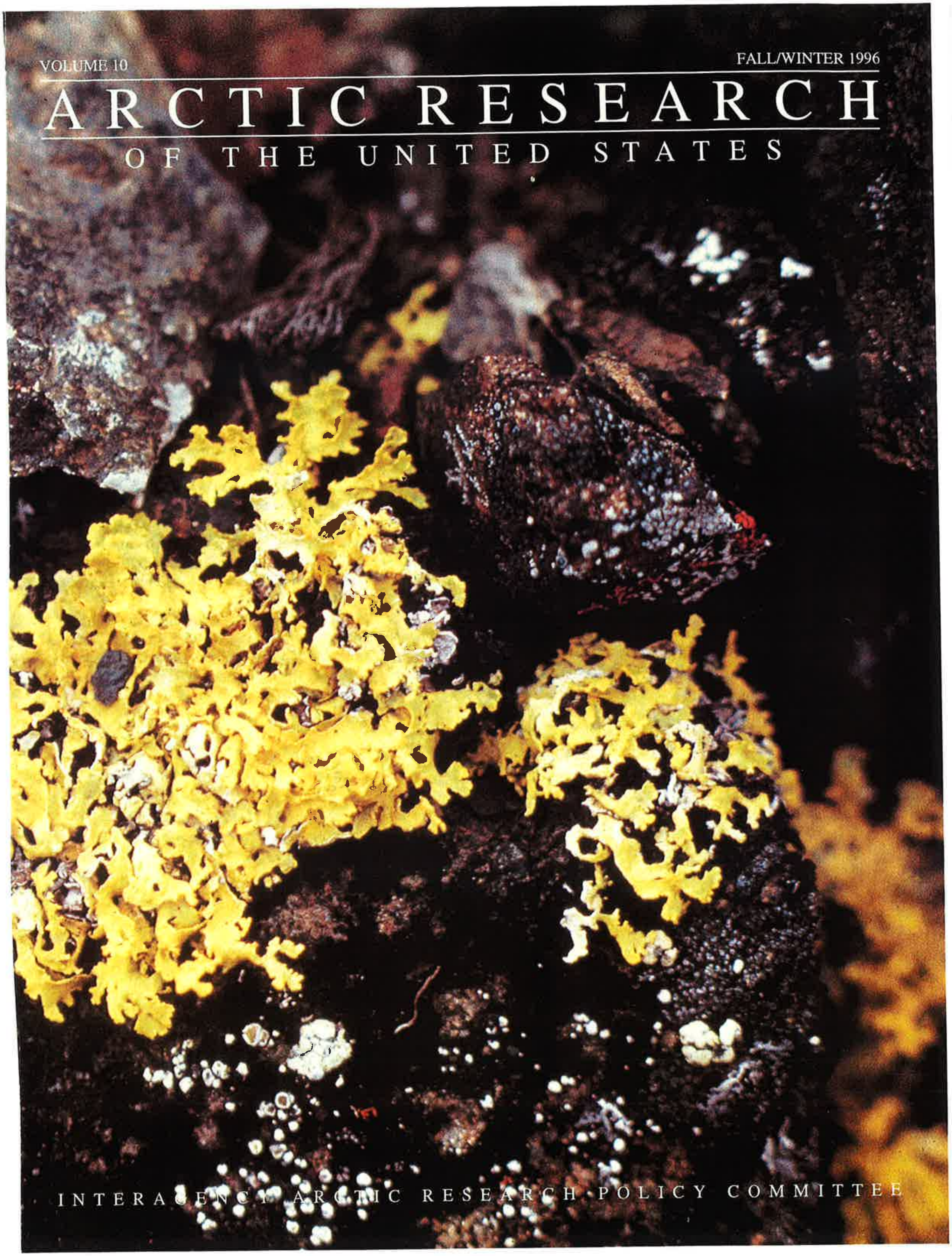
VOLUME 10 FALL/WINTER 1996

ARCTIC RESEARCH OF THE UNITED STATES



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About the Journal

The journal *Arctic Research of the United States* is for people and organizations interested in learning about U.S. Government-financed Arctic research activities. It is published semi-annually (spring and fall) by the National Science Foundation on behalf of the Interagency Arctic Research Policy Committee and the Arctic Research Commission. Both the Interagency Committee and the Commission were authorized under the Arctic Research and Policy Act of 1984 (PL 98-373) and established by Executive Order 12501 (January 28, 1985). Publication of the journal has been approved by the Office of Management and Budget.

Arctic Research contains

- Reports on current and planned U.S. Government-sponsored research in the Arctic;
- Reports of ARC and IARPC meetings;
- Summaries of other current and planned Arctic research, including that of the State of Alaska, local governments, the private sector and other nations; and
- A calendar of forthcoming local, national and international meetings.

Arctic Research is aimed at national and international audiences of government officials, scientists, engineers, educators, private and public groups, and residents of the Arctic. The emphasis is on summary and survey articles covering U.S. Government-sponsored or -funded research rather than on technical reports, and the articles are intended to be comprehensible to a nontechnical audience. Although the articles go through the normal editorial process, manuscripts are not refereed for scientific content or merit since the journal is not intended as a means of reporting scientific research. Articles are generally invited and are reviewed by agency staffs and others as appropriate.

As indicated in the U.S. Arctic Research Plan, research is defined differently by different agencies. It may include basic and applied research, monitoring efforts, and other information-gathering activities. The definition of Arctic according to the ARPA is "all United States and foreign territory north of the Arctic Circle and all United States territory north and west of the boundary formed by the Porcupine, Yukon, and Kuskokwim Rivers; all contiguous seas, including the Arctic Ocean and the Beaufort, Bering, and Chukchi Seas; and the Aleutian chain." Areas outside of the boundary are discussed in the journal when considered relevant to the broader scope of Arctic research.

Issues of the journal will report on Arctic topics and activities. Included will be reports of conferences and workshops, university-based research and activities of state and local governments and public, private and resident organizations. Unsolicited nontechnical reports on research and related activities are welcome.

Address correspondence to Editor, *Arctic Research*, Arctic Research and Policy Staff, Office of Polar Programs, National Science Foundation, 4201 Wilson Boulevard, Arlington VA 22203.

Cover

Lichens on cliff overlooking the Noatak River, Alaska. Hardy lichens are frequently useful as bioindicators in monitoring and assessing environmental change. Lichens have proven especially useful in measuring toxic elemental pollutants and radioactive metals since they bind these substances and concentrate them over time. (Photo by John Haugh.)

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U.S. Arctic Policy and the Arctic Council

In 1994 the United States announced a policy to deal with emerging issues in the Arctic region, following a detailed review of its Arctic interests. The principal objectives of this new policy are:

- Protecting the Arctic environment and conserving its living resources;
- Promoting environmentally sustainable natural resource management and economic development in the region;
- Strengthening institutions for cooperation among the eight Arctic nations; and
- Involving the indigenous people of the Arctic in decisions that affect them.

The Arctic Council, as outlined in the Declaration signed September 19, 1996, is entirely consistent with these objectives and offers an important vehicle for pursuing them.

The Arctic Council brings together the environmental conservation elements of the Arctic Environmental Protection Strategy (AEPS) and combines them with broader issues related to sustainable development. The challenge for policy makers and practitioners will be to integrate the twin concerns of "environmental protection" and "sustainable development" into a coherent program to achieve, at the same time, environmental protection, economic and social development, and cultural well-being throughout the Arctic for all the people of the Arctic.

The article that follows traces the evolution of the AEPS up to the establishment of the Arctic Council. Although it is a nongovernmental account, it challenges us, at the national level, to pursue an aggressive Federal effort in the Arctic and notes some of the pitfalls that await us. For example, the development debate needs to be cast in such a way so as not to place an even greater strain on the biodiversity of the region.

Finally, a mechanism is needed to ensure the practical involvement of the indigenous community of the North. Their knowledge of the environment plays an important part in understanding the North. Our ability to find the means for their practical involvement will reflect our commitment to the full consultation and involvement of the region's indigenous communities, as articulated in the Arctic Council Declaration and our own Arctic policy statement.

The Arctic Environmental Protection Strategy and the New Arctic Council

This article was prepared by Bruce A. Russell, Director, JS&A Environmental Services, Inc., Chevy Chase, MD 20815.

Introduction

The Arctic Environmental Protection Strategy (AEPS), founded at the first ministerial conference in Rovaneimi, Finland, in June 1991, is a nonbinding environmental protection agreement among the eight Arctic nations (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and the United States). Some, but not all, elements of the indigenous peoples of the Arctic are represented through the Indigenous Peoples Secretariat representing three AEPS Permanent Participants: the SAAMI Council (Nordic countries and western Russia), the Inuit Circumpolar Conference (U.S., Canada, Greenland and Russia) and the Association of Indigenous Minorities of the North, Siberia and the Far East of the Russian Federation.

The impetus for the Arctic Environmental Protection Strategy was primarily three-fold:

- Reports coming out of the former Soviet Union of past Arctic Ocean dumping of radioactive and other hazardous materials, which called international attention to potential threats to human health and the environment;
- The openness of the Russian Federation to discussing these problems in their search for bilateral and multilateral assistance to clean up and manage present and future environmental problems; and
- Scientific findings of abnormally high levels of persistent organic pollutants and heavy metals in Arctic indigenous people and their food sources, which likely come from air, water circulation and possibly ice transport mechanisms from industrial nations in the northern hemisphere.

The Arctic Environmental Protection Strategy has no enforcement powers, is funded by ad hoc contributions of member nations, and implements its activities (other than research) through other international forums [for example, the United Nations Environment Program (UNEP) and the International Maritime Organization (IMO)] or through bilateral and/or multilateral agreements. The chairmanship and secretariat rotate among the Arctic nations every two years.

On September 19, 1996, the eight Arctic nations signed a declaration creating the Arctic Council. The Arctic Council will be a consensus forum to provide a means for cooperation, coordination and interaction among the eight Arctic states and Arctic peoples (Native and others) on common environmental and sustainable development issues. The Council will subsume four AEPS programs—the Arctic Monitoring and Assessment Program (AMAP); Conservation of Arctic Flora and Fauna (CAFF); Protection of the Arctic Marine Environment (PAME); and Emergency, Prevention, Preparedness and Response (EPPR)—and terminate the activities of the AEPS task force on Sustainable Development and Utilization. A new sustainable development program will be the fifth Arctic Council program. Drafting and adopting terms of reference for this new sustainable development program, as well as rules of procedures for Council and program meetings, will be the first order of business in the coming year.

The four programs of the Arctic Environmental Protection Strategy will be pillars of the Council. In the early stages of the Council, it appears that the new sustainable development program will stand alone from the AEPS programs as a separate pillar. This separation is, in part, a recognition that there are some environmental issues that are not sustainable development issues (such as nuclear waste contamination); there are some sustainable development issues that are not environmental (such as telecommunications, and drug abuse among Arctic inhabitants); and that there are issues that are both (such as the indigenous peoples' concerns of the effects of trade barriers on certain natural resources on their society). Indeed sustainable development for Arctic inhabitants appears to have been the driving force behind the politics of the eventual evolution of the Arctic Environmental Protection Strategy to the still-to-be-defined Arctic Council. Similar to the AEPS, the Arctic Council will have no enforcement powers, will likely be funded by ad hoc contributions of member nations, and will implement its activities (other than research) through other international forums (for example, UNEP and IMO) or through bilateral and/or multilateral agreements.

The Arctic Council and its new sustainable development program are in flux, and the details are still being defined. The information in this article represents the author's best estimate at the time it was written. For the latest information on the Arctic Council, contact Robert Senseney, Polar Affairs Chief, Office of Oceans and Polar Affairs, U.S. Department of State, Washington, D.C. 20520.

The Arctic Environmental Protection Strategy

The Ministerial Conference and the Role of the Senior Arctic Affairs Officials

The cornerstone of the deliberations and activities of the AEPS has been the biennial ministerial conference, reporting on the activities of the AEPS working groups and ad hoc task forces, and declaring national commitment and priorities over the two-year cycle of research, evaluation, and policy development and implementation.

The work of the AEPS is overseen at the national level by Senior Arctic Affairs Officials (SAAO), who meet periodically to monitor and coordinate the activities of the working groups and ad hoc task forces and propose the two-year action plan and declaration of ministers. The SAAO is normally appointed from the ministry of foreign affairs (in the U.S., the State Department).

Canada has just finished its two-year role as the secretariat for the AEPS, hosting the SAAO meeting and the ministerial conference. (Canada is still the lead country for the Arctic Council, however.) Much of the tone and agenda of the ministerial conference is often set by the host country. Canada has pushed in the last two years for the sustainable development and utilization focus of the AEPS and the Arctic Council. The Norwegians are now the Secretariat for the AEPS.

Domestically the SAAO tries to coordinate U.S. international Arctic activities. Because this is an underfunded activity (and will likely remain so even with the pending elevated status of the Arctic Council), the SAAO has little oversight of domestic activities other than through the interagency process via the "Arctic Policy Group." The Arctic Policy Group is an informal group of representatives of responsible Federal agencies, with the State of Alaska as an observer. Environmental nongovernmental organizations, research institutions, indigenous peoples' organizations and industry participate through the Federal or state agency representatives, as members of delegations to working group meetings or the SAAO meetings, and through periodic briefings and meetings held by the State Department's Polar Affairs program managers.

Indigenous Peoples' Participation

Three indigenous peoples' organizations are represented as Permanent Participants: the SAAMI Council, the Inuit Circumpolar Conference, and the Association of Indigenous Minorities of the North, Siberia and the Far East of the Russian Federation. The Indigenous Peoples' Secretariat, established in 1994, facilitates Native participation in the AEPS and encourages the incorporation and acceptance of "indigenous knowledge" into the interpretation of science as policy recommendations of the AEPS. Further, their role underscores the economic impacts of environmental degradation and protection on indigenous peoples.

The Canadian and U.S. indigenous communities not represented by the ICC (in particular the Athabascans and the Aleut) are pushing for expansion of the number of Permanent Participants. There is major concern about the number and make-up of groups to be recognized as Permanent Participants, with the Russians opposing expansion beyond a limited group.

Observers

Non-Arctic countries, environmental groups, academic institutions and organizations, and other multilateral governmental bodies and organizations have been invited to observe the deliberations of the AEPS and participate in AEPS working groups on an ad hoc basis. Early drafts of the terms of reference for the new Arctic Council addressed observer participation in the Arctic Council but the issue remains unresolved.

Accredited observers include the Federal Republic of Germany, the Netherlands, Poland, the United Kingdom, the Nordic Council, the Northern Forum, the United Nations Environment Program (UNEP), the United Nations Economic Commission for Europe (UN-ECE) and the International Arctic Science Committee (IASC). The World Wide Fund for Nature, the International Fund for Animal Welfare and Japan have applied for accredited observer status. Chile has expressed interest.

The Role of the Working Groups

The work of the AEPS has been accomplished through five working groups:

- The Arctic Monitoring and Assessment Program (AMAP) conducts, coordinates and evaluates research on chemical and radioactive contaminants in the Arctic. AMAP is scheduled to present its findings in a June 1997 symposium. Norway chairs this program.
- The program for the Conservation of Arctic Flora and Fauna (CAFF) conducts, coordinates and evaluates research on threatened and endangered Arctic species and develops action plans among the Arctic nations. Canada formerly chaired this program; Iceland now chairs the program.
- The working group on the Protection of the Arctic Marine Environment (PAME) examines findings of AMAP, CAFF and other national and international bodies for gaps in knowledge of the effects of anthropogenic activities on the marine environment and recommends and promotes national and international legal regimes to address problems. Norway chaired this program in its first stages, awaiting reports from the AMAP program in June 1997, and several country-led efforts, for example, offshore oil and gas guidelines. Canada now chairs this working group.
- The working group on Emergency, Prevention, Preparedness and Response (EPPR) examines risks from transboundary accidents and promotes international cooperation in accident mitigation. Sweden chairs this working group.
- The working group on Sustainable Development and Utilization (SDU) (formerly a task force) fosters the sustainable utilization of natural resources in the Arctic by local and indigenous populations, through research and resolution of trade barrier policies. Norway chairs this working group. The Arctic Council will call this program the Sustainable Development Working Group. The terms of reference of this new working group are under development. The deliberations of the SDU task force were contentious, as many activities focused on "trade barriers," that is, the U.S. ban on importation of marine mammal products.

An underlying principle in the analysis and recommendations of each working group is to ensure that the findings and recommendations are both consistent with and integral to parts of other ongoing international efforts with which each Arctic nation is party. Each working group is chaired by a host country as noted above, with the host country assuming most administrative and often operating costs.

AMAP and CAFF function in more of a coordinating and facilitating role when compiling and evaluating research. That is, most research is conducted by national governments and universities in coordination with the working groups. Ad hoc studies are undertaken by national governments in coordination with the working groups, most often funded and conducted by a lead country. For example, the U.S. Office of Naval Research's Arctic Nuclear Waste Assessment Program is a cornerstone of the AMAP report.

Working Group Program Reports and Activities Highlights

The Arctic Monitoring and Assessment Program. AMAP is one of the original AEPS working groups, chaired by the Norwegians with contributions from other nations. AMAP objectives are "... to monitor the levels of and assess the effects of, anthropogenic pollutants in all components of the Arctic environment." AMAP is often viewed as the core working group from which others are supposed to base their reports and recommendations. Gaps in research have delayed many AMAP reports; a comprehensive report is now scheduled for June 1997. AMAP coordinates and compiles research in the following areas:

- Persistent organic pollutants and heavy metals: these pollutants are brought to the Arctic by long-range transport mechanisms (air circulation and ocean currents) and bio-intensify in the lipids (fatty tissues) of carnivores, in particular marine mammals and the Inuit;
- Radioactivity: these pollutants come from nuclear waste dumping by the former Soviet Union, atomic testing by the former Soviet Union before the test ban treaty, Chernobyl fallout, and nuclear waste processing facilities in the North Sea (the U.K.);
- Acidification of forests and freshwater lakes: sources include 1950s-era industrial plants in Russia, eastern Europe and China, and power plants in the U.S. midwest;
- Climate change and UV radiation: this is a concern because of impacts of the melting of the polar ice cap, and ozone holes in polar regions impacting human health and natural ecosystems;
- Oil pollution: following the revelations of the Komi oil spill from deteriorated Russian oil pipelines in 1994, with concern for the vast amount of oil spilled on the Russian Arctic tundra and its seepage into Arctic rivers, the ministers recently called for an assessment by AMAP of the nature and extent of historic and future contamination; and
- Organitin in the marine environment: this antifouling paint additive may cause sexual abnormalities in some invertebrates, acutely affecting the food chain.

While the final outline for the June 1997 AMAP report is still in flux, the process by which this report is prepared is important. For example, the chapter or sectional reports on Arctic peoples' health and UV radiation are being drafted by internationally recognized experts and will be circulated for peer review.

In addition to assessing the level and impact of contaminants in the Arctic, AMAP is identifying sources of contaminants for the purposes of pollution prevention investments and strategies, particularly in Russia. AMAP's work, as well as that of PAME, was instrumental in supporting action in international forums to reduce land-based sources of marine pollution, in particular, persistent organic pollutants.

Conservation of Arctic Flora and Fauna. CAFF is a "...distinct forum for scientists, indigenous peoples and conservation managers engaged in Arctic flora, fauna and habitat related activities... to collaborate as appropriate for more effective research, sustainable utilization and conservation." CAFF's programs are conservation oriented, with consideration of indigenous knowledge and sustainable development. CAFF is:

- Developing a Circumpolar Protected Area Network to promote habitat conservation through an Arctic Habitat Conservation Strategy (which includes, for example, proposed protected areas);
- Examining conservation and sustainable use of Arctic flora and fauna through species conservation, especially rare and endangered species; for example, the Circumpolar Seabird Working Group is examining the serious decline in seabird populations (the murre, for example) from fishing gear, oil pollution and excessive exploitation, and has developed an action plan for murre conservation, which was endorsed by the Arctic ministers; and
- Drafting a Cooperative Strategy for the Conservation of Biodiversity in the Arctic Region, consistent with the goals of the Biodiversity Convention; Finland is leading this project.

Protection of the Arctic Marine Environment. At the Second Ministerial Conference, 14–16 September 1993 at Nuuk, Greenland, the Ministers noted that recent and ongoing studies found that threats to the Arctic marine environment from land-based and maritime sources indicated that there was a need to undertake a joint process to assess the need, taking into consideration the nature of the threats, for further action or instruments on the international or national level to prevent pollution in the Arctic marine environment, and to evaluate the need for coordinated action in appropriate international forums to obtain international recognition of the particularly sensitive character of the ice-covered parts of the Arctic.

PAME has completed its preliminary review and has determined that controlling land-based sources are a priority because as much as 75–90% of the pollutants entering the marine environment are from land-based sources. Canada and the U.S. will lead in developing an Arctic Regional Action Program for land-based sources of marine pollution. As noted above, PAME's work, as well as that of AMAP, was instrumental in supporting action in international forums to reduce land-based sources of marine pollution, in particular, persistent organic pollutants.

PAME has facilitated the development assistance to be provided to Russia to manage nuclear waste to eliminate the need for ocean dumping of radioactive wastes.

Canada is now coordinating efforts, through the International Maritime Organization, to develop "navigation" standards for Arctic shipping (marine transportation).

The U.S. has taken the lead in developing offshore oil and gas development guides, because oil and gas reserves in the Arctic may dwarf those in the Middle East, and there is some exploration of, and interest by the offshore oil industry in, Arctic petroleum reserves. The National Oceanic and Atmospheric Administration has established an interagency committee, with input from nongovernmental organizations, the oil and gas industry, the State of Alaska and other interested parties, to develop a draft for consideration by other AEPS countries.

Emergency, Prevention, Preparedness and Response. The EPPR working group promotes mutual aid, early notification of significant accidents and pollution prevention through preparedness, and infrastructure investment. Significant activities of the EPPR working group include:

- A detailed risk analysis of national activities having the potential for transboundary impacts, and the effectiveness of national and bilateral legal instruments and agreements to prevent, prepare for and respond to each (the U.S. is lead);
- A field guide for Arctic oil spill response (Canada is lead);
- An Arctic response guide (a resource directory) (coordinated by Sweden); and
- A review of the emergency notification system (the U.S. is lead).

Every year a country has hosted a meeting of the EPPR around issues of that nation's interest. In 1994 the U.S. hosted a table-top disaster response exercise (a nuclear power plant and a leaking oil tanker). In 1995 Russia hosted a meeting on pollution prevention in Norilsk, Russia, at the site of one of the world's largest nickel smelters, believed to be a major source of heavy metals in the Arctic. In 1996 Canada hosted a meeting in Yellowknife, Northwest Territories, focused on indigenous peoples' participation in emergency planning.

Sustainable Development and Utilization. At the Second Ministerial Conference, March 1994, a task force was created to study sustainable development and utilization issues to "...propose steps governments should take to meet their commitment to sustainable development in the Arctic, including the sustainable use of renewable resources by indigenous peoples, taking into account that management, planning and development activities shall provide for conservation, sustainable use and protection of Arctic flora and fauna for the benefit and enjoyment of present and future generations, including local populations and indigenous peoples."

The SDU Task Force has studied "trade barriers" in domestic legislation in the U.S. and Europe for economic impacts on Arctic inhabitants, specifically the Marine Mammal Protection Act, the 1973 Polar Bear Agreement, the Canadian and Greenland seal fur trade, and the European Community trade bans on furs from the trapping of wild animals in North America. The U.S. held firm against any interference with U.S. domestic policy and backsliding on existing treaties (for example, the 1973 Polar Bear Agreement) by the Arctic Environmental Protection Strategy. Indeed several studies by the task force related to the lifting of hunting and harvesting bans were suspended.

In another study, eco-tourism was used as a "case study" of sustainable development without detrimental environmental impacts.

Member countries and a permanent participant indigenous organization independently conducted and submitted studies to the SDU Task Force. For example, the Inuit Circumpolar Conference conducted a study on options for fur sealing.

At the March 1996 ministerial meeting the Task Force on Sustainable Development and Utilization was elevated to working group status, pending the creation of the Arctic Council. Terms of reference for the working group remain contentious. The U.S. has held firm in its resolve to limit studies contrary to U.S. domestic policy and to ensure that the AEPS and the Council understand that sustainable development has large environmental preservation as well as conservation components. Critical to the future direction of this work will be terms of reference of the working group on Sustainable Development and Utilization and in particular the organization and structure of the Arctic Council through the wording of the declaration and implementing policies.

In the March 1996 Inuvik Declaration, ministerial report language laid the groundwork for the deliberations of the Sustainable Development and Utilization working group to look at the problems of pollution prevention and the upgrading of aging Russian infrastructure through cooperative bilateral and multilateral funding. The ministers also instructed that environmental impact assessment guidelines be developed. (Finland has the lead.)

Interestingly, in the Arctic Council declaration, the working group on Sustainable Development and Utilization becomes the "Sustainable Development" program. In initial drafts for terms of reference for this program, the U.S. position calls for no formal working group. Rather, the program would be the aggregate of sponsored projects having regional interest and support.

The deliberations prior to the signing of the Arctic Council were in large part filled with controversy with respect to the nature and scope of the Arctic Council's sustainable development activities. There were many who felt that, contrary to what the ministers may have officially stated, the goals of the Rio summit's statement on sustainable development were at risk of being diluted. In the end, most recognized that there are some environmental issues that are not sustainable development issues (such as nuclear waste contamination); there are some sustainable development issues that are not environmental (such as telecommunications, and drug abuse among Arctic inhabitants); and there are issues that are both (such as the indigenous peoples' concerns about trade barriers on certain natural resources on their society).

Further, there are excellent successes among indigenous people and wildlife conservation agencies co-managing natural resources and having limited environmental impacts.

The Arctic Council

Next Steps

How the Council will differ from the AEPS remains to be seen. The Council will have no enforcement authority and will likely be underfunded, as the AEPS has been. The perceived elevation of the AEPS to Council status may have some impact on deliberations and national commitments. On the other hand, the State of Alaska sees many opportunities from the new Sustainable Development Program.

Many in the environmental community view the Arctic Council as one step closer to the "Arctic Ring of Life." Public statements made by Canada's Circumpolar Ambassador suggest otherwise. The Canadian government has been touting to its northern communities a high-profile Arctic Sustainable Development Initiative, in conjunction with the creation of the Arctic Council. To some, this has meant increased harvesting of marine mammals and other wild fur-bearing animals concurrent with expanded export markets.

Norway is now the AEPS chair and secretariat, and it is also head of the working group on Sustainable Development and Utilization. As such it controls much of the agenda and schedule.

Canada is the chair and secretariat of the Arctic Council. During this transition period—through the summer of 1997—there is both an Arctic Council (with Canada as the lead country) and the AEPS (with Norway as the lead country). Each has a different view of their respective roles and the role of the Arctic Council. Several of the Arctic nations would have been content to continue the Arctic Environmental Protection Strategy, with Norway perhaps among those who saw limited need for the Arctic Council. This dynamic, and the transition to the Arctic Council under Canadian leadership for the first years, bears watching.

Observer Participation

Details concerning observer participation and accreditation will be resolved after the new Council meets, as the first order of business is to adopt rules of procedures for its meetings and those of its working groups (programs).

Observer status to the Arctic Council will be open to nongovernmental organizations, non-Arctic states, and intergovernmental and interparliamentary global and regional organizations that "the Council determines can contribute to its work." It is intended that those already accredited as observers to the AEPS will be accredited observers to the Arctic Council.

Permanent Participants

Indigenous peoples' participation as permanent participants is similar to that of the AEPS but will be expanded to include:

- Other Arctic organizations of indigenous peoples representing a single indigenous people residing in more than one Arctic state; or
- More than one Arctic indigenous people residing in a single Arctic state.

