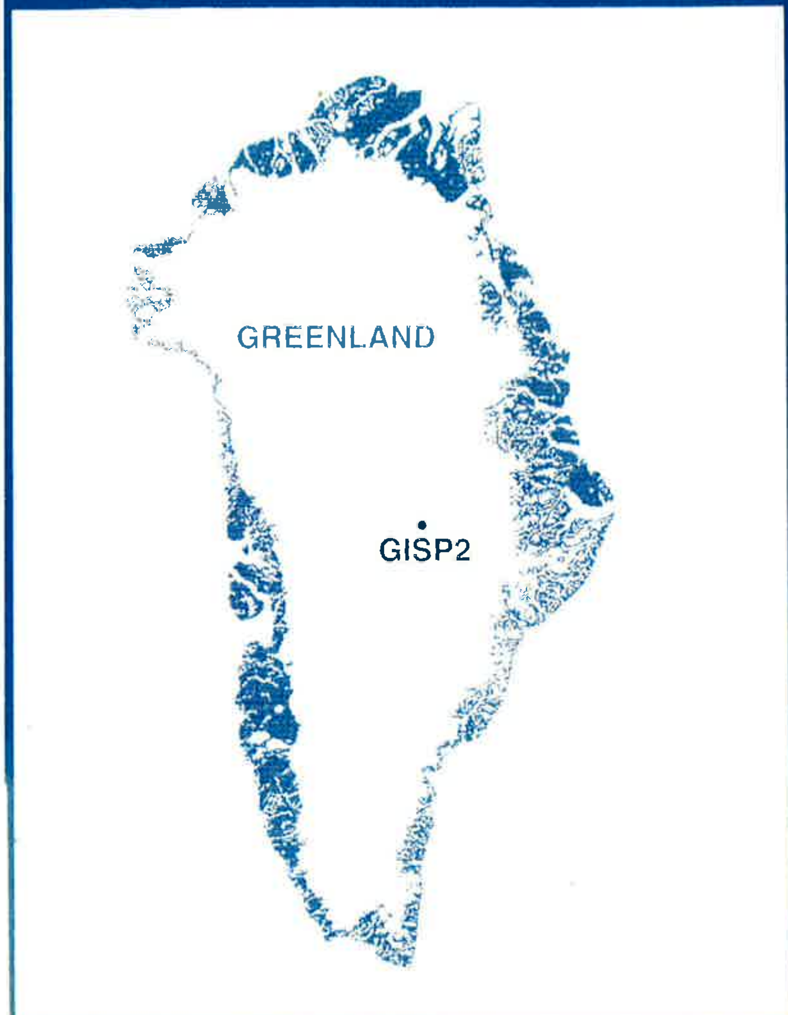
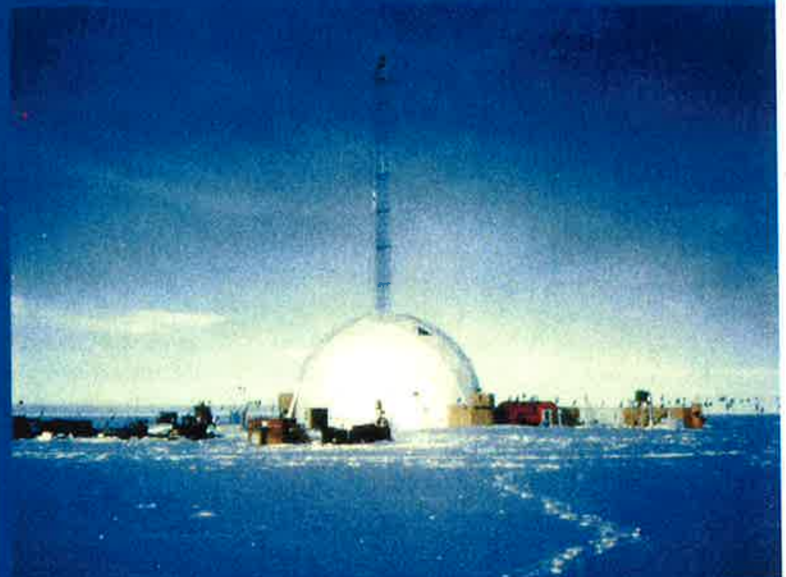
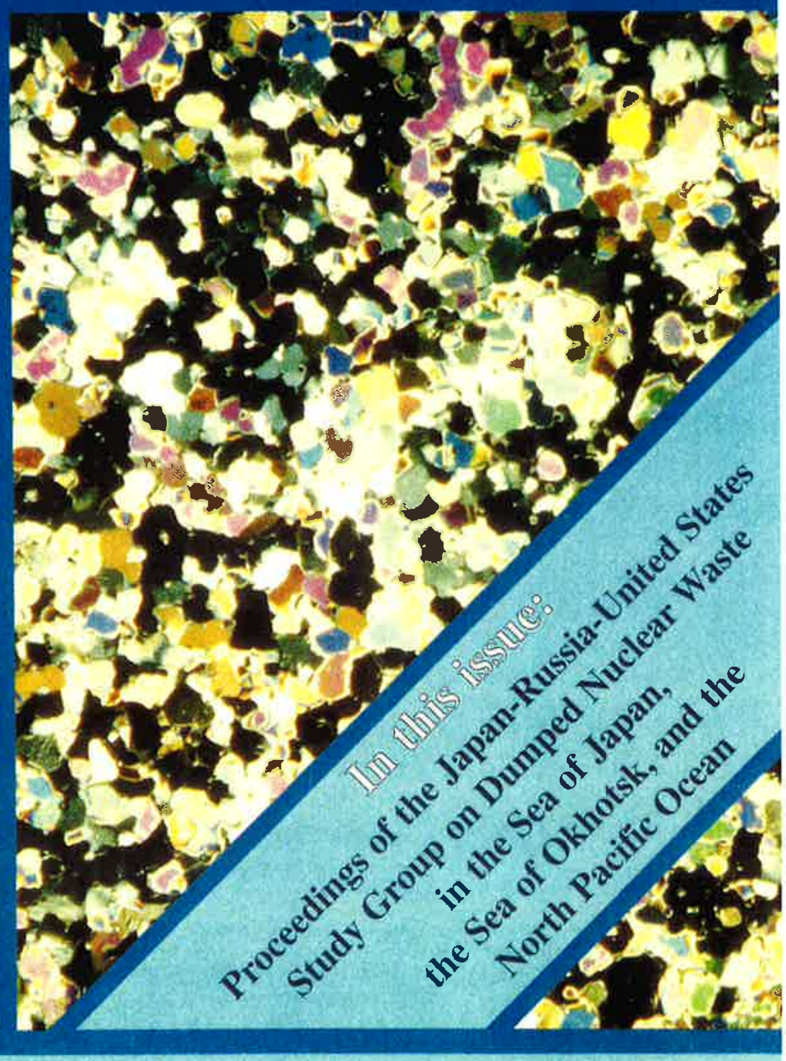
VOLUME 9 FALL/WINTER 1995

