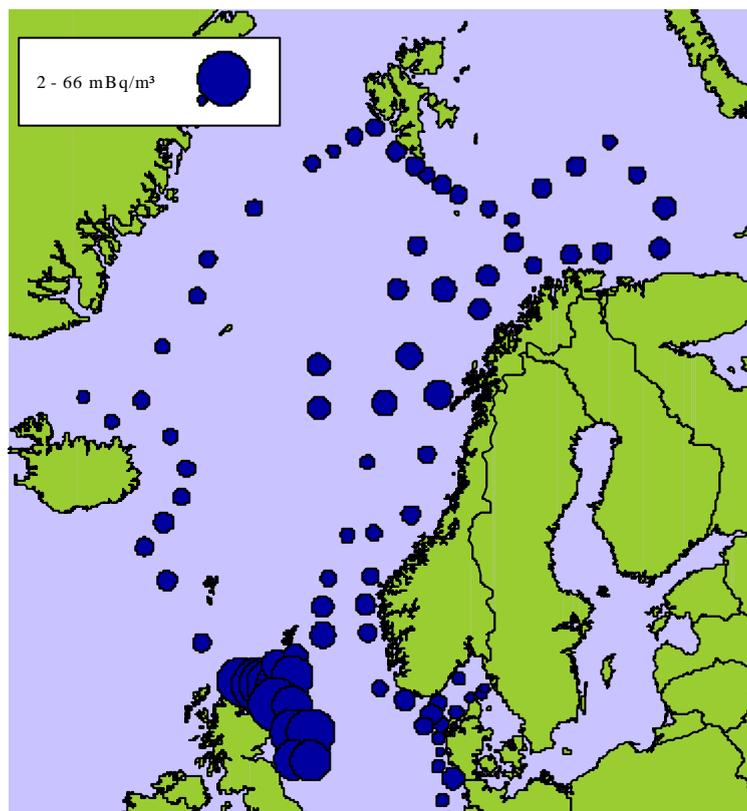


Figure 6. Distribution of $^{239,240}\text{Pu}$ in surface sea water (mBq/m^3) of the northern seas in 1995

that Sellafield-derived plutonium is likely to have been transported with the surface circulation pattern into the Norwegian Sea, the Barents Sea, the Greenland Sea and the Iceland Sea. A ^{238}Pu to $^{239,240}\text{Pu}$ ratio of 0.2 is characteristic of sediments in the Irish Sea and remobilization of particle-associated

plutonium may be a contributor to the levels in surface waters. A study by Cook *et al.* (1997) demonstrated that the remobilization of radionuclides in the Irish Sea discharged from Sellafield is substantial. The plutonium present in the waters of the Irish Sea in 1992 was dominantly (90-100%) derived from Irish Sea sediments rather than contemporary discharges from the Sellafield reprocessing plant. This implies that a large fraction of the Sellafield-derived plutonium observed in northern marine environments also might originate from contaminated sediments of the Irish Sea (Grøttheim, 1999).

2.7 Underground Nuclear Detonations

Recently, there has been new information on local contamination resulting from peaceful underground nuclear explosions carried out by the former Soviet Union. Research has shown that these explosions led to considerable contamination of localised areas. The sites “Craton-3” and “Crystal” in the republic of Sakha, where peaceful nuclear explosions have been conducted, contain residual radioactive contamination in spite of the earlier clean-up efforts. Measured concentrations of plutonium in lichen in the contaminated areas of the “Craton-3” and “Crystal” sites are relatively high. Average plutonium concentration in lichen of the most contaminated parts of Craton-3 is equal to 2.1 kBq/kg, which is greater than the background value by a factor of 780. However, such levels of contamination exist only in the immediate vicinity of these sites. For instance, at the “Crystal” site, ^{239,240}Pu concentrations in soils and lichens at distances about 2 km from the crater are 3-4 orders of magnitude less than the maximum values. Measurements of the concentration of ²³⁹⁺²⁴⁰Pu in bottom sediments point to the discharge of radionuclides into the Markha river with the potential for remobilization and transport over larger areas (Gedenov *et al.*, 1999).

The USA conducted underground nuclear explosions at Amchitka Island during the period 1965 to 1971. With the exception of the Long Shot site radioactive gas leakage, radionuclides in the Amchitka freshwater and terrestrial environment are essentially of fallout origin (Dasher *et al.*, 1999). This is also consistent with the hydrogeological information and some limited modelling that indicate that leakage from the underground test cavities will occur into the near shore marine environment (Wheatcraft, 1995).

3. Consequences of Present and Future Radioactive Contamination of the Arctic Environment

There are three topics discussed under this heading. The first is the concept of vulnerability and the second is analogous to the concept of critical loads applied to non-radioactive contaminants. These two concepts are discussed in the following two sections of this document. The final topic is that of doses to Arctic populations from the natural radionuclide ²¹⁰Po.

3.1 The Concept of Vulnerability

Vulnerability is a concept reflecting variations in the environmental transfer of radionuclides from sources to locations at which they impose doses to humans. Variability in the kinds and distributions of soils, vegetation, edible natural foodstuffs, animals responsible for the transfer of radionuclides from vegetation to humans, etc., all affect the relationships between the rates of introduction of radionuclides to the environment and associated exposures. It is the spatial variability of these transfer functions that is of interest in the application of vulnerability.

Estimates of doses to the public, based on measurements or model predictions frequently generalize variations in environmental conditions, either because of the limited availability of data or an inadequate detailed knowledge of conditions in the environment that influence resultant exposures. Such generalizations mask considerable variability in the distribution of dose both in space and time even if the input rate of radionuclides to the environment is essentially uniformly distributed. While this is of little moment in respect to the calculation of collective dose, variations in individual doses resulting from variations in vulnerability can be masked and locations and populations receiving comparatively high doses may not be identified. Paying attention to vulnerability allows these variations to be taken into account in individual dose calculations and predictions and this provides for

much improved insights into the potential doses that would occur in the case of unexpected accidental releases. This is particularly valuable in the case of the Arctic because of the comparatively heavy reliance on country foods and semi-natural foods within the populations of the Arctic.

In the first phase of the Arctic Monitoring and Assessment Programme, the Radioactivity Expert Group concluded that: “Internal exposure to the average Arctic population from radiocaesium contamination has been five times greater than that to populations of temperate areas with the same levels of contamination. Parts of the Arctic population could be several hundred times more exposed than the average population of temperate areas” (AMAP, 1997). The largest contribution to radiation doses to populations in northern areas has come from fallout from nuclear tests in the 1950s and 1960s. In some areas, Chernobyl fallout has also contributed significantly to total dose (AMAP, 1998). Figure 7 shows the dose contribution from global fallout and Chernobyl fallout to two Saami populations and a segment of the Russian population in the area affected by Chernobyl fallout.

On a regional basis, the first AMAP assessment showed that areas in the Arctic with high precipitation rates had received much higher amounts of global fallout than areas receiving little precipitation (Wright *et al.*, 1999). Accordingly, communities in high precipitation areas, which herd semidomestic reindeer or hunt wild caribou, were probably the most highly exposed (and therefore the most radioecologically vulnerable) to radiocaesium as a result of atmospheric weapons testing. It should be noted that the ecological half-life of radiocaesium in these semi-natural and natural products is often very long. It is therefore important to take account of contamination by the more persistent nuclides already present in the event of an accident affecting the Arctic.