The number of permanent participants (indigenous organizations participating in the Arctic Council) will always be limited to fewer than the number of member Arctic states (that is, fewer than eight). The Indigenous Peoples' Secretariat established under AEPS will continue under the Arctic Council. These permanent participant organizations will have no voting rights but will otherwise be full participants in all Council activities in a consultative capacity. There may be as many as three new permanent non-voting participants: one each from the U.S., Canada and Russia. In the U.S., the Aleut and the Athabascan peoples are exploring options, both internationally and domestically, to seek permanent participant status.

Terms of Reference

The rules and administrative operating procedures by which the Arctic Council and its programs will operate are being developed. Deliberations in the drafting of the Arctic Council Declaration were delayed by discussions on the rules of procedure for the Council and the terms of reference for the sustainable development program.

Several unresolved issues will make drafting and adopting terms of reference for the new sustainable development program, as well as rules of procedures for the Council and program meetings, difficult. There has been an ongoing concern that there is insufficient dialogue or liaison among the AEPS working groups. There is much interest among most of the Senior Arctic Affairs Officials to require liaison among the programs, which should ensure a balanced approach to programs with both environmental and sustainable development aspects. While this may seem like good management, there were those who viewed this as an attempt to balance the Council against economic development in favor of the environment.

Russia continues to look for foreign investment to improve their infrastructure. There has been little or no money available for this. This has led some to question the effectiveness and the purpose of a nonbinding, poorly funded consensus forum, especially when dealing with the scope of problems in Russia. Further, a significant amount of foreign investment in Russia has been bilateral. In the U.S., for example, the Gore–Chernomyrdin Commission has been seen by many as a better forum than the AEPS for infrastructure improvements in Russia.

The scope of activities that can be labeled "sustainable development" is quite large and is certainly diverse. Management and oversight of the projects and funding can be an administrative and operational, as well as a public policy, concern. Studies approved by the Arctic Council may carry an implicit stamp of approval and thus become an unanticipated intervention. These issues all contribute to the difficulty in drafting and adopting terms of reference.

Concluding Remarks

The AEPS and the new Arctic Council, when coupled with the recently announced U.S. policy of environmental security, should provide a strong rationale for Arctic research. Policy makers must heed the requirement, both on scientific and social grounds, for research directed toward the objectives of the AEPS and its working groups. Arctic research can also support other working groups besides AMAP and CAFF. The scientific community has an opportunity to ensure the success of the AEPS and the Arctic Council and should therefore maintain a dialogue with both state and Federal officials on the importance of the AEPS and Arctic Council tenets.

In the U.S. the AEPS and the Arctic Council have not been seen as strong tools of foreign policy. Perhaps the Arctic is too remote for many. The Gore–Chernomyrdin Commission has sought, for the most part, bilateral discussions and funding to address Russian nuclear waste and infrastructure problems, on an almost sister agency to sister agency level. In the U.S. many policy makers believe that work in Russia has a better chance of acceptance and success through the Gore–Chernomyrdin Commission than through the AEPS.

Even with the understanding that bilateral arrangements or limited multilateral arrangements stand a better chance of success, there has been little thought by the AEPS ministers to take their findings to international funding institutions such as the World Bank or the European Development Bank to address some of the problems in Russia. That approach often comes with a price tag: seven of the eight Arctic nations are seen as wealthy and expected to have deep pockets. These international funding institutions look for donor countries to support their programs and projects. What makes the Arctic more economically valuable to a region or country than more hospitable climates? Perhaps, then, welcoming more observer countries would ease the financial burdens.

Some questions should be asked:

- Does the U.S. have an Arctic policy? Yes, it is a well-written document drafted in an interagency process chaired by the State Department.
- Does the U.S. have an Arctic program? Yes. Agencies have Arctic monies to support Arctic activities, but they are often subsets of larger programs. The Office of Naval Research's Arctic Nuclear Waste Assessment Program was such an example; Congress provided, however, no FY 96 or 97 monies. The interagency Arctic Policy Group functions as a clearinghouse, though some ad hoc committees do produce coherent positions for international deliberations. The Interagency Arctic Research Policy Committee (IARPC), through the development of the U.S. Arctic Research Plan, coordinates U.S. research programs to support U.S. Arctic policy.

The Arctic Council is an opportunity to gel a stronger, more permanent interest in the Arctic. Next year's AMAP report and the subsequent work of PAME may be catalysts for attention. Certainly the sustainable development program has great potential.

U.S. agencies can and will work with the Arctic Council to facilitate communication and cooperation and develop bilateral and multilateral programs such as the Gore–Chernomyrdin Commission, AMAP and the U.S. offshore oil and gas program. The Arctic Council will serve to enhance such opportunities.

DECLARATION ON THE ESTABLISHMENT OF THE ARCTIC COUNCIL

The representatives of the Governments of Canada, Denmark, Finland, Iceland, Norway, the Russian Federation, Sweden and the United States of America (herein referred to as the Arctic States) meeting in Ottawa;

Affirming our commitment to the well-being of the inhabitants of the Arctic, including recognition of the special relationship and unique contributions to the Arctic of indigenous people and their communities;

Affirming our commitment to sustainable development in the Arctic region, including economic and social development, improved health conditions and cultural well-being;

Affirming concurrently our commitment to the protection of the Arctic environment, including the health of Arctic ecosystems, maintenance of biodiversity in the Arctic region and conservation and sustainable use of natural resources;

Recognizing the contributions of the Arctic Environmental Protection Strategy to these commitments;

Recognizing the traditional knowledge of the indigenous people of the Arctic and their communities and taking note of its importance and that of Arctic science and research to the collective understanding of the circumpolar Arctic;

Desiring further to provide a means for promoting cooperative activities to address Arctic issues requiring circumpolar cooperation, and to ensure full consultation with and the full involvement of indigenous people and their communities and other inhabitants of the Arctic in such activities;

Recognizing the valuable contribution and support of the Inuit Circumpolar Conference, Saami Council, and the Association of the Indigenous Minorities of the North, Siberia, and the Far East of the Russian Federation in the development of the Arctic Council;

Desiring to provide for regular intergovernmental consideration of and consultation on Arctic issues.

Hereby declare:

1. The Arctic Council is established as a high level forum to:

   (a) provide a means for promoting cooperation, coordination and interaction among the Arctic States, with the involvement of the Arctic indigenous communities and other Arctic inhabitants on common Arctic issues[1], in particular issues of sustainable development and environmental protection in the Arctic.

   (b) oversee and coordinate the programs established under the AEPS on the Arctic Monitoring and Assessment Program (AMAP); Conservation of Arctic Flora and Fauna (CAFF); Protection of the Arctic Marine Environment (PAME); and Emergency Prevention, Preparedness and Response (EPPR).

   (c) adopt terms of reference for, and oversee and coordinate a sustainable development program.

   (d) disseminate information, encourage education and promote interest in Arctic-related issues.

2. Members of the Arctic Council are: Canada, Denmark, Finland, Iceland, Norway, the Russian Federation, Sweden and the United States of America (the Arctic States).

   The Inuit Circumpolar Conference, the Saami Council and the Association of Indigenous Minorities of the North, Siberia and the Far East of the Russian Federation are Permanent Participants in the Arctic Council. Permanent participation equally is open to other Arctic organizations of indigenous peoples[2] with majority Arctic indigenous constituency, representing:

   (a) a single indigenous people resident in more than one Arctic State; or

   (b) more than one Arctic indigenous people resident in a single Arctic state.

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1. The Arctic Council should not deal with matters related to military security.
2. The use of the term "peoples" in this Declaration shall not be construed as having any implications as regard the rights which may attach to the term under international law.

The determination that such an organization has met this criterion is to be made by decision of the Council. The number of Permanent Participants should at any time be less than the number of members.

The category of Permanent Participation is created to provide for active participation and full consultation with the Arctic indigenous representatives within the Arctic Council.

3. Observer status in the Arctic Council is open to:

(a) non-Arctic states;

(b) inter-governmental and inter-parliamentary organizations, global and regional; and

(c) non-governmental organizations

that the Council determines can contribute to its work.

4. The Council should normally meet on a biennial basis, with meetings of senior officials taking place more frequently, to provide for liaison and co-ordination. Each Arctic State should designate a focal point on matters related to the Arctic Council.

5. Responsibilities for hosting meetings of the Arctic Council, including provision of secretariat support functions, should rotate sequentially among the Arctic States.

6. The Arctic Council, as its first order of business, should adopt rules of procedure for its meetings and those of its working groups.

7. Decisions of the Arctic Council are to be by consensus of the Members.

8. The Indigenous Peoples' Secretariat established under AEPS is to continue under the framework of the Arctic Council.

9. The Arctic Council should regularly review the priorities and financing of its programs and associated structures.

Therefore, we the undersigned representatives of our respective Governments, recognizing the Arctic Council's political significance and intending to promote its results, have signed this Declaration.

Signed by the representatives of the Arctic States in Ottawa, this 19th day of September 1996.

FOR THE GOVERNMENT OF CANADA

FOR THE GOVERNMENT OF DENMARK

FOR THE GOVERNMENT OF FINLAND

FOR THE GOVERNMENT OF ICELAND

FOR THE GOVERNMENT OF NORWAY

FOR THE GOVERNMENT OF THE RUSSIAN FEDERATION

FOR THE GOVERNMENT OF SWEDEN

FOR THE GOVERNMENT OF THE UNITED STATES OF AMERICA

Assessment of Contaminant Risks in the Arctic

Pathways and Processes that make the Arctic Ocean Unique

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Support for this research was provided by the National Science Foundation, the Office of Naval Research (under the High Latitude Program and the Arctic Nuclear Waste Assessment Program) and the State Department.

Traditionally the Arctic has been thought of as a pristine and remote region, where risks to humans were produced by the "hostile" environment itself. Therefore, it was a surprise when western industrial contaminants were first detected there in the 1960s and alarming when recent measurements showed some of these contaminants to be sufficiently concentrated to represent "unacceptably high intakes" and exceed "tolerable daily intakes" for some populations of people dependent on "country" foods. Health concerns have been raised about the levels of PCBs in Inuit mothers' milk and polar bears, mercury in humans and tissues of marine mammals, lead in Greenlanders, and chlordane in polar bears. Clearly some contaminants, such as toxaphene, could not be coming from local sources but rather from sources thousands of kilometers away. And often it is contamination of the marine food chain that has been identified as posing the greatest risk for higher predators, including humans. The immediate questions provoked by these observations are: What causes contaminants to accumulate in some places and not in others? Does it have to do with physical processes that enhance the delivery to the region and its biota, or is it processes within the food chain itself?

Although we focus in this paper mainly on physical processes and pathways, it is clear that the biology is also unique and a crucial part of the contaminant sequence. Species diversity is relatively low, often with only one or two sources of prey at each step along the food chain, making it vulnerable to disruption. Many species migrate long distances and may ingest contaminants in a different place than where they themselves are consumed. The Arctic marine food chain is long and unusually dependent on fat, which results in extreme biomagnification of some chemicals, especially those that are soluble in lipid. Some organisms are long-lived and can therefore accumulate chemicals to a marked degree as they age. There is a relatively large human population dependent for most of their nutrition on country food. As a result the Arctic marine food chain constitutes a remarkably efficient collection and transport vector for contaminants to humans. This biological "magnifying glass" is the final step that completes the contaminant journey set in motion by physical and chemical processes operating on global and regional scales.

For any chemical, risk is a combination of hazard, which depends on the toxic properties, and exposure or dose. Put simply, once a contaminant is released to the environment, a major component of risk is produced by the "critical path" that puts that specific contaminant on some person's or some animal's dinner plate. There are three components to assessing this critical path: release, transport and uptake. The partitioning of the contaminant between the gas, dissolved and particle phases is perhaps the single most important factor that affects transport and scavenging of contaminants. Particles, either in the atmosphere or aquatic environments, tend to settle and take a different transport pathway than do dissolved constituents. However, phase partitioning is complex and reflects changes in environmental and chemical conditions. For example, a contaminant sorbed to particles in fresh water may be dissolved in ocean water or vice versa. Most contaminants of concern in the Arctic are generally associated with particles, for example, lead and most other metals, dichlordiphenyltrichlorethane (DDT) and highly chlorinated PCB congeners. Examples of contaminants that tend to be conservative, as opposed to trapped with particles, include:

- Organic pesticides such as toxaphene, hexachlorocyclohexane (HCH), hexachlorobenzene (HCB);
- Radionuclides such as ^{137}Cs, ^{90}Sr, ^{129}I, ^{3}H (tritium);
- Cadmium and copper (under certain conditions); and
- Lower chlorinated congeners of PCBs.

In this paper we discuss some of the physical aspects of the Arctic marine system that make it unique in the delivery and processing of contaminants. We will show that it is inappropriate to simply adopt results from research done on risk assessment in other parts of the world. Three physical features combine to set the stage for a host of interacting processes:

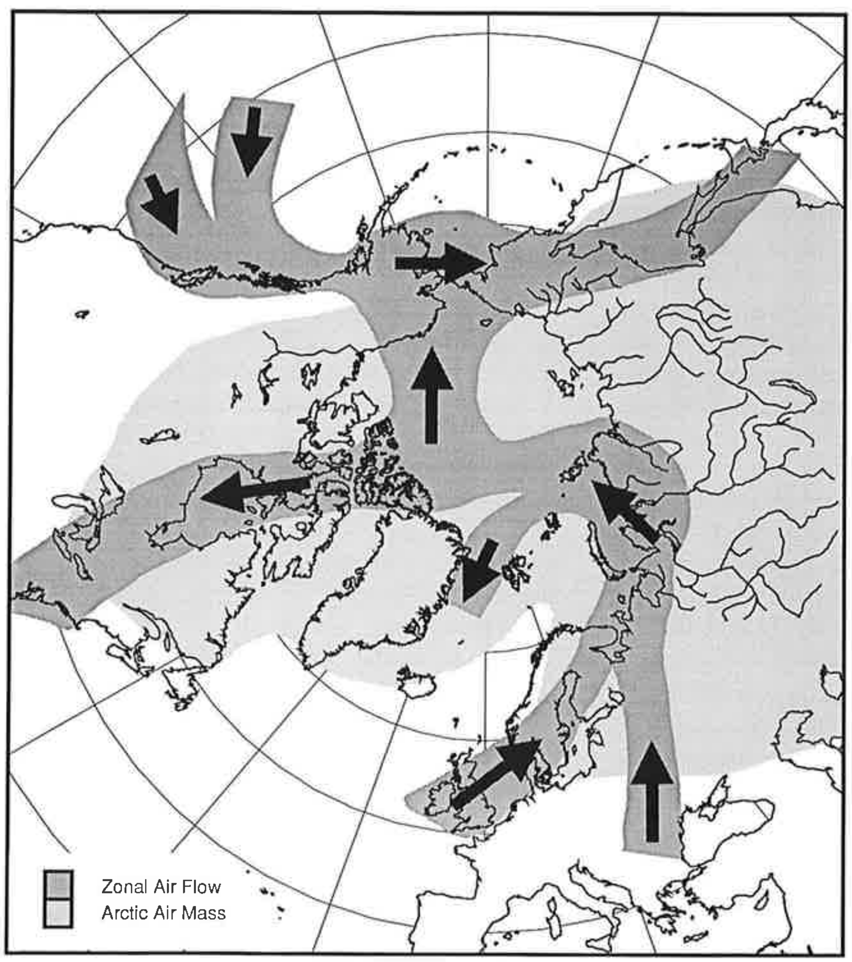
- The Arctic Ocean is an inland sea;
- The Arctic region encompasses the coldest places in the Northern Hemisphere; and
- The length of the day changes from zero in winter to 24 hours in summer.

Environmental Setting

The geography of the Arctic Ocean is unusual in that it is largely encircled by land. This feature makes it similar to marginal seas, such as the Mediterranean and the Gulf of Mexico. The Pacific, Atlantic and Indian Oceans all have much broader regions where there is open communication for water masses at all depths. In the Arctic, deep water (greater than 2000 m) is only exchanged through a relatively narrow portion (about 250 km at 80°N) of Fram Strait, where the sill depth is about 2600 m; the Barents Sea has a sill depth of about 250 m, the Bering Strait is 50 m deep, and the Canadian Archipelago is a little over 100 m deep. This configuration of land and sea means that continents have a large influence on the ocean. Since contaminants are released primarily by industrial, agricultural and municipal activity on land, anthropogenic influences are therefore likely to be high.

Although it may seem trite to say it, the Arctic is the coldest place in the Northern Hemisphere. Ice is ubiquitous: in the form of snow; sea, river and lake ice; glaciers; and permafrost. Spanning the ecosystem from ice algae to humans, ice provides a platform for building, transportation, feeding and in some cases breeding. Because ice cycles so dynamically and is continually being formed, moved and melted, it is uniquely vulnerable to changes in temperature. Furthermore, low temperatures slow down reaction rates, so chemicals degrade more slowly. From January to March, air temperatures reach minimums of less than –52°C, with monthly averages less than –32°C, over the central Arctic pack ice and into the Canadian Archipelago. In contrast, air temperatures over open water are much higher because the sea surface temperature cannot drop below the freezing point, which is about –1.8°C for a salinity of 33‰. Even in summer, sea ice persists over the central part of the Arctic Ocean, while glacial ice covers some continental regions. The perennial ice cover of the central Arctic means that the summer air and water temperatures tend to hover around the freezing point, although maximum air temperatures in June, July and August may exceed 8°C. The maximum summer air and water temperatures over the marginal seas and continents rise much higher, to more than 28°C.

Arctic air mass in winter. The arrows show the main zones of air flowing into and out of the Arctic. (From Pfirman et al. 1996, adapted from Raatz in Sturges 1991). © Environmental Defense Fund 1995, reproduced by permission.



A long, dark winter followed by continuous sun at a relatively low angle almost certainly affects photolytic reactions. In addition, the strong Arctic seasonality couples melting and the input of contaminants to the period of maximum biological growth.

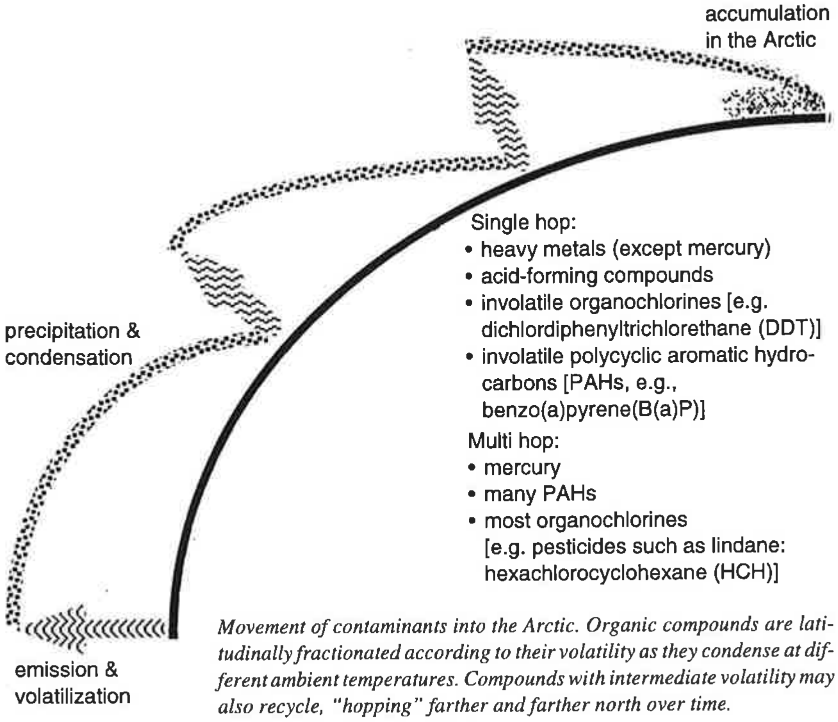
In the following we review some of the physical processes and pathways in the marine environment that require special consideration in Arctic risk assessment. Our intent is not to be comprehensive but rather to focus on examples that highlight differences between the Arctic and more temperate latitudes, such as:

- Arctic haze;
- Cold trapping and global distillation;
- Fog;
- Sea ice;
- Spring river break-up;
- Distribution of river runoff;
- Formation of dense waters; and
- Variability.

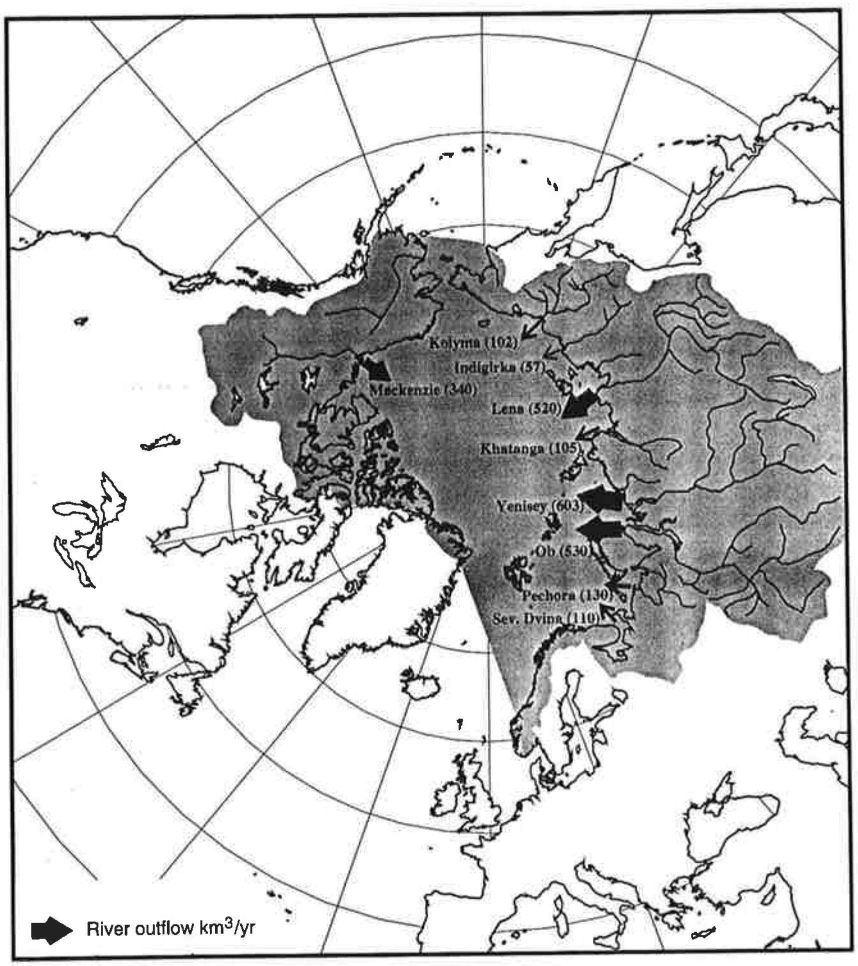
The Northern Hemisphere is the Arctic's Catchment Area

Delivery from the Atmosphere

During winter the Arctic air mass extends southward, encompassing much of the Northern Hemisphere. Atmospheric emissions from industrial and agricultural sources are swept north by the prevailing winds. Once they reach the Arctic, the low temperatures result in a relatively stable atmosphere. Because of the low levels of precipitation, the residence time of aerosols becomes unusually long, shifting from days (in low latitudes) to weeks in the Arctic. Aerosols trapped in



Movement of contaminants into the Arctic. Organic compounds are latitudinally fractionated according to their volatility as they condense at different ambient temperatures. Compounds with intermediate volatility may also recycle, "hopping" farther and farther north over time.



Arctic Ocean watershed. The watershed is huge—much larger than the ocean basin into which it drains. As a result, river effluent plays a greater role in the Arctic than in any other ocean basin. (From Pfirman et al. 1996) © Environmental Defense Fund 1995, reproduced by permission.

the winter Arctic air mass form Arctic haze, which has been called the most massive aerosol air pollution on earth. The sources for Arctic haze, defined by the "fingerprint" of their trace chemical composition and by atmospheric models, are located mainly in Eurasia, with a secondary contribution from eastern North America.

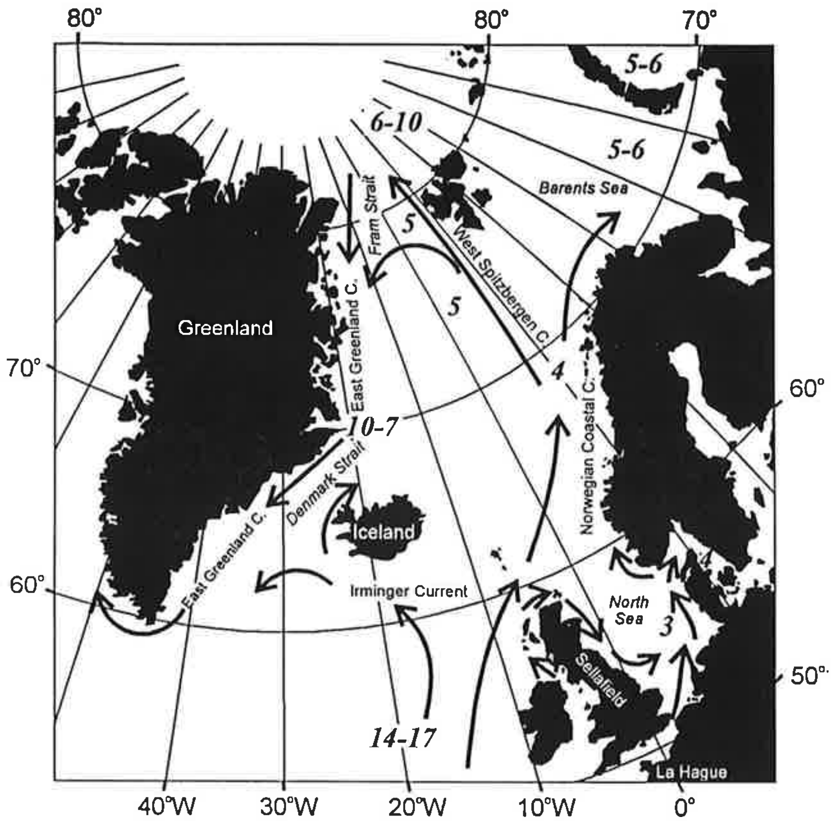
In late spring and early summer, Arctic haze disappears. It's not known exactly where the contaminants are deposited, but deposition may focus where warm, moist air underruns and destabilizes the cold Arctic air mass. This means that aerosols and gases would deposit with precipitation as the cold air mass flows over oceans, where there is substantial heat and moisture. As a result the North Atlantic, the Norwegian Sea and possibly the Bering Sea are likely recipients of atmospheric pollutants.

Organochlorines and other volatiles and semivolatiles, such as mercury, tend to volatilize at high temperatures and condense at low temperatures. Regulation and prohibition has shifted the use of organochlorine pesticides from the most developed countries to developing countries in tropical regions. Volatilizing under warm tropical conditions, organochlorines move from low to high latitudes. The semivolatiles may condense and revolatilize several times before "hopping" to the Arctic, where the temperatures are the lowest of anywhere in the Northern Hemisphere. This process, variously called cold trapping, cold condensation and global distillation, means that certain chemicals may be transported long distances from the source areas and accumulate in the Arctic. Because some of these compounds are implicated as endocrine disrupters, concern is growing about such widespread redistribution. This process affects the Arctic more than the Antarctic, since most of the world's land mass, including industrial, agricultural and population centers, is located in the Northern Hemisphere.

Delivery by Rivers

Several aspects of river discharge into the Arctic Ocean are unique. The catchment area of the Arctic Ocean is 2.5 times larger than the area encompassed by the ocean basin, which is the reverse of the global ocean/land distribution. This means that river runoff plays a much larger role than usual. The watershed itself is diverse, extending as far south as 45°N and encompassing regions with continuous, discontinuous and no permafrost.

In temperate regions, lakes often act as a sink for river-borne materials, reducing the land-to-ocean flux of contaminants. Despite the extraordinarily large number of lakes in Arctic river systems, the hydrology (timing of snowmelt vs.