# ARCTIC RESEARCH OF THE UNITED STATES





In this issue:

Proceedings of the Japan-Russia-United States Study Group on Dumped Nuclear Waste in the Sea of Japan, the Sea of Okhotsk, and the North Pacific Ocean

INTERAGENCY ARCTIC RESEARCH POLICY COMMITTEE

# 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

*(clockwise from upper left)*

*Location of the GISP2 (Greenland Ice Sheet Project 2) drill site.*

*GISP2 drill dome.*

*Horizontal thin section of GISP2 ice from 94 m deep, viewed between crossed polarizers to reveal the crystal texture. The crystals averaged about 2.5 mm in diameter at this depth.*

*Removing ice core from the drill barrel inside the drill dome.*

VOLUME 9 FALL/WINTER 1995

# ARCTIC RESEARCH

## OF THE UNITED STATES



Editing and production: Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire
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# Arctic System Science

*Prepared by Charles Myers, Office of Polar Programs, National Science Foundation*

The National Science Foundation established the Arctic System Science (ARCSS) program in FY89. ARCSS is structured as a regional component within the U.S. Global Change Research Program and is coordinated by the Office of Polar Programs. Through a series of workshops and interactions with a broad scientific community, ARCSS aims to understand the role of the Arctic in global change and how the Arctic will respond to global change. ARCSS is an interdisciplinary program that examines the interactions within and between the climatic, geologic, biologic and socioeconomic subsystems of the Arctic.

ARCSS has five linked components:

- The Greenland Ice Sheet Project (GISP2);
- Paleoclimates from Lakes and Estuaries (PALE);
- Ocean–Atmosphere–Ice Interactions (OAII)
- Land–Atmosphere–Ice Interactions (LAII); and
- Synthesis, Integration and Modeling Studies (SIMS).

It is a phased long-term program. GISP2 was initiated in 1989 and will be terminated in 1997. PALE and OAII began in 1990, with LAII and SIMS beginning in 1993 and 1995, respectively.

Steering committees for each component facilitate and enhance the ARCSS program and provide a focal point for communication with the scientific community. Overall coordination and integration of the ARCSS components are accomplished using the advice of the ARCSS Advisory Panel. The panel includes representatives from each steering committee and other scientists who enhance the breadth and experience of the group.

ARCSS has been particularly successful at establishing partnerships with other Federal agencies. Significant cost sharing on Arctic Ocean science for ARCSS projects came from ONR (Office of Naval Research). ARCSS anticipates considerable cooperation with NASA, DOE, ONR and NOAA in the future on aspects of common concern, such as Arctic climate and ocean process and modeling research.

This issue of *Arctic Research of the United States* highlights selected accomplishments of the Greenland Ice Sheet Project, the first ARCSS component to reach a major milestone. Future issues of *Arctic Research of the United States* will contain reports on other components of ARCSS.

# The Greenland Ice Sheet Project Two (GISP2)

*Prepared by Paul A. Mayewski, Glacier Research Group, Institute for the Study of Earth, Oceans and Space, University of New Hampshire, Durham, New Hampshire 03824. Dr. Mayewski is Chief Scientist for GISP2.*

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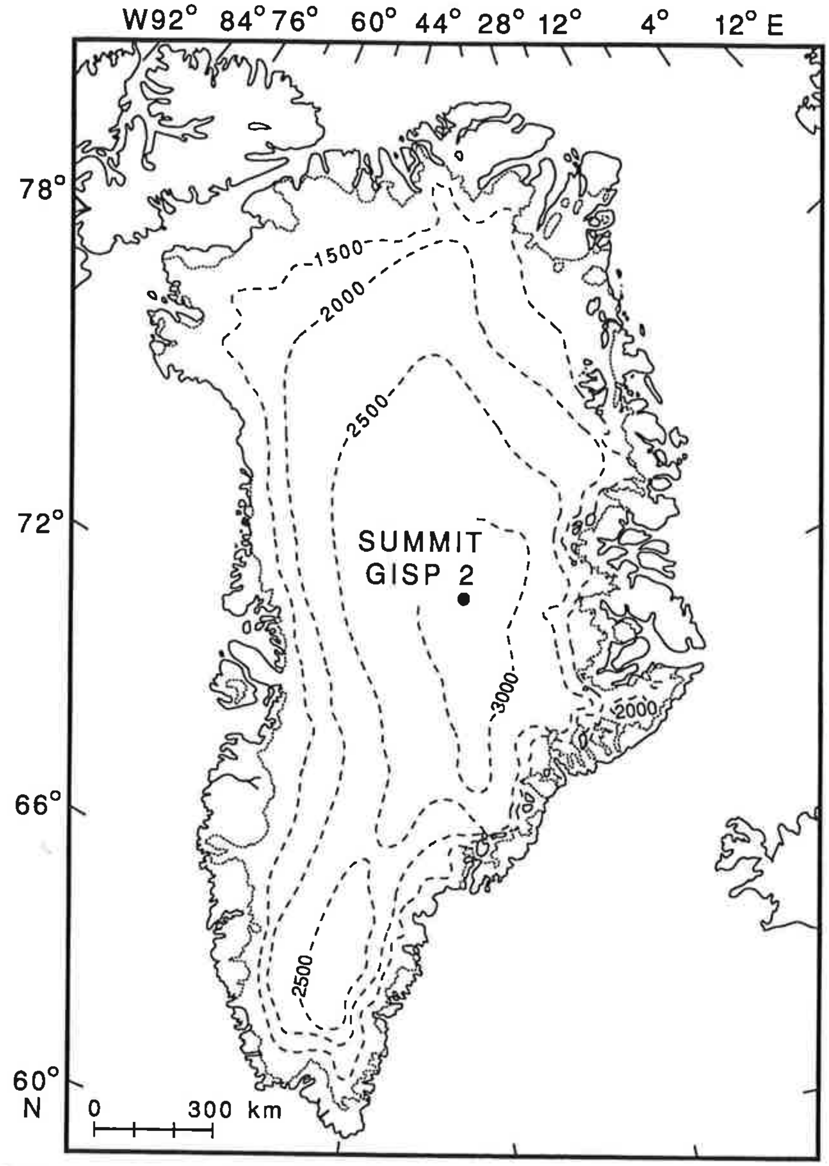
On 1 July 1993, after five years of drilling, the Greenland Ice Sheet Project Two (GISP2) penetrated through the ice sheet and 1.55 m into bedrock, recovering an ice core 3053.44 m in depth, the deepest ice core thus far recovered in the world. With the completion of the GISP2 drilling program and a companion European ice coring effort [the Greenland Ice Core Project (GRIP), located 28 km to the east], a new era in paleoenvironmental investigation has been opened. These records are of extreme significance to our understanding of environmental change because they not only provide the highest-resolution, continuous, multi-parameter view produced thus far, but as important, the two records can be used to validate each other (for example, dating, presence of events, length of the environmental record, presence or lack of discontinuities), the only such experiment of this magnitude in ice core research.