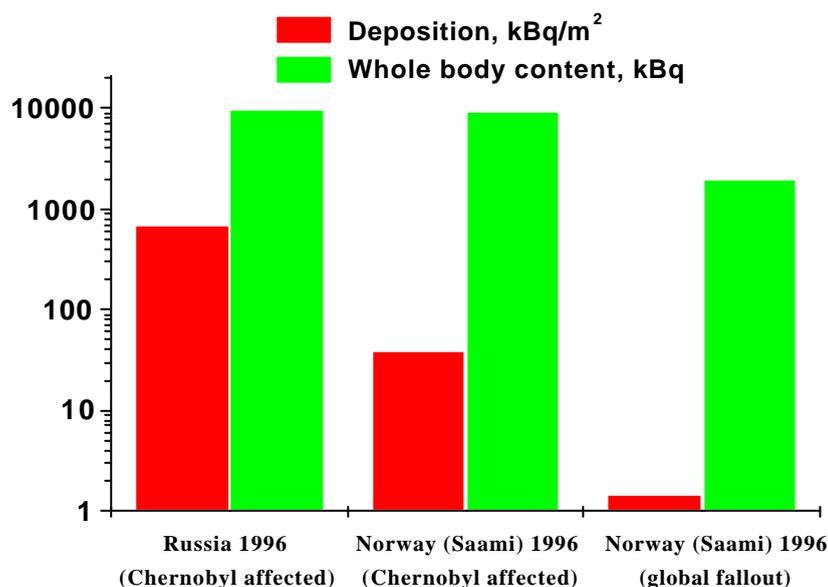


Figure 7. Whole body contents of some population groups in areas of different ¹³⁷Cs deposition in 1996 and the relationships between whole body content and deposition among these populations. The Chernobyl fallout in both the Russian (Novozybkov district) and Norwegian (Southern Saamis in Mid-Norway) areas studied was significant and resulted in extensive use of countermeasures. The effect of countermeasures is evident in the relationships between whole body content and deposition values compared to those occurring for the Norwegian Saami unaffected by Chernobyl fallout.

3.2 Analogy to the Critical Load Concept Applied to Other Environmental Contaminants

The so-called “critical load concept” has been developed for the purposes of environmental protection in respect to a range of non-radioactive contaminants. Critical load in this context is defined as:

“a quantitative estimate of an exposure to one or more pollutants below which significantly harmful effects on specified vulnerable elements of the environment do not occur according to present knowledge.” (Nilsson and Grennfelt, 1988).

Critical loads are damage thresholds for pollutant deposition and imply that if deposition is below the threshold then there is no effect and thus no problem whereas if it is above the threshold then harm will occur. The concept is represented schematically in Figure 8, although the type of effect/load relationship can obviously vary from that represented in this figure.

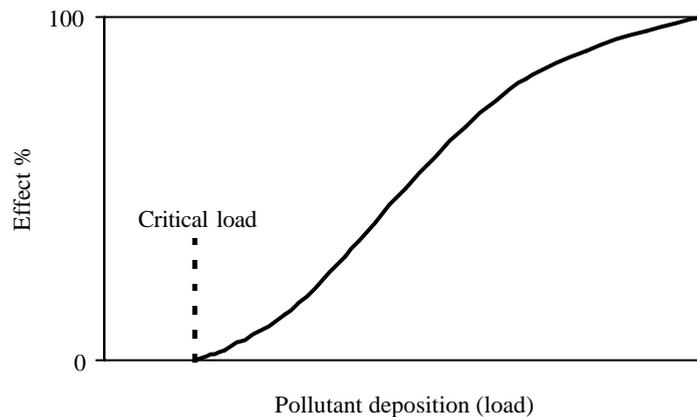


Figure 8. Theoretical dose-response curve and the critical load at which effects can be observed.

This concept, however, cannot be directly applied to the protection of the environment and humans from the effects of radionuclides because of the quite different basis used for radiological protection compared to that used for other contaminants. In radiological protection, it is assumed that any artificially enhanced exposure results in increased risk and that risk should be minimized to the degree consistent with technical, social and economic circumstances. Accordingly, it will only be possible to apply the concept in a somewhat analogous form that takes account of the differing basis for radiological protection.

From a radioecological perspective, the critical load for a food product, for example, could be defined as the level of radionuclide deposition (Bq/m^2) that leads to activity concentrations in the food that exceeds the relevant intervention level at some given time after deposition. This approach was initially developed for radiocaesium using empirically-derived aggregated transfer coefficients ($T_{\text{ags}} - \text{Bq/kq}$ per Bq/m^2) for clay, loam, sand and peat soil groups in the medium to long-term after a radiocaesium deposition event with respect to the ^{137}Cs transfer to cow's milk (Wright *et al.*, 1998). Estimation of critical loads has also been incorporated within semi-mechanistic models, allowing the dynamic quantification of radiocaesium critical loads for many food products following deposition (Howard *et al.*, 1999). If critical loads are based on soil to plant uptake, they are not relevant to the early phases of deposition when surface contamination dominates. In such circumstances, short-term thresholds could be defined in a similar manner as critical loads but dependent on the extent of interception and weathering on plant surfaces. Such thresholds would merely serve to indicate conditions under which some consideration of the consequences would be required. For this reason, the term "action loads" has been suggested as a suitable analogy to the critical load concept for the purposes of radiological protection. The initial "action" might merely be some consideration of the desirability of introducing additional protection measures and these could, in turn, be very analogous to the requirements for intervention, namely justification and optimization. Maps of such action loads for different food products can be combined with maps of deposition for potential or future nuclear accidents for the rapid identification of areas that are alternatively the most vulnerable or most resilient to radiocaesium deposition. This would then permit the more effective deployment of resources in the event of accidents.

3.3 Doses to Arctic Peoples from Natural ^{210}Po

The component of the natural background radiation dose associated with ^{210}Po was discussed in the first AMAP assessment. It has long been known (Pentreath *et al.*, 1979) that seafood consumers have a higher exposure to this natural radionuclide than the consumers of most terrestrial foods.

Recent studies have shown that the transfer of the natural radionuclide ^{210}Po is greater than earlier anticipated in the lichen-reindeer-man food chain (Tracy and Walsh, 1995; Tracy *et al.*, 1997). In Arctic areas, the ^{210}Po concentrations in soil are greater than in temperate latitudes due to the extent of snow cover in winter that reduces radon emanation from soils. Furthermore, the low average temperatures in tundra and marshy waters in summer accelerate the dissolution of radon in water.

Humans having substantial intakes of reindeer meat receive a significantly higher amount of ^{210}Po through diet. The value of the gastro-intestinal (GI) absorption factor, f_1 , for humans was raised by the ICRP from 10% to 50% in 1993 (ICRP, 1993). An experimental study by Tracy *et al.* (1999), involved 14 volunteers consuming various amounts of caribou meat with known concentrations of ^{210}Po . Urine and faeces samples were taken before, during and after the consumption period. The experimental values for f_1 varied from 0.35 to 0.80 with a mean of 0.61. This may indicate that the GI absorption factor is in fact higher than the 0.50 recommended from the ICRP. Average intakes of 73 kg/y of reindeer meat are not unusual for humans in many parts of the Arctic. With a concentration of 25 Bq/kg of ^{210}Po , the resulting radiation dose would be 2.7 mSv/y based on an $f_1 = 0.61$. This clearly exceeds the average natural background dose of 2mSv/y for this area (Tracy *et al.*, 1999).

Data on the uptake of ^{210}Po are still sparse. Considering the potentially increased natural radiation doses for people in the Arctic as a result of increased intakes of ^{210}Po in diet, this topic merits greater scientific attention in future studies within the Arctic.