Circulation of surface waters in the European Arctic. The numbers refer to transit times (in years) from Sellafield, England, a source of radionuclide contamination. (After Dahlgaard 1995.)

lake turnover), ice cover and low productivity tend to restrict the ability of Arctic lakes to sequester contaminants. Detailed studies at one Canadian site, Amituk Lake, show that only a small portion of the organochlorines delivered to the catchment area is actually retained in the lake; most of the contaminant burden is channeled through, with the lake acting simply like a segment of the river.

Many of the smaller rivers completely freeze over in winter, resulting in dramatic seasonal differences in river discharge. However, some of the larger ones flow year-round, albeit with reduced discharge. Some of these, like the Lena, are fed by groundwater in winter, resulting in a different water chemistry than that observed during the summer.

Since rivers flow toward the north, ice in the headwater region melts first and progresses downstream. Spring break-up, with ice jams and overbank flooding, is an extremely turbulent event. Contaminants stored in various parts of the watershed, including the riverbed, could be mobilized and move downstream. Surprisingly the fast ice filling the Ob and Yenisey estuaries remains in place during the spring discharge, not breaking up until July. This means that contaminants could settle out under the fast ice and accumulate in the estuary for long periods of time. Sedimentation of contaminants close to the source may explain the observations that the waters of the Ob, Yenisey and Lena Rivers can be considered pristine with respect to trace metals. In other rivers, discharge occurs over the ice surface, extending far out onto the fast ice. Puddled fresh water on the ice surface may break through, forming a whirlpool that penetrates to the sea floor and forms distinctive erosional features, called strudel scours.

Delivery by Ocean Currents

The Arctic marine food chain largely depends on productivity in the upper water column and shallow shelves. Therefore, we focus this discussion on potential contaminant exposure from surface and near-surface waters. Trace substances enter the Arctic through ocean currents, especially the inflow of Atlantic water through Fram Strait and Pacific water through Bering Strait. Atlantic water enters via the Norwegian Sea in a current that flows along the sea surface. It is relatively warm and saline and is practically in equilibrium with the atmosphere with respect to trace gases. Once this water moves north into the Barents Sea and the region west of Svalbard, it cools, becomes denser and sinks below the less-dense Arctic surface water, thus becoming isolated from further communication with the atmosphere. The Atlantic layer is found throughout the entire Arctic Basin, in most places at depths of about 200–800 m. Constrained by the strong Coriolis effect existing at high latitudes, the Atlantic inflow tends to hug the basin boundaries. In the central basins it typically forms well-defined currents along topographic features such as the Gakkel, Lomonosov or Alpha-Mendeleyev Ridges.

The Atlantic layer provides one of the clearest examples of contaminant transport from lower latitudes into the Arctic Ocean. As it moves along the European margin, it picks up a radionuclide contaminant signal from reprocessing plants in France and Britain. Presently the radionuclides originating from Sellafield and Cap La Hague entering the Arctic Ocean via this route dominate the overall radionuclide balance of the Arctic Ocean. As discussed below, the Atlantic-derived waters reside in the Arctic Ocean for periods that typically are longer than the mean residence times of near-surface waters, which carry the bulk of the river discharge (including dissolved contaminants).

The Bering Strait is a shallow (50 m) passage that connects the Arctic Ocean with the Pacific via the Bering Sea. It allows an inflow of relatively fresh water, which adds buoyancy to the surface waters (in addition to that supplied by rivers) and further stabilizes the density stratification of the surface layer. As in the case of the Atlantic-derived water, it represents a route for the transport of contaminants from lower latitudes into the Arctic

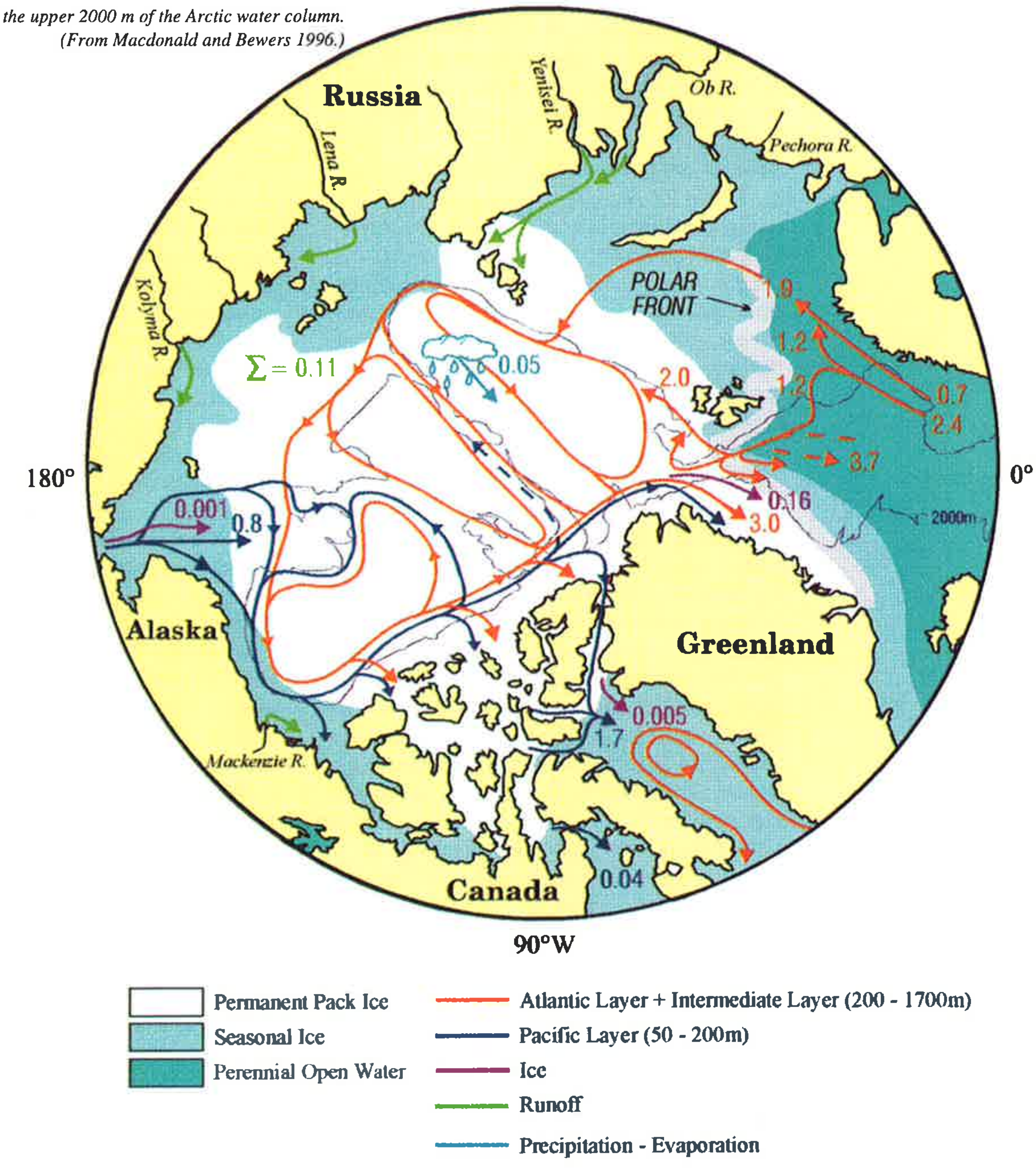
Ocean (especially those that are not particle-associated, such as HCH). In contrast to the Atlantic-derived waters, the Bering Strait inflow stays closer to the surface and enters a smaller pool of water. Therefore, it can exit the Arctic Ocean faster than the Atlantic-derived waters found below the surface waters.

Although not unique to the Arctic Ocean, it is unusual that the surface layer and deeper layers flow in opposite directions. The surface waters are driven primarily by winds and the less-dense water contributed by river runoff and the Bering Strait. Circulation is in a large clockwise gyre comprising the Beaufort Gyre and the Transpolar Drift Stream, which is reflected in the sea ice circulation. Waters below the halocline (Atlantic-derived water) generally circulate in a counterclockwise direction. This means that if contaminants are introduced into the upper water column, they may move in the opposite direction from ones transported deeper down.

Redistribution of Contaminants within the Arctic

Particle-bound contaminants introduced along the continental margins by rivers and coastal processes are likely to be deposited on the shelves. More conservative contaminants that do make their way off the shelf are likely to be advected with sea ice or water masses. They will typically be redistributed within the Arctic system before they are

Circulation and fluxes in the upper 2000 m of the Arctic water column. (From Macdonald and Bewers 1996.)



deposited or degraded within the Arctic or transported out of it through Fram Strait, the Canadian Archipelago or the Barents Sea (in the case of sea ice, the marginal ice zone is also a site for contaminant release). This is because there are low vertical fluxes and slow degradation rates, and the combined effects of a fairly continuous sea ice cover and a strong stratification of the surface waters strongly reduces the loss of dissolved gases from the water (for example, HCH). In most cases, contaminant concentrations dilute along the transport pathway, such as when contaminated water mixes with surrounding water masses. Mixing is important because it may lower the concentration of specific dissolved contaminants below thresholds of concern for ecosystem exposure. However, there are other processes that may combine to actually enhance concentrations at the point of delivery to primary producers, such as condensation from fog to the surface microlayer, and release from sea ice during the spring bloom.

Atmospheric Processes, including Fog

Within the Arctic the primary atmospheric transport pathway is from Eurasia to the North American continent. Aerosols are relatively long lived in the winter and may be transported long distances. They deposit more quickly, closer to the source, in the summer. Constituents, such as PCBs, may continue to undergo thermal cycling, volatilizing from the snowpack in summer, only to recondense in winter.

Much of the Arctic is extremely foggy because of the juxtaposition of cold air overlying warmer ocean waters in some places and warm air overlying colder ice in others. In some regions it is typical to have more than 100 days per year with fog. In summer the ice retreats towards the north, exposing open water, and warm air moves in over the ice and cold water. Sublimating ice and condensing water form thick fog fields that envelope the marginal ice zones, with peaks in relative humidity over water in August. Fog may condense on land, ice and the ocean surface, influencing biota in all regimes. In winter, when sea ice extends from shore to shore, the relative humidity of the air is often slightly supersaturated with respect to ice, while it is not saturated with respect to water. Hoar frost formation begins when a value slightly over 100% has been reached at air temperatures of about –30°C. In winter, "sea smoke" or steam fog forms over open water leads in the pack ice.

A recent study on levels of pesticides in Arctic marine fog observed significant concentrations of currently used pesticides (Chernyak et al. 1996). In addition, elevated levels of trifluralin found in a surface ocean microlayer sample were attributed to a recent fog event. The authors postulated that:

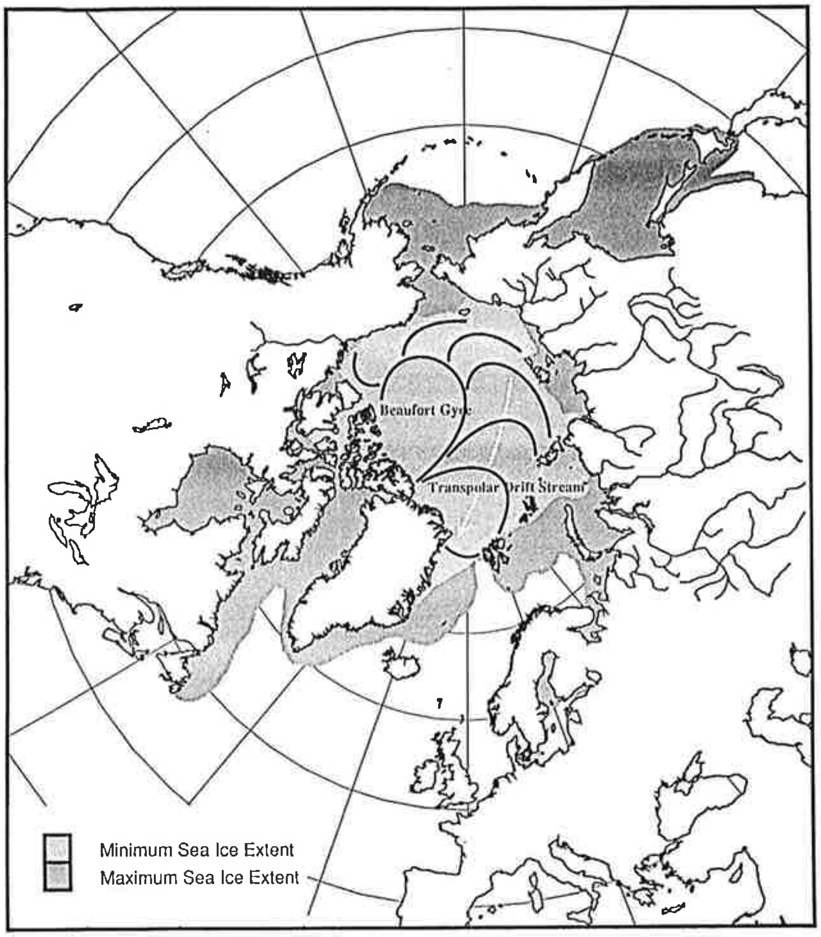
- Pesticides used in April–June may condense on Arctic aerosols;
- The surface of fog itself may scavenge gas and particle-phase contaminants from the air;
- Sublimation from the ice could act as a trap for airborne pesticides; and
- There may be reduced destruction of easily hydrolyzed pesticides, causing their build-up.

River Discharge

Because of the extreme seasonality in river discharge, the shelf seas, except for the Barents Sea, are dominated in summer by plumes of low-salinity surface water with very stable stratification. As the rivers discharge to the north, transport is generally deflected eastward along the coast by the Coriolis effect, until hindrances such as shallow grounds and archipelagos are encountered. In the Kara Sea, Ob, Yenisey and Piasina River water exits the sea both north and south of Severnaya Zemlya, flowing into the Laptev Sea, perhaps with some entrainment into the Transpolar Drift Stream. Water from the Khatanga, Lena and Yana Rivers, discharged into the Laptev Sea, are also transported eastward toward the New Siberian Islands, where much of the flow is diverted to the north. Here river water exits the shelf and is entrained into the Transpolar Drift Stream.

Analyses of salinity, oxygen isotope ratios, total alkalinity and total carbonate show that there is a sharp front extending through the Nansen Basin, with waters to the north being more influenced by river discharge than waters to the south. This front extends all the way into Fram Strait. Balances of mass, salinity and oxygen isotopes suggest that about 10%, or the equivalent of about 10 m, of the upper 100 m of the water column consists of river water, essentially forming a diluted river plume extending across most of the central Arctic Basin. Mixing is reduced by a large supply of buoyancy, with the river discharge forming a very stable pycnocline (halocline), as well as by the ice cover, which reduces wind-induced turbulence in the surface mixed layer. There is no other ocean basin where river discharge plays such a large role and where river discharge can be tracked over such large distances with so little mixing.

River water from Siberian discharge, as well as from the Mackenzie and other North American rivers, appears to be entrained in the Beaufort Gyre, where it may accumulate over many years, forming a large freshwater lens. Not enough is known about the dynamics of the Beaufort Gyre. It seems to undergo reversals in direction during



Arctic sea ice circulation. During winter, sea ice extends far into the marginal seas. In summer, melting ice exposes the surface waters of the shelf seas to atmospheric processes. Ice in the Beaufort Gyre typically recirculates longer than does ice entrained in the Transpolar Drift Stream. (From Pfirman et al. 1996) © Environmental Defense Fund 1995, reproduced by permission.

the summer when the winds change (based on ice/atmosphere investigations). On a time scale of decades, there may be large variability, with changes in the size and location of the gyre. When such changes occur, the water stored in the gyre may be forced out through either the Canadian Archipelago or Fram Strait to generate phenomena like the "great salinity anomaly." With respect to surface water (less than 50–100 m), it is estimated that about an equal amount exits through the Archipelago as through Fram Strait. This is important because it is the surface water that is most significant for the transport of contaminants and their entry into the biosphere.

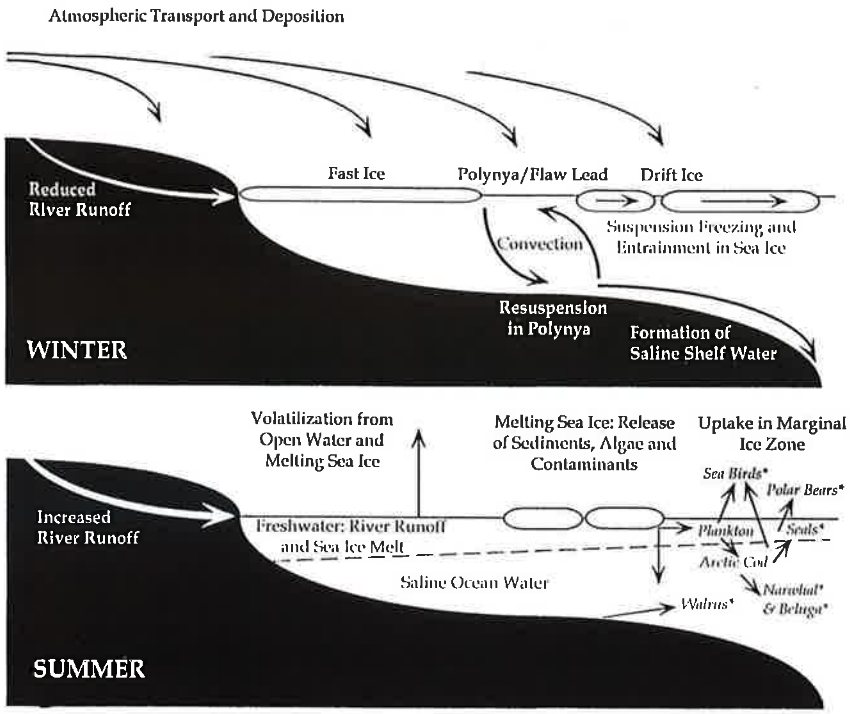
Sea Ice

Arctic sea ice plays a unique role in air–sea exchange of contaminants, in their transport and as a biological habitat. Unlike other ice-forming seas, about half of the Arctic Ocean is perennially covered, with complete ice melting occurring only in the marginal seas. The persistence of ice over the central part of the basin, shifting from 1% open water in winter to about 10–20% open water in summer, greatly reduces gas exchange between the ocean and atmosphere throughout the year. One consequence is that the highest concentrations of HCH in the world oceans are presently observed in the surface water of the Beaufort Gyre. Concentrations in this ice-covered region lag behind the atmospheric concentrations, which, with reduced emissions, have declined during the past decade. In addition to inhibiting the exchange of vapor-phase (gaseous) contaminants, it is clear that the perennial ice cover also captures particulate contaminants and condensates, preventing them initially from entering the water.

Much of the perennial ice forms on the shelves in coastal polynyas or flaw leads and is then advected offshore. Ice that survives the first summer's melt may be caught up in either the Beaufort Gyre or the Transpolar Drift Stream, where it can circulate for years before melting or exiting the Arctic Basin, primarily through Fram Strait or the Barents Sea. Because ice circulates for years and is formed in one place and melts in another, it provides a mechanism for transporting contaminants over long distances.

Perhaps the most obvious example of the power of sea ice to affect the fate of a contaminant would occur in the event of an oil spill. Low temperatures and ice cover will slow degradation, dispersion and evaporation of the oil components. As the oil moves with the ice, the annual freeze/melt cycle will tend to pump oil into leads and onto the ice surface during summer, maximizing the potential interaction with ice biota and migrating birds. But there are other less obvious and equally important examples of contaminant/ice interactions. Ice can accumulate contaminants in several ways:

Contaminant transport via sea ice. New sea ice forms along the flaw lead/coastal polynya that persists at the edge of the fast ice. Ice forming over shallow water may entrain resuspended sediments and contaminants. Ice formed early in the winter has the greatest chance of being advected offshore before summer melting begins. During drift, melting in the summer and under-ice growth in winter result in an accumulation of particles (orginally distributed throughout the ice column) at the ice surface. Deposition from the atmosphere may increase the contaminant burden. Some sediments and contaminants are lost during drift, while the remainder is deposited at the marginal ice zone when the entire floe melts. (From Pfirman et al. 1995.)



Contaminant transport along the Arctic margins during winter and summer. In winter, sea ice may be contaminated by deposition from Arctic haze and condensates on the surface, as well during ice formation and entrainment of resuspended sea floor sediments. In summer, river runoff over and under the ice and ice melt stabilize the water column. Open waters maximize direct air–sea gas exchange. Contaminant uptake from surface waters and ice may peak during the spring bloom. Organisms with asterisks are consumed by some Arctic peoples. (After MacDonald and Bewers 1996.)

- Directly from the water column and through the incorporation of resuspended sea floor sediments and contaminants during ice formation;
- Along its transport path by wet (snow, rain, fog) or dry deposition from the atmosphere; and
- By skimming off a surface ocean microlayer enriched in contaminants.

During drift, new sea ice grows at the bottom of the multi-year ice floes each winter, and it melts and runs off the surface each summer. We don't know exactly what happens to contaminants during the freeze/melt cycle, but it seems likely that soluble contaminants are released through brine channels and meltwater, while particle-bound contaminants are moved toward the ice surface. After melting and ablation, particulate matter is often found in cryoconites, which are sediment-laden pits on the ice surface that form by differential absorption of solar radiation. Because many important contaminants sorb onto particles, it is likely that much of the contaminant burden is retained and concentrated at the ice surface to be released during complete melting.

Several recent studies link contaminants directly with sea ice or with particles carried by ice. Concentrations of ^{137}Cs up to 70 Bq/kg have been observed on sediment-laden floes. These concentrations are similar to those found in the Yenisey estuary and are much higher than is typical in other shelf sediments. Also, based on elevated concentrations of chlorpyrifos (a currently used pesticide) in sea ice and seawater near ice, it appears that ice released this pesticide to the sea surface during summer.

It is not yet clear how much contaminants enter the food web through ice algae and how much through pelagic algae, but the contaminant-to-ice-to-ice-algae pathway seems to provide a possibility for direct coupling. Enhanced biological activity at all trophic levels occurs along the marginal ice zone. The process starts with ice algae blooming in April and May. Then, as the ice melts and retreats during the spring and summer, nutrient-rich, under-ice water is exposed to sunlight, and algae blooms are kept near the surface by the same steep density gradient that maintains the contaminants at the surface. The bloom trails the receding ice edge in a band about 50 km wide in the Barents Sea, Fram Strait and the Bering Sea. Zooplankton, fish, birds and marine mammals congregate to feed along the marginal ice zones. Since this is the time when most ice melts, the potential for contaminant uptake seems to be highest at exactly the time (spring bloom) and place (surface water along the marginal ice zone) to maximize uptake. Such processes could connect the high organochlorine concentrations observed in sea ice and in marine mammals off Svalbard.

In addition to its direct effect on contaminant transport and distribution, Arctic sea ice also has physical properties that affect contaminants and our ability to study them. Sea ice hinders navigation, meaning that research is more difficult, as are transport, rescue and cleanup operations. Most surface ships cannot cross the permanent pack, which means sea traffic must often travel farther, through vulnerable, productive coastal regions. Ice ridges, produced by pressure, are accompanied by under-ice keels that can gouge seafloor sediments in waters as deep as 60 m. Icebergs, which form when glaciers calve into the sea, may extend even

Sediments incorporated in sea ice when it formed in shallow seas and entrained resuspended seafloor material. After melting and ablation, sediments are frequently found in cryoconites, or pits, on the ice surface.

Spring algae bloom, which follows the retreat of the ice edge when nutrient-rich waters are exposed and stabilized by melting ice. Massive amounts of biologic material in the water column give it the color and consistency of pea soup, as shown in this photograph from Spitsbergenbanken.

deeper into the sea. Because the Arctic shelves are so broad and shallow, large areas of sediment may be reworked and mixed by the ubiquitous pressure ridges. This mechanism can reintroduce sediment-bound contaminants into the biosphere. Icebergs, even though they are far less frequent, provide the additional risk of colliding with and rupturing sunken containers and ships containing, for example, radioactive waste.

Formation of Dense Waters

Dense waters form in only limited places around the world, typically where the surface salinity increases because of sea ice formation or evaporation, where saline waters are cooled, or where mixing of two water masses with similar density forms another water mass that is denser (cabelling). In the Arctic Ocean, sea ice formation and surface cooling produces dense water in a variety of environments. In winter, brine produced by the rapid formation of ice in polynyas and flaw leads destabilizes the water column, and top-to-bottom convection can occur over large areas. In the case of sufficiently vigorous ice growth, dense water can be formed, which subsequently flows along the shelf bottom to enter the ocean interior at depth. Not only will the formation of dense water cause intense mixing of the water column and renewal of bottom waters, but contaminants may be transported to different depths and locations from where they were injected. Just as salt is rejected when sea ice forms, other dissolved contaminants, such as dissolved aromatic hydrocarbons, may also be rejected and concentrated in the brine plumes. The sinking brines may also enhance the settling of contaminants sorbed to particles; sensors drifting with sea ice observed that during periods of brine production, plankton seemed to be transported with the brines out of the surface layer and down to depths below 100 m.

Water in basins that would be considered isolated by sills could be replaced by denser waters following sea ice formation events. The Novaya Zemlya Trough is thought to be flushed regularly by this means. In the Barents Sea, dense waters filling basins on the shelves accumulate from one year to the next and seem to be released in episodic discharges.

Since about 60% of the total volume of Arctic Ocean water is found below the Atlantic-derived layer (at depths below about 800 m), dense water formation could, in principle, allow dissolved contaminants to penetrate into a large pool of water, which would act as a dilution basin. However, deep and bottom water formation rates in the central Arctic are relatively low compared to the transport rates of surface waters, preventing efficient use of this considerable potential for dilution of contaminants introduced to surface waters. Dense waters formed on the Arctic shelves are transported down the continental slope and are entrained in decreasing amounts into halocline waters, Atlantic-derived water, Eurasian Basin deep water, and Eurasian and Canadian Basin bottom water. Some of the waters flowing off the shelves are confined in fairly narrow boundary currents. These currents can extend across topographic features such as the Lomonosov Ridge, resulting in the exchange of waters and dissolved trace substances between individual basins. Because of the relatively small injection rates of shelf waters into waters below the halocline, dissolved contaminants delivered to the Arctic by river runoff and by dumping into the shelf seas are more or less "sandwiched" between the sea ice cover and the Atlantic-derived water, limiting the dilution effect to a relatively thin near-surface layer.

Recycling of Nutrients

In view of their attraction to lipids, organochlorines (and organo-mercury compounds) can be expected to follow organic carbon in the food web. The Arctic marine food web is unique in the timing of production (primarily spring bloom), the presence of ice algae and the contrast between the interior and the margins. For convenience, the production of organic carbon in marine systems (primary production) has been classified into two categories: new (exportable) production and recycled production. While this concept is an oversimplification, it is useful in distinguishing between carbon that moves in a closed loop within the food web and carbon that becomes discarded or exported from the food web. In general, primary production in the Arctic Ocean is lower than in temperate oceans, which limits the flux of organic carbon out of the surface layer. However, what is unique about the Arctic is the difference between the marginal seas, where new production is supported by a number of processes (seasonal clearing of ice, mixing by winds, upwelling and inputs from the land), and the interior ocean, where, under the permanent pack, supplies of new nutrients are limited and recycling in the upper water column becomes most important. With tight carbon cycling it can be expected that lipophilic contaminants will also be captured and maintained within the food web, with only limited losses through the vertical flux of particles. As new contaminants are added from the atmosphere, they load onto the ones already cycling until a steady state is achieved. For a recycling system, the steady-state concentration of contaminants will be higher than for one with substantial export. Although direct measurements of vertical fluxes of contaminants under Arctic conditions are still lacking, the small vertical flux of carbon under the pack ice supports the concept. Therefore, large portions of the Arctic Ocean may be limited in their ability to discard contaminants to sediments or the deeper ocean by this mechanism.