In 1989 the Office of Polar Programs (OPP) (formerly the Division of Polar Programs) of the U.S. National Science Foundation (NSF) officially initiated GISP2. It was developed as the first in a series of integrated studies, administered by OPP under its Arctic System Science (ARCSS) program, an initiative focusing on environmental change in the Arctic. The primary goals developed at that time for GISP2 included:

1. Recovery of a high-resolution record of Holocene and pre-Holocene climate;
2. Characterization and interpretation of the gaseous, soluble, insoluble, electrical, structural and physical properties of the core and of the partitioning, reservoir exchange and production rates for the various source contributions to the atmosphere of central Greenland (for example, anthropogenic, volcanic, biogenic, oceanic, terrestrial, cosmogenic);




*Location of GISP2, at 72.58° North latitude, 38.48° West longitude at an elevation of 3207 m. The mean annual temperature at GISP2 is –31 °C and the modern acumulation rate is 0.23 m $H_2O$ equivalent per year.*

3. Investigation of the timing, effects and forcing of climate change as revealed by the comparison of the measured core parameters that provide high-resolution views of climate (for example, temperature, precipitation, atmospheric circulation strength and pattern), radiatively important gases (for example, $CO_2$, $CH_4$) and aerosols (for example, volcanic, marine, crustal and anthropogenic), biogeochemical cycling (for example, carbon, nitrogen, oxygen and sulfur), and other climate system boundary conditions (for example, ocean temperature, level and circulation; sea ice extent; ice volume; volcanic activity; and atmospheric turbidity); and
4. Development of accurate dating techniques and flow modeling for Holocene and pre-Holocene ice.

As of January 1995, close to 100 peer-reviewed contributions have emerged in response to these goals. They cover a broad range of topics, including site survey; analytical and statistical techniques; bipolar, Arctic and GISP2/GRIP comparisons; transfer functions (atmosphere–snow); unique events (volcanism, biomass-burning, anthropogenic emissions); paleoenvironmental reconstruction; and physical processes of snow and ice.

As the final analyses of the GISP2 record emerge, it is the intention of those of us who have produced the GISP2 record that it provide the perspective needed to dramatically advance our understanding of climate change (response and forcing) and perhaps the perspective needed to understand the consequences of human involvement in this dynamic environment. As a review of the papers in this volume will indicate, we have made major strides in this endeavor. In addition, we expect that it will provide the framework needed to incorporate and further interpret the wealth of other proxy environmental records that are already available (for example, tree rings and marine and lake sediments), leading toward even more robust paleoenvironmental reconstructions.

In addition to a continued stream of peer-reviewed publications, the joint results of the GISP2 and GRIP activities will be produced as a volume following the final joint meeting of these groups in the fall of 1995. Even the GISP2 field site remains active as investigations that began as complements to the deep drilling continue to yield results, allowing further refinement of our understanding of modern and paleoclimate.