4. Protection of the Environment from the Effects of Radiation

The current system of radiological protection is based on the protection of Man. This is because the international advisory body on such matters, the International Commission on Radiological Protection (ICRP), has maintained a strong bias towards human health issues. The ICRP has stated that: “*The ICRP believes that if man is adequately protected then other living things are also likely to be sufficiently protected*” (ICRP, 1977). No evidence is given to support this ICRP statement of philosophy; indeed, it has been shown in at least one situation that the ICRP belief is invalid. For example, in the case of the deep sea disposal of radioactive wastes (although no longer practised) biota can be exposed to harmful doses while the doses to man are well below the recommended dose limits (Pentreath, 1998). It could be anticipated that in the Arctic, where population densities are very low and exposure pathways to humans can be relatively long, a similar situation might also arise. For these reasons there has been increasing pressure to explicitly demonstrate environmental protection from radiation and incorporate environmental considerations into the system of radiological protection. The subject is specifically addressed in some agreements, for example the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. Furthermore, the second principle of the IAEA Safety Fundamentals for the Management of Radioactive Waste states that: “Radioactive waste shall be managed in such a way as to provide an acceptable level of protection of the environment.”

At present there is no internationally accepted methodology for including potential effects on the environment in impact assessments for nuclear practices and thus there are no means of demonstrating that the environment is, in fact, being protected from ionising radiation. This is clearly not a satisfactory situation and can lead to reduced public confidence in radiological protection measures. As a corollary, it might be noted that there are some inconsistencies among the approaches used for environmental protection from the adverse effects of other non-radioactive substances such as heavy metals and organic chemicals. In these latter instances, specific environmental protection criteria are often applied, *e.g.*, concentration standards in specified biota. There is considerable potential benefit in the development of more comparable and consistent approaches towards the protection of the environment from the effects of a broad range of both radioactive and non-radioactive substances.

As a first step to the resolution of this problem, a framework for the development of a coherent and logical environmental impact assessment methodology for ionising radiation is essential (Pentreath, 1999). A number of components that could form the basis for such a system include:

- a set of reference organisms - clearly not all organisms can be studied, necessitating a selection procedure.
- a set of quantities and units to express doses to biota. Currently, doses are expressed in Grays per unit time, which clearly does not reflect the differing biological effects arising from equal absorbed doses of differing radiation types.
- a defined set of dose models for a number of reference flora and fauna. Calculation methodologies exist allowing the calculation of doses to organisms with varying geometries, (*e.g.*, consensus is required in adapting these algorithms for use within a protection framework.)
- a set of dose-effects relationships for reference organisms that could include data from low exposure, (*e.g.*, cytogenetic effects) to high exposure (*e.g.*, lethal effects) situations.

Further discussions in conjunction with the International Union of Radioecology (IUR) have led to the adoption of these criteria into a proposed strategy comprising three key components (IUR, 2000):

(a) **Exposure Pathways and Retention of Radionuclides by Biota**

The study of exposure pathways would be based on the acquisition and synthesis of information concerning the ecological characteristics of selected ecosystems and radionuclide uptake by the biological components of these ecosystems. Assessment can then be applied to the available information and understanding of the environmental behaviour of radionuclides in the chosen ecosystems. Combined with equilibrium and dynamic modelling approaches, organisms with enhanced exposure can then be identified. Integrating these findings with a selection based on other relevant criteria, *e.g.*, radio-sensitivity, would allow reference organisms to be defined. Finally, simple reference models will be developed for the simulation of radionuclide migration and uptake to the whole-organism (and organs if applicable) for these reference species living in representative terrestrial and aquatic ecosystems.

(b) **Dose Calculations**

For reference organisms, corresponding radiation dosimetry models will be developed. These would be designed to estimate the actual or potential absorbed dose-rates to the organisms from internal and external sources of α , β and γ -radiation, given information on the distributions of natural and contaminant radionuclides in the organism's environment. The final output would be a tabulation of absorbed dose rate coefficients (Gy h^{-1} per unit radionuclide activity concentration in the relevant environmental compartment) for each reference organism for the radionuclides of concern in radioactive waste management. A review should be made of the approaches that have already been adopted for the estimation of radiation dose to non-human biota (largely, but not exclusively, for the marine environment) to determine if these are appropriate or can form a basis for development. If the approaches are acceptable, then they can be directly applied to other aquatic ecosystem. Work in terrestrial environments has been less extensive than for aquatic environments. Several problems require a solution here, including the development of models to account for density differences between the organism and the surrounding atmosphere. In this respect, Monte Carlo methods may be required to derive dose coefficients. For both terrestrial and aquatic environments, the requirement for additional target organs and tissues in some species should be considered. It is to be expected that the reproductive organs will be important targets for inclusion in the dosimetry models. The output from the dosimetry models can be given in terms of absorbed dose rate. It is recognised, however, that α -particles (high Linear Energy Transfer (LET)) are likely to be more effective in causing damage than β and γ radiation (low LET) for equal absorbed doses. The available information on the relative effects of these radiation types on the endpoints of concern in the natural environment should be reviewed to determine whether a sufficient basis exists to develop a dosimetric quantity corresponding to the "equivalent dose" (absorbed dose x radiation weighting factor) used in human radiological protection practice.

(c) Dose-effect Relationships

Endpoints of concern in individual generic organisms would be defined and dose rate/response relationships for the chosen endpoints tabulated. This would involve the integration of data from earlier reviews and assessments of the potential impacts of radiation in the environment, of the wider radiobiological literature and of newly available information from the Kyshtym and Chernobyl accidents. The relevant effects of radiation will probably include, but not necessarily be restricted to, changes in morbidity, mortality, fertility, fecundity, and mutation rate. The available information will be organised into a format that will indicate the approximate dose rate - response relationships and, therefore, the threshold dose-rates at which minor radiation effects can currently be expected to become apparent in the defined biological processes in the selected generic organisms. An attempt should be made to quantify the intrinsic (*i.e.*, the radiobiological) uncertainty in these threshold dose-rates (e.g. through the extrapolation of laboratory data to natural conditions) and to indicate possible modifying influences (e.g. the influence of other environmental variables). Because ionising radiation primarily induces damage in cellular DNA (although it is not unique in this respect), and this may be quantified as chromosome aberrations, an attempt could be made to correlate such cytogenetic damage with the degree of response in other endpoints of interest. This could then provide an indicator of radiation damage that is easier to measure and monitor. The information on dose-response relationships will also form an input to the definition of the reference organisms (through the implicit examination of radiosensitivity).

As a result of this work, it should be possible to define the appropriate level in the biological hierarchy (over the range from cell to ecosystem) at which protective action should be directed. It will also be possible to propose minimum/threshold dose rates at which effects in the environment would be expected to be minimal with an acceptable degree of confidence. Any assessment should include the sources of uncertainty in the proposed dose rates and the effects that this might have on the degree of assurance that the desired level of environmental protection could be achieved.

The need for developing a system for assessing the consequence of radiation exposure for Arctic flora and fauna should have a high priority. This work needs collaboration at an international level and, with this in mind, AMAP and IUR will work together on this topic. The European Commission has also taken initiatives on the inclusion of further scientific development on this topic during the European Commission's Fifth Framework through two research projects entitled "Framework for Assessment of Environmental Impact" (FASSET) and "Environmental Protection from Ionising Contaminants in the Arctic" (EPIC). These projects should be in a sufficiently advanced stage by the time of preparation of the Report to Ministers in 2002 to permit the inclusion of many of their findings and conclusions in this latter report.