Role of Shelves

The Arctic Ocean has broader and shallower shelves than any other ocean, consisting of about 25% of the world total. Therefore, shelf processes will have exceptional influence on, for example, reworking of continental inputs, sea ice formation, biologic and chemical cycling, and navigation.

Shelves do not simply transmit terrestrial inputs to the interior ocean. There is substantial reworking. In winter the supply of contaminants from runoff is much reduced, as is the supply of particles to scavenge them. However, convection of the water at this time of year has the potential to move contaminants away from the surface into the deeper layers of the ocean interior (that is, into and possibly below the halocline). Furthermore, nutrients and other sediment components or products, including contaminants, can be remobilized and entrained in the brine leaving the shelf. In summer, contaminants may enter the surface from river runoff, sea ice melt and the atmosphere. At this time, runoff and meltwater contribute to the general stability of surface waters. Therefore, conservative contaminants will remain near the surface because of the strong seasonal stratification, which prevents mixing, and so may be exported from the shelf in the surface layer. Bioactive or particle-reactive contaminants enter the food web or become scavenged by particles to settle toward the shelf bottom, where they may interact with benthos.

The Arctic shelves are important routes for animal migration and feeding. Vigorous benthic ecosystems support migrating species such as the California gray whale, which undertakes the longest known migration of any mammal (22,000 km). Each year California gray whales migrate from the Pacific coast of Baja California to spend the summer in the Bering and Chukchi Seas, where they feed on bottom-dwelling amphipods and other invertebrates.

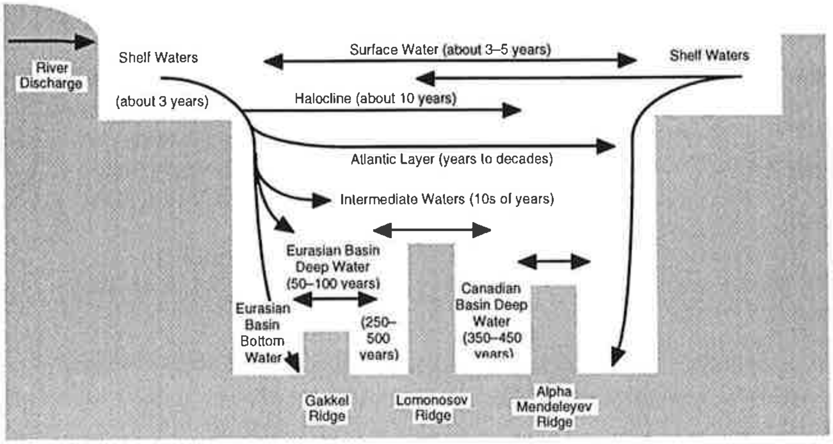
Dotted with numerous archipelagos and peninsulas, potentially rich with natural resources and of strategic importance, the Arctic shelves are of interest to commerce and subject to territorial claims extending far out into the sea. For virtually all transport corridors, navigation must be coordinated between at least two parties when research expeditions are planned along the margins.

Residence Times of Contaminants in the Arctic

In addition to the processes responsible for redistributing contaminants and the pathways along which the redistribution occurs, it is important to understand the time scales involved in the penetration of contaminants into specific reservoirs (the mean residence times of contaminants). These time scales are, of course, the same as those required to remove the contaminants from the affected reservoirs.

Transport by the atmosphere is most rapid and occurs typically within several days to weeks, depending on the season and pressure system. Transport by sea ice is fairly rapid in the eastern Arctic, with ice from the Kara Sea exiting through Fram Strait in about two years, with a minimum transit time of as little as nine months. On the other hand, ice may be trapped within the Beaufort Gyre and recirculate for many years.

Typically waters spend about three years on the shelf before they are detrained and participate in the circulation of the waters in the central basins. Mean residence times of contaminants in the surface ocean (waters above the halocline) may be less than five years. This is the time scale needed for transit from the shelf break to exit points such as Fram Strait. The residence time of waters found in the upper water column increases from several years in the surface waters to roughly one decade in the halocline. Below the halocline the mean residence times are roughly a few decades for Atlantic-derived water, about 50 years in Eurasian Basin deep water, about 250 to 300 years in Eurasian Basin bottom water and about 300 years in Canadian Basin deep water. In this context, mean residence time is defined as the time that a water parcel spends in a specific reservoir or ocean basin. This has to be distinguished from the mean isolation time or mean "age" of a water parcel, which means the time that has passed since this water parcel left the sea surface where it equilibrated with the atmosphere and by definition acquired an "age" of zero.



Physical transport processes and residence times in the Arctic. Atmospheric transport is most rapid, followed by sea ice, surface waters, boundary currents and deeper waters. (Revised from Schlosser et al. 1995.)

For example, there is a difference of about 150 years between the isolation time (about 450 years) and the mean residence time (about 300 years) for Canadian Basin deep water. Transit in the deep basins via boundary currents may be relatively rapid. For example, the distance around the periphery of the Eurasian Basin from Fram Strait to the North Pole could be accomplished in less than three years. However, the deep waters are often trapped in the individual basins by sills, resulting in the long mean residence times mentioned above, which were derived from measurements of natural and anthropogenic tracers [^{14}C, ^{39}Ar, tritium (^{3}H), ^{3}He, CFCs, ^{85}Kr].

Seasonality

The Arctic experiences extreme seasonality: conditions in the winter are very different from those in the summer. Unfortunately most data on the marine environment come from observations made in the summer or in the marginal seas. Since Nansen's famous voyage in the *Fram*, which ended 100 years ago this year, only a few ice camps have been staffed year-round for scientific purposes. Much of this work was done by the Russians and is only now becoming available to the Western scientific community. The lack of knowledge about winter conditions makes it difficult to adequately assess contaminant pathways and uptakes for risk assessments.

Extension of the field season into the winter in perennially ice-covered areas can be accomplished in a number of ways:

- Time-series measurements from bottom-moored or drifting instrument packages, such as current meters, sediment traps, upward-looking sonar and other sensors;
- Declassification of existing data obtained by the U.S. Navy from submarines, and scientific research programs on future submarine expeditions; and
- Ice camps or freezing-in platforms for overwinter experiments (such as the upcoming program to examine the surface heat budget in the Arctic Ocean, SHEBA).

Seasonal differences in the Arctic

	Winter	*Summer*
Semivolatiles	condensation	volatilization
Rivers	low or no discharge	extreme
Precipitation	snow	rain
Sea ice	maximum	minimum
Surface water density gradient	minimum	maximum
Daylight	none	total
Migration	south	north

Interannual Variability

Not only are there large changes from winter to summer, but there are also large changes from one year to the next:

- Last year the sea ice was much less extensive than usual in the Siberian seas. Expeditions designed to sample ice had to go much farther north than expected. Historical records, remote sensing and declassified submarine data show that there are variations in ice extent and thickness ranging from several years to decadal time scales.
- Year-to-year variations in river runoff are as much as 50% of the long-term mean.
- Convection in the Greenland Sea seemed to extend into the deep and bottom waters during extended periods before the 1980s, when for some reason it decreased dramatically and the bottom waters began to age.
- The Beaufort Gyre shifts in location and size.
- The layer of Atlantic water in the Arctic is warming up. At certain sites it is now 0.5–1°C warmer than in any historical observations and we don't know why.

When natural variability is high and measurements are limited, it is difficult to isolate a clear signal. To assess trends and determine natural from anthropogenic signals, it is necessary to have a program of long-term monitoring, as well as multidisciplinary investigation of natural archives, such as ice cores, tree rings and sediment cores from lakes and the ocean.

Monitoring and Assessment

To constrain and verify models of contaminant distribution, we require information on contaminant burdens and trends. A major step forward in documenting contaminant levels in the Arctic will come in 1997, with the publication of the State of the Arctic Environment Assessment Report by the Arctic

Climate Change and Arctic Contaminants

Predicting how contaminants might be affected by global climate change in the Arctic is fraught with difficulty. First, we are not sure how the Arctic will respond to change, although we do know that the average temperature there is likely to increase. Second, even if we could predict the form of change in the Arctic, our knowledge of the behavior of contaminants is not sufficient to state with confidence how they would in turn respond. Nevertheless, it is an important issue, so let's speculate on some possible effects of warming in the marine environment. The following changes could occur:

- Longer time periods and larger areas of open water (probably combined with a later freeze-up);
- Shift in marginal ice zone/high productivity to the north—perhaps off the shelf over areas of deep water;
- Increased incidence of fog due to increased areas of open water;
- Decreased thermal contrast between polar and temperate regions;
- Increased amount and duration of traffic and development on northern sea routes;
- Increased rate of chemical reactions leading to degradation;
- Increased river water discharge; and
- Continued permafrost degradation.

Scenario

Warming will reduce the ice cover, probably most importantly as later freeze-up. Shelves will be open longer, and the system will evolve toward more "temperate" conditions. Primary production could increase significantly, driven by enhanced coastal upwelling and shelf mixing. With an added supply of nutrients, the system would tend to shift toward new production as opposed to recycled production. More open water increases the atmospheric exchange with the sea, more fog enhances contaminant scavenging, and more new production enhances the loss of organochlorines from the ocean surface. Higher temperatures generally reduce the global thermodynamic forcing for semivolatile contaminants (distillation) and increase the kinetic loss. Taken together, warming could lead to a greater loss or dilution of contaminants and, therefore, the contaminant burdens in top predators could decrease.

However, a more friendly ice climate would encourage traffic and industry, both of which will increase site-specific (harbors and sea routes) impacts from contaminants. Substantial proven reserves of hydrocarbons have been found on the shelves, and production would be easier in a warmer regime.

How might convection be affected? The loss of ice cover in the fall would lead to a "saltier" shelf preconditioning because late-season storms could blow summer freshwater stocks off the shelf and mix up deeper, saltier water. If this freshwater removal is greater than the loss of ice formation due to the late start and increased river runoff, we can expect convection to be enhanced. Enhanced convection would increase the removal of surface contaminants to deep water. On the other hand, if the shelves reach the point where increases in freshwater runoff and decreases in ice production stall convection, we can expect this route of contaminant loss to be decreased or shut off entirely.

Monitoring and Assessment Program (AMAP) of the international Arctic Environmental Protection Strategy. This report is based on monitoring by the eight Arctic rim countries (Canada, Greenland/Denmark, Finland, Iceland, Norway, Sweden, Russia and the United States) and will provide important new information on the circumpolar distribution of contaminants.

Much could be gained by adding contaminants investigations to ongoing and future Arctic research programs in terms of utilizing platforms deployed for Arctic research to obtain samples, as well as to conduct research in the shelf seas and in the central basins.

Conclusions

The Arctic environment fundamentally differs from environments at lower latitudes. As a result, contaminant cycling and organism exposure will depend on processes that play a minor or nonexistent role in other environments. Cold trapping and global distillation result in the accumulation of semivolatile agricultural and industrial contaminants in the Arctic. Persistence of aerosols in the stable winter atmosphere results in the widespread distribution of Arctic haze, aerosol contaminants primarily from Eurasia. River run-off transects the entire ocean basin, extending from sources on the Beaufort and Siberian shelves to the far shores of Greenland and the Canadian Archipelago. Sea ice entrains and redistributes contaminants contributed from both the ocean and the atmosphere, at the same time hindering direct ocean–atmosphere exchange. In some locations, dense waters, which formed at the ocean surface by cooling and sea ice formation, convect, redistributing anthropogenic signals to deeper levels in the ocean. Over the central Arctic the halocline hinders vertical mixing. Low vertical fluxes coupled with tight cycling of carbon near the surface mean that compounds that follow carbon (like organochlorines) also are not removed to deeper ocean depths. Although we are beginning to learn more about these processes, predicting their impact on actual ecosystem contaminant exposure is difficult, because of the lack of an integrated understanding of pathways, levels and cycling.

In the future, we hope that research can be carried out in the Arctic that addresses not only traditional physical, chemical and biological aspects, but also processes and pathways involved in the delivery and uptake of contaminants.

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Decision Science for Arctic Resource Management

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Motivating Problem

Managing the world's natural resources responsibly is a well-established concern. How can they be developed productively for the benefit of some yet adequately preserved for all and for posterity? Letting the competing interests play out unfettered, according to the influence they happen to wield, runs the risk that the environment will be devastated, or conversely that economic welfare will be sacrificed.

Nowhere is the problem more acute than in the Arctic. It contains economically valuable resources; the environment is fragile; the impacts of human intervention are multiple, intangible and uncertain, and they propagate throughout the world far from their source; and protecting the environment requires coordinated interaction among political jurisdictions with different capacities, roles and priorities.

There are highly visible cases in point. Nuclear contamination has aroused international alarm and has recently been the focus of major research efforts (see the Fall 1995 issue of *Arctic Research of the United States*). Russia desperately needs the foreign income that development of the immense Yamal gas fields would provide, but major environmental concerns are holding up their development. Oil drilling in the Arctic National Wildlife Refuge may aid national energy independence but endanger a national environmental treasure.

Among the pressing techno-political issues are how to help key players in the decision process make their own best choices and how to help public bodies to police them and assure that the rights of the rest of us are responsibly protected.

In this paper we explore a way for the emerging field of decision science to contribute to this cause. It proposes a way of integrating the well-established practice of risk assessments with value judgments and other considerations, which are taken as given, into a comprehensive evaluation of policy options.

The Need for a Reviewable Rationale

The need for a reviewable rationale for environmental management in the United States dates back at least to the 1969 National Environmental Policy Act (NEPA). Alaska was the site of perhaps the first environmental impact study almost a decade earlier (O'Neill 1994). NEPA and subsequent legislation require a multi-agency and public review of the environmental impacts of a proposed Federal action. Single agencies continue to make decisions about those actions, but they must explain their preference and fully answer other agency and public objections.

Despite a long history of open decision making, U.S. Arctic resource decisions remain ad hoc, with no consistent approach or use of structured analytic techniques. Despite extensive research programs and wide public review, decisions can *appear* to be arbitrary, even when a reviewable rationale has been used, as in the oil permitting case described below. In either case a reviewable rationale is missing. The result can be political and legal battles in which the facts and public interest are buried beneath slogans and simplified images.

In Russia the situation is now similar. In Soviet times many Arctic problems were declared "secret" for military reasons. Central ministries were the dominant decision makers. Now the government must explain Arctic decisions to the general population and participating groups. The decisions must be well prepared, logical and rational, and they must show why the selected option is the best. The need is new for government administrators in Russia, where the tradition of authoritarian rule is strong. Every application of decision analysis must continually demonstrate its usefulness to all participants in real decision-making processes.

Decision Tasks to be Aided

Two types of decision task need to be aided, both to make better choices or, often more important, to communicate their basis for others to appraise. In "contemporaneous" decisions the need for a choice has already arisen. Then there are "prospective" decisions, requiring contingent decision rules, intended to help deciders—or those who would constrain them—to make future decisions. A notable case is when a government agency may have rules regulating potentially hazardous or threatening activity by those it regulates. One decision aid may be used prospectively first and then another aid may be used contemporaneously later, when the contingency arises. Presumably a contemporaneous decision is easier to make if a decision rule has been promulgated beforehand.

Potential Contributions from Decision Science

Decision science, including risk analysis, can address such concerns in principle. However, prac-

The research described in this article was supported by the National Science Foundation's Arctic Social Science program.

tical implementation needs substantial adaptation to ensure that people can supply the inputs and use the outputs, and that the outputs follow from the inputs. It requires drawing on social sciences (such as psychology and anthropology) and logical sciences (such as statistics and philosophy).

There are several broad schools of decision science, at varying stages of development and application. They include purportedly objective and impersonal approaches, such as much of what is known as probabilistic risk assessment (PRA). These have been applied with some success in domains where "objective" data, such as engineering reliability, provide most of the relevant knowledge, where the options are standard, and where there are clear-cut criteria, such as the risk of fatalities. Nuclear regulation comes as close as any to meeting this test, but Arctic resource management rarely does. Critical Arctic knowledge is heterogeneous and incomplete; options are varied; and criteria include many intangible and uncertain considerations and have multiple constituencies.

Decision Analysis

A school we have found more promising, commonly known as decision analysis, is intrinsically subjective and personal. It is a broad paradigm for the systematic evaluation of alternative actions, based on all available information, as a basis for choice among them. Its purpose is to make decisions better and clearer. Its inputs attempt to use all the knowledge and judgment a decider has: his perception of what the options are, what their consequences might be, and their relative importance.

Decision analysis has two main variants: qualitative and quantitative. The former has been associated with Russian decision analysts, the latter with Western. They may draw out different aspects of the same problem.

Qualitative or verbal decision analysis (VDA) relies on natural language and non-numerical categorization of the considerations in a choice. Its major appeal is that it taps effectively into informants' knowledge and values in a familiar form, without distortion or grief, while subjecting them to some discipline and new insights.

Quantitative or numerical decision analysis (NDA) represents uncertainty and value in the form of numbers, and combines them in a quantitative model (derived from statistical decision theory). Its major appeal is that it adds a powerful and novel logic to informal thinking, is universally and systematically applicable, and lends itself to rigorous review.

Each method organizes the data, knowledge and priorities the decision makers would normally use, in a structured, transparent way that clarifies the options, arguments and implied decision. They are intended to enhance the perceptions of individual decision makers. Both methods, especially the quantitative one, have been widely used throughout the world to make public and other decisions sounder and to communicate their grounds and assumptions to interested parties.

Verbal Decision Analysis. VDA tries to use the natural language of the decision maker, other active parties and potential experts to structure a problem. Evaluation criteria are defined for the options initially considered. For each an evaluation scale is constructed with a small number of quality grades ranging from best to worst. These are drawn from natural language, for example, "no damage to the environment;" "moderate damage to environment;" "major damage to the environment." One VDA method is pair-wise compensation, where the options—typically few—are compared qualitatively pair-wise, identifying their relative merits and deficiencies.

At every stage of the decision process, VDA helps the decision maker reduce the decision to a more manageable size. For instance, evaluations on criteria that are not substantially different are eliminated, and a representation is sought where the disadvantages of one option are clearly seen to outweigh the disadvantages of the others. The answers of the decider are periodically checked for contradictions, and if necessary he is invited to reconsider them. A situation of noncomparability may arise, where some evaluations are better for the first option and some better for the second. A new, more promising option may be created by making adaptive changes in existing options. The methodological basis of VDA is described in Larichev and Moshkovich (1996).

Numerical Decision Analysis. Numerical decision analysis (NDA) essentially translates judgment and knowledge relevant to a choice into a quantitative model. It is well known in the West (Raiffa 1968, Watson and Buede 1987, Zeckhauser et al. 1996). Normally it calculates a numerical value for each option, so that the best is clear. A familiar variant attaches a probability and utility to each possible consequence of each option, and the option with the highest probability-weighted (expected) utility is logically preferred. This type of model often suits a case where uncertainty is critical.

Another common variant lists all competing criteria, along with a numerical indication of the relative importance of each. The impact of each option is scored on each criterion, and the preferred option is the one with the highest importance-weighted impact. Thus, high impact in areas of little importance balances out small impact in areas of great importance. This variant often works well in many environmental management decisions, where the critical issue is conflicting objectives, and is the one we will give special attention to here.

An NDA approach is normally comprehensive, in the sense that it should characterize all considerations relevant to a choice (that is, value judgments and factual assessments) at a highly aggregated level. Unlike VDA, NDA does not usually attempt to replace the real situation with a less complete but more tractable one. For example, an importance-weighted impact model does not necessarily reduce the number of criteria, though it may group them into a few classes.

The NDA may use qualitative assessments and natural language, preparatory to developing numerical values. This qualitative step may prove all that is necessary, without quantification, and is in fact advocated by leaders in the field. The theoretical foundations of decision analysis are based on statistical theory (Raiffa and Schlaifer 1962) but are still evolving, and implementation is still primitive. It has enjoyed widespread application to certain environmental problems, such as nuclear power generation, but as yet almost none specific to the Arctic.

Research Project

This paper reports on a research effort by a joint U.S.–Russian research team composed of decision analysts and specialists in Arctic development. The findings of this research are reported in Andre'eva et al. 1996, Andre'eva and Larichev 1996, Brown et al. 1996, Flanders et al. 1996, Larichev 1996, Larichev et al. 1995a,b,c, 1996a,b, Larichev and Moshkovich 1995). The research had twin goals:

- To evaluate and enhance available methodology, including a comparison of VDA and NDA; and
- To adapt this methodology to the needs of those with responsibility for Arctic resource decisions.

Our research tools included theoretical exploration of the empirical and logical properties of each approach. They also include inductive distillation of the large and varied body of the researchers' decision-aiding and field work experience in Arctic and other applied contexts.

However, the primary focus was case testing: to observe and reflect on how VDA and NDA play o ut in the real world, in a loose approximation to a scientific experiment. We addressed illustrative real problems using one approach or the other, and we appraised the extent to which it helped the deciders or other interested parties, with whatever implications it may have for the usefulness of one approach or the other, or any formal approach, for that matter.

Search for Suitable Cases

The choice of cases needs to balance variety against comparability. Above all they had to be real decision-aiding attempts (and not just realistic, let alone laboratory artifacts).

The search for suitable cases proved much more time consuming and frustrating than we ever imagined, with a number of false but illuminating starts. From these it was impressed on us that a sound decision, or even the demonstration of a sound decision, is not always the highest priority in politically charged problems of the type we were pursuing. Previous research had suggested much the same thing (Porter 1989).

Initially we had sought a domain where both countries had an interest in the same issue. A prime example appeared to be the problem of nuclear contamination of the Arctic Ocean. Both countries (and much of the rest of the world) are affected by the consequences, and indeed joint action may be called for. After extensively researching this topic, including several visits to Russia and one to Norway, we reluctantly decided to drop it for two reasons.

As a decision case it turned out to be premature. For the time being, international emphasis was on characterizing the scale and nature of the contamination problem, rather than what to do about it (though we did consider some short-term international initiatives, such as alternative implementations of the London Dumping Convention). In addition, political sensitivity discouraged the Russian members of the team from participating.

The search for an American case also did not run smoothly. We considered in turn the awarding of individual transferable quotas in the Bering Sea fisheries and renovating the Trans-Alaska Pipeline System. We explored the interest of senior participants and researched the problem backgrounds, but in each case either the problem proved unsuitable for our purposes, or the necessary level of intimate collaboration with deciders could not be assured.

Initial attempts to find a Russian case were no less difficult. The first promising option had to do with whether to develop the vast gas reserves on the Yamal Peninsula in western Siberia. The Deputy Minister of Oil and Gas Construction, Ivan Mazur, was under pressure from a new Ministry of Ecology to demonstrate sound and responsible attention to environmental and social concerns before he was permitted to go ahead. He requested our help. We visited Russia and Norway, interviewed several key players and researched the problem.

However, the development of the Yamal gas fields had become a matter of national imperative. On our second trip to Moscow, we learned that President Yeltsin had decided to go ahead with development, implicitly favoring economic over environmental considerations. In any case there was no further practical interest at a decision-making level in having us address this case.

Two cases were developed, both in the domain of oil and gas construction, which both countries had a keen interest in. A Russian case addressed a contemporaneous decision: whether to pipe gas from the Yamal Peninsula over land or under sea. An American case addressed a decision rule for a class of decisions: what procedure Federal regulators should adopt in deciding whether to permit oil and gas construction projects in Alaska.

Russian Pipeline Case

However, there were still controversial and perplexing decisions to be made in implementing the decision to exploit the Yamal gas fields. One supplied us with an excellent case study. During the development of the Yamal gas project, the idea of straightening out the pipeline, by crossing Baidaratskaya Bay, received strong support. The alternative was a longer land route that would cross the Yamal Peninsula east of the bay. The choice of options had been the subject of bitter discussion between two project institutes over several years. Both had arguments for and against the sea and land routes. The decision and the start of pipeline construction had been recently postponed, partly because of the complexity of this choice. The top officials of the Russian Stock Holding Company, Gasprom, offered to use our methodology as background for making the decision.

The Russian team members worked closely with the various parties involved to apply VDA in resolving the controversy. In the process they tried to attract the decision makers' attention to the significance of uncertain factors under Arctic conditions, the assessment of risk situations, and the possible economical, environmental and social consequences of the risk and uncertainty. After the project feasibility analysis by the Russian team members, the main disadvantage of the prior decisions became salient: it was not enough to show where the possible weak points of the project were; it was more important to elaborate on the reliable means of mitigating them. Both institutes had mistakes in their background papers, particularly in their poorly developed methodology for accounting the costs of the Russian economic transformation and for estimating all the uncertain factors. Under Arctic conditions the uncertain factors might bring about major changes in the real costs of construction and affect the exploitation period.

Largely for political and institutional reasons, a firm decision has still not been made. We entered the problem four years ago, and the problem had begun to be explored some years before that. At the time of this writing some technological and financial problems need more study.

However, the exercise had observable effects on the pipeline route decision process. First, the significance of and urgent need for more reliable information on decisive factors was recognized. New experiments and studies are underway, and more than one option is under consideration. Although the sea route version was finally assessed as preferable, it has been reviewed for more reasonable solutions of its drawbacks.

The American researchers made a notional attempt to apply NDA to the same problem, based on the same knowledge and perceptions used in the VDA. Since they had no direct contact with the active participants, little could be learned about practical impact, but technical feasibility was demonstrated.

American Land Use Regulation Case

A suitable opportunity for an American case appeared in 1993 when the U.S. Arctic Research Commission, with the encouragement of the Alaska Oil and Gas Association, asked us to explore analytic methods to resolve controversial regulatory decisions on a "scientific" basis. In particular, when and under what conditions should the Federal government permit oil construction projects that threaten the environment? This represented a case in prospective (rather than contemporaneous) decision making, where aid was sought in developing a contingent decision rule.

The prime motivating example was drilling in the Arctic National Wildlife Refuge (ANWR). The 1973 Arab boycott experience convinced the American public that domestic sources of oil were important to the national weal. The development of the pipeline and the North Slope fields appeared to be a successful national policy. The state and regional governments were also interested in North Slope development. Since 1977 the State of Alaska has earned over 80% of its income from the oil industry. The future ability of the North Slope Borough to pay its creditors depends upon continuing oil production within the borough.

Congress recognized the potential in the Alaska National Interest Lands Conservation Act of 1980, which left open the possibility that the coastal plain of ANWR could be opened to exploration and development. In the 1980s, however, the environment reappeared as a counter concern. In 1991 Congress voted against the development of ANWR.

The decision was not final, however. Both sides, environmentalists and industry, saw permitting decisions on smaller fields as skirmishes preliminary to another ANWR battle. This on-again, off-again sequence, buffeted by political winds, generated a widespread wish, especially in the oil industry, for a defensible, predictable and stable process of permit planning.

Research Approach

We formulated the decision aiding task as follows. We were to develop an analytic vehicle for communicating and understanding the implications of available knowledge and judgment, and for incorporating new data and other input. It was to be used for indicating requirements, receiving permit application, communicating among regulatory parties, making rulings and justifying to third parties. This "meta" case was itself researched with case testing, that is, a regulatory aid was developed by attempting to apply it to representative examples of recurrent regulatory decisions.

To minimize the risk of exposing a preliminary effort to undesirable publicity before we were ready, we sought to take our first steps away from the glare of live hot topics. Nevertheless, we needed examples representative of those controversial cases we wished ultimately to help. Therefore, we chose as an illustrative instance a past case that involved some controversy.

Background on Niakuk Causeway Example

In the late 1980s, British Petroleum (BP) sought permission to develop an oil field on an artificial island 1.25 miles off the Arctic Beaufort Sea shore, with a gravel causeway to pipe the oil ashore. It represented several environmental hazards, including disruption of fish habitat and degradation of water quality. Other means of transporting the oil were available to BP, notably slant drilling (directional drilling from the shore, which did not affect the sea directly). However, they were more expensive and might make the development of the oil field unprofitable. BP argued that a significant source of domestic oil would be lost to the U.S., with implications for its energy independence, a national policy objective.