# *GISP2 Programs and Principal Investigators*

| *Investigator* | *Institution* | *Subject* |
|---|---|---|
| Alley, Richard* | Penn State Univ. | • Physical properties of core; continuous visual logging of core, density, texture and fabric |
| Bales, Roger | Univ. of Arizona | • Snow–atmosphere transfer function for hydrogen peroxide |
| Barry, Roger<br>Armstrong, Richard | Univ. of Colorado | • Data management |
| Bender, Michael | Univ. of Rhode Island | • Occluded gas analyses; $\delta^{18}O$ of $O_2$, $\delta^{15}N$ of $N_2$, $O_2/Ar$ ratio, $N_2/Ar$ ratio |
| Biscaye, Pierre | Lamont–Doherty Earth Observatory | • Origins of atmospheric dust in GISP2 ice |
| Bolzan, John | Ohio State Univ. | • Surface strain net, velocity, accumulation, ice flow modeling |
| Borys, Randy | Desert Research Institute | • Crystal habits and rime chemistry |
| Boyle, Ed* | MIT | • Trace metal chemistry |
| Craig, Harmon* | Scripps Inst. of Oceanography | • Helium isotopes |
| Davidson, Cliff | Carnegie Mellon Univ. | • Major ions and trace metals of aerosols and snow |
| Dibb, Jack | Univ. of New Hampshire | • Radionuclides in aerosol and snow |
| Gow, Tony*<br>Meese, Debra* | Cold Regions Research and Engineering Laboratory | • Physical properties of core; annual layering, core relaxation mechanisms, and precision density measurements |
| Grootes, Pieter*<br>Stuiver, Minze* | Univ. of Washington | • $\delta^{18}O$ record of ice |
| Hodge, Steve | U.S. Geological Survey, St. Olaf College | • Airborne ice radar determination of the surface and bed topography |
| Lal, Devendra | Scripps Inst. of Oceanography | • Cosmogenic in-situ $^{14}CO$, $^{14}CO_2$ and atmospheric $CO_2$ |
| Mayewski, Paul* | Univ. of New Hampshire | • GISP2 Science Management Office; major anions and cations, total acidity and ionic balance |
| Mosher, Byard | Univ. of New Hampshire | • INAA analysis of aerosols and snow |
| Nishiizumi, Kunihiko*<br>Arnold, James*<br>Finkel, Robert* | Univ. of California–Berkeley, Lawrence Livermore Laboratory | • Cosmogenic radionuclides, $^{10}Be$, $^{26}Al$, $^{36}Cl$ |
| Ram, Michael* | SUNY Buffalo | • Continuous particulate concentrations |
| Saltzman, Eric* | Univ. of Miami | • Methanesulfonic acid (MSA) and iodine (iodide and iodate) in ice |
| Stearns, Charles | Univ. of Wisconsin | • Automatic weather stations |
| Taylor, Ken* | Desert Research Institute | • Continuous electroconductivity of core |
| Waddington, Edwin | Univ. of Washington | • Temperature history inference from borehole temperature measurements |
| Wahlen, Martin*<br>Broecker, Wallace* | Scripps Inst. of Oceanography, Lamont–Doherty Earth Observatory | • $CO_2$/air ratios, $\delta^{13}CO_2$ in occluded gas, total gas content, $CH_4$ and $N_2O$ concentrations, bubble volume |
| White, James* | Univ. of Colorado | • $\delta D$ ($^2H/^1H$ ratio) of ice |
| Wilson, Alex*<br>Donahue, D.J.* | Univ. of Arizona | • $^{14}C$ dating of core from occluded $CO_2$ |
| Wilson, Alex* | Univ. of Arizona | • Concentration and $\delta^{13}C$ of $CO_2$ in occluded gas |
| Zielinski, Greg* | Univ. of New Hampshire | • Insoluble particles; mass concentration, size distribution, chemical composition and morphology |

* GISP2 deep drilling investigator.

# GISP2 Deep Ice Core Drilling

*This report was prepared by Dave Giles, Polar Ice Coring Office, 205 O'Neill Building, University of Alaska Fairbanks, Fairbanks, Alaska 99775-1710; Walter Hancock, Chemistry Department, University of Nebraska, Lincoln, NE 68588-0304; and John Kelley, Bruce Koci, Kerry Stanford and Victor Zagorodnov, all from the Polar Ice Coring Office.*

The Polar Ice Coring Office (PICO) was established by the National Science Foundation (NSF) in 1979 to provide coordinated drilling services for the scientific community. During the past five years PICO has been operated through the University of Alaska Fairbanks (UAF). Within that time GISP2 was successfully conducted. There were three major functions of PICO involvement in the project: deep ice core drilling, logistics support of field operations and management. To support these activities, PICO developed new ice and rock core drilling technologies, logistics systems and lines of organization. The scientific success of the GISP2 project was directly associated with these technical and organizational developments.

## History of the U.S. deep ice core drill

The first scientific approach to deep ice coring was proposed and accomplished for the glaciological program of the International Geophysical Year by the U.S. Army Snow, Ice and Permafrost Research Establishment. Between 1956 and 1958, four deep holes were cored by modified conventional rotary equipment. In the summers of 1956 and 1957, boreholes of 305 and 411 m were drilled in northwest Greenland at Site II. In Antarctica at the beginning of 1958, a 308-m borehole was drilled at Byrd Station. By the end of the year, a 256-m borehole was drilled on the Ross Ice Shelf at Little America V. During that time the major elements of ice drilling technology were successfully tested. These included a technique of borehole casing for use with a cold-air chip transport system, coring bits and a constant-rate feed device. The first successful drilling with a hydrophobic drilling liquid (Diesel Fuel Arctic grade, or DFA) was completed in the Little America V borehole in the last 5.5 m. This section of ice core had only a few cracks, which did not penetrate the ice core deeper than 12 mm. At that time the use of liquid in the borehole for obtaining good-quality ice core was proposed, and certain problems were recognized. The use of industrial-type drilling equipment had several drawbacks: heavy weight (three shipments totaling 40 tons), a long setup time, slow performance and poor ice core quality (Lange 1973).

In 1961 and 1962, dry and oil-filled boreholes were drilled at Camp Century in Greenland with cable-suspended thermal drills developed by specialists from the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) (Ueda and Garfield 1969). After field tests, it was found that these drilling systems were not reliable for a proposed 2000- to 3000-m-deep ice core (Bader 1962). The first cable-suspended electromechanical rotary drill suitable for glacier ice operations was developed at CRREL in 1964 (Ueda and Garfield 1968). This drill was a modified rock drill developed by Armais Arutunoff. In 1968 and 1969 it was successfully used for deep drilling at Camp Century (Greenland) and Byrd Station (Antarctica), where holes of 1390 and 2164 m were drilled. The average drilling rate was about 2.5 mm/s, which is close to that of a conventional pipe-driven drill, but the core quality and penetration rate were significantly improved. The deep portion of the Byrd Station hole was filled with a DFA and trichlorethylene (TCE) mixture to maintain a proper density of the borehole liquid (920 kg/m$^3$). About 22 m$^3$ of ethylene glycol were used during the Byrd Station deep drilling, along with 49 m$^3$ of DFA and 8 m$^3$ of TCE.