5. Risk Management

The goal of risk management is to assess risks associated with nuclear operations and activities with the specific aim of mitigating the risk in a manner that optimises the use of prevention and preparedness resources and methods to achieve a risk acceptable operational environment. A major underlying foundation of the AMAP 2 programme design is to ensure that planned monitoring and assessment are formulated to correspond with the comparative risk. This planned monitoring and assessment must include appropriate prevention and preparedness strategies to ensure that protective actions can be implemented to mitigate the risk.

Risk management must be based on the relevance of the hazards and the consequence that can be expected from the predominant hazard, compilation of hazards, or changes to the characterisation of hazard. Thus, risk management is a continuing process whereby consequences that can be expected must consider the risk posed by normal nuclear operations and activities, coupled with the consequences associated with sources of radioactivity (*i.e.*, fallout, other facility operations) and nuclear accidents or incidents.

Risk management is nominally based on analyses of consequence assumptions derived from the hazards involved in a nuclear operation or activity. This approach ranks a given risk among the various risks estimated from existing and potential consequences. However, for this approach to be

effective, risk management must include such factors as accumulated radionuclides, time and differing ecosystems to fully explore the range of consequences that could be expected. Thus, substantial risk (among those from the various sources and practices) may well require the conduct of improved assessments especially if the uncertainties associated with the consequence are large. Equally important is that they may require protective actions to mitigate or reduce the risk. Such protective actions may be necessary to permit operation of the facility or activity.

Estimation of overall risk is a convenient way of identifying those hazards (sources and activities) deserving priority consideration from the perspective of protective actions and potential intervention. However, protective actions seldom obviate the entire risk associated with a hazard. More commonly, protective actions reduce the risk rather than avoiding it entirely. Accordingly, a more appropriate measure of the benefits of protective actions is not the overall risk but the proportion of risk that is potentially averted by protective actions.

Environmental impact assessments are also an important component of the evaluation of options for actions to reduce or mitigate risks. Environmental impact assessments are a means of determining that there is an overall net benefit for any protective action measure under consideration.

5.1 Risk Management Approach

The first AMAP assessment identified known sources of radioactivity in the Arctic. These range from atmospheric fallout from nuclear weapons tests, past and present nuclear reactor operations, nuclear vessel operation, spent nuclear fuel and the Chernobyl accident. The presence of radionuclides in the Arctic from these sources will diminish with time. Nevertheless, the greatest radiological risk to the Arctic would appear to be associated with the continuing accumulation of spent nuclear fuel or a nuclear accident.

In its most basic format, the risk management process consists of a sequence of steps. These are: identification of the hazard; assessment of the risk presented by the hazard; identification and analysis of options for risk reduction through the imposition of preventive measures to mitigate the risk; application of prevention and preparedness measures to reduce the consequence; the design and implementation of associated performance evaluation; implementation of surveillance measures to provide early warning or detection of releases of radioactive material; and emergency response programs to mitigate societal impacts if there is a nuclear incident or accident.

Identification of Risk

The sources of radionuclides in the Arctic were identified in the first Phase of AMAP. The Radioactive Experts Group has prioritised the risk presented by these sources as follows:

High Risk – High Hazard

- Spent nuclear fuel in interim storage including improperly stored fuel elements and decommissioned vessels with nuclear fuel in place;

Lower Risk – High Hazard

- Accidental releases from nuclear power plants during normal operations;
- Accidental releases from nuclear fuel reprocessing plants during normal operations;

Lower Risk – Lower Hazard

- Accidental releases from nuclear facilities during normal operations; and
- Normal operation of nuclear power vessels.

NOTE: Nuclear accidents or incidents involving the operation of nuclear reactors within the Arctic, nuclear power plants within 1000 kilometres of the Arctic, and nuclear powered vessel are viewed as outside the norm and, therefore, are identified as High Hazards.

Other Sources

The following historical sources continue to pose a threat to man, plants and animals in the Arctic but these hazards are diminishing.

- Global fallout from atmospheric nuclear testing;
- Fallout from the Chernobyl accident; and
- Previous underground nuclear detonations.

Analysis of Risk

The next step of the risk management process is to analyse the risks and consequences associated with nuclear operations and activities. The elements of a risk analysis are:

- Define the facility and operation;
- Identify the hazards and determine the risk level (screening);
- Characterise the hazard that presents the greatest risk;
- Postulate and analyse possible event scenarios; and
- Estimate the consequences of the postulated scenarios.

A risk analysis leads to a plan for the development of risk management programmes that are commensurate with each specific activity. The results of the risk analysis process are used to consider and analyse options for prevention, preparedness and response strategies to minimise the consequences of releases of radionuclides.

5.2 Risk Management Results

Risk management results provide the basis for protective actions to ensure protection of man, plants, animals and the environment. It is imperative that protective actions and prevention, preparedness and response planning be based on the hazards and the consequences that can be expected and the results of any such actions taken are assessed in terms of risk reduction and mitigation even when the action could initially lead to an increase in risk that diminishes with implementation of the protective actions (see Figure 9).

Risk management is vital to bridging the gap between risk assessment and protective actions to mitigate consequences. Implementation of a sound risk management programme includes identification of all hazards and analysis of the consequences that can result from these hazards. The second phase consists of designing and implementing protective actions and prevention, preparedness and response strategies to minimize the identified risks.

To ensure success, risk management should be undertaken as a source control pilot project within the Arctic to cover the most immediate threats. The risk management pilot should focus on both a chemical source as well as a nuclear source. This would enable the development of a methodology for radionuclides in a manner that is consistent with current international standards for chemical hazards. While this may not achieve adoption of an international standard for radionuclide sources, it could provide a precursor for establishing such standard if adopted by the Arctic Council for use in the Arctic.

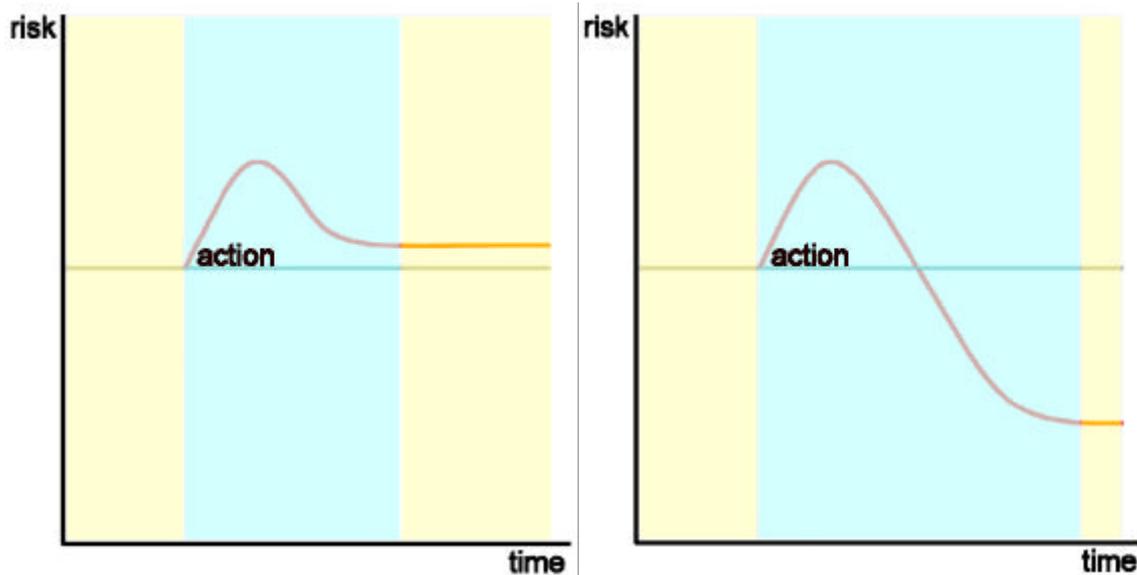


Figure 9. An action can lead to both increased and reduced risk if that action isn't based on risk and impact assessments.