The major disadvantages of the causeway over slant drilling were in impacts on anadromous fish, ecosystem quality and pro-environment public sentiment. It had advantages in construction employment and a precedent effect for the oil industry. The precedent effect means that causeways would continue to be an available option for the industry in oil-field development.

The regulatory regime to which the permitting decision had to conform consisted of numerous sprawling, uncoordinated state and Federal statutes, administered, largely in isolation, by different government agencies. They required that a permissible project must not exceed certain levels of different kinds of environmental damage, and also that it should "not be contrary to the public interest." There were three salient permitting options: no oil field, one with a causeway and one without a causeway (using slant drilling).

As required, BP submitted a detailed permit application in a loosely structured format of its own, consisting mainly of qualitative arguments. As lead agency the Alaska District of the Corps of Engineers (CoE) issued a permit to develop the oil field but without the causeway (on the grounds that it failed a fish habitat standard). After some national controversy, following a BP appeal to the administration, Corps headquarters in Washington rescinded the findings pending additional data. The Congress conducted hearings on possible improper political influence on that rescission. BP eventually opted to develop the field using slant drilling. It proved profitable.

Niakuk Decision-aiding Effort

The full research team (American and Russian) met with the CoE regulatory team in Alaska, four years after the events described, to develop an NDA-oriented aid that *could have* been used to support the initial local permitting decision or the subsequent challenges to it. In developing the aid we worked with the same government and industrial institutions, and the key specific individuals within them, who had originally been involved. The research team then developed an analysis of the Niakuk proposal, to be treated *as if* BP had submitted it in support of their application. BP did not participate in the analysis. The analysis was intended to faithfully reflect whatever knowledge and thinking was available at the time (without attempting to improve them). The sought-for contribution was to find the best way to communicate the likely consequences of each option and also to determine if those consequences were acceptable.

We considered three alternative formats within an NDA paradigm:* qualitative, graphic and numerical. In each case all consequences—economic, environmental, strategic, etc.—were considered, no matter how intangible. The impacts on them were based only on knowledge available at the time. Options were evaluated based both on acceptable thresholds for each impact and on compensation among impacts. We assumed that the industry applicant would make whatever case it normally

* Technically, a linear additive multiattribute utility analysis model (MUA).

would, but in this format, and the regulators would respond to the applicant. The intent was that this format could lead to a sounder or more easily reviewed decision.

Qualitative Representation

Although expressed qualitatively, without numbers, the initial organization of available knowledge and judgment had an implicitly quantitative structure, with little adaptation needed for NDA. This was an attempt to bypass the common resistance to numerical representations of assessment and value, which was a central motivation for VDA. It was presented first to the deciding group, with the plausible expectation it would be all that was needed to organize their thinking about the problem and make a choice, without any explicit quantification.

We used a table to show how an applicant might have presented its argument. It is based solely on the researchers' reading of the actual application in traditional discursive format and may not be how the applicant in the Niakuk case would actually have completed the analysis.

We proceeded to explicit quantification, but in a graphic form, again intended to avoid common "numerophobia." The graph expresses essentially all the same judgments as the table, but quantitatively and more precisely, in the form of rectangles.

The level of each impact is represented by the width of the box, corresponding to the net effect of an option on a given criterion. For example, in the first row (fish population), high impact is replaced by a bar about 3/4 of the width of that cell. That corresponds to a very high impact, interpreted as "10 years to restore." (Equivalently, that impact could be given a *numerical* score on a scale from 0 to 100, correspondingly defined).

The height of the box represents the importance of that criterion. Thus, the most important environmental dimensions (regardless of the impact on them of any particular option) are animal population, endangered species and water quality.

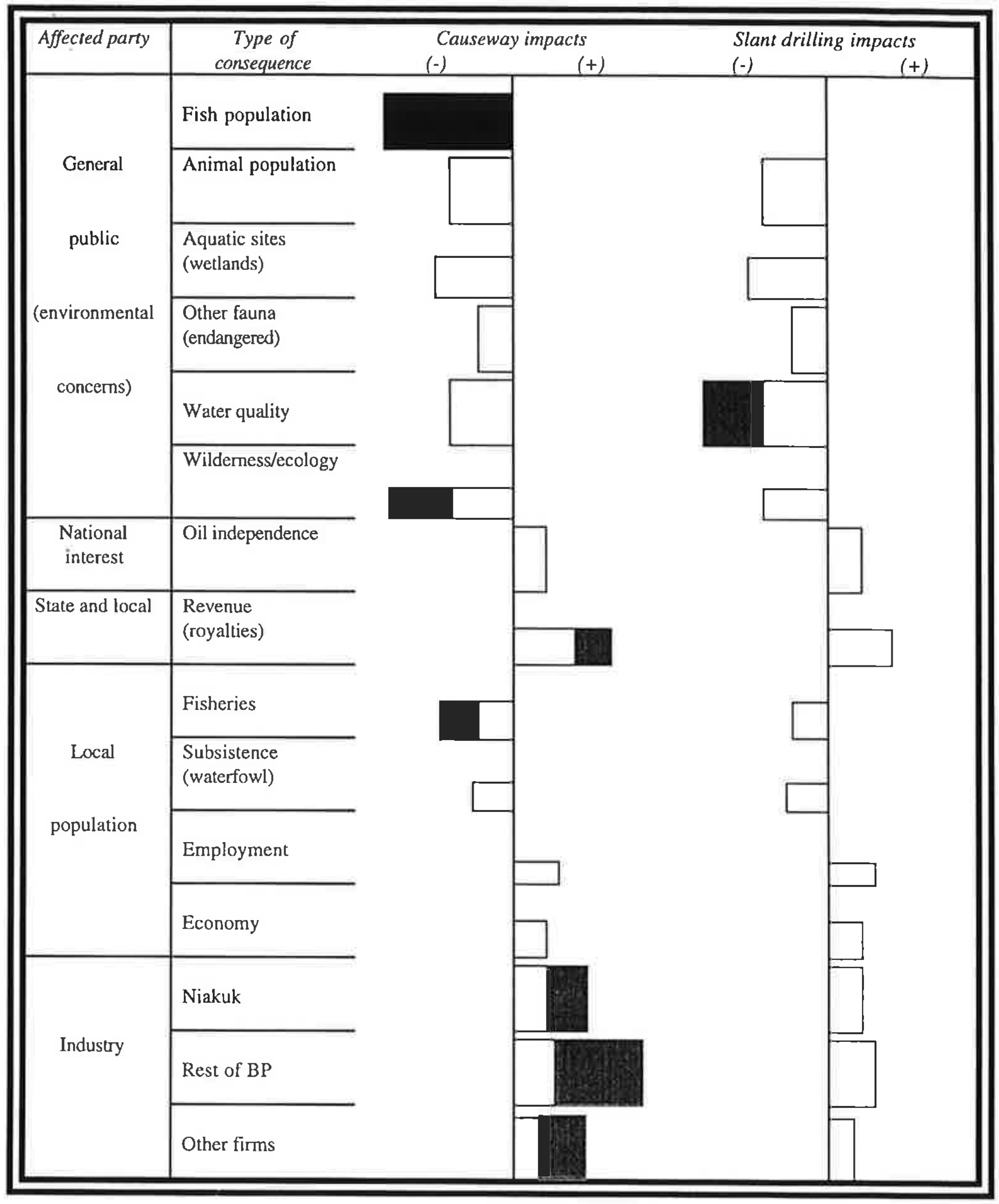
These two dimensions, impact and importance, are combined in a box whose area is their product. This area gives an indication of the net effect of an option's consequence on that criterion. Thus, the causeway has a significant effect via fish population (shown by a large box) because the size of the impact is large and the importance is substantial (though not as high as some others.)

By comparing the total area of boxes favoring the causeway (shown in black) with those favoring

Affected party	*Type of consequence*	*Causeway impacts*	*Slant drilling impacts*	*Definition of very high impact*	*Unacceptable*	*Importance*
General public (environmental concerns)	Fish populations	High	V. Low	10 years to restore	High	Δ Δ
	Animal populations	V. Low	V. Low	10 years to restore	Low	Δ Δ Δ
	Aquatic sites (wetlands)	Low	Low	Comparable to Everglades	High	Δ Δ
	Other fauna (endangered species)	V. Low	V. Low	Probability of extinction up 5%	——	Δ Δ Δ
	Water quality	V. Low	Med.	Two spills over project life	Low	Δ Δ
	Wilderness/ ecology	High	Low	Comparable to Deadhorse	——	Δ Δ
National interest	Oil independence	V. Low	V. Low	5% less oil imports	——	Δ Δ Δ
State and local	Revenue (royalties)	Low	V. Low	$1B over life of field	——	Δ Δ
Local population	Fisheries	V. Low	V.Low	One major species out one year	——	Δ Δ
	Subsistence (waterfowl)	V. Low	V. Low	One major species out one year	——	Δ
	Employment	Low	Low	200 more permanent jobs	——	Δ
	Economy	V. Low	V. Low	20% improvement	——	Δ
Industry	Niakuk profitability	Med.	V. Low	$1B earnings (cumulative)	V. Low	Δ Δ Δ
	Other BP profitability	V. High	Low	$1B earnings (cumulative)		Δ Δ Δ
	Other firms' Profitability	High	V. Low	$1B earnings (cumulative)	——	Δ Δ Δ

Unacceptable Level *Desirable Impacts*

Qualitative Impacts of Niakuk Options
(Assessments by a hypothetical applicant)



Quantitative Evaluation of Niakuk Options *(Hypothetical)*

slant drilling (gray), we have an indication of which option is preferred,* Since the causeway area is clearly, by eye, larger than the slant drilling area—and assuming that the impact and importance inputs are accepted—the causeway should be preferred. One can see, also by eye, that the greater area favoring the causeway is due largely to the high impact and high importance attached to the three measures of industry profitability. This is what one might accept if this were a submission from the oil company applicant. The regulators do not have to accept that, of course, and they can substitute their own assessments when coming to a decision.

A calculated representation of the comparison is given by the bars at the bottom, whose length (calculated from box areas) summarizes the relative weight of arguments favoring the two options. Determining whether the project (with the causeway) has positive value compared with abandoning the oil field entirely involves comparing the total plus and minus areas (both blank and shaded) on

* An approximation to the more rigorous MUA.

the right and left, respectively, of the middle line of the causeway column. It is not now obvious, by eye, whether the "plus" area is greater than the "minus" and therefore whether the project (with causeway) is "worth doing," taking all considerations into account.

A numerical counterpart to the graphic format was developed but excited little interest except as backup to the graphic input and to suggest that the utility of the project was slightly negative, even with the causeway.

Regulator's Evaluation of the Applicant's Case

We reran the above analysis, in the same format, but now with inputs corresponding to the judgment of people associated with the Corps of Engineers in Alaska knowledgeable about the original decision. They were free to adopt or not any feature of the applicant's submission but were asked to use their recollection of the knowledge and judgments they had at the time (rather than hindsight). The new analysis agreed reasonably closely with the mock "applicant's" submission. However, it took issue with the heavy weight put on "industry economics," resulting in much reduced height of those boxes, and therefore less area. It also involved some reformation of attributes (for example, to include a new one for "regulatory precedent").

The result of the adjusted evaluation did, in fact, confirm the original decision of the Alaska District of the Corps of Engineers: to permit development of the Niakuk oil field but on condition that an alternative to a causeway be used to transport the oil. In view of the ongoing controversial circumstances of the case, we do not give actual inputs used due to political sensitivity.

VDA of the Niakuk Incident

The Russian researchers on our team observed the whole process of applying NDA and had a brief opportunity to suggest to the "clients" how they might approach the Niakuk problem using VDA. The clients' initial response was that it looked more attractive than NDA for making a single contemporaneous decision, because it tracked more closely the CoE's usual deliberative processes. However, after further exposure to NDA, including a similar later case, and increasing mastery of the decision analysis "language," they judged that the potential of NDA might be greater than VDA and may add enough to making and communicating multiple permitting decision to justify any investment in technical training.

We noted a marked training effect with practice, as participants climbed the learning curve, in terms of their understanding of the message communicated, psychological acceptance and adeptness in using the aid themselves. Nevertheless, there was still a critical facilitating role for a trained consultant/practitioner to play, particularly in generating initial inputs.

Reaction to Handling of Uncertainty

The most serious reservation of most respondents about the format as it stood was that it does not allow explicitly for uncertainty, a major consideration in Arctic decisions. Uncertainty can be addressed explicitly by adjusting the impact estimates (for example, by making conservative estimates of uncertain benefits, such as oil independence).

That device was attempted but found unsatisfactory for two reasons: option evaluators want to see an explicit measure of uncertainty, so they can second-guess it directly; and they want to be able to use sensitivity analysis to assess what effect further research to reduce uncertainty might have. We are considering possible refinements to the box format to accommodate this requirement, such as margins of error attached to boxes, or differential shading according to degree of uncertainty.

Use of the Format for Communication in Various Groups Involved

The "boxes" aid was used by the CoE-associated people to focus and resolve differences of opinion about the permitting decision. Differences appeared in the weight given to some criteria. The aid made clear their role in choosing between the causeway and other options.

We presented essentially the same analysis to other participating Federal and state regulatory agencies, notably the EPA officer who had been principally involved originally. He clearly understood the meaning of the analysis and indicated he would find it helpful in confirming or responding to an argument on the permit decision, whether presented by the CoE or an applicant. The other regulators had more trouble digesting it and would no doubt require some training in the aid "language."

We also presented this analysis to the head of the regulatory branch at CoE headquarters in Washington, with his staff. He felt that something along these lines could be offered to districts as a resource, making it optional whether they used it or not. This would be in keeping with the decentralized tradition of the Corps. He did not feel tight guidance should be given on the definition or weighting of criteria, since these are almost always situation specific. Any guidance would be largely procedural, such as on structuring the charts and how to elicit input and interpret output, possibly accompanied by some training.

The presentation was also made to the original applicant and other Alaskan oil and gas companies. What we feared from a premature reaction to a live case in fact occurred with this retrospective case. When we attempted to get feedback from the oil industry applicant on our approach, by presenting this as a notional analysis with hypothetical input, the senior executive primarily involved in the original incident reacted negatively to the substance of the input. Even though it supported BP's position, he was resistant to the procedure, especially that part dealing with including and weighting their economics. One can only speculate on the grounds. It may have re-opened old wounds, but in any case he withdrew from further participation in the project.

This confirms our other consulting experience, which suggests that people are uncomfortable having to produce or respond to a too transparent and systematic appraisal of their decisions or recommendations. It may make them more subject to external influence and take away from their power.

One might reasonably expect that if regulation were to require applicants to submit applications in this format, they would have no choice but to go along. However, they presumably have some say on whether they can be required to submit in this form if they participate in the rule-making process.

Outcome

After the completion of the Niakuk post analysis, CoE District staff invited us to look at a current permitting decision: whether to permit BP (again) to construct a dock at Badami with a buried pipeline. With our help, they got as far as constructing and supplying complete input to a boxes aid. However, we could not apply the acid test of observing how it affected their actual permitting decision and its aftermath. This was due to a lengthening of the permitting process, which has extended beyond the end of our research project.

Promise of this Approach in Arctic Policy

Without a more extensive file of cases, the evidence on the potential of such an aid cannot be much more than anecdotal. Any findings can only be suggestive, even if supplemented by experience on analogous cases. The most productive uses of the methodologies explored and applied under this grant may be in support of the regulatory process, both national and international.

Based on this research experience, a procedure along the following lines may be worth pursuing. Regulatory bodies might evaluate any environmentally sensitive proposal in a format of the type presented here. It could be a compact graphic display of the likely relevant consequences of options, both pro and con, tangible and intangible, on a scale whose endpoints are unambiguously defined. It could be either in a qualitative or quantitative form and could include uncertainty (which currently our version does not).

The determination of whether the consequences as presented are acceptable for a permit is evaluated either informally or in the box format. Permissibility is tested quantitatively by comparing the sum of box areas with some critical threshold. Importance weights may be set more centrally in the regulatory organization than impact estimates. This procedure could either be required by some central authority or it could be optional. The permitting decision may be automatic or allow for regulator discretion in how to use the quantitative evaluation.

Which of the above technical options should be exercised will depend on existing statutes, institutional culture, familiarity with technical philosophy or specifics, and other factors that are part of ongoing research.

What Next?

More research is needed before an operational prototype can be developed for practical adoption. Case-oriented research of the type reported here is no doubt worth accumulating. However, it should now be addressed to live (not retrospective) cases, in a build-test-build-test mode. Initially it might be limited to a specific situation, such as controversial issues, of a particular type, such as involving land use.

This may lead to more systematic research, for example, laboratory psychological experiments on cognitive fit, analytic theory, algorithms and computerized aid design, which may call for research skills different from ours. It would also draw on independent developments by others on the general state of the art of decision aiding, including decision analysis.

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A Framework for Assessing the Potential Health Risks of Contaminants in the Arctic Environment

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This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory. Funding was provided by the Office of Naval Research.

The presence of radioactive and nonradioactive contaminants in the Arctic environment has prompted concerns regarding the potential threat they pose to Arctic populations. To address such concerns, it is necessary to characterize the relationship(s) between the occurrence of a given contaminant in the environment and the nature and magnitude of its potential health effects. An understanding of the linkages between a contaminant source and the associated effects is crucial to subsequent actions aimed at reducing risks. Because risk-management actions such as the implementation of pollution control technologies and the promulgation of environmental regulations can have substantial costs, it is increasingly important to base such actions on scientifically sound assessments of the risks posed by environmental contaminants. One potential framework for investigating the consequences of contaminants in the Arctic is based on a methodology that addresses the principal factors controlling the potential risks of environmental contaminants. In this paper I review a systematic approach for assessing the risks of Arctic contaminants and discuss various issues pertinent to its implementation.

Overview of the Risk Assessment Methodology

An integrated assessment of the risk posed by a contaminant released directly into the Arctic environment (or a contaminant released from a source outside the Arctic) includes several distinct components. The basic foundation of any risk assessment is the source-term characterization of the contaminant(s) being addressed. The goals of this component of an assessment are to determine the inventory (for example, the radioactivity or contaminant mass) of the contaminants available for release into the environment and to quantify time-varying emissions to the atmosphere, ocean, land, river, etc. Next, environmental measurements and models are used to determine the transport and fate of the contaminants in the environment. An important output of the transport component of the assessment is the prediction of the spatial and temporal distributions of contaminant concentrations in environmental media, for example, dispersion in ocean waters or the atmosphere, and transport in ice. Once the contaminant concentrations in the environment are determined, an analysis is conducted of the mechanisms that bring humans in contact with the contaminants via ingestion, inhalation and dermal uptake. Exposures to a contaminant are then translated to internal doses to body tissues and organs using models that simulate its uptake, distribution, retention and elimination. Dose-response functions are used to relate biologically effective doses to toxic endpoints (for example, the probability of incurring cancer or neurotoxicity). Finally, sensitivity and uncertainty analyses are performed to guide the interpretation of the predicted risks.

An integrated assessment incorporating the elements discussed above is inherently multidisciplinary, that is, it depends on a coordinated series of analyses and studies by individuals whose expertise addresses one or more of the key elements of the overall assessment. The integration of various disciplinary analyses represents one of the key challenges in conducting a risk assessment because:

- The results of one component of the assessment must meet the requirements of other analyses (for example, the output from the source-term assessment must be consistent with the model used to simulate the contaminant transport); and
- The sophistication of the individual source-term, transport, exposure and dose-response analyses must be commensurate with the overall uncertainties in an assessment.

An important concept in the execution of an assessment is the use of a value-of-information criterion for guiding the individual research elements. For example, if a source-term analysis provides estimates of a contaminant release that are expected to be within a factor of five of an actual release, then it would be difficult to justify expensive improvements to a transport model that might provide only a relatively modest improvement (such as a 20% increase in accuracy) in predicted concentrations of the contaminant. In this example, a case could be made to devote additional resources to reducing the uncertainty in the source-term analysis as a means of improving the risk assessment. This approach for guiding and integrating studies runs counter to the strong disciplinary focus of research projects addressing specific biogeochemical processes in the Arctic. Nevertheless, risk assessments of Arctic contaminants depend ultimately on the results of both disciplinary and multidisciplinary studies.

Source-Term Assessments

The kinds of contaminant sources dealt with in Arctic risk assessments can be categorized in terms of the types of contaminants released (for example, radionuclides, metals or organics), the location of the source (within the Arctic region or outside of it), and timing (that is, a historic, current or future source). Sources of radioactive contaminants within the Arctic, for example, include nuclear wastes dumped in the Kara Sea by agencies of the former Soviet Union (Yablokov et al. 1993) and the nuclear weapons accident at Thule, Greenland (Smith et al. 1994). A prime illustration of a nuclear source located outside of the Arctic Ocean is the Sellafield nuclear processing facility located in Great Britain. Discharges of radioactive effluents to the Irish Sea from that facility in the 1970s now constitute a major source of the radionuclide cesium-137 in the Arctic Ocean as a result of the long-range transport from the Irish Sea via ocean currents (Kershaw and Baxter 1995). The Chernobyl reactor accident in 1986 is also a source of cesium-137 in the Arctic Ocean. The Ob and Yenisey Rivers, which drain large areas of the former Soviet Union and discharge to the Kara Sea, are additional sources of radionuclides derived from global fallout and discharges from nuclear facilities (Trapeznikov et al. 1994, Vakulovsky et al. 1995). Metals and organic compounds in the Arctic have received considerable attention in recent years, with mounting evidence that such substances originate at sources located outside the Arctic and are transported into the Arctic by ocean currents and atmospheric flow patterns (Barrie et al. 1992).

A risk assessment of Arctic contaminants derived from the sources noted above is either retrospective, because it seeks to assess the risks of contaminants that are already in the Arctic environment due to previous or existing releases from a given source or sources, or prospective, because it addresses the risks of a future release of a contaminant. An important part of a retrospective assessment is the reconstruction of the historic releases from a given source by:

- Using historic measurements involving the releases;
- Inferring the release amounts using contaminant transport models with source terms that provide the best agreement between predicted concentrations in environmental media and observed levels; and
- Using operating histories of a given facility along with process models to derive estimates of the magnitude of potential releases.

Measurements of radionuclides in ocean waters and sediments of the Arctic, for example, have been used to assess radionuclide inventories at waste sites (Smith et al. 1994) and to identify radionuclide sources using isotopic ratios as characteristic signatures of a given source (Hallstadius et al. 1986, Raisbeck et al. 1995). Similar environmental measurements can be used to investigate sources of metals and organic substances in the Arctic seas. An example of the use of a transport model to reconstruct a source term is given in Gudiksen et al. (1989). They were able to estimate the magnitude of the cesium-137 release from the Chernobyl reactor accident by running a three-dimensional air dispersion model with an emission rate of cesium-137 that gave the best agreement with observed concentrations in the atmosphere. The initial estimates of the inventories of radionuclides in naval reactors disposed of in the Kara Sea were based on process models used to estimate the historic energy production in naval reactors prior to disposal and the associated amount of radioactive isotopes generated (Mount et al. 1994).

In contrast with retrospective source assessments, prospective assessments of a given source usually must rely on published emission factors for releases to the environment or on the development of scenarios to represent accidental discharges. An emission factor simply relates the emission rate of a contaminant to a basic measure of input or output for the type of facility being assessed (for example, grams of contaminant released into the atmosphere per tonne of coal combusted in a power plant). Sometimes a source-term emission factor must be derived from measurements associated with an existing source. To illustrate, Pereira and Hostettler (1993) estimated the quantities of herbicides discharged from the Mississippi River based on measurements of the herbicide concentrations in water and data on water discharge. The estimated fluxes, along with data on the quantities of herbicides applied to farmlands in the Mississippi River basin, can be used to calculate a source-term factor relating riverine discharges with herbicide applications. Future projections of herbicide discharges are then scaled according to the magnitude of herbicide usage. In principle, this technique can also be used to establish source terms for selected contaminants discharged from Arctic rivers.

Contaminant Transport: Modeling and Measurements

The transport and fate component of a risk assessment establishes the crucial link between the release of a contaminant from a given source and its occurrence in exposure media that individuals come in contact with via ingestion, inhalation and dermal uptake. Ideally the characterization or simulation of the transport of a contaminant in the air or ocean requires a coordinated program of modeling, experiments and measurements to ensure that model predictions are based on relevant input data and to provide data that can be used to validate model predictions. For example, the water movements predicted by ocean circulation models should be compared against measurements of ocean currents at different locations in the Arctic Ocean (for example, inflow from the Pacific Ocean through the Bering Strait) and the results of isotopic tracer studies that provide information on water exchanges between the Arctic seas (Schlosser et al. 1995). A systematic review of the input requirements of an atmospheric or ocean transport model as well as the available data for meeting those requirements will help to reveal potential data gaps. Such an audit can also serve as an important element in the model selection process, for if the data requirements of a given model cannot be satisfied, then simpler, less data-intensive models should be considered.

Another consideration in the model selection and implementation process is the computational requirements for simulating contaminant releases over long time scales (for example, decades). In situations where the actual computational periods on a computer last weeks or even months, it becomes increasingly difficult to conduct repetitive runs of different contaminants, input parameters, release scenarios, etc. However, alternative modeling strategies can be devised to support risk assessments that take advantage of both computationally intense numerical models of contaminant transport and models that are based on less refined representations of transport processes. Marietta and Simmons (1988), for example, employed a numerical ocean circulation model to estimate the water exchange rates between the ocean compartments of a simpler, less computational intense model used to predict concentrations of radionuclides in ocean water resulting from potential releases at a seabed disposal site for nuclear wastes. Nielsen et al. (1995) used a similar approach to assess the transport of nuclear wastes dumped in the Arctic Ocean.

Atmospheric transport models are also computationally intense, so it is desirable to limit the source-term scenarios and meteorological cases that are simulated to those that are most important in terms of contaminant transport to the Arctic. One way of identifying important transport pathways is to use air trajectory models to examine atmospheric flow patterns from source areas external to the Arctic and receptor locations within the Arctic. Harris and Kahl (1994), for example, employed an isentropic air trajectory model to characterize air trajectories for Barrow, Alaska, that originated in Russia, Europe and the North Pacific. The results of this type of trajectory analysis were used to determine the frequencies with which atmospheric transport originated in a given region by time of year. Identification of the meteorological regimes leading to enhanced transport to the Arctic can serve as the basis for simulations of atmospheric releases of contaminants within the source regions using a numerical dispersion model (Sullivan et al. 1993).

Exposure Assessment

The assessment of exposures to contaminants requires three basic types of information:

- The characteristics of the human populations that influence the frequency and duration of contacts with contaminated media, including soil, food, water and indoor/outdoor air;
- The physicochemical properties of the contaminant; and
- Properties of the environmental media (Layton et al. 1994).

Important exposure-related parameters for populations include their dietary characteristics, activity patterns and breathing rates. One topic that needs to be dealt with in risk assessments of Arctic contaminants is identifying and assessing groups that may receive elevated exposures to a given contaminant because of their lifestyle characteristics.

Arctic populations are likely to include critical groups, largely because of their dietary intakes of subsistence foods consisting of marine mammals, fish and caribou. One exposure pathway that has led to elevated exposures to cesium-137 deposited on the Arctic tundra is the transfer of cesium-137 from lichen to caribou to man (Hanson 1994). The magnitude of associated exposures depends on the spatial and temporal deposition patterns; the relationship of those deposition patterns with the feeding habits of caribou; the deposition, retention and excretion of cesium-137 in caribou; and importantly, the consumption of caribou meat by critical groups. The linkages identified in this exposure pathway underscore the need for the integration of the source term, transport and exposure components of a risk assessment dealing with an Arctic contaminant. Similar linkages have to be addressed for radionuclides, metals and organics present in marine foods consumed by Arctic populations.