In the 1970s a last attempt was made to modify the rotary pipe-driven drilling system for use in cold ice drilling to depths greater then 1000 m (Hanson 1976). From previous experience with rotary drilling on glaciers, it was clear that industrial-type drilling equipment is too heavy (Lange 1973). Special fiberglass-reinforced epoxy pipes (FRPs) with steel connectors were designed at CRREL. Compared with industrial-type drill pipes, FRPs are three to ten times lighter. To avoid the time-consuming hoisting and disassembly of the drill pipe, the core was retrieved by a wireline system: a core barrel coupled with cable. The core-loaded barrel travels inside the drilling tubes suspended by a cable. Therefore, the ice core can be retrieved without disassembling the drilling pipe string. The drilling rig weight was reduced by using a reverse air-vacuum or reverse air circulation for removing the cuttings. This makes it possible to exclude heavy air-cooling devices. Adaptation of the system for drilling on the East Antarctica Ice Sheet to a depth greater than 1000 m employed circulation of cold DFA. This system was used during the 1976-77 season for core drilling (air-vacuum) to a depth of 313 m (Antarctica, Ross Ice Shelf, J-9). During the 1977-78 season the wireline coring system was used with cold DFA circulation to remove cuttings from a 170-m borehole. For various reasons the full potential of the drilling system was never realized. However, it appears that the system is ideal for drilling intermediate-depth (a few hundred meters) boreholes in regions with good surface transportation. This system is also capable of coring subglacial material. The use of chilled drilling liquid (for environmental reasons, DFA is no longer acceptable) may freeze unconsolidated subglacial deposits and permit coring.

The next advance in deep ice drilling technology happened at the end of the 1970s, when a new electromechanical drill (called ISTUK) was built at the University of Copenhagen, Denmark (Gundestrup et al. 1984). The ISTUK drill was developed as part of the Greenland Ice Sheet Program (GISP) conducted by Danish, Swiss and U.S. investigators (Langway et al. 1985). The major drilling principles remained the same as with the CRREL and other electromechanical drills, but several innovations for reducing the drill weight and power consumption were used. The direct result is a reduction of the cable diameter and the weight of the winch. To compensate for the lithostatic pressure of the ice, the hole is filled with a hydrophobic liquid. For reasons of higher purity, Jet A-1 (aircraft fuel) was used as a major component of the borehole liquid. To maintain the density of the liquid close to that of ice, perchlorethylene (PCE) was added to the kerosene. Adding 10% of PCE was enough to increase the liquid density to 950 kg/m$^3$. Compared with TCE, PCE presents less inhalation danger because of its lower vapor pressure. However, to reduce the presence of the toxic fumes from the borehole liquid, a ventilation system was used in the drill shelter.

The ISTUK drill was successfully used for deep drilling in central Greenland at the Dye 3 station, where a 2037-m hole was drilled during 1979–1981 as part of the GISP project. Then, during 1990–1992, a 3029-m hole was drilled in the ice sheet at Summit, Greenland (GRIP project). The quality of the ice cores was excellent. The investigations in central Greenland show that the ISTUK drill cannot operate below –40°C or much deeper than 3000 m, and it is not capable of rock coring.

To have a reliable drill for coring in the central regions of Greenland and the Antarctic Ice Sheet at ice temperatures to –55°C and depths to 4000 m, a new development program was proposed (*Recommendations for a U.S. Ice Coring Program* 1986).

## *PICO electromechanical ice core drill*

The concept of a modular drill, including a description of its main elements and operating principles, was proposed by Bruce Koci in 1986 (Koci 1989). The drill is capable of dry-hole coring, deep fluid-filled-hole ice core drilling, and debris-laden ice and rock coring (Kelley et al. 1994, Stanford 1994, Wumkes 1994).

The drill sections are connected in the following top-to-bottom sequence: slip ring, load cell, anti-torque system, transformer section, electronic instrument section, DC motor (0–2500 rpm), gear reducer (ratio 17:1), first filter section, bearing section, second filter section, pump, core barrel and cutting head (0–150 rpm). The drilling head is rotated by a long shaft, which passes through the filter sections and which also drives a Moyno-type pump.

The coring head consists of three cutters and three core catchers similar to the PICO shallow-depth drills. Two cutter profiles have been tested. Shallow chevron-profile cutters were developed for stabilizing the drilling head and reducing axial vibration. A more common type of cutter with a straight cutting edge shows essentially the same core production capability. However, the straight-type cutter produces a larger, more easily trapped ice chip. Both cutter types were used with a penetration shoe that controls the amount of ice removed with each revolution of the cutting head. Experiments with aggressive carbide-edge cutters demonstrated their excellent cutting ability, but their construction made them brittle and fragile, particularly when any debris was encountered in the borehole.

At first the drill was used for boring and reaming a dry hole. This was necessary for casing the upper portion of the deep borehole to prevent the drilling fluid from migrating through the firn. Chips from the cutting head are transported to the collecting screen inside the inner core barrel (above the core) by helical flights similar to shallow dry-hole drills. Three vertical strips were welded inside of the outer core barrel to help provide circumferential shear for moving chips to the chip collector. For further fluid drilling, a double-tube core barrel without flights or strips has been used very successfully. In this case the ice chips and drilling liquid mixture are sucked up through the annulus between the inner and outer core barrel tubes and then pass through the Moyno pump and the filter. Though it is heavy, the Moyno pump has several advantages. It can pump fluids with a wide range of viscosities. It is robust and capable of pumping ice chips (with rock fragments) in the drilling fluid with minimal damage. It is powered by the same shaft that turns the core barrel, and it works well in the required rpm and power range.

The design of the cuttings filter was adapted from the water well industry. Stainless steel well screens with a gap of 0.2 mm typically stop clay-size particles with a small pressure drop. This screen is robust, straight and strong enough to be incorporated in the drill without requiring a support structure. For ice drilling applications a special version of the screens was made. The filter reliably separated chips from fluid during deep-drilling operation.

To use the drill for rock coring, the structure of the instrument was modified. The top anti-torque, electronics and motor-gear reducer sections remain the same as for ice coring. One screen section was also used to filter out ice chips while permitting fluid to flow through the rock drill. A smaller Moyno pump, a core breaking hammer and a core barrel stabilizer were incorporated into the drill. An industrial-standard thin-kerf core barrel with a diamond bit was used for rock penetration (Wang et al. 1994). Since diamond bits require a high rotation rate (at least 500 rpm), a 5:1-geared speed increaser was included in the rock drill section in series with the 17:1-ratio gear reducer. Many of the drill components and special tools, such as the finger couplings, side reamer and motor canister, were designed at PICO or at the Geophysical Institute at UAF. Nearly all drill fabrication was done at UAF.