6. AMAP Data Centre for Radioactivity

In 1993 the Ministers of environmental departments in the eight Arctic countries: Canada, Denmark, Finland, Iceland, Norway, Sweden, United States and Russia, asked for a database on radioactive contamination and actual or potential sources for radioactive contamination in the Arctic areas. This database was set up in autumn 1994 and is known as the AMAP Thematic Data Centre (TDC) for Radioactivity at the Norwegian Radiation Protection Authority (NRPA).

The aim of the AMAP radioactivity TDC is to provide a platform for the storage and retrieval of spatial data on environmental radioactive contamination of the Arctic.

6.1 New Data

New data has been received including data from the U.S. ANWAP programme, which was officially released at the 4th International Conference on Environmental Radioactivity in the Arctic in September 1999.

Close links have been established with the EU Commission and several data sets have been promised and/or given to the data centre both from projects under DG 11 and DG 12. Some of these data are already incorporated in the data centre but most of the data will be incorporated in the near future. New national data is also transferred to the data centre especially from Russia and Norway.

6.2 Spatial Modelling

AMAP data is currently being used for the spatial modelling of environmental radioactive contamination in both terrestrial and marine environments. For the terrestrial part a prototype structure is now ready, however much work is needed for parameterisation and validation of the model. The internal dose model is a deterministic model that must be supplied with parameters such as rates of radiocaesium transfer between the different entities represented by the arrows in the flowchart as shown in Figure 10 below. Data from the AMAP TDC is used for the *parameterisation* of the internal dose model. The work is done jointly with several other efforts.

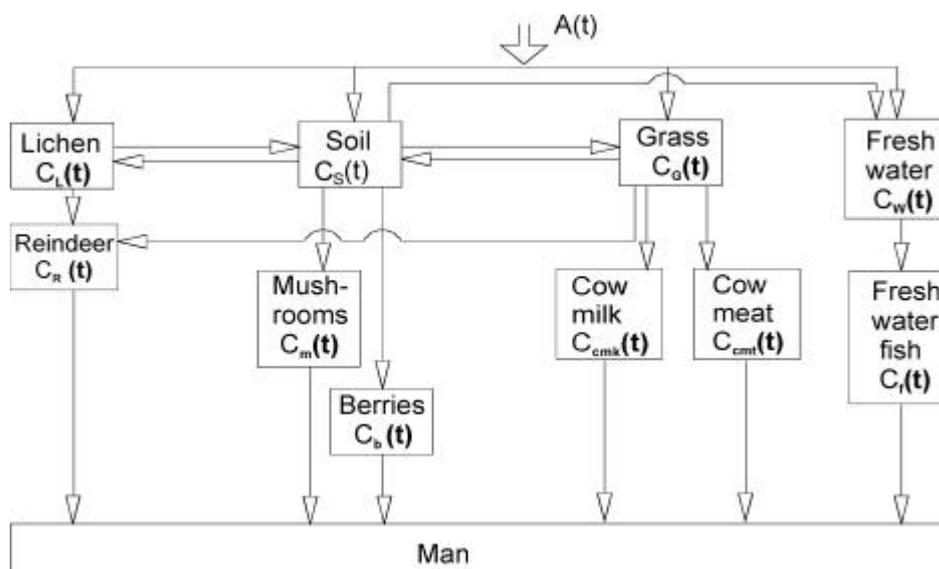


Figure 10. Flowchart of the internal dose model

6.3 Marine Box Modeling

The work in connection with spatial marine modeling in the AMAP data centre has benefited from several initiatives. It is the marine modeling, which at the present is being further developed at the data centre. The integration of both the model and data in a geographic information system is one of the tasks for the AMAP data centre. The marine modeling is based on a box model approach. Box-models can be easily used for large distances (> 1000 km) and long time-scales (up to centuries or even millennia) covering whole processes such as transport, transfer and uptake of radionuclides, which are important for a radiological assessment. Therefore, the AMAP programme has adopted the box-modelling concept.

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Mercury in the Arctic: An Update

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1. Introduction

The Heavy Metal chapter of the AMAP Assessment Report (AAR) (AMAP 1998, Chapter 7) presented data available up to 1996 on heavy metals in Arctic air/precipitation, seawater and sediments, and in terrestrial, freshwater and marine biota. Since then, new data and information have emerged that address some of the knowledge gaps identified in the first AMAP assessment concerning spatial and temporal trends, as well as biological effects. Particularly significant are new findings concerning mercury (Hg), a brief overview of which is presented in this update, with some information on other metals included for explanatory or comparative purposes. As such, this report constitutes an intermediate update on mercury in the Arctic, prior to the next full assessment of mercury and other heavy metals in the Arctic by AMAP, which is due to be completed in 2002.

2. Sources Inventories and Emissions

A major revision of the 1983 data on emissions of heavy metals presented in the 1997 AMAP assessment has been completed by Pacyna and Pacyna (2000a). Estimates of worldwide atmospheric emissions of heavy metals, including mercury, from major anthropogenic sources in 1995 are presented in Table 1. These results demonstrate that the major source of mercury (66%) is stationary fossil fuel combustion, namely coal combustion.

Table 1. Worldwide emissions of some heavy metals to the atmosphere from major anthropogenic source categories in the mid-1990's (in tonnes/year).

Source Category	As	Cd	Cr	Hg	Ni	Pb
Stationary fossil fuel combustion	809	691	10 145	1 475	86 110	11 690
Vehicular traffic						88 739
Non-ferrous metal production	3 457	2 171	-	164	8 878	14 815
Iron and steel production	353	64	2 825	29	36	2 926
Cement production	268	17	1 335	133	134	268
Waste disposal	124	40	425	109	129	821
Other				325 ^{*2}		
TOTAL	5 011	2 983	14 730	2 235	95 287	119 259
1983 emission ^{*1}	18 820	7 570	30 480	3 560	55 650	332 350

^{*1} Nriagu and Pacyna (1988)

^{*2} Emission of Hg from gold production

Between the early-1980's and mid-1990's, European and North American anthropogenic emissions to the atmosphere were halved for several heavy metals, namely those metals that have emissions due mainly to coal combustion. In the case of mercury, 1995 global anthropogenic emissions are ca. 60% of those in 1983.

These reductions are due to major improvements in the efficiency of technological measures introduced at power plants, etc., to control emissions of fine particles. These control measures are also effective at reducing emissions of heavy metals. The reductions have been achieved in spite of the fact that consumption of coal in Europe and North America has not changed substantially over this period. Heavy metals emissions in Europe have also decreased as a result of changes from coal to oil and natural gas combustion in the electricity-generating industry, as well as increased contributions from nuclear energy and hydro-power in some countries. Emissions of metals such as vanadium (V) and nickel (Ni) that are associated with oil rather than coal combustion have correspondingly increased.

The demand for coal-based energy in the Asian countries has, however, increased significantly between the beginning of the 1980's and mid-1990's. Consequently, the pattern of decreasing heavy metal emissions in Europe and North America has been offset by increased emissions associated with the growing demand for electricity in Asia. Emissions of Cd, Cr, Cu, Mn, Mo, Pb, and Sn from stationary fossil fuel combustion have, therefore, not changed significantly on a global basis between the beginning of the 1980's and the mid-1990's.