Dose-Response Assessment

The goal of the dose-response assessment component of the risk assessment is to define the relationship(s) between the intake of a contaminant and potential health effects, including carcinogenic and noncarcinogenic responses. There are basically two types of toxic substances addressed in risk assessments: those that exert effects once a threshold intake rate is exceeded and those that pose some health risk at any intake level, with risks generally decreasing as contaminant intakes decrease. For many substances, safe intake rates have been defined by regulatory agencies, such as the U.S. Environmental Protection Agency. However, for other chemicals, particularly substances that have the potential for causing cancer, the actual dose-response functions are unknown, so they must be estimated using available data from human epidemiological studies or animal cancer bioassays. Uncertainties associated with the development of such dose-response functions arise from a lack of knowledge on the mechanisms of carcinogenesis, the ability of animal cancer bioassay data to predict human health risk, inter-individual variability in metabolic capacity, dietary differences, susceptibility to cancer induction, etc. (Layton et al. 1995). The potential risk posed by an Arctic contaminant (and its associated uncertainties) must be balanced against the cultural, nutritional and health benefits of traditional foods (Kinloch et al. 1992, Kuhnlein 1995).

Risk Characterization

The final component of an integrated risk assessment is the characterization of the risk posed by the contaminant(s) of concern. Usually health risks are expressed as the probability of incurring cancer as a result of exposure to the contaminant(s), as a comparison of the predicted intake of a contaminant against acceptable intake rates, or alternatively the probability of exceeding a prescribed intake rate via inhalation, ingestion or dermal uptake. The risk characterization addresses the key contributors to risk, including the identification of the most important exposure pathways and contaminants. Uncertainty and sensitivity analyses augment the basic assessment by demonstrating which components of the assessment contribute the most to the uncertainties/variabilities in the predicted risks. A common method of assessing uncertainties is to use Monte Carlo sampling to propagate uncertainties/variabilities in the parameters used in the risk models (McKone and Ryan 1989). The major uncertainties addressed in the risk characterization can then be addressed in follow-on research designed to reduce those uncertainties. A final consideration that needs to be addressed in the characterization component of a risk assessment is the communication of the predicted risks (Hunter et al. 1994). This is never an easy task, given the broad backgrounds, interests and risk perceptions of the Arctic peoples who might receive the results of an assessment. Nevertheless, if the communication-related aspects of the risk assessment are not addressed, there is an increased likelihood that the results may be misinterpreted, misunderstood or, worse, misused.

Risk Management

The results of a risk assessment serve as the basis for subsequent actions to manage the predicted risks. If the risks are above levels that would trigger a regulatory response, then efforts would begin to examine and implement risk-reduction alternatives. Examples include implementing pollution controls, establishing regulations that define acceptable concentrations of a contaminant in environmental media, foods, etc. Although risk assessment has been viewed traditionally as an independent input to risk management, it is clear that in cases such as the Arctic where multiple contaminants occur, there must be a closer coupling of the two processes to ensure balanced responses to the potential risks.

Because the costs of risk-reduction actions are receiving increased scrutiny, the need for uncertainty analyses that describe the confidence in the predicted risks is becoming more essential. As an illustration, let's assume that there are two hypothetical Arctic contaminants that pose equal health risks and have the same risk-reduction costs. However, the predicted risk for one contaminant is far more uncertain than that of the other contaminant. In this case, it would be more prudent to allocate funds to deal with the contaminant for which the predicted risks are more certain to ensure that real risk reduction will be achieved. It is also reasonable to allocate additional research funds to reduce the uncertainties in the potential risks posed by the other contaminant.

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Sixth Biennial Report of the Interagency Arctic Research Policy Committee to the Congress
February 1, 1994, to January 31, 1996

Prepared by the National Science Foundation for the Interagency Arctic Research Policy Committee

Background

Section 108(b) of Public Law 98-373, as amended by Public Law 101-609, the Arctic Research and Policy Act, directs the Interagency Arctic Research Policy Committee (IARPC) to submit to Congress, through the President, a biennial report containing a statement of the activities and accomplishments of the IARPC. The IARPC was authorized by the Act and was established by Executive Order 12501, dated January 28, 1985.

Section 108(b)(2) of Public Law 98-373, as amended by Public Law 101-609, directs the IARPC to submit to Congress, through the President, as part of its biennial report, a statement "dealing with particularity the recommendations of the Arctic Research Commission with respect to Federal interagency activities in Arctic research and the disposition and responses to those recommendations." In response to this requirement, the IARPC has examined all recommendations of the Arctic Research Commission since February 1994. The required statement appears in Appendix A.

Activities and Accomplishments

During the period February 1, 1994, to January 31, 1996, the IARPC has:

- Prepared and published the fourth biennial revision to the United States Arctic Research Plan, as required by Section 108(a)(4) of the Act. The President transmitted the Plan to Congress on July 14, 1995.
- Published and distributed four issues of the journal *Arctic Research of the United States*. The journal reviewed all Federal agency Arctic research accomplishments for FY 92 and 93 and included summaries of the IARPC and Arctic Research Commission meetings and activities. The Spring 1995 issue contained the full text of the fourth biennial revision of the U.S. Arctic Research Plan.
- Consulted with the Arctic Research Commission on policy and program matters described in Section 108(a)(3), was represented at all meetings of the Commission, and responded to Commission reports and recommendations on Arctic Ocean and Bering Sea studies, land–atmosphere interactions, upper atmosphere and space studies, engineering, people and health, natural resources, the environment, long-term studies, education, research infrastructure (including logistics) and data and information. (Appendix A).
- Continued the processes of interagency cooperation required under Section 108(a)(6), (7), (8) and (9).
- Provided input to an integrated budget analysis and crosscut for Arctic research for the President's budget, which estimated $191 million in Federal support for FY 94 and $175 million in FY 95.
- Arranged for public participation in the development of the fourth biennial revision to the U.S. Arctic Research Plan as required in Section 108(a)(10).
- Converted the Arctic Environmental Data Directory (AEDD), which now contains information on over 400 Arctic data sets, to make it available from Alaska as a resource on the World Wide Web on the Internet.
- Continued the activities of an Interagency Social Sciences Task Force, including participation in an Arctic Health Seminar. Of special concern is research on the health of indigenous peoples and research on the Arctic as a unique environment for studying human environmental adaptation and sociocultural change.
- Assisted in the establishment of an Alaska regional office of the Smithsonian's Arctic Studies Center in cooperation with the Anchorage Historical Museum to facilitate education and cultural access programs for Alaska residents.
- Supported continued U.S. participation in the non-governmental International Arctic Science Committee and U.S. participation in the Committee's International Conference on Arctic Research Planning held in Hanover, New Hampshire, in December 1995.
- Participated in the National Security Council review of U.S. policy in the Arctic. This review resulted in a new U.S. policy for the Arctic that expanded the focus of U.S. Arctic policy to include greater emphasis on science and environmental protection.
- Participated in policy formulation for the development of the Arctic Environmental Protection Strategy. This strategy contains a

set of principles and objectives for the protection of the Arctic environment. IARPC's Arctic Monitoring Working Group serves as a U.S. focal point for the Arctic Monitoring and Assessment Program (AMAP) and coordinates domestic monitoring efforts.

- Focused attention within the U.S. Government on the dumping of nuclear waste and other toxic waste materials by the former Soviet Union on land and into the Arctic Ocean, seas and rivers; also provided assistance to the Department of Defense Arctic Nuclear Waste Assessment Program (ANWAP).
- Approved a coordinated Federal agency research initiative on Arctic contamination at its June 1994 meeting. The initiative augments individual agency mission-related programs and expertise to address the key unanswered questions about Arctic contamination. The initiative is intended to help guide internal agency planning. The goal of the IARPC Arctic contamination research initiative is to assess the sources, transport, fate, effects and risks of contaminants directly disposed of in the Arctic, as well as contaminants accumulating in the Arctic from non-Arctic sources, in relation to human health and ecosystems in Alaska, the remainder of the Arctic and the Earth as a whole. This initiative proposes the development of an integrated, comprehensive assessment including: 1) data rescue and synthesis; 2) observations; 3) process-oriented research; 4) model development; 5) impacts analysis and determination of risk; and 6) information management. Funding for the initiative should be included in agency budget submissions if the initiative is of sufficiently high priority to each agency.
- Convened two formal meetings of the Committee, in June 1994 and May 1995, and twenty-six meetings of IARPC staff committees, working groups and task forces to accomplish the above items.

Appendix A: Interagency Arctic Research Policy Committee Responses to Recommendations of the Arctic Research Commission

Section 108(b)(2) of Public Law 98-373, as amended by Public Law 101-609, directs the IARPC to submit to Congress, through the President, as part of its biennial report, a statement "dealing with particularity the recommendations of the Arctic Research Commission with respect to Federal interagency activities in Arctic research and the disposition and responses to those recommendations." In response to this requirement, the IARPC has examined all recommendations of the Arctic Research Commission since January 1994. The previous IARPC report, submitted in January 1994, responded to Commission recommendations through 1993. Many of these recommendations deal with priorities in basic and applied Arctic research that ongoing agency programs continue to address.

The following recommendations are from the Arctic Research Commission report Goals and Priorities to Guide United States Arctic Research (January 1995).

Basic Research Priorities

Arctic Ocean and Bering Sea Studies

1. The Commission recommends a concentrated, multi-agency program of intensive study of the Arctic Ocean and Bering Sea based upon the following six areas of opportunity.

i. An intensified program of study of Arctic Ocean Energetics including the DOE's Atmospheric Radiation Measurement (ARM) program and the interagency Surface Heat Budget of the Arctic (SHEBA) program.

Preparation is well underway for initial deployment of the ARM site on the North Slope of Alaska near Barrow, beginning in 1997. In addition to a long-term site near Barrow, ARM plans to deploy instrumentation in support of the SHEBA program (1997–1998).

NSF has initiated Phase 1 of SHEBA to support activities that require long lead times before the experiment takes place. Proposals to analyze existing data sets, define ice–ocean models and design new instruments for use in the experiment have been funded. A science plan for the experiment exists, and an Announcement of Opportunity will be published in 1996. NSF expects the experiment to commence in late summer 1997.

NOAA's National Weather Service (NWS) has been actively involved in DOE's ARM program by providing logistical support (use of the Barrow Weather Service Office), communications (NWS communications lines) and measurements (additional upper air balloon releases).

In 1995, NOAA's National Environmental Satellite, Data, and Information Services implemented a number of experimentally operational products to support the ARM program. These products, produced from the high-resolution infrared sounder instrument carried on the NOAA polar-orbiting environmental satellites, are:

- The downward long-wave radiation at the surface of the earth;
- The outgoing long-wave radiation at the top of the atmosphere; and
- The long-wave cooling profile.

Based on its experience and general expertise in polar remote sensing as a result of its participation in the Arctic Leads Experiment, NOAA is developing and constructing a Doppler cloud radar, a lidar and a Doppler wind profiler for future deployment in the main ice camp of SHEBA during the spring of 1997. These systems will be used in conjunction with other surface-based remote sensors for studies of boundary-layer dynamical and cloud-aerosol/radiative effects on the ice surface energy budget. All three systems will feature high reliability in Arctic conditions and will operate "unattended" except for occasional changing of storage media or transfer of data. A prototype wind profiler and the lidar will be tested in Alaska in 1996. Testing and SHEBA deployment of these systems is being closely coordinated with the Arctic component of the ARM program.

NOAA's Climate Monitoring and Diagnostics Laboratory (CMDL) continues to measure solar and infrared radiation at the observatory at Barrow, Alaska. The data are especially applicable to Arctic Ocean energetics and surface heat budget studies. A Memorandum of Understanding links NOAA and DOE in the ARM program.

ii. An organized study of the physical oceanography of the Arctic Ocean focusing on both the general circulation and the process of deep water formation. This study should build upon the achievements of the 1993 and 1994 expeditions.

A prominent feature of the Arctic Ocean is its permanent, dynamic ice cover. This marine cryosphere significantly impacts the environment on all scales, from climatic to molecular. Critical processes occur in the atmosphere and oceanic boundary layers above and below the ice. A major IARPC priority is the development of the next generation of operational ice forecasting tools and models. A systematic program of oceanographic, cryospheric and atmospheric measurements by conventional technologies, as well as new technologies such as autonomous underwater vehicles, is planned to support the objectives of this research.

The agency objectives are to:

- Determine the processes, history, dynamics and mechanisms of ice production, deformation, advection and decay;
- Determine the processes of renewal and mixing of Arctic and Subarctic water masses from large to small scales;
- Determine the large-scale circulation of the Arctic Ocean, and circulation dynamics, including the role of shelf seas, boundary currents and exchanges with adjoining seas;
- Develop advanced methods of unmanned environmental monitoring such as buoys and AUVs; and
- Determine the mean and natural range of variability of currents and hydrographic features in the nearshore region of the Bering, Chukchi and Beaufort Seas.

NSF, the Office of Naval Research, and other agencies plan to fund research to analyze data collected on earlier cruises to the Arctic Ocean for investigation of the general circulation and deep water formation.

In 1995 the U.S. Navy carried out an unclassified scientific mission under the Arctic ice from a nuclear submarine. A multi-agency (DOD, NSF, NOAA, Interior) open invitation was issued to the scientific community to submit proposals for data acquisition. This program will continue for at least five years.

iii. A concentrated and systematic study of the biologic structure of Arctic Ocean and Bering Sea communities. This too should build on the 1993 and 1994 expeditions and on the Bering Sea ecosystem report published by the Polar Research Board.

The biota of marine and coastal ecosystems are influenced by physical processes, including seasonal extremes of light and temperature. Arctic marine ecosystems are dominated by sea ice, while coastal ecosystems are influenced by freshwater input and seasonal sediment loads, as well as by seasonal sea ice. NSF, NOAA and other agencies plan to support research to quantify the resulting variability in the rates of biological production of marine living resources through long-term interdisciplinary research.

The research objectives are to:

- Determine the status of fish, bird and marine mammal populations and identify the habitat requirements;
- Monitor coastal ecosystems to detect and quantify temporal changes in nutrient and energy exchange and their effect on biota;
- Determine the magnitude and variation of marine productivity in Arctic areas;
- Consider the influence of ice and human activities on both the biotic and abiotic components of the Arctic environment;
- Study the influence of Arctic marine productivity on the global cycling of biologically active materials, including carbon and nitrogen; and
- Understand the physical and biological processes that affect fisheries recruitment in the U.S. waters of the Bering, Chukchi and Beaufort Seas.

iv. An intensified study of fisheries in the Arctic region with a special emphasis on the Bering Sea fishery.

During 1994 and 1995, NOAA's Coastal Ocean Program and the National Marine Fisheries Service, in cooperation with NOAA's Pacific Marine Environmental Laboratory, participated in the Bering Sea Fisheries Oceanography Coordinated Investigations. The project is designed to provide information to reduce the uncertainty in resource management decisions by conducting research into the walleye pollock population of the southeastern Bering Sea shelf. The activities have included a review of pollock surveys, international agreements to share data and resources, and the development of a genetic probe to distinguish different populations, suggesting major differences between eastern and western Bering Sea pollock. A multi-year ecosystem study, titled "Southeast Bering Sea Carrying Capacity," will be initiated in 1996. This study will examine juvenile pollock in terms of their linkages to other species and environmental factors. Investigators will interact closely and provide information to the North Pacific Fishery Management Council.

NOAA's National Marine Fisheries Service Alaska Fisheries Science Center (AFSC) continues to annually and triennially assess stock conditions for most species of marine finfish and shellfish having commercial, recreational and/or ecological significance in the Bering Sea and Aleutian Islands. These assessments provide measures of population abundance and also address the status and health of the marine ecosystem as a whole. In 1994 the AFSC conducted comprehensive bottom trawl surveys of Bering Sea and Aleutian Islands finfish and shellfish and a survey of Bering Sea pollock. In 1995 the AFSC continued the annual survey effort in the Bering Sea with a bottom trawl survey of finfish and shellfish on the eastern Bering Sea shelf. This survey is planned to be conducted again in 1996.

v. A coordinated, multi-agency study of the geodynamics of the Arctic region including the evaluation of natural hazards associated with plate margins.

The Arctic continental margin and deep ocean basin constitute one of the least understood geological regions of the world, partly because much of the offshore area is covered with sea ice. A better understanding of the tectonic history, geologic structure, sediment processes and distribution, and climatic and glacial history of the deeper basin is an IARPC objective. NSF, with limited assistance from the Office of Naval Research, is supporting extensive geophysical and geological research and the integration of newly collected data on an international scale. Agencies will consider joint interagency proposals to study the geodynamics of the Arctic region, including the evaluation of natural hazards associated with plate margins.

vi. An intensified study of the paleoceanography and paleoclimatology of the Arctic region. This study should be coordinated with the Marine aspects of Earth System History (MESH) program.

NSF and other agencies recognize the need for paleoceanographic and paleoclimatic studies of the circumpolar Arctic. NSF has responded to this by supporting research activities across a wide range of the paleosciences. Perhaps the best known is the second Greenland Ice Sheet Project (GISP2), which is currently coming to an end after successfully retrieving the world's deepest ice core. The analysis of paleoatmospheric composition and physical–chemical characteristics is a major achievement of the science community and has impacted many aspects of paleoclimatology. Together with the European ice core project (GRIP), this work represents a critical contribution to the global change sciences.

The paleoenvironments from Arctic Lakes and Estuaries (PALE) project is the terrestrial complement to the ice core work in Greenland. The project focuses on the paleoenvironmental record from Alaskan and Canadian lake sediments and on joint activities with scientists from Russia and Iceland. PALE seeks to better understand the spatial and temporal resolution of paleoclimate in the Arctic and will establish the envelope of natural climatic variability and the baseline of pre-anthropogenic environments.

Both of these projects have clear links to the Earth System History program. They form the Arctic anchor for much of the paleoscience research of the lower latitudes. Both of these projects are also linked to the international effort in global change research. Past Global Changes (PAGES), a core project of the International Geosphere–Biosphere Program, recognizes these projects as being essential elements of the overall effort.

2. The Commission notes the very substantial dependence of scientific progress in the Arctic Ocean on scarce and expensive facilities and notes again its recommendation for the acquisition of the Arctic Research Vessel.

Vessels supporting research in ice-covered areas fall into three categories, based on their ice-going capability. The categories are:

- Icebreakers operated by the Coast Guard;
- Ice-capable and ice-strengthened vessels for research and survey purposes; and
- Nuclear submarines provided by the U.S. Navy.

The Arctic Research and Policy Act (ARPA) confirms the Coast Guard's role as manager of the Nation's icebreaker fleet to serve the Nation's interests in the heavy ice regions of the Arctic. This includes security, economic and environmental interests. Coast Guard icebreakers support research in these regions in two general ways: on dedicated science deployments and, as opportunities arise, in conjunction with other missions. The Coast Guard has two icebreakers and is acquiring a third. A design and construction contract was awarded to Avondale Industries, Inc., of New Orleans in July 1993. The Coast Guard icebreaker *Healy* is scheduled to be delivered in 1998. A fourth research vessel is operated by NSF in the Antarctic.

A research vessel providing all-season access to the Arctic region is essential for many research requirements. As part of the planning process for such a vessel, the National Academy of Sciences conducted a review and evaluation of the scientific requirements for an Arctic research vessel in the context of current national research needs in the Arctic ocean regions. The study included an assessment and update of past studies, a comprehensive analysis of all Arctic facilities and their roles in meeting research requirements, and recommendations for national planning and coordination. The panel found that the new Coast Guard icebreaker *Healy* could provide a usable platform for Arctic science if changes were made in crew size and experience and in the space available for science. In an additional report the General Accounting Office (GAO) said that the need for an additional

Arctic research vessel has not been demonstrated. The GAO report indicates that national research needs can be adequately met with a fleet of four vessels.

Land–Atmosphere Interactions

The Commission recognizes the significance of the NSF Land–Atmosphere–Ice Interaction program and recommends a broad, interagency effort to extend and amplify the benefits of this study.

NSF currently supports a large Land–Atmosphere–Ice Interactions (LAII) research program in Alaska. EPA, NOAA, DOE and other agencies support the basic thrust of the LAII program. Over the last five years, NOAA has developed an extensive capability for polar measurements for the Arctic Leads Experiment. In 1994 analysis of the data enabled researchers to improve their understanding of the physical processes dominating the dynamics of the Arctic atmospheric boundary layer. In 1995 the data set was used for initializing and verifying boundary layer, radiation, mesoscale and global climate models.

Preparation is well underway for initial deployment of the ARM site on the North Slope near Barrow, Alaska, beginning in the spring of 1997. See *Arctic Ocean and Bering Sea Studies* above.

Upper-Atmosphere Studies

1. The Commission emphasizes the need to intensify the studies of the downward and equatorward propagation of high-latitude disturbances caused by solar variability and their possible effects on the global Earth system.

Unique observations of the Earth's magnetosphere and ionosphere are conducted from the Arctic because of its location close to the geomagnetic pole. Plans are being considered for a Polar Cap Observatory (PCO) near the Earth's geomagnetic pole at Resolute Bay on Cornwallis Island in the Northwest Territories of Canada. The scientific requirements for the PCO have been identified by a series of workshops that brought together leading upper-atmosphere researchers. Two chains of incoherent scatter radar facilities, one in North America and one in Europe, currently provide measurements of ionospheric electron content, plasma drifts, electron and ion temperatures and a variety of other atmospheric parameters that are derived from these quantities. The Polar Cap Observatory would constitute an apex of both of these chains. The plans call for the main component of the PCO to be a state-of-the-art incoherent scatter radar consisting of a high-power transmitter and a large steerable antenna that allows atmospheric properties to be measured over a large portion of the polar cap. Also included would be a suite of smaller optical and radiowave devices for remotely sensing atmospheric parameters not measured by the incoherent scatter radar.

The state of the space environment near Earth and its response to solar inputs has come to be known as "space weather." At present there is a multiagency effort to coordinate research and model development in this area, with the goal of enabling improved space forecasting abilities. Arctic observations, such as would be made by the Polar Cap Observatory, are critical to the success of these efforts.

NOAA's Space Environment Laboratory continues to fly space environment monitor (SEM) packages on each of the polar-orbiting satellites. They measure the total power input to the upper atmosphere due to particles entering the atmosphere from the magnetosphere. They routinely monitor the response of the particles to high-latitude disturbances. An upgraded SEM is scheduled for flight on NOAA-K scheduled for launch in 1996.

2. The Commission reiterates the recommendation of an expanded program of ground-based and satellite ozone measurements to assess the full extent, causes and consequences of stratospheric ozone depletion in the Arctic.

An extensive program of research into atmospheric ozone, involving ground-based, aircraft and satellite measurements, is continuing. These efforts are sponsored, in part, by the U.S. Global Change Research Program under the U.S. Interagency UV Monitoring plan. Research involves studies of the solar output, ozone depletion, stratospheric dynamics and chemistry. This program will continue, but funds are not available to expand it.

NOAA's Aeronomy Laboratory continues to conduct both ground-based measurements and modeling of ozone depletion in the Arctic. In 1995 a visible/ultraviolet spectrograph was installed at Kangerlusaag, Greenland, where it is now monitoring ozone and other gases. NOAA intends to continue this monitoring for several years in order to better understand interannual variations in Arctic ozone.

NOAA's Climate Monitoring and Diagnostics Laboratory has measured total column ozone at its Barrow, Alaska, observatory for more than 20 years. Measurements of ozone profiles by balloon-borne sondes have been made from Barrow and other Arctic locations. NOAA plans to continue its assessment of global ozone trends and anomalies.

NOAA's National Environmental Satellite, Data, and Information Services continues to gather a long-term time series of measurements of total and layer ozone in the Arctic using the solar backscatter ultraviolet and the high-resolution infrared sounder instruments.

Studies from Space

The Commission recommends that NASA establish a link with the community of Arctic researchers through an annual workshop on opportunities for polar research from satellites and that an appropriate balance between Arctic and Antarctic research needs be maintained in this forum.

NASA's Arctic program is focused on the role of sea ice in the global climate system and on the mass balance of the Greenland ice sheet and its effect on sea level. Most of the research is conducted at universities. In FY 95, NASA's Polar Research Program allotted funds to an Earth Observing System (EOS) interdisciplinary investigation and to upper-atmosphere research at high latitudes. In addition, NASA supports the development and operation of data systems that serve the polar community. Through the Alaska SAR Facility, researchers have access to Arctic data.

Periodically NASA solicits proposals, via NASA Research Announcements (NRAs), on various aspects of Earth system science. Recently NASA completed the selection process for two NRAs (Pathfinder Data Sets and RADARSAT) that will result in support for several projects addressing high-latitude research and several others that will compile polar data sets.

The program is slated for progressive funding reductions in both FY 96 and 97. NASA will consider an annual workshop on research opportunities for polar research from satellites if funds become available to support new research activities.

NOAA will work with NASA to further opportunities for polar research from satellites. NOAA's Coastal Ocean Program supports coastal environmental research in the Arctic with its operational node located in Anchorage. The program provides satellite imagery (advanced very-high-resolution radiometer) and other environmental data to researchers and resource managers. In FY 96, through cooperation with NASA and international space agencies, the imagery available will include high-resolution ocean color, synthetic aperture radar and scatterometer. NOAA monitored the advance of the Hubbard Glacier and its impact on the resources of adjoining Russell Fjord. Landsat thematic mapper imagery was used to create digital maps used for change detection, documenting the movement of Hubbard Glacier and resulting changes in water levels of Russell Fjord. These digital maps are completed and available to the research community.

EPA supports studies of high-latitude disturbances caused by solar variability and their effects on the global earth system. EPA also supports the collection of ozone measurements to assess the severity and impact of stratospheric ozone depletion in the Arctic.

Applied Research Priorities

Arctic Engineering

1. The Commission recommends that the IARPC agencies and other interested organizations organize the immediate start-up of a program of effective housing design, construction and in-situ testing in the Arctic.

There is significant benefit to be derived from a technology program focused on housing. Many new materials and construction approaches have evolved in recent years, some of which have the potential to improve the quality and efficiency of Arctic housing and utilities. Within current budget constraints and downsizing of many Federal programs, starting new programs may be a significant challenge. Other approaches such as adaptation and demonstration of current and emerging technologies may provide timely solutions to housing and utilities issues.

Ongoing Federal programs may also produce technologies and knowledge that have direct relevance to the improved design and construction of housing and utilities in the Arctic. Opportunities exist for research and development on technologies that address the needs of Arctic communities. There is existing authority for partnerships between Federal agencies and the private sector for both research and technology applications. Cost sharing is possible between agencies that have direct infrastructure missions and those industries that provide infrastructure services.

With the variety of conditions and needs of villages in different parts of Alaska, it is probable that the most cost-efficient solutions will be region specific, as opposed to generic solutions applicable everywhere. Application and demonstration of new approaches and technologies in individual regions may result in a greater variety and more efficient solutions than efforts at a single site. For example, solutions to utilities problems at Barrow (Utilidors) and Bethel (surface circulating) can provide greater understanding than concentrating research at a single site. There is also an opportunity at some sites to exploit available resources such as waste heat from power generation to aid in improving infrastructure performance.

Due to the premium placed on home and building weatherization and energy conservation in Arctic and Subarctic environments, indoor air quality issues are also of concern. EPA proposes to augment Arctic engineering research, subject to the availability of funds, to include studies of the human health implications (e.g. exposure and epidemiology) and the identification of mitigating solutions associated with indoor air quality impacts.

2. The Commission recommends that the IARPC agencies and other interested organizations, in particular the Alaska Science and Technology Foundation, organize the immediate start-up of a program for the design, construction and testing of adequate, appropriate, cost-effective, maintainable and affordable water and sewer systems for Arctic villages.

In the Department of Health and Human Services, the Indian Health Service, through its Alaska Area Native Health Service (AANHS), provides comprehensive medical care, public health and environmental health and engineering services to eligible American Indian and Alaska Native peoples and communities. The Office of Environmental Health and Engineering's Sanitation Facilities Construction (SFC) program continuously endeavors to identify and report the sanitation needs of all American Indians and Alaska Natives and carry out a program in cooperation with Alaska Native villages and other Federal and state agencies to meet those needs.