### *Drill control instrumentation*

A navigation system was designed for the 5.2-inch deep drill in 1988 (Hancock and Koci 1989, Hancock 1994). The original purpose of the system was to inform the drill operator whether the drill was staying vertical and what the drill's orientation was relative to magnetic north. The microprocessor and digital converter had extra capacity and could accommodate additional drilling parameters, such as motor current, voltage, rpm, drill weight, fluid pressure, battery voltage and a range of temperatures. The presence of the microprocessor in the drill made it possible to use a more powerful drill motor by controlling a reversing relay in the drill. This allowed the use of a high-voltage AC current in the 4-km-long drill cable, thereby minimizing resistive losses and delivering more power to the drill motor.

The control panel at the surface was designed to be compact and lightweight, and provide all the information and controls an operator needed to run the drill. It was designed around the same type of "computer-on-a-chip" microprocessor as was used in the drill. It did all the calculations on the data from the drill and also kept track of the drill depth by counting pulses from a shaft encoder mounted on the drill tower. Any drill parameter could be selected to be displayed on its digital readout. It was also designed to send all the data to a computer for logging. This feature later allowed a fast computer to display all the drilling parameters at once on a monitor screen while still logging the data.

The system was first tested at Dye 3 in Greenland in 1988 using a 1000-m cable. In 1989 the system was tested at Summit in Greenland, and in 1990 the 1000-m system was used to drill to 330 m using butyl acetate as the hole fluid. In 1991 a new winch and 4000-m cable were used. This required a redesign of the transformers using materials suitable for use in butyl acetate and a higher voltage because of the extra length of the cable. The drilling proceeded to about 1600 m in 1991, but the instrument package seals had problems with the butyl acetate hole fluid. In 1992 the seals were redesigned and a new type of O-ring grease was found that was resistant to the hole fluid, and the drilling proceeded to about 2200 m. In 1993 the hole was completed at 3053.5 m, and the system was taken to Antarctica, where a new 1000-m winch was used to drill to 550 m at McMurdo Dome.

### *Borehole liquid*

Environmentally appropriate drilling fluids were sought to support the deep ice coring objectives of the glaciological programs of the National Science Foundation (Gosink 1989). In the past several decades, three types of fluids have been used for ice coring activities:

- Fuel oil (DFA), usually containing several percent of a dense halogenated solvent;
- Aqueous ethanol or glycol solutions; and
- N-butyl acetate.

Each has advantages and disadvantages. PICO conducted a chemical literature survey in an effort to identify a drilling fluid suitable for deep ice coring that would have the appropriate viscosity, temperature and density characteristics; cause minimal potential health and safety risks for workers; cause minimal environmental impact; and maintain the highest integrity of ice core for scientific analysis. Of nearly 250,000 compounds electronically surveyed in the literature search, 11 potential drilling fluids were tentatively identified as suitable. N-butyl acetate satisfied most of the requirements (Gosink et al. 1991).

### *Cable*

The GISP2 program was the first time a Kevlar (aramid) electromechanical cable had been used for deep drilling. The weight reduction due to the 5-to-1 advantage in specific strength over steel offered significant savings in power and winch requirements as well as elongation advantages. Cortland Cable Hi Wire conductors were chosen as power and data communication conductors. The cable used four #20 shielded wires surrounded by ten #18 conductors to supply power to the drill. The conductor bundle was surrounded by a double-layer woven Kevlar strength member. The tested breaking strength of this cable was 22,200 pounds (10,000 kg).

The suggested minimum sheave diameter allowed with this type of woven strength member was 75 cm (30 times the cable diameter), and the working load limit was 1000 kg. The drill was operated above both limits, as the actual sheave diameter was 63.66 cm (28.5 times the cable diameter), and the working load was 1360–1500 kg. Kevlar has a high abrasion resistance but not when rubbing against itself. In general, any low-temperature drilling fluid dissolves and removes lubricant provided with steel or aramid-reinforced cables. This resulted in an abrasion-induced loss of tensile strength in the first aramid cable.

Most electromechanical cables are used for borehole logging and generally are not subjected to the number of sheave- and load-induced bending and tension cycles associated with ice core drilling while immersed in a strong solvent. Thus, little information on abrasion damage was available about Kevlar cables used for long-term ice coring operations. It is known that this type of failure can occur under similar operating conditions in seawater. Since a breaking strength of 10,000 kg is near the maximum for a double-layer construction, the alternatives for obtaining higher breaking strength are increased sheave diameters, a lighter drill and different cable designs. Limiting cable use to 2000 m of drilling is another possibility. A cable design approach that was successfully used on the Taylor Dome borehole involved the use of four-layer unidirectional lays of Kevlar with no weave in the structure. No cable lubricant was required, and no abrasion-induced cable damage was noted during drilling. After-project tensile tests have not yet been run to determine the actual residual cable strength.

### *Drill performance*

During four summer seasons the deepest glacier borehole (3053.5 m) was drilled near the summit of the Greenland Ice Cap. The full potential of the drill was demonstrated during the second half of the third season and during the final season, when the depth of the hole doubled and rock core was recovered. The GISP2 ice coring was conducted with an average penetration rate of 240 m/week. The maximum penetration rate of 45 m/day was reached when the hole depth was about 1750 m. Perhaps new deep-drilling projects can be done with a penetration rate close to 300 m/week. Technical problems related to concurrent development of the drill used on the GISP2 project delayed the project completion. Every element of the drill was originally designed and built specifically for the GISP2 project. For instance, to obtain the best possible quality of ice core, extra time was spent to find the proper geometry for the cutters. Significant time was also spent in the search for the best drilling fluid. Therefore, the completion of the GISP2 drilling project had another realized goal: proof test of a new and environmentally safe ice core drilling technology. That the technology development and the ice core recovery programs were conducted simultaneously and successfully is indicative of the tremendous effort put forth by PICO personnel.

After preliminary tests of the industrial rock coring bit and core barrel under laboratory conditions to determine power and bit weight requirements, the rock drill section was designed and used for rock recovery from the bottom of the GISP2 deep borehole. After four drilling runs, six pieces of crystalline-type rock core were recovered. The total length of the rock core recovered from the borehole was 155 cm.