Estimates of global anthropogenic heavy metals emissions from various continents are presented in Table 2. For all metals considered, emissions from sources in Asia are clearly the largest, in part due to the increase in industrial output from this part of the world. Increased mining activities in Russia and China, and other parts of the World, may also lead to additional emissions of mercury.

Table 2. Worldwide atmospheric emissions of some heavy metals from major anthropogenic sources in the mid-1990's, according to region (in tonnes/year).

Continent	As	Cd	Cr	Hg	Ni	Pb
Europe	607	362	3 353	313	20 417	28 091
Africa	324	172	847	389	10 690	11 349
Asia	2 416	1 463	6 234	1 121	41 228	51 212
North America	658	482	3 284	215	11 236	17 015
South America	925	452	623	84	11 092	9 118
Australia & Oceania	81	52	389	113	624	2 474
TOTAL	5 011	2 983	14 730	2 235	95 287	119 259

Mercury is released as a result of combustion of fossil fuels in power plants and heat producing units, particularly those burning coal. A major part of the emission occurs in the form of gaseous Hg, which passes control equipment and enters the atmosphere. Almost 1500 tonnes of Hg were emitted from fossil fuel combustion in stationary sources in 1995 (the accuracy of emission estimates from stationary fossil fuel combustion are ca. $\pm 25\%$). The ten largest Hg emitting countries are presented in Table 3.

Table 3. The ten largest emitter countries of Hg from stationary fossil fuel combustion in 1995 (emissions in tonnes).

No.	Country	Emission
1	China	495
2	India	117
3	Australia	97
4	Zaire	90
5	United States	77
6	South Africa	76
7	Russia	54
8	Japan	45
9	Korea (Rep. Dem.)	44
10	Kazakhstan	36

China alone accounts for one third of total global emissions of Hg from stationary combustion sources, mainly from coal burning, followed by India. Together, Asian countries are responsible for almost 50% of the total Hg emissions, and 60% of emissions from stationary combustion sources.

As a part of recent emission inventory activities, the global inventory of atmospheric emissions of mercury from anthropogenic sources for the reference year 1990, which was reported in AMAP's 1997 assessment, has been updated for the reference year 1995. This inventory contains emissions data for more than 150 countries, and includes major source categories and point sources in each country. In addition to emissions of total mercury, global emissions of three different chemical species of mercury have been estimated for the first time. The species gaseous elemental mercury (Hg^0), gaseous bivalent mercury (Hg^{2+}), and particulate mercury contribute ca. 53%, 37%, and 10% of the total atmospheric Hg emissions, respectively (Pacyna and Pacyna 2000b).

Generation of a gridded spatial distribution of these data is a prerequisite to their use as input for long-range transport models, however, this activity is subject to provision of necessary funding. Preparation of both the new inventory and the spatially distributed data sets were identified as key activities to forward modeling work at the 1999 AMAP Workshop on *Techniques and Associated Uncertainties in Quantifying the Origin and Long-Range Transport of Contaminants to the Arctic*. Construction and improvement of global emission inventories for other priority metals under AMAP, in particular lead (Pb) and cadmium (Cd), were also recommendations of the workshop. As for mercury, the global inventory of lead from atmospheric emissions for 1989 has been updated for the reference year 1995 (Pacyna and Pacyna 2000a); at present, however, no global emissions inventory for cadmium is under development or planned.

In general, estimates of heavy metal emissions from natural sources are lacking. These estimates are important for long-range transport modelling of mercury in particular. New studies on estimates of heavy metal emissions from natural sources are currently being carried out in Canada by the Geological Survey of Canada (Robert Garrett, pers. comm.) and in the U.S. by the University of Nevada in Reno in collaboration with Oak Ridge National Laboratory (Gustin and Lindberg; Lindberg, pers. comm.); the results of these studies are expected in the near future.

3. Long-range Transport and Atmospheric Deposition of Mercury

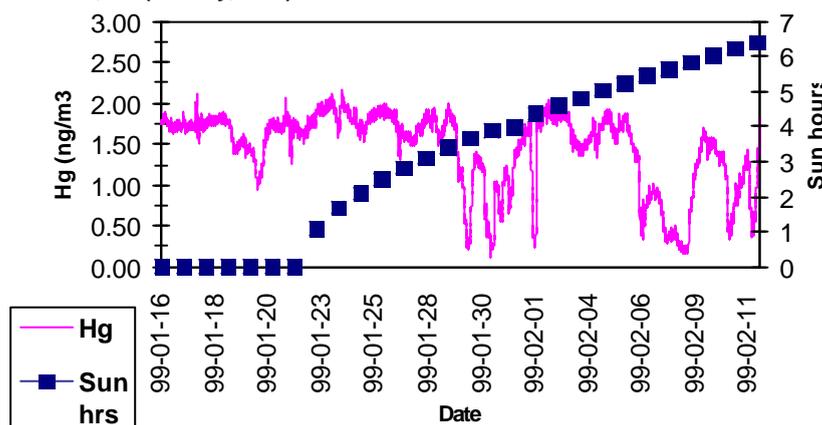
Cheng and Schroeder (2000) evaluated the long-range transport of gas-phase (elemental mercury) to determine potential atmospheric pathways of the mercury being measured in the Canadian High Arctic. Mercury vapour has a residence time of 0.5-2 years in the atmosphere and is thus susceptible to long-range transport to the Arctic from distant sources. In autumn/winter, anthropogenic contributions from sources in populated areas of Europe and North America were identified. Total gaseous mercury has been continuously measured at the Alert monitoring station on Ellesmere Island in the Canadian High Arctic since 1995 (Schroeder et al. 1998). Similar measurements have also been made at Point Barrow, Alaska since 1998 (Lindberg et al. 2000a). The Alert measurements were the first to reveal a distinct seasonal pattern in gaseous elemental mercury (GEM) with a perennial springtime mercury depletion phenomenon, and summer increases in GEM concentrations followed by a decrease to steady background levels in autumn (Schroeder et al. 1998).

The discovery of such mercury depletion events (MDE), characterized by extremely low levels of elemental mercury vapor (Hg^0) and elevated levels of other mercury species including total particulate mercury (TPM) and reactive gaseous mercury (RGM), first at Alert, and later at Barrow suggests a possible mechanism for Hg accumulation in the Arctic from the global background pool of elemental Hg. The data from Barrow support the hypothesis that this mechanism involves transformation of Hg^0 to reactive gaseous mercury (RGM) species, while the Alert data suggests an equally important role of particulate Hg formation. Although the majority of atmospheric mercury is present in elemental form, reactive forms of mercury have greater local impact on the environment and are of significant concern. To further investigate possible mechanisms behind MDEs, polar sunrise experiments (PSE) were conducted at Alert in 1998 and 2000, and at Barrow in 1999 and 2000 focussing on the photochemical reactions taking place in air (both in the gas phase and on aerosols), and in snow, snowpack and ice (Schroeder, pers. comm). Preliminary results from both sites have indicated significant increases in total mercury concentrations in snow deposited during MDEs. Hg speciation is now being investigated at Ny-

Ålesund on Svalbard, where depletion of gaseous Hg following polar sunrise has also been observed; at Barrow, Alaska where the MDE phenomenon was recently confirmed and where the phenomenon of direct, in-air RGM formation was discovered (see below); and at Station Nord, Greenland where a Tekran analyzer came on-line in August 1999. Plans are in place to introduce mercury monitoring using a Tekran analyzer at Amderma, Russia.