The Alaska Area SFC program obligated $17 million for sanitation facilities construction and began construction on 45 projects; 26 of these were new sanitation facilities and 19 were expansions of previously developed projects. The SFC program closely coordinates projects and funding with the State's Village Safe Water program, the EPA, the Department of Housing and Urban Development, the Farmers Home Administration, Regional Housing Authorities, and the Department of Transportation. Funds were allocated to provide opportunities for village operators and administrators to attend training in sanitation facilities operation and maintenance and utility management.

AANHS Office of Environmental Health and Engineering professional staff are active members of the Governor's Council on Rural Sanitation. The work of the Council is to develop the best, most cost-efficient way to deliver sanitation services to Alaska rural communities.

People and Health

1. The Commission recommends that the Department of the Interior proceed with the compacts for Beringia as consistent with the President's Arctic Policy concerning environmental protection and involvement of indigenous peoples.

Since the inception of the Shared Beringian Heritage Program in 1991, the National Park Service has taken action to involve indigenous people, both in Alaska and the Russian Far East. (The Shared Beringian Heritage Program is the general research and planning program in support of the proposed international park.) There have been meetings at the village and regional levels over the years, and a number of local indigenous people have been involved as collaborative researchers in the research projects. *Beringia Notes,* a biannual newsletter, was developed specifically to inform indigenous people about developments and research related to the proposed Beringian Heritage International Park.

Compacts are but one tool to involve indigenous people, and they may not always be the best or only appropriate tool to gain the necessary involvement. Compacts may limit involvement because only eligible groups can participate; eligibility is now restricted to those groups who meet specific criteria and have been officially determined to be eligible. Thus, sole reliance on compacts may be exclusionary and work against the broadest possible involvement of indigenous people. Ironically, NANA Regional Corporation is not currently eligible for compacting nor are any of the other groups in the Kotzebue region. At this time Kawarak, Inc., is the only group eligible for compacting in the vicinity of the proposed Beringian Heritage International Park. Thus, to encourage the broadest possible participation of indigenous people in the Beringian Park development, both in Alaska and the Russian Far East, IARPC encourages a broader approach. An array of mechanisms or tools (employment, grants, contracts, workshops, frequent meetings and development of better communications) will be used to increase indigenous involvement in research and planning for the proposed Beringian Heritage International Park. Placing singular emphasis on compacts may restrict the potential for partnerships with indigenous peoples and limit the tools that can be used to further these partnerships.

2. The Commission recommends that health researchers in Alaska should organize a center.

IARPC endorses this recommendation. The Department of Health and Human Services is prepared to consider support for such a center, subject to the availability of funds. IARPC is aware of the health challenges facing the indigenous peoples of Alaska and the Arctic. It is clear that strategies to improve the health of this population must deal with linguistic and cultural barriers to traditional programs, as well as geographic, socioeconomic and underserved population problems. However, progress is being made toward addressing the chronic health problems of Alaska Natives, and strategies for future interventions have been developed. Efforts are currently underway that relate specifically to such health problems as cancer, diabetes, infectious diseases, communication disorders, hearing, speech and language disorders, and mental health (including some forms of depression), among others. Research on fundamental health science questions that can be uniquely studied in the Alaskan and Arctic environments continues, primarily through the support of the National Institutes of Health.

Natural Resources

The Commission reiterates its research priorities from previous reports.

1. The Commission recommends a study of food web and environmental relationships of key commercial and subsistence species sufficient to support an effective long-term management plan of the biotic resources and their ecosystem on a sustainable basis.

The Fish and Wildlife Service (FWS) investigates the relationship between the harvest of commercial fish and the availability of these same fisheries resources to seabird species. The FWS is also studying long-term management strategies for sustaining populations of other marine mammals, especially polar bears and walruses. In the Aleutian Islands and Southeast Alaska it continues to study sea otter populations and the effects of increasing numbers of otters on the availability of commercial shellfish. In the freshwater environment the Forest Service and the Cooperative State Research Education and Extension Service continue to investigate the fundamental dynamics of food chain relationships, focusing on aquatic invertebrates as the critical link in sustaining subsistence fisheries.

NOAA's National Marine Mammal Laboratory has conducted research on the cause(s) of the decline of Steller sea lions and the northern fur seal in FY 94 and 95, as specified in the Recovery Plan for the Steller seal lion and the Conservation Plan for the northern fur seal. The causes of these declines may be linked to the synergistic effects of commercial fisheries, changes in oceanographic and atmospheric conditions, or both. Research on the abundance, distribution and stock structure of beluga whales in Alaska were conducted by NOAA researchers in cooperation with the Alaska Beluga Whale Committee (ABWC). Specifically, aerial surveys to determine relative abundance, genetic studies to determine stock structure and tagging studies to determine a correction factor for the sighting surveys were conducted in FY 94 and 95 in Cook Inlet. Further, NOAA, in cooperation with the ABWC, the Alaska Department of Fish and Game, and the Cook Inlet Marine Mammal Council, collected information on the level of subsistence utilization of beluga whales in Cook Inlet and Bristol Bay.

In the terrestrial environment the Bureau of Land Management (BLM) is studying the population dynamics and movements of caribou and moose, species of important subsistence significance, in the Steese–White Mountain area. The National Park Service (NPS) is also studying these two subsistence species. In the Noatak River drainage area, studies are focusing on the ecology and population biology of wolves and brown bears and the relationship of these predators to caribou and moose populations. Recent range extension and population changes of moose are also of interest. In the Denali area the focus of NPS research is more on caribou.

2. The assessment of the role and consequences of biodiversity in Arctic marine and terrestrial communities as indicators of condition and trends of biotic systems especially those affected by environmental changes.

The National Park Service has designated Denali National Park as a prototype park for inventory and monitoring. Research focused on predators and their interactions with prey species is contributing to the understanding of information needed to effectively monitor environmental conditions and trends. The NPS is also studying other animals in the park, including migratory birds, to understand and evaluate environmental conditions and population trends. The Forest Service studies key species to provide information on organisms that play dominant roles in determining conditions and trends in northern forest ecosystems.

The NSF, in cooperation with other agencies, supports research focused on ecosystems studies, population biology and physiological ecology. Long-Term Ecological Research (LTER) sites in Alaska provide basic information on environmental relationships between species. The results of this research are used by others to provide a basis for long-term management of biotic resources and ecosystems on a sustainable basis.

3. The integration of indigenous knowledge with modern science and technology to improve sustained levels of resource development consistent with acceptable environmental and cultural values.

The IARPC Social Science and Health Task Force supports Native science and education and the integration of indigenous knowledge with modern science and technology. The Task Force consists of staff from NSF, EPA, the Department of State, the Bureau of Indian Affairs, the Department of Health and Human Services, NOAA and the Smithsonian Institution, and it has a liaison with the State of Alaska.

The concept of an Alaska Native Science Commission, with a particular focus on indigenous and local knowledge, has been formulated by Alaska Natives. This Commission, supported by NSF, will encourage the incorporation of indigenous knowledge in science, resource management and education. The NSF has supported partnerships in science and education through awards to Alaska Native institutions, including the Alaska Federation of Natives, the Alaska Native Whaling Commission, and the Association of Village Council Presidents.

The amended Marine Mammal Protection Act (MMPA) specified that NOAA may enter into cooperative agreements with Alaska Native organizations to conserve marine mammals and provide co-management of subsistence use by Alaska Natives (16 U.S.C. 1388, Sec. 119). In FY 95, NOAA's National Marine Mammal Laboratory (NMML) initiated discussions with Alaska Native organizations regarding the development of co-management plans for three stocks of marine mammals in Alaska: Gulf of Alaska harbor seals, Cook Inlet beluga whales and Norton Sound beluga whales. These efforts will continue into FY 96. According to the MMPA these agreements with Alaska Native organizations may include grants to collect and analyze data, monitor the harvest, participate in research conducted by the Federal government, states, academic institutions and private organizations.

4. The management of sustainable ecological systems, restoration of damaged systems, and the interface between ecological processes and human social systems, particularly where natural resources are extracted, processed, transported and utilized in the Arctic.

The Fish and Wildlife Service (FWS) is conducting studies directed at understanding factors affecting population levels of species important for subsistence and human use. A major objective of these studies is to be able to understand population viability to help establish harvest limits to assure sustainable use of the resource over time. The BLM is studying the impacts of recreation and other human activities, such as placer mining, reclamation and hunting, on ecosystems and trying to determine the limits of acceptable change. The NPS has aggressive research programs focused on ways of restoring native flora and fauna to streams impacted by placer mining and restoring natural vegetation along roadsides and other transportation corridors. A major objective of Forest Service, Natural Resources Conservation Service, and Cooperative State Research Education and Extension Service research is to assure the sustainability of forest ecosystems through better understanding and use of natural ecosystem processes. Current research is directed at gaining a better understanding of aquatic–land interactions, the ecology of fire, and weed control in tree plantations.

Environment

The Commission recommends that the Interagency Coordinating Committee on Oil Pollution Research and Federal agencies with mandated oil spill cleanup responsibilities (especially EPA, NOAA and the USCG) take action on the following:

1. An immediate program of research on in-situ burning as an oil spill cleanup procedure for ice-infested waters.

In-situ burning is the "in place" combustion of an oil spill on the water. In-situ burning is viewed with growing interest as a response tool because the apparent environmental effects associated with its use may be less than those resulting from alternative response methods (mechanical cleanup, dispersants, etc.). It offers removal efficiencies that are greater and more consistent than those for other spill response methods and techniques. This is especially true in areas such as high-latitude waters (Arctic), where other techniques and methods may not be possible or advisable due to the physical environment (e.g. ice impeding skimmer operations and the maneuverability of skimming vessels), where extremely low temperatures persist (which adversely affect the viscosity and emulsification of the spilled oil, thereby reducing oil recovery efficiency) or where there is a lack of response recovery and disposal systems.

In the Arctic the magnitude of an oil spill may overwhelm the containment and storage equipment systems deployed or available for the region, necessitating the consideration of other methods in an overall response strategy. A considerable amount of research has already been conducted on in-situ burning. In the Alaskan Arctic, the oil industry has had to meet very stringent State of Alaska and Federal requirements for environmental protection, prevention, response cleanup and monitoring whenever major exploration has occurred. As a result, significant progress has been made in understanding Arctic-region oil spill response techniques, including in-situ burning. In addition, research on in-situ burning as an oil spill cleanup method for ice-infested waters has been conducted through joint cooperation and studies by the State of Alaska, industry, Environment Canada, NIST and the U.S. Minerals Management Service.

In-situ burning in the Arctic is a proven technology. Experiments in the Arctic to measure burn efficiencies for crude oil in simulated ice floe conditions yielded burn efficiency rates of 67–90%. Similar studies have been conducted at the Oil and Hazardous Materials test facility in New Jersey. NOAA's National Weather Service (NWS), in collaboration with the Alaska Federal Regional Response Team and NOAA's National Ocean Service (NOS), is assisting in defining atmospheric stability conditions in Alaskan waters for safe burning.

Upon consideration, an "immediate program of research" by the Interagency Coordinating Committee on Oil Pollution Research may be premature. Rather, before any further research is conducted, agencies will ascertain if there are major discrepancies with existing research results or if there are any areas where research remains to be done. The primary focus should be on special requirements for containment booms for in-situ burning in ice-infested waters, ignition techniques in ice- infested waters, and combustion byproduct (particulate matter) concerns specific to the Arctic.

2. Research to understand combustion properties, processes and products in the Arctic as they may relate to oil spill cleanup in ice-infested waters.

The response to No. 1 is applicable here. These factors have been examined as reported in the many independent and joint research studies conducted by the State of Alaska, Norway, the oil industry, Environment Canada, NIST and the U.S. Minerals Management Service. For example, it has been reported that it is much harder to ignite spilled oil in ice-infested waters due to very low surface water temperatures. Further research and development is required to develop ignitors, which could reduce the difficulty of igniting oil in ice-infested waters.

3. Applied research and field testing of the equipment and processes that may be involved in alternative cleanup techniques to in-situ burning.

The oil industry in Alaska has expended considerable effort and funds examining and field-testing alternative cleanup techniques as a condition of exploration in the Alaskan Arctic. According to the NOAA Scientific Support Coordinator for Alaska, the response community in Alaska is comfortable with in-situ burning as a viable technique. Additional work on alternative methods is not planned.

Norway has conducted research on special equipment needs pertaining to alternative methods and techniques for ice-infested waters. The U.S. Coast Guard Research and Development Center has a request from Norway to conduct further joint research on this matter. Environment Canada has also conducted considerable research in this area.

In light of the various studies, it has become evident that the Arctic region poses unique concerns where alternative techniques and methods may not be possible or advisable due to the physical environment (e.g. ice impeding skimmer operations and the maneuverability of skimming vessels) and extremely low temperatures (which adversely affect the viscosity and emulsification of the spilled oil, thereby reducing oil recovery efficiency).

In-situ burning is apparently the most promising alternative to mechanical recovery methods. Research is needed on how alternate cleanup techniques could be used in conjunction with in-situ burning for a single oil spill incident.

4. Research on logistics systems for spilled oil detection and cleanup.

Research on logistics systems for spilled oil detection has been sparse and is sorely needed, particularly for detecting and tracking oil spill movement under the ice. In the late 1970s and early 1980s, several research studies were initiated but were curtailed due to a lack of funds. Environment Canada conducted research using infrared camera detection techniques in general but never conducted sufficient experimentation in ice-infested waters. This has been reaffirmed by the oil industry representatives and Alaska Clean Seas, the Alaskan Arctic oil industry spill cleanup co-op. IARPC agrees that research on the detection and tracking of oil in, on and under ice is crucial for maximizing the effectiveness of response actions.

5. Ecological studies of marine mammals and birds that may be affected by oil spills in ice-infested waters.

Much research has been conducted by Environment Canada, NOAA, the State of Alaska and the oil industry in Alaska on the migration of whales and fish, seasonal habitats of birds and mammals. In the late 1970s and early 1980s, ecological studies were conducted as part of the Federal OSCEAP program.

For example, in 1994, NOAA's National Marine Mammal Laboratory (NMML) was heavily involved in the review and authorization of a request to take marine mammals incidental to oil and gas exploration activities in Alaska.

However, to a large extent, Congress independently established a new protocol for issuing Letters of Authorization (LOA) related to taking by harassment of small numbers of marine mammals [Sec. 101(a)(5)] in amendments to the Marine Mammal Protection Act, passed in 1994.

6. Analysis of the institutional barriers to the development and acceptance of new oil spill cleanup technologies, the meaningful involvement of Arctic residents in planning and evaluating cleanup procedures, and an active program focused on transferring relevant information to the public.

Federal, state and industry representatives in the Arctic fully understand the importance of conveying information to the public. For risk communications purposes, it is useful to compare the risk expected from methods such as in-situ burning to other more familiar risks.

Alaskan Clean Seas has already fostered a strong program of involvement and information transfer to Arctic residents. Similarly, Area Committees and a Regional Response Team have initiated risk communication programs through joint industry–government initiatives. The Area Contingency Planning process was designed to involve "stakeholders" in gaining their acceptance of new oil spill cleanup technologies and to minimize institutional barriers. Although not finished, steady progress has been made.

7. Industry collaboration with international bodies in developing environmental guidelines for Arctic oil exploration, development and production, and assistance in monitoring key variables.

Because the Arctic is particularly vulnerable to oil contamination and because other countries (such as Russia) are entering into or expanding oil exploration, development and production in the Arctic, industry collaboration with international bodies for developing environmental guidelines is highly desirable. The recent massive oil spills from the Komineft pipeline in Russia's Komi Republic focused concern on oil spill impacts in the Arctic.

There are several organizations studying the effects of oil spills in the Arctic. Leveraging U.S. government and industry resources in partnership with international bodies is desirable due to the significant implications for international oil supply and prices and the potential significant impacts in the environmentally sensitive Arctic.

Long-Term Studies

1. The Commission recommends that EPA-EMAP begin a focused program of environmental monitoring in the Arctic.

An EPA-EMAP project has begun to address the Commission's objective. The Alaska Regional–Environmental Monitoring and Assessment Program focuses on two North Slope estuaries over a two-year period. At this time it is not known whether EMAP will have the funds necessary for focused program of long-term environmental monitoring in the Arctic.

Based in part on funding limitations and also on scientific reviews conducted by the National Research Council and EPA's Scientific Advisory Board, EMAP is being re-evaluated and redirected in FY 96. The redirection is part of an interagency framework for ecological monitoring and research sites being developed by a working group of the Committee on Environment and Natural Resources. The framework will include a limited number of sites for intensive, long-term data collection and a broader network of less intensively monitored sites. The network is intended to cover all of the Nation's ecological resources, including those in the Arctic.

The Barrow, Alaska, observatory of NOAA's Climate Monitoring and Diagnostics Laboratory (CMDL) could play a key role as a facility to support expanded environmental monitoring in the Arctic. Moreover, the 20-plus-year records of ozone, aerosols, radiation, meteorology, halocarbons, carbon dioxide and methane from Barrow are available to the research community. CMDL has participated in AMAP assessments in the past and could continue to do so. CMDL has facilitated several campaigns to study Arctic haze using NOAA aircraft as the principal measurement platform.

2. The Commission recommends that an organized AMAP secretariat be established in the U.S. and that a support level of approximately $500,000 per annum be established for organized and effective participation in AMAP and associated AEPS activities.

IARPC supports this recommendation. Provision of $500,000 per annum is dependent upon the availability of funds from the participating agencies. In FY 95, approximately $270,000 was provided in direct support to AMAP in the U.S. In addition, the Office of Naval Research, through the Arctic Nuclear Waste Assessment Program, provided an additional $300,000 for AMAP-related studies.

3. The Commission recommends that the IARPC Arctic Contaminants Initiative be fully funded.

The IARPC Arctic Contaminants Initiative is one of four focused programs in the 1996–2000 Biennial Revision to the U.S. Arctic Research Plan. Funding for the initiative should be included in agency budget requests if the initiative is of sufficiently high priority within each agency.

In support of the Arctic Contaminants Initiative, the DOE/Environmental Measurements Laboratory Global Atmospheric Sampling Network, operating since the 1950s, will continue to measure the occurrence of anthropogenic and natural radionuclides at several surface air and deposition collection sites located in the Arctic and near-Arctic. This worldwide network recently identified ultra- low levels of radionuclides in air sampled at Barrow, Alaska, that were released by an explosion in Tomsk, Russia.

Education

The Commission recommends that the IARPC agencies work together to establish programs of scientific education following the Commission's three priority recommendations.

1. The Commission recommends that IARPC undertake a program to inform the public about our growing scientific and technical understanding of the Arctic.

The Alaska Native Science Commission, with a particular focus on indigenous and local knowledge, has been formulated by Alaska Natives. This institute, supported by NSF, will encourage the incorporation of indigenous knowledge in science, resource management and risk assessment and management. The institute will actively support programs to inform the public about our scientific and technical understanding of the Arctic and will serve as a link between scientific investigators and the people living in the areas being investigated. It will serve to report results of scientific investigations to local communities.

As part of the Atmospheric Radiation Measurement (ARM) program, DOE will stimulate interest in scientific careers at the high school and junior college level and involve local (North Slope) students with ARM projects pertinent to North Slope interests.

NSF is initiating a new coordinated public outreach and education effort through the Arctic Research Consortium of the United States (ARCUS). This program will involve both scientific data and information as well as classroom materials. NSF is producing a World Wide Web Arctic Home Page. Improved communication with the Native community will be facilitated through cooperation with the Alaska Native Science Commission.

The Smithsonian's Arctic Studies Center opened a regional office in Anchorage in cooperation with the municipality of Anchorage and the Anchorage Museum. This office will assist in the development of cultural programs, museum education and exhibition development, and it will provide Alaskans with access to Smithsonian collections and archives. Native museum training programs and educational outreach will be featured. This office cooperates with the National Park Service, NSF and other organizations.

2. The Commission recommends a continued effort in the education of professional Arctic researchers.

IARPC agencies actively support the creation of partnerships in science and education. For example, the IARPC Social Science and Health Task Force supports Native science and education in Alaska.

The Department of Health and Human Services, Indian Health Service (IHS), provides opportunities for village operators and administrators to attend training in sanitation facilities operation and maintenance and utility management. IHS works with the University of Alaska Engineering Department and the Alaska Science and Technology Foundation to evaluate alternate sanitation technologies and provided technical information and review for the Office of Technology Assessment report titled "An Alaskan Challenge: Native Village Sanitation."

The National Institute on Drug Abuse funded its first post-doctoral fellowship at the University of Alaska, Anchorage, and is working with the University to encourage and support minority researchers, especially Alaska Natives. In addition, the University of Alaska is exploring opportunities for developing a higher education training program to promote and encourage education and research opportunities to promising Alaska Native and other minority students.

NSF has extended the Dissertation Improvement Grant Program to all disciplinary areas in the Arctic natural and social sciences. This program has already benefited Native scientists.

In FY 95 and 96, EPA's Office of Research and Development issued announcements of the availability of environment-related fellowships, some of which may focus on Arctic investigations.

3. The Commission recommends that the IARPC agencies establish a program to directly communicate to U.S. Arctic communities the results of research under their sponsorship.

IARPC publishes the journal *Arctic Research of the United States* to directly communicate to U.S. Arctic communities the results of research under their sponsorship. Plans for 1996 include development of an IARPC home page on the Internet's World Wide Web.

In addition, the NSF Arctic Social Sciences Program has consistently encouraged and supported Native involvement in science and education.

Besides meetings with Native organizations in Alaska, including the Alaska Federation of Natives Youth Conference, the Arctic Social Sciences Program has acted as a liaison for Native groups with NSF. Many scientific proposals dealing with culturally relevant science curriculum development, rapid social change and community viability have been funded. The Arctic Social Sciences Program is coordinated with the Arctic Systems Science Program and the Human Dimensions of Global Change Program.

The Smithsonian Institution's Arctic Studies Center has planned a five-year education and training program to increase knowledge of traditional and contemporary Native cultures for Alaska scientists and visitors. The program includes traveling exhibitions, seminars, museum training workshops, publications and electronic information services. Experiments will be supported to bring results of scientific studies and existing museum resources to rural Alaska communities.

Plans for local community involvement in the Atmospheric Radiation Measurement (ARM) program are also well underway, with partnerships being forged with Native corporations and an educational program being developed in conjunction with the North Slope School District and Community College.

Research Infrastructure

Management

The Commission recommends that the IARPC planning system increase its efforts to lead in the formulation, organization and implementation of new research programs in the Arctic.

The Arctic Research and Policy Act requires cooperation among agencies of the U.S. Government having missions and programs relevant to the Arctic. It established the Interagency Arctic Research Policy Committee to "promote Federal interagency coordination of all Arctic research activities." The Interagency Committee, under the chairmanship of the Director of the National Science Foundation (NSF), continues to provide the mechanism for developing and coordinating U.S. Arctic research activities. The biennial revisions of the U.S. Arctic Research Plan serve as guidance for planning by individual agencies and for coordinating and implementing mutually beneficial national and international research programs.

Since the last revision of the Plan, significant progress in implementing recommendations has been made. The Act mandates a requirement for implementing a coordinated U.S. Arctic research program. Three levels of coordination and cooperation are part of an effective national Arctic research program:

- Individual research programs;
- National coordination; and
- International collaboration.

Each element requires a mechanism for internal program development, review and implementation, and each needs to be linked to the other two. The national effort is organized through the Interagency Committee. A staff oversight group of the Interagency Committee provides coordination, assisted by working groups representing specific agency programs. The Working Group on Arctic Ocean/Atmosphere has developed specific program strategies, as has the Social Science Task Force. A data and information group and a logistics and operational support group are pursuing a number of interagency activities. The Environmental Monitoring and Assessment Working Group prepared the Arctic Contamination Research and Assessment initiative.

Many interagency agreements and planning and coordinating activities already exist. Coordination with global change programs is an integral part of Arctic program development and implementation. IARPC supports improved communication at all levels through existing newsletters and journals.

Logistics Support

1. The Commission urges NSF to proceed with the construction of the ARV.

Vessels supporting research in ice-covered areas fall into three categories, based on their ice-going capability:

- Icebreakers operated by the Coast Guard;
- Ice-capable and ice-strengthened vessels for research and survey purposes; and
- Nuclear submarines provided by the U.S. Navy.

The Arctic Research and Policy Act (ARPA) confirms the Coast Guard's role as manager of the Nation's icebreaker fleet to serve the Nation's interests in the heavy ice regions of the Arctic. This includes security, economic and environmental interests. Coast Guard icebreakers support research in these regions in two general ways: on dedicated science deployments and, as opportunities arise, in conjunction with other missions. The Coast Guard has two icebreakers and is acquiring a third. A design and construction contract was awarded to Avondale Industries, Inc., of New Orleans in July 1993. The Coast Guard icebreaker *Healy* is scheduled to be delivered in FY 98. A fourth research vessel is operated by NSF in the Antarctic.

A research vessel providing all-season access to the Arctic region is essential for many research requirements. The University National Oceanographic Laboratory System (UNOLS) published updated Scientific Mission Requirements for the Arctic Research Vessel in 1993 and completed the Arctic Research Vessel Preliminary Design Report in 1994.

As part of the planning process, the National Academy of Sciences conducted a review and evaluation of the scientific requirements for an Arctic research vessel in the context of current national research needs in the Arctic ocean regions. The study included an assessment and update of past studies, a comprehensive analysis of all Arctic facilities and their roles in meeting research requirements, and recommendations for national planning and coordination. The panel found that the new Coast Guard icebreaker could provide a usable platform for Arctic science if changes were made in crew size and experience and in the space available for science. In an additional report the General Accounting Office (GAO) said that the need for an additional Arctic research vessel has not been demonstrated. The GAO report indicates that national research needs can be adequately met with a fleet of four vessels.

2. The Commission applauds the signing of the multi-agency Memorandum of Agreement (MOA) for the use of Navy nuclear submarines for civilian scientific research, awaits further progress in this field, and will actively support such efforts.

In late 1994 the U.S. Arctic Research Commission assisted in drafting and implementing a Memorandum of Agreement (MOA) that lays the foundation for a series of annual nuclear submarine cruises dedicated to science in the Arctic Ocean, starting in the spring of 1995. This new series of science cruises is a follow-on to the very successful proof-of-concept deployment of the USS *Pargo* in the summer of 1993. The 1995 cruise was on the USS *Cavalla*. During these cruises the principal mission of the submarines is to conduct unclassified experiments selected from competitive proposals. The submarines spend 40–60 days each year collecting data in the Arctic, with the costs being shared by the U.S. Navy (which provides the Arctic-capable submarine at no cost to the science community) and the participating science agencies (who fund the experiment and the unique data collection systems). Each cruise is supported by the Naval Undersea Warfare Center's Arctic Submarine Laboratory, which has coordinated all the Navy's Submarine Arctic Exercises for the past 40 years. Scientists conducting key experiments may be able to accompany the ship on the cruises.

The unique opportunities for collecting comprehensive data in areas of the Arctic Ocean, many of which are routinely accessible only by submarine, are significant, particularly because the Navy intends to declassify all data and make them available to the world science community. Some of the types of data to be collected include:

- Water samples at various depths;
- Depth and roughness of the ice canopy;
- Meteorological observations;
- Topographic, bathymetric and gravity profiling; and
- Studies of Arctic Basin water masses and their sources and circulation.

Measurements will be taken while underway and submerged, when surfaced through the ice, or by the deployment of automatic buoys, which can provide continuous data via satellite long after the submarine has departed.

In addition to these purely scientific benefits, the knowledge gained during these cruises will assist policymakers in making decisions regarding environmental protection, fisheries management, natural resource distribution, and exploitation and management of the Arctic Ocean and adjoining coasts.