## *Conclusions*

Now that deep drilling in Greenland and an additional project at Taylor Dome, Antarctica, are complete, it may be stated that the PICO drill demonstrated an ability to penetrate thick ice sheets, recover high-quality ice core and obtain bottom geologic samples. The analysis of the drill performance during the GISP2 and Taylor Dome projects suggets modifications, which could permit the use of a lighter, faster and more efficient drill in future ice coring research projects.

There are two factors that limit the core recovery rate: hydrodynamic-drag-limited rates for lowering and raising the drill, and surface handling of the drill components, ice core and ice chips. Another important operation that consumes a lot of time in the field is setup of the equipment. For maximum cost-effectiveness of the drilling equipment, it should be possible to modify the drill for greater simplicity and lighter weight.

The first change would be in the drill and borehole geometry. Increasing the clearance by 3 mm radially should allow the lowering and raising speed to be increased by about 50%. A new 15-cm inner core barrel, drill centralizers and a modified coring head are the only requirements. It may also be possible to eliminate the outer barrel and replace it with tubes or simply to flush the drill fluid through the core barrel. Both of these modifications would allow significant reduction in the hydrodynamic drag of the drill as it is pulled through the borehole. Potentially this increase in transit speed could bring the core recovery rate up to as much as 450 m/week.

Shortening the drill by one screen section (6 m) and reducing the core barrel length to 3 or 4 m may allow an additional increase of lowering and raising speed by about 10% due to reduced drag. The shorter drill would also require a shorter tower and lighter surface handling equipment. The deep-hole drill rate would be reduced somewhat due to the shorter core barrel, however.

The current drill motors could be replaced by lower-inductance motors to minimize arcing and brush wear at the commutator. New motors should also have mechanically attached magnets and an epoxy-type winding varnish to minimize chemical attack while operating in n-butyl acetate in the event that the motor canister seals leak. Further work is also needed on lubricant-free or ceramic bearings. A more permanent solution is to use brushless DC motors with an electronic control package. This is a costly fix, however.

Because this is a new drill system that has only been set up and used for two projects, many small incremental changes to the system can yet be made. Each of these changes could save field time, and their cumulative effect would be significant.

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# *The Role of Glacier Geophysics in the GISP2 Ice Core Program*

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Together, the GISP2 ice core and the companion GRIP core from near the summit of the Greenland ice sheet have provided an unprecedented high-resolution view of the climate in Greenland over the past 90,000 years or more. Many important climate-related parameters have been measured in both ice cores (Johnsen et al. 1992, Taylor et al. 1993a, Dansgaard et al. 1993, Mayewski et al. 1994). Some of the success of these ice core projects can be attributed to accompanying glacier geophysical research programs investigating the dynamics and temperature of the ice sheet in central Greenland. For example, selecting good drilling sites requires geophysical surveys and analysis, and determining two of the most basic paleoclimate parameters from an ice core (temperature and net snowfall) depends on geophysical methods.

## *The connection between ice dynamics and ice core paleoclimate*

The importance of ice dynamics to ice core research was recognized by the Committee for Science Planning in Central Greenland (Mosley-Thompson et al. 1985) in their science plan that led to the GISP2 project. New glacier geophysical methods and models developed in the past decade have contributed to the GISP2 program in additional ways that were not anticipated. It is now widely recognized that geophysical surveys and geophysical models should be a fundamental component of future ice core programs, from site selection to final paleoclimate interpretation.

Ice flow and temperature models, constrained and guided by geophysical data collected from a large area surrounding the ice core sites, can provide the additional information needed to resolve a number of ice core interpretation problems:

- Ice core geochemists measure properties of the ice core, and from these data they infer properties of the local and global paleoclimate. However, their view is restricted to a very small sample of ice (the GISP2 ice core is a cylinder with a cross-sectional area of 0.014 square meters), which may not be representative of the region.
- The core has been extracted from a dynamically changing ice sheet, and changes in the height or extent of the ice sheet can in turn affect the local component of the climate signal.
- Ice sheet flow can carry ice to the coring site from other parts of the ice sheet that may have climates different from the core site, confounding spatial variability on the ice sheet surface with temporal changes of climate.
- The ice flow deforms and distorts the ice in which the geochemical signals are embedded. Any attempt to use the observed annual layers in the ice to deduce the history of snow accumulation rate or chemical impurity fluxes onto the ice sheet surface requires corrections to account for the fact that annual layers are continually thinned by the ice flow after deposition.
- In extreme cases, ice deformation overturns stratigraphic layers. If undetected, this introduces errors into the ice core chronology.
- Geochemical signals in ice cores record relative changes and trends in the climate. Some of these signals (for example, the stable isotope paleothermometer) have been calibrated with geophysical data to reveal absolute rather than relative climate parameters.

Measurements of surface topography, bedrock topography, ice motion, accumulation rate patterns and temperature patterns on and in the ice sheet are essential for a well-balanced and satisfactory ice coring program. Geophysical data typically might cover an area of 100 by 100 km or more around an ice core site; this is a trillion times larger than the area sampled by the ice core itself. Not surprisingly, geophysical data combined with geophysical modeling are better able to reveal spatial ice dynamical influences on the ice core signal than the ice core record alone.

A basic ice core paleoclimate history should provide at least three records:

- A climate temperature history (the changing temperature at a constant height, as distinct from the temperature at the surface of the ice sheet, which thickens or thins over time);
- Net precipitation or snowfall history; and
- A depth–age curve that tells us the correct age of each event in the temperature and precipitation histories.

The climate temperature history can be estimated from the stable isotopes in the ice core. Oxygen and hydrogen atoms each come in two stable (non-radioactive) forms, or isotopes, with different atomic weights. Oxygen comes in the form of $^{18}O$ (relatively rare) and $^{16}O$ (common oxygen). Hydrogen has the forms $^{2}H$ (deuterium, sometimes written as D) and $^{1}H$ (common hydrogen). The stable isotope composition of the ice (the ratio between the heavy and light isotopes) is often written in a form called $\delta^{18}O$ and $\delta D$ for oxygen and hydrogen, respectively. These stable isotope ratios are often used as a proxy for the temperature in the cloud where the snowflakes formed. However, the temperature in the cloud depends on the height of the cloud as well as the climate, and the clouds tend to be higher (and therefore colder) when the ice sheet is thicker. To get the climate temperature from the cloud temperature, a correction must be made for the changing ice sheet thickness and the associated changing cloud height. As snow compacts into solid ice, air bubbles become trapped in the ice. The air pressure in these bubbles (known as Total Gas) acts as a recording barometric altimeter, telling us the height of the ice sheet at the time when those bubbles formed. This elevation history makes the correction from ice sheet temperature to climate temperature possible.