While the MDE and associated mercury deposition that occur during and after the Arctic sunrise are becoming increasingly well documented, the cause-effect relationships responsible for the Hg depletion remain uncertain. A mechanism involving reactions between bromine compounds and some of the key mercury species has been hypothesized. Bromine budgets are most likely associated with sublimation of seaice during the Arctic sunrise. A more complete understanding is needed, involving study of several Arctic sunrise episodes, where inventories of the participating chemical compounds are compiled and subsequently integrated into a modeling framework, before implications of these events for mercury pollution in the Arctic can be fully assessed. One example of such research involves the routine measurement of gaseous Hg at Barrow, Alaska, using a Tekran analyzer (the same as the equipment operated at Alert and Ny-Ålesund), which was initiated in September 1998. The aim of the study was to investigate the hypothesis that Hg^0 is transformed into a reactive gaseous mercury (RGM) species during mercury depletion events, which then deposits locally. The initial year's data provided confirmation that the MDE observed in the Canadian High Arctic also occur at this more southerly Arctic site (Lindberg et al. 2000a). The events began within a few days of polar sunrise (Figure 1), and persisted until snow melt.

Fig. 1. First Confirmation of Mercury Depletion Events in the U. S. Arctic, Barrow, AK (January, 1999).



During this period, Hg exhibited a strong correlation with ozone, suggesting a possible link to the chemical reactions that destroy tropospheric ozone. A simple model, which closely simulated the patterns of depletion events, was developed using local meteorological data; results from this model suggest that turbulence and temperature are also important factors. A number of potential reaction pathways with Hg and Br have been postulated to explain the depletion events, and indicate that during these events Hg^0 is oxidized to RGM. The model predicts a Hg deposition rate that is much higher than that measured in the eastern U.S. The data also suggest that some of the oxidized Hg in the snowpack may be reduced and evaded as Hg^0 following snow melt (Lindberg et al. 2000a). RGM measurements using a newly available Tekran (automated annular denuder) method prior to and following polar sunrise during winter/spring 2000 have been used to test this hypothesis, and the results were announced during several presentations this summer in the U.S. and Europe (Lindberg et al. 2000b, 2000a). The new Barrow data strongly support the hypothesis that GEM transported to the Arctic in the global Hg pool is being transformed from this less reactive form to the highly reactive species termed RGM, and is accumulating in the Arctic snowpack at rates far higher than are currently measured along the highly industrialized east coast of the U.S.

In July, 2000 the first International Conference on Trans-Pacific Transport of Atmospheric Contaminants was held in the U.S. This conference represents a first step in initiating international dialogue on the

potential long-range transport of contaminants from sources located in the Pacific Rim countries (including Japan, China, Korea, Russia, Canada, and the U.S.), including their pathways and effects. Concerns about possible long-range transport to, and contamination of the Arctic are reflected in the Conference consensus statement.

4. Modeling and Monitoring

Modeling activities concerned with long-range transport of heavy metals are being carried out under the UN ECE European Monitoring and Evaluation Programme (EMEP), led by its Meteorological Synthesising Centre, MSC-East, in Moscow. This work is directly related to the LRTAP Protocol on Heavy Metals that was adopted in 1998. The new LRTAP Protocols (on Heavy Metals and POPs) have led to a need for new and improved models within EMEP, in particular in relation to mercury, that cover the global/hemispheric scale transport rather than just transport on a Pan-European scale. Mercury modeling linked to AMAP activities is also being developed through groups working at the Danish National Environmental Research Institute and the Meteorological Service of Canada. There exists, therefore, considerable potential for increased cooperation between AMAP and EMEP in the field of emissions inventory development and long-range transport modeling work.

EMEP has also undertaken inter-comparisons of various models, mainly those in use in Europe. However, so far, these intercomparisons have concerned mainly metals such as Pb and Cd. In general, activities aimed at modeling Hg are less developed, although major improvements in regional (European) modeling of Hg have been made through two projects (MAMCS and MOE) carried out within the EU European Land-Ocean Interaction Studies (ELOISE). Both projects, due to be completed in the year 2000 use models that focus on the improvement of air-sea exchange process parameterization.

Data on metals in air/aerosols and precipitation are being collected by several countries. These data continue to extend time series reported under the first phase of AMAP, and are routinely reported to and compiled at the AMAP atmospheric thematic data centre (TDC) at the Norwegian Institute for Air Research (NILU). During the period since 1996, additional metals data have been reported to the TDC for the following monitoring stations: Alert (Canada), Station Nord (Greenland), Irafoss and Storhofdi (Iceland), Pesosjarvi, Vuoskojarvi and Pallas (Finland), Jergul, Øverbygd, Karpdalen and Svanvik (Norway) and Ny-Ålesund (Svalbard). The stations at Alert, Station Nord and Ny-Ålesund, together with Barrow (Alaska, operating from 1999) and Amderma (Russian European Arctic, operating from 2000) form the basis of a circumpolar background mercury monitoring network. Tekran mercury monitoring equipment is installed at each of these stations, and plans are underway to add further stations, one of which it is hoped to locate in the Russian Far East.

5. Environmental Concentrations

Mercury and other contaminants that reach the Arctic as a result of long-range transport tend to accumulate there. Significant efforts are ongoing to measure current concentrations of mercury and other heavy metals in different media, and to identify trends associated with their accumulation. Results from studies in Greenland have recently been published in a special issue of *Science of the Total Environment* (Hamilton and Nriagu 2000).

Concentrations and trends in sediment and soil

Sediments provide a good record of environmental contamination over time. Therefore, most Arctic countries have instituted programmes to assess sediment contamination. In the U.S., sediment cores are being analyzed from the Beaufort and Chukchi Seas, the Bering Sea coast, and Cook Inlet to determine long-term trends in heavy metal deposition. A two year study of the historical changes in concentrations of heavy metals and hydrocarbons in inner shelf sediments of the Beaufort Sea was completed in 1999. The study included determination of gross sediment concentrations of total Hg and methyl Hg from the near-shore Beaufort Sea, and comparison of these over a 30 year period, prior to and following petroleum-related industrial development. A down-core increase in MeHg was believed to be related to increased methylation of Hg, and to higher scavenging of MeHg by volatile acid sulfides in progressively more anoxic subsurface layers (Naidu, pers. comm.).

The dynamics of mercury trends in Greenland marine sediments have been investigated by Asmund and Nielsen (2000). Following correction for diagenetic activity, they found that the mercury flux to these sediments has doubled during the last century, possibly due to anthropogenic inputs. The mercury flux to the sediments was generally proportional to the Pb-210 flux indicating that the mercury is derived mainly from atmospheric deposition. Anthropogenic mercury inputs to marine sediments appear comparable to natural inputs. This suggests that continued global energy demand and possible associated increases in mercury emissions will result in increased transport of mercury to the Arctic. Selenium seems to be present in the Arctic at concentrations high enough to detoxify methyl-mercury in a large number of marine species (including polar bear and ringed seal) and the highest concentrations of mercury reach a molar ratio with selenium of 1:1. It is uncertain whether an anthropogenic increase in mercury contamination might affect this balance (Dietz et al. 2000).

Danish investigations of mercury in samples from peat bogs in Southern Greenland (Goodsite 2000) have shown a ten fold increase in Hg concentrations during the last century. Peat bog profiles are believed to provide a faithful archive of atmospheric deposition, since peat deposits receive metals and organic contaminants only from atmospheric sources. The profile from Southern Greenland provides the first complete, long-term record (over 3000 years) of atmospheric Hg deposition for the Arctic (Shotyk et al. submitted). Additional investigations on peat bog deposits are underway for samples from Southern Greenland, the Faroe Islands, Spitsbergen, and Bathurst Island (Canada). Resulting data are expected to provide a 9000 year record of atmospheric depositions of Hg, as well as Cd and POPs.