The Arctic Science Submarine Cruise MOA is the product of several years of effort and negotiation among numerous agencies, with the assistance of the Arctic Research Commission. The MOA was signed by the National Science Foundation, the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, the Chief of Naval Research, the Director of the Submarine Warfare Division in the Office of the Chief of Naval Operations, and the Commanders of both the Atlantic and Pacific Submarine Forces. It is a significant document that demonstrates a unique interagency partnership established to address national and global issues for the benefit of all, while using available resources. The resultant availability of submarines provides a new source and level of operational support for research and will both expand and improve the quality of data sets from the central Arctic Ocean.

3. The Commission also urges implementation of its recommendations regarding the logistics support of U.S. research in Greenland as a result of withdrawal by the U.S. Air Force from operation of facilities in Sondrestrom (ARC 1990b).

IARPC supports the recommendations that are still relevant. Although the Department of Defense terminated operations at Sondrestrom Air Base in 1992, Air National Guard flights continue for transport of passengers and cargo. The NSF-funded Polar Ice Coring Office employs new operational modes for support of research in Greenland as projects require.

4. The Commission approves of the steps being taken to improve logistics support on land and sea in the Arctic and recommends their continuation and expansion.

IARPC supports this recommendation. As an example of the continuation and expansion of interagency logistics support in the Arctic, NOAA continues to provide ship and aircraft support for NOAA's Arctic programs. In FY 96 and 97, NOAA plans to use helicopters to support polar bear surveys conducted by the U.S. Fish and Wildlife Service.

5. The Commission finds that it is time to develop a comprehensive system in which logistics support of Arctic research at NSF is budgeted separately from science support, as is the practice for Antarctic research.

In response to this recommendation, in 1995 NSF established a separate funding component, in addition to the funding already provided through research grants, for Arctic logistics support. IARPC believes that science programs should be developed first, and logistics support should be budgeted to support the needed science. As a long-term goal, the provision of a separate budget for logistics support would be useful in some agencies. In agencies that conduct much of their research in-house, separate budgets already exist for research and logistics. In agencies that support research through external grants or contracts, a separate logistics budget could provide long-term efficiencies.

Data and Information

The Commission urges continued efforts toward the implementation of the recommendations in its report *Arctic Data and Information: Issues and Goals* (ARC 1989a). This will require specific funding for data and information management from the principal agencies sponsoring Arctic research. The IARPC agencies have made significant progress in addressing each recommendation.

A. The IARPC should take the lead in developing U.S. policy directives for the management of Arctic data and information that provide for agency coordination and still allow agencies the degree of independence required to meet their mission objectives.

The IARPC agencies worked closely with the Committee on Environment and Natural Resources (CENR) to develop a suite of guidelines for the uniform and open management of scientific data and information. These policy statements apply explicitly to global change data and information. The programs and tools put into place for Arctic data and information are completely compatible with these policy statements.

B. Arctic data policy and guidelines should be based on the needs of the user community and should take into account the needs for the coordination and pooling of data and information resources with State of Alaska agencies, local government agencies and the private sector.

The Arctic data and information system began in 1987 at a workshop attended by representatives of 65 agencies, academic institutions and private organizations. Since then a series of workshops have been held in Anchorage, AK; Boulder, CO; Fairbanks, AK; Hanover, NH; Juneau, AK; and Reston, VA; meetings of the working groups have been held in conjunction with conferences of the American Geophysical Union in San Francisco, CA; and members have given presentations to professional or public organizations. The purpose of these public meetings has been to inform scientists and data users about progress and plans and to seek input from members of the community about their needs. IARPC agencies have assembled the Arctic Environmental Data Directory (AEDD), two CD-ROMs compiling descriptions of Arctic data and information, and a variety of resources available on the World Wide Web, all of which are used by agencies, schools and businesses in Alaska.

C. An adequate portion of funds allocated to Arctic research by the Federal government should be set aside for the successful management (collection, archiving and dissemination) of resultant data and the dissemination of information on pertinent research operations and their results. In particular, the Federal funding agencies should provide effective incentives to their grantees for the creation of universal data sets in critical areas of environmental, social and biomedical research.

A significant number of data sets, large and small, have been created by IARPC agencies and their grantees. Data sets derived from satellite sensors are especially important in the Arctic due to adverse weather conditions and the expense of field measurements. Extensive support is given to data from satellite sensors. The advanced very-high-resolution radiometer and the operational linescan system provide data in the visible and infrared wavelengths. The synthetic aperture radar (SAR) data are valuable in depicting ice cover, even through cloud cover. Side-looking airborne radar is used to view through glaciers to study the underlying geologic framework. The U.S. Interagency Arctic Buoy Program uses the Global Telecommunications System to report on meteorological data. The National Snow and Ice Data Center's World Data Center-A for Glaciology compiles and maintains extensive Arctic data sets, including an inventory of glaciers; Arctic sea ice and snow coverage; data from passive microwave sensors; and information on permafrost, solar radiation and paleoclimates. Since the circumpolar Arctic environment is impacted significantly by activities in other nations, the IARPC agencies have coordinated closely to share Arctic data and information with the other nations with territories and activities in the Arctic.

There are some gaps where funding has not yet permitted data and information to be assembled to the extent that might be prudent. In particular, issues related to Arctic contamination, health and medicine, and socioeconomics do not benefit from a wealth of data. The IARPC agencies have identified these gaps and will address them as funds permit.

D. An Arctic Data and Information System (ADIS) should be planned and developed under the guidance of IARPC to handle publicly a vailable scientific and technical data and information related to the Arctic, including health and socioeconomic data. The Arctic Environmental Data Directory presently being developed under the guidance of IARPC should serve as an initial step toward achieving this goal.

The IARPC agencies have taken the approach that the ADIS will be distributed, with each agency and country responsible for their data, but shared by means of the Internet and some common protocols. The Arctic Environmental Data Directory (AEDD) describes the data and information holdings of the IARPC agencies. It is maintained by the U.S. Geological Survey with funding support from the IARPC agencies. AEDD describes more than 450 Arctic data sets that reside in the IARPC agencies and has become the model for an international network of related databases, the Arctic Data Directory (ADD). Building on AEDD, the ADD is moving towards a circumpolar data and information resource that will describe assets in each nation with Arctic territory or activities. Two ADD nodes are now operational: AEDD for U.S. Arctic territories, and a counterpart for Nordic territories operated by the United Nations Environment Program/Global Resource Information Database (UNEP/GRID) in Arendal, Norway. A third node, to be established by 1996 in Moscow, will be used to gather information about data describing the Russian Arctic. Future nodes are targeted for Canada, Iceland, Denmark/Greenland and perhaps Japan, the United Kingdom and Germany. The ADD is built on international standards, including information exchange protocols, and the use of the Internet. The objective is to make scientific and technical data and information related to the Arctic available to researchers, educators, policymakers and the interested public around the world.

E. The policy and plans for an ADIS should address, resolve and, where feasible, implement the following, listed in order of decreasing priority or urgency:

1. Interlinking data and information.

The use of AEDD and related directories in individual IARPC agencies, plus the Internet, is the mechanism of choice to make it as easy as possible to access and use Arctic data and information. Information products, such as the PolarPac CD-ROMs, help to identify where data are available and sources of help to use these data.

2. Defining needs for environmental monitoring and long-term data.

The IARPC agencies continually seek input from interested parties on the priorities for Arctic data and information, through workshops, seminars and public meetings. As embodied in the 1991 Policy Statements on data management, by the President's Science Advisor, policy "requires an early and continuing commitment to the establishment, maintenance, validation, description, accessibility, and distribution of high-quality, long-term data sets."

3. Ensuring quality control of data.

The AEDD working group has instituted a process of peer review to assure that descriptions of agency data sets are consistent, correct and complete. Where data sets are known to be of uneven or uncertain quality, AEDD documents the uncertainty so that researchers are aware of what the data are. Data set descriptions are reviewed on a regular cycle, with updates made available to the community as quickly as possible.

4. Devising strategies to arrest the proliferation of "gray literature."

The IARPC subscribes to the strategy that data and information, including the products that result from use of the data, should be made available publicly as quickly as possible. To this end, it is key that the underlying data should not be sequestered out of the public view. According to the 1991 Policy Statements on data management, "For those programs in which selected principal investigators have initial periods of exclusive data use, data should be made openly available as soon as they become widely useful. In each case the funding agency should explicitly define the duration of any exclusive use period." In addition, significant bodies of data and information that had been unavailable to the research community due to national security classification are in the process of being declassified. Data repositories supported by IARPC agencies have been identified to store these data and make them available for use.

The Policy Statements directly encourage the rapid publication of results and release of data for multiple use. The IARPC agencies have addressed ARC concerns about the "increasing disenchantment of scientists with traditional journals" by designing and publishing a prototype digital data journal, the Arctic Data Interactive (ADI). The ADI, which won the Presidential Design Achievement Award in 1994, presents multimedia information using a CD-ROM. Using the Internet, presentations of Arctic data and information are now available interactively on the World Wide Web at http://www-ak.wr.usgs.gov/aedd.

5. Improving the mechanisms for international exchange of Arctic data and information.

The IARPC agencies have made significant progress in this arena. The development of the Arctic Data Directory (ADD) described above is an example. The IARPC agencies have also taken leadership positions in related programs that use large quantities of environmental data and information, especially the Global Change Research Program and its international counterparts. By sharing standards among the directories (for example, the Directory Interchange Format for entries in all of these related directories), it is easy for users to access and use information from these resources. In addition, the IARPC agencies have organized groups in interested nations to work together on issues of mutual benefit. For example, the Committee on Earth Observing Satellites (CEOS) meets regularly, with IARPC agency participation, to discuss the issues that relate to standardizing and sharing information from a variety of satellites measuring the Earth, regardless of the nation launching the satellite.

6. Providing for standardization of data and information.

The IARPC agencies have provided a rigorous framework for standardization of data and information (see the discussion of Policy Statements for data management in A above); for the metadata used to describe the available data sets; for access mechanisms that use the Internet or other electronic media; and for conformance to standards accepted internationally. Specifically, systems are designed with the objective of making it as easy as possible to find and use data and information. As the use of the Internet continues to increase, the electronic tools available to access multiple sites or systems, such as the nodes in the Arctic Data Directory and the Global Change Master Directory, continue to become easier for the user. According to the Policy Statements, "National and international standards should be used to the greatest extent possible for media and for processing and communication of global data sets."

7. Minimizing the cost to the user of data and information services.

Arctic data and information are principally accessed using the Internet and the World Wide Web. Costs to the user for acquiring these data from IARPC agencies are normally zero or nearly zero. According to the Policy Statements, "Data should be provided at the lowest possible cost to...researchers in the interest of full and open access to data. This cost should, as a first principle, be no more than the marginal cost of filling a specific user request. Agencies should act to streamline administrative arrangements for exchanging data among researchers."

8. Safeguarding confidentiality where required.

The IARPC agencies are sensitive to issues of confidentiality where appropriate. The great bulk of Arctic environmental data, however, is public. According to the Policy Statements, "Full and open sharing of the full suite of global data sets for all...researchers is a fundamental objective."

9. Providing for the recording of historical and proxy data.

Much of the data and information describing the Arctic environment is historical and on media not conducive to electronic access and use. As funds permit and programs dictate, these data are targeted to be captured in digital form. Successes are most prominent in the body of Russian Arctic data and information, where significant quantities of historical and proxy data have already been converted to electronic form. For example, a large body of Russian permafrost data and information are now available in a digital database and are being integrated with similar data from Alaska and other Arctic areas. The process of capturing and converting such data to digital form requires an opportunistic approach when funding sources develop that are congruent with research needs.

10. Protecting data and information from environmental and human hazards.

This issue is addressed in the Policy Statements: "Preservation of all data needed for long-term... research is required. For each and every...data parameter, there should be at least one explicitly designated archive. Procedures and criteria for setting priorities for data acquisition, retention, and purging should be developed by participating agencies, both nationally and internationally. A clearinghouse process should be established to prevent the purging and loss of important data sets."

F. IARPC should consider a cooperative interagency agreement as the vehicle for the implementation of Arctic data and information policy and the establishment and operation of ADIS.

The IARPC agencies have cooperated voluntarily with each other in matters related to data and information, with the result that the establishment and operation of an ADIS has been executed at a low to moderate cost. A formal cooperative interagency agreement might lead to a more robust operation and will be explored.

Environmental Impact Statement Process

The Commission continues to support our original recommendations.

IARPC responded to the Commission's original recommendations in its 1992 Report to Congress and continues to support the recommendations. Since the publication of that report, and as a direct result of the original Commission recommendations, the Council on Environmental Quality hosted an interagency discussion of the Environmental Impact Statement (EIS) process, and the Department of Energy agreed to apply Commission recommendations to the EIS for the Atmospheric Radiation Measurement (ARM) program.

International Coordination

The Commission's recommendations are primarily focused on the International Arctic Science Committee (IASC). The Commission recommends that the Polar Research Board should urge IASC to consider the following areas for international research collaboration:

- **Research to determine indicators in time (rate) and space (extent) of climate change in the Arctic;**
- **Circumarctic environmental monitoring and assessment;**
- **Research on the dynamics of the Arctic Ocean;**
- **Research on the geology and geophysics of the Arctic Basin; and**
- **Research on major mortality and morbidity causes and treatment effectiveness among circumarctic residents.**

IARPC agencies fully support these recommendations to the Polar Research Board. Representatives of many IARPC agencies participated in the International Conference on Arctic Research Planning in Hanover, New Hampshire, in December 1995 to support international research collaboration. The results of the conference will be published by the International Arctic Science Committee.

United States Arctic Research Commission

December 11 and 12, 1995

The Arctic Research Commission met at the new facilities of the Monterey Bay Aquarium Research Institute at Moss Landing, California. The meeting began with a discussion of congressional actions, including a report by David Garman of Senator Murkowski's staff. It continued with an extended discussion of the recent NAS/NRC Report on Arctic Ocean Research and Supporting Facilities. The meeting continued with agency reports from NSF, the Coast Guard, the U.S Geological Survey and NOAA. The afternoon was taken up with reports from the Commission Task Forces on Housing and Sanitation, Oil Spills and Logistics.

The Tuesday morning session was devoted to a discussion the recent International Northern Sea Route Program Meeting in Tokyo by Capt. Lawson Brigham, USCG. Travel reports and correspondence filled the remainder of the morning; an executive session occupied the afternoon.

March 25 and 26, 1996

The U.S. Arctic Research Commission met in Washington, D.C. The morning of the 25th was spent meeting jointly with the Arctic Research Consortium of the U.S (ARCUS) to discuss the common interests of ARCUS and the Commission and to explore ways of working together. Items of particular interest included the Commission-sponsored report on Arctic logistics, which ARCUS is in the process of preparing, and the Commission's task forces in Arctic housing, sanitation and oil spill technology. The joint meeting continued by considering potential partnerships, Arctic education initiatives and Arctic information dissemination.

The Commission met in regular business session on the afternoon of the 25th and heard a report from the AAAS on the future of Federal research funding. Burt Hartley, Jr., of Hartech Inc., discussed the Komi oil spill cleanup and showed a videotape of the work in progress. This was followed by reports from Congressional liaisons and agency reports including a report on the Arctic Military Environmental Concerns program at the Department of Defense. A wide-ranging discussion followed with Dr. Neal Lane, Director of NSF.

The entire morning of the 26th of March was taken up by a review of NOAA Programs at NOAA Headquarters in Washington.

June 20 and 21, 1996

The U.S. Arctic Research Commission met in Arlington, Virginia. The Commission visited the headquarters of the U.S. Geological Survey in Reston, Virginia, and received a briefing on the Survey's activities in Alaska and the Arctic. The Commission held a forum on U.S. participation in the Arctic Environmental Protection Strategy, with briefings from the U.S. leaders of the principal working groups and from the U.S. State Department.

After the June meeting Chairman O'Dowd and Commissioners Newton and Glenn, along with the Commission staff, State Department representatives and NSF Arctic Section staff, traveled to Greenland to study logistics operations. They were transported by the 109th Airlift Wing of the New York Air National Guard on their ski-equipped LC-130 aircraft. The 109th has been the mainstay of Greenland logistics for many years and has recently become the provider of LC-130 support for the U.S. Antarctic Program as well. The LC-130s proved to be remarkable aircraft, allowing access to what would otherwise be an entirely remote area for research. The Commission visited Kangerlussuaq, Dye-2, Summit, Thule and North GRIP. Dr. Jorgen Taagholt of the Danish Polar Center accompanied the Commission.

August 19–21, 1996

The Commission met again on the 19th and 20th of August, 1996, in Anchorage, Alaska, and on the 21st of August in Unalaska (Dutch Harbor), Alaska. On the evening of the 19th the Commission sponsored a public forum, which presented three Bering Sea research programs: Dr. David Policanski reported on the recently published NRC report entitled "The Bering Sea Ecosystem," Dr. Vera Alexander reported on the initial stages of the Southeast Bering Sea Carrying Capacity Study and Dr. Gunter Weller reported on the Bering Sea Impact Study, a proposed project to study the impact of global change on the Bering Sea region. The forum was well attended, and a sprightly question and answer session followed. The Commission then moved on to Unalaska (Dutch Harbor), where they were warmly welcomed. The same three speakers spoke to a substantial crowd, and the clear interest of the fishing industry representatives in a sustainable and economically viable fishery was apparent throughout the meeting.

Selected Meetings of Interest

Listed here is a compilation of recent and forthcoming meetings, workshops and conferences on Arctic or northern topics and activities. Readers are invited to submit information on upcoming meetings, as well as reports on national or international meetings attended, to Editor, Arctic Research, Arctic Research and Policy Staff, Office of Polar Programs, National Science Foundation, 4201 Wilson Boulevard, Arlington, Virginia 22203.

1997

27th Arctic Workshop
27 February – 2 March 1997, University of Ottawa, Ottawa, Ontario, Canada
Contact: Dr A. Lewkowicz, Chair, Organizing Committee, 27th Arctic Workshop, Department of Geography, University of Ottawa, Ottawa, Canada
Fax: 1-613-562-5145
E-mail: geolan@aix1.uottawa.ca
Web site: http://www.science.uottawa.ca/arctic97/

Gordon Research Conference - Sea Ice Ecology
27 March 1997, Ventura, California, USA
Contact: Stephen F. Ackley, Chairman, GRC on Sea Ice Ecology, Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755, USA
Fax: 1-603-646-4644
E-mail: sackley@crrel.usace.army.mil
or
Gordon Research Conferences, University of Rhode Island, P.O Box 984, West Kingston, RI 02982-0984, USA
E-mail: grc@grcmail.grc.uri.edu
Web site: http://www.grc.uri.edu

Workshop on Sea Ice Thickness Measurements and Data Analysis
combined with
Fourth Session of the ACSYS Sea Ice Ocean Modeling (SIOM) Panel
7–11 April 1997, Monterey, California, USA
Contact: Roger Colony, International ACSYS Project Office (IAPO), Post Office Box 5072, Majorstua, N-0301 Oslo, Norway
Phone: 47 22 95 96 05
Fax: 47 22 95 96 01
E-mail: acsys@npolar.no

8th International Symposium on Ground Freezing and 3rd International Symposium on Frost in Geotechnical Engineering
14–17 April 1997, Luleå, Sweden
Contact: Sven G O Knutsson, Luleå University of Technology, S-951 87 Luleå, Sweden
Phone: 46 920 913 32
Fax: 46 920 720 75
E-mail: sven.knutsson@anl.luth.se
Web site: http:/www.luth.se/depts/anl/frost97/

Securing Northern Futures: Developing Research Partnerships
1–4 May 1997, Canadian Circumpolar Institute, University of Alberta, Edmonton, AB, Canada
Contact: Secretariat, Canadian Circumpolar Institute, University of Alberta, 8820-112 Street, Edmonton, Alberta T6G 2E1, Canada
Phone: 1-403-492-4512
Fax: 1-403-492-1153
E-mail: canadian.circumpolar.institute@ualberta.ca

ISCORD '97, International Symposium on Cold Regions Development
4–19 May 1997, Anchorage, Alaska, USA
Contact: Chairman of the Organizing Committee, The Northern Forum, 4101 University Drive, APU Garr-Gottstein Center, Suite 221, Anchorage, Alaska 99508, USA
Phone: 1-907-561-3280
Fax: 1-907-561-6645
E-mail: iscord97@ccmail.orst.edu
Web Site: http:/www.orst.edu/-vinson/iscord.html

ISOPE-97: 7th International Offshore and Polar Engineering Conference
25–30 May, 1997, Honolulu, Hawaii, USA
Contact: Jin S. Chung, ISOPE, P.O.Box 1107, Golden, Colorado 80402-1107, USA
Phone: 1-303-273-3673
Fax: 1-303-420-3760

International Symposium on Snow and Avalanches
26–30 May 1997, Chamonix Mont-Blanc, France
Contact: Secretary General, International Glaciological Society, Lensfield Road
Cambridge CB2 1ER, United Kingdom
Phone: 44 - 1223-355974
Fax: 44-1223-336543
E-mail: 100751.1667@compuserve.com

AMAP International Symposium on Environmental Pollution of the Arctic
and
Third International Conference on Environmental Radioactivity in the Arctic
1–5 June, 1997, Tromsø, Norway
Contact: AMAP Secretariat, P.O. Box 8100 Dep, N-0032 Oslo, Norway
Fax: 47 22 67 67 06
or
Norwegian Radiation Protection Authority, P.O. Box 55, N-1345 Østerås, Norway
Fax: 47 67 14 54 44

International Symposium on Physics, Chemistry, and Ecology of Seasonally Frozen Soils
10–12 June 1997, University of Alaska, Fairbanks, Fairbanks, Alaska
Contact: Dr Pieter Groenevelt, Program Chair, Department of Land Resource Science, University of Guelph, Guelph, Ontario N1G 2W1, Canada
For information about the symposium program contact:
Brenton Sharratt
Phone: 1-612-589-3411
E-mail: bsharratt@mail.mrsars.usda.gov
or
Jerry Radke
Phone: 1-515-294-0213
E-mail: jkradke@iastate.edu
For symposium logistics contact: Conferences and Special Events
Tel: 1-907-474-7800
E-mail: fyci@aurora.alaska.edu

> The International Arctic Science Committee has established a new service to the Arctic research community: an Arctic meetings listing available via the Internet. Called SAM (Survey of Arctic Meetings), it contains information on international Arctic meetings, as well as major national meetings with international participation. The World Wide Web address for SAM is http://www.npolar.no/iasc/sam.htm.

Circumpolar Change: Fifth Circumpolar Universities Cooperation Conference
10–12 June 1997, Luleå, Sweden
Contact: Paula Wennberg, Conference Coordinator, Luleå University, S-971 87 Luleå, Sweden
Fax: 46 920 721 60
Phone: 46 920 914 05
E-mail: cucc@ies.luth.se

International Symposium on Antarctica and Global Change
14–18 July 1997, University of Tasmania, Hobart, Australia
Contact: Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, United Kingdom
Phone: 44 1223 355974
Fax: 44 1223 336543
E-mail: 100751-1667@compuserve.com

8th Meeting of the Canadian Quaternary Association (CANQUA) (held jointly with the Canadian Polar Commission)
August, 1997, Kuujjuaq, Nouveau-Quebec (with field trips in Ungava)
Contact: Michel A Bouchard, Albert Haller Department of Geology, Canadian Polar Commission, Universite de Montreal, 1710-360 Albert Street, P.O. Box 6128, Station Centre Ville, Montreal, Quebec K1R 7X7, Canada
Phone: 1-514-343-6821
Fax: 1-514-343-5782
E-mail: bouchami@ere.umontreal.ca

Naval Arctic Research Laboratory's 50th Anniversary Celebration
1–9 August 1997, Barrow, Alaska, USA
Contact: Glenn W Sheehan, Executive Director, Barrow Arctic Science Consortium (BASC), P.O. Box 955, Barrow, AK 99723, USA
Phone: 1-907-852-4881
Fax: 1-907-852-8213

Second International Conference on Cryopedology
5–8 August 1997, Syktyvkar, Russia
Contact: Prof. I.V. Zaboeva, Institute of Biology, Komi Center, Russian Academy of Sciences, 167610 Syltuvkar, Komi Republic, Russia
Phone: 7-821-22-25213
Fax: 7-821-22-25231
E-mail: gilichin@issp.serpukhov.su

11th Northern Research Basins Symposium and Workshop
18–22 August 1997, Prudhoe Bay to Fairbanks, Alaska, USA
Contact: Professor Douglas L. Kane, Water Research Center, University of Alaska, Fairbanks, Alaska, 99775-5860 USA
Phone: 1-907-474-7808
Fax: 1-907-474-7979
E-mail: ffdlk@aurora.alaska.edu

IV International Geomorphology Conference and IPA Executive Committee Meeting (and pre- and post-conference permafrost excursions)
28 August–3 September 1997, Bologna, Italy
Contact: M Panizza, University Degli Studi di Moden, 59-41100 Modena, Italy
Phone: 059 23 0394
Fax: 059 21 8326

NAFO Symposium "Visioning Sustainable Harvests from the Northwest Atlantic in the Twenty-First Century"
10–12 September 1997, St John's, Newfoundland, Canada
Contact: Hans Lassen, Danish Institute for Fisheries Research, Charlottenlund Slot, K-2920, Charlottenlund, Denmark
Phone: 45 33 96 33 00
Fax: 45 33 96 33 33
E-mail: hl@dfu.min.dk
or
Tissa Amaratunga, NAFO Secretariat, P.O. Box 638, Dartmouth, Nova Scotia, Canada B2Y 3Y9
Phone: 1-902-469-9105
Fax: 1-902-469-5729

International Symposium on Fishery Stock Assessment Models for the 21st Century: Combining Multiple Information Sources
8–11 October 1997, Anchorage, Alaska, USA
Contact: Brenda Baxter, Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks, USA
E-mail: FNBRB@aurora.alaska.edu

1998

International Society of Soil Science Congress-Cryosols
8–17 July 1998, Montpelier, France
Contact: David Gilchinsky, Institute of Soil Science and Photosynthesis, Russian Academy of Sciences, 124292 Pushchino, Moscow Region, Russia
Phone: 7 095 923 3558 (Moscow)
Phone: 7 095 923 1887 (Pushchino)
E-mail: gilchin@issp.serpukhov.su

Seventh International Conference on Permafrost
27–31 July 1998, Yellowknife, Canada
Contact: J.A. Heginbottom, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, Canada
Phone: 1-613-992-7813
Fax: 1-613-992-2468
E-mail: heginbottom@gsc.emr.ca
Web sites: http://www.nrcan.gc.ca/gsc/permaf_e.html (English)
http://www.nrcan.gc.ca/gsc/permaf_f-html (French)

International Symposium on Interaction Between Ice Sheets and Landscapes
August 1998, Kiruna, Sweden
Contact: Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, United Kingdom
Phone: 44-1223-355974
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IASC/SCAR Symposium on Global Changes in the Polar Regions–Results and Challenges from Bipolar Science
August/September 1998, Tromsø, Norway
Contact: Executive Secretary, IASC, Secretariat, P.O. Box 5072, Majorstua, 0301 Majorstua, Oslo, Norway
Phone: 47 22 95 96 00
Fax: 47 22 95 96 01
E-mail: iasc@npolar.no

International Conference on Snow Hydrology: The Integration of Physical, Chemical and Biological Systems
6–9 October 1998, near Windsor, Vermont, USA
Contact: Janet Hardy, Chair, Snow Hydrology Conference, Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755, USA
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Revision of U.S. Arctic Research Plan

Readers of *Arctic Research of the United States* are invited to comment on the U.S. Arctic Research Plan and suggest improvements. The Fourth Biennial Revision of the Plan was published in this journal, volume 9, Spring 1995.

In accordance with Section 109 of the Arctic Research and Policy Act, the next biennial revision of the Plan is to be prepared by July 1997.

Please send your comments to Charles E. Myers, Head, Arctic Interagency Staff, Interagency Arctic Research Policy Committee, Office of Polar Programs, National Science Foundation, Arlington, VA 22230.

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