In Iceland, 60 sediment samples were collected between 1990 and 1996. Some samples collected close to Reykjavik appear to be contaminated with heavy metals. Lead concentrations are up to three times higher and mercury five times higher than the respective natural background levels of these metals (Egilson et al. 1999).

Concentrations and trends in biota

In the Faroe Islands, a study of the accumulation of mercury and POPs has been conducted in long-finned pilot whales. The study comprising 417 long-finned pilot whales taken in the drives of 1997, showed that the pod mercury concentration (average for pod age composition) varied from 0.9 to 2.6 mg/kg in muscle (Dam and Block, in press). These concentrations are comparable with those reported for Faroese pilot whales sampled in the late-1970s.

The Icelandic Fisheries Laboratory has participated since 1989 in the international marine monitoring programme conducted under the auspices of OSPARCOM. The longest time series are for Cd, Cu, Zn, Hg, and Pb. Mercury is measured in the flesh of the fish (cod and dab that are collected every year, in late winter, from 4 areas around Iceland), while other metals are assayed in the liver. No significant trends have been observed for Hg. Levels of mercury and lead in tissue of mussels (*Mytilus edulis*) are below ICES/OSPAR levels of concern; levels of copper, zinc and arsenic were, however, close to levels of concern. Elevated levels of some other heavy metals (cadmium, chromium, nickel) are probably due to natural sources associated with volcanic activity. Riget and Dietz (2000) examined data on mercury and cadmium in marine biota from Greenland with respect to temporal trends, mainly comparing results from samples collected in the mid-1980's and mid-1990's. Overall, they found no consistent temporal trends in mercury or cadmium concentrations over the period assessed (up to 20 years). Natural fluctuations caused by factors such as shifts in feeding behaviour, rather than anthropogenic exposure, were considered the most likely explanation for variability in observed levels. However, as most of the comparisons were based on data from only 2 years, the initiation of studies capable of providing longer time series was recommended. This recommendation is supported by an evaluation of the AMAP 1994-95 programme for Greenland conducted by Riget et al. (2000b) using power analysis. Time trend studies are, therefore, now included as part of the Danish/Greenlandic Phase II of AMAP.

Icelandic monitoring data also include measurements of mercury concentrations in the feathers, down, and livers from seabirds collected from Látrabjarg (Westfjords, Iceland) in 1995 and analyzed in 1997 (Lilliendahl et al. 1997). Relatively high concentrations were found in feathers. In comparison with birds from Scotland and Norway, the concentrations were highest in 4 bird species from Látrabjarg. The source of this mercury is not clear. Mercury concentrations in livers were low, however young birds

exhibited relatively high mercury concentrations that seemed to lessen with age. Both studies suggest that either the mercury contamination is not local to Iceland or that Látrabjarg is unique for some reason (Lilliendahl et al. 1997).

In the U.S., a two year study has begun to investigate the concentration of total mercury and methyl mercury in salmon and King crab in the eastern Bering Sea. The purpose of this study is to assess concentrations of Hg in subsistence and commercial food species, as well as to gain a better understanding of the sources of Hg in the region in relation to Bering Sea sediments and the movement of Hg through the marine food chain. Early observations from limited sampling of salmon indicate low methyl-mercury levels in some tissues. Mercury concentrations in black guillemot from the western Beaufort Sea are also being measured (Horrell and Duffy 1999). A new study initiated in 2000 will assess contaminants in whitefish of the western Alaskan North Slope. The long term assessment of contaminants in bowhead whales on the North Slope is ongoing (Bratton et al. 1997; Krone et al. 1999; Woshner 2000).

In Canada, the historical increase in atmospheric inputs of mercury is a matter of concern in the Northwest Territories / Nunavut where a number of lakes already contain predatory fish exhibiting tissue concentrations of mercury at or near guideline limits for human consumption (i.e., 0.2 µg/g wet weight for subsistence users consuming large quantities of fish, or 0.5 µg/g wet weight at which commercial sale of fish is regulated). Increased mercury inputs may result in a greater number of lakes containing fish with elevated mercury in their tissues. Slightly higher levels of mercury in fish from lakes located on faults compared to nearby lakes not on faults indicates a geological influence, however, this appears to be minor in relation to other factors controlling mercury in fish (Lockhart and Evans 1999). More research is required on the factors affecting elevated mercury levels in northern lakes, including process rates within lakes, sources and loadings, and improved geographic coverage documenting the extent of the problem. The impacts of elevated mercury levels on the fish, and the possible human health effects of dietary fish intake, are not known. Other metals are also of concern.

The accumulation and transfer of heavy metals within food webs is under investigation in the U.S. Duffy (pers. comm.) reports that biogenic transport by returning salmon is responsible for delivery of ca. 1 kg of Hg per year to the western Alaskan freshwater environment. River otters inhabiting coastal environments are also believed to transport nutrients and minerals between marine and terrestrial parts of their ranges. In one study, levels of Hg in river otter hair are being compared to levels found in preferred prey fish. In another study, heat shock proteins are being used as biomarkers for Hg exposure in subsistence fish including northern pike, burbot, whitefish, grayling, and sheefish. Mercury levels in muscle tissue of these fish averaged 0.382 µg/g. The primary mercury species found in Alaska freshwater subsistence fish muscle was methyl-mercury (Duffy et al. 1999, 2000). Zhang et al. (2000) showed methyl-mercury to be about 75% of salmon muscle Hg in western Alaska. Riget et al. (2000a) also found methyl-mercury to be the main species of mercury (72-92% of total mercury) in muscle of Arctic char sampled in Greenland.

Mercury concentrations in reindeer/caribou sampled in Greenland were found to be higher than those found at lower latitudes (Aastrup et al. 2000). In considering seasonal effects, late winter concentrations of metals were generally significantly higher than early winter levels, especially in lichen-rich localities, and thus availability of lichens as winter forage may be a key factor in determining levels of metals in reindeer/caribou.

AMAP is working with the Association of Indigenous Peoples of the North, Siberia, and the Far East of the Russian Federation (RAIPON) to implement a GEF funded project entitled 'Persistent Toxic Substances (PTS), Food Security and Indigenous Peoples of the Russian North' that will investigate levels of mercury and other contaminants in traditional foods in selected areas of Arctic Russia.

6. Effects

One of the greatest challenges in AMAP Phase II is to address the effects of heavy metals on Arctic biota, both at the individual and ecosystem level. Several studies are underway to address this challenge, however, results of these studies are generally not yet available. Mercury, together with arsenic, cadmium, lead and selenium have been identified as elements of toxicological concern in a study including

four species of Arctic marine mammals (bowhead whales, beluga whales, ringed seals, and polar bears) sampled on the basis of their importance to Native subsistence users and value as indicators of Arctic contamination (Woshner 2000). In particular, there exists a need to identify techniques for studying higher order effects (neurotoxicology, immunosuppression) of methyl-mercury. Combined effects of mercury and other contaminants are also being investigated. For example, a thorough pathological investigation of East Greenland polar bears is being conducted, primarily to evaluate effects of POPs. However, the high levels of mercury observed in livers and kidneys will also be considered during this work.

Studies concerning effects of mercury and other contaminants in relation to human health are considered under the AMAP human health assessment.

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