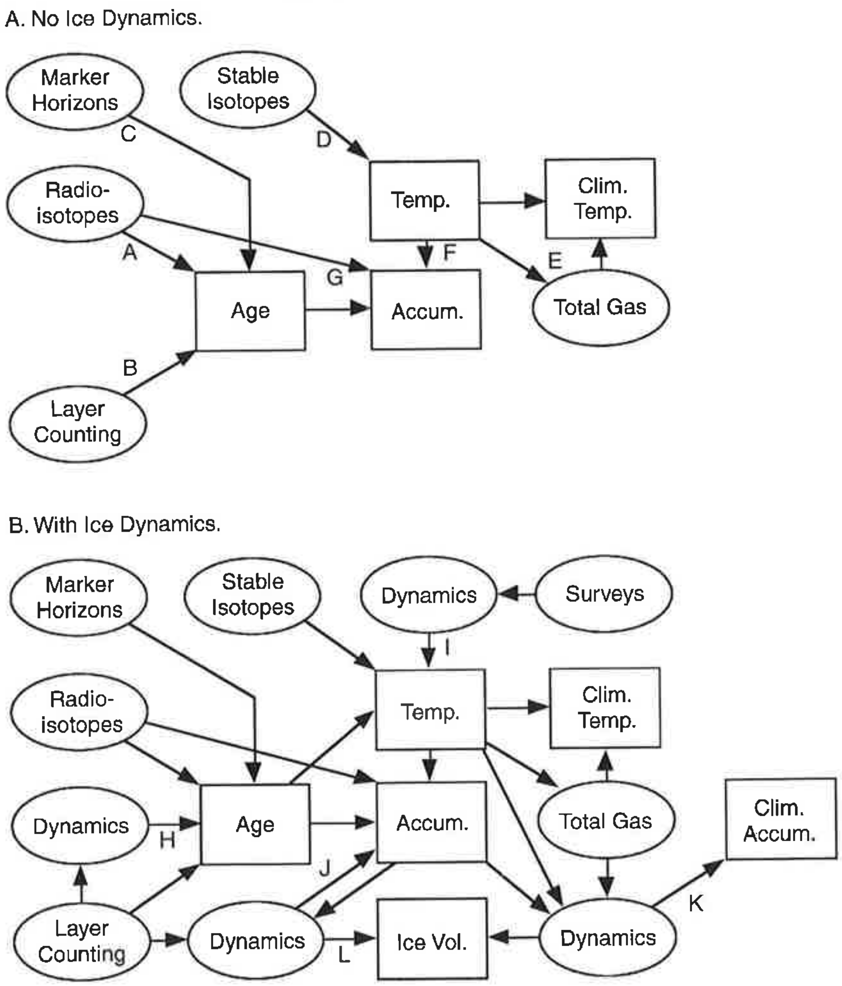
Second, annual layers consisting of summer and winter snow with different dust and impurities can be seen to great depths in the ice core. It is possible to estimate the snowfall in the past from the thickness of these annual layers, at least in the recent past where ice sheet flow has not yet distorted their thickness. If we believe that snowfall is controlled by temperature (the lower the temperature, the less it snows), then it is also possible to estimate snowfall from the temperature history.

Finally, it is possible to date the ice by counting the annual layers. Marker horizons, such as volcanic ash layers from known volcanic eruptions, also help to date the ice. Radioactive isotopes such as carbon-14 can also be found in ice in very small quantities. Experiments are underway to date the ice with $^{14}C$, just as wood and other biological samples can be dated.

The paleoclimate reconstruction described above needs only geochemical data from the ice core itself. However, it is widely recognized that some of these calculations rely on uncertain assumptions. The temperature depends on the correct conversion factor to convert stable isotopes to temperature (other variables besides temperature may influence the isotope record) and on the reliability of the Total Gas altimeter, which is in turn sensitive to temperature. The snowfall history depends on the unknown degree of ice-flow-induced thinning of the annual layers and the assumed correlation between snowfall and temperature. Independent determinations of the temperature, snowfall rate and age are desirable to calibrate, verify and extend the geochemically derived climate history. Geophysics provides all these.

The figure to the left summarizes the greatly expanded paleoclimate benefits from an ice core program when ice dynamics research, supported by geophysical surveys, is carried out in parallel with ice coring. It is apparent, just from the number of boxes and arrows, that ice dynamics adds many more valuable linkages between various inputs (ellipses) and results (rectangles), generates independent measurements and creates new possibilities for paleoclimatic reconstruction. As Alley (1991) explained, without ice dynamics,

> "...a geochemical study focused on local conditions can yield: three estimates of the ice time scale (A, B, and C); one estimate of local temperature history (D), one estimate of how any temperature change is partitioned between climate change and motion of the ice source through the atmospheric lapse rate (E); and two estimates of the accumulation history (F and G). All these estimates have associated errors, of course."




*Effect of ice dynamics on interpretation of an ice core, showing a geochemistry program without and with an ice dynamics component. Ellipses show inputs and rectangles show results; some results serve as further inputs. The letters on the arrows are explained in the text. Ice dynamics adds independent tests of geochemical paleoclimate parameters and also adds new paleoclimate information. [The figure is taken from Alley (1991).]*

However, when an ice dynamics program is included,

> "... we obtain an additional estimate of time scale (H); an additional estimate of temperature history (I); and an additional estimate of accumulation-rate history (J); plus, we obtain an estimate of changes in ice sheet shape that may have affected orographic precipitation (K); and an estimate of how ice volume changed (L). Again these estimates contain errors, but they are largely independent of the geochemical errors. The ice dynamics program thus will increase the accuracy of some paleoclimatic reconstructions and will allow us to make other paleoclimatic reconstructions."

Much of the geophysical research described in this paper focuses either on selection of the drill site or on these additional linkages and the corresponding results that improve our knowledge of the past climate.

## *Ice Core Site Selection and Geophysical Surveys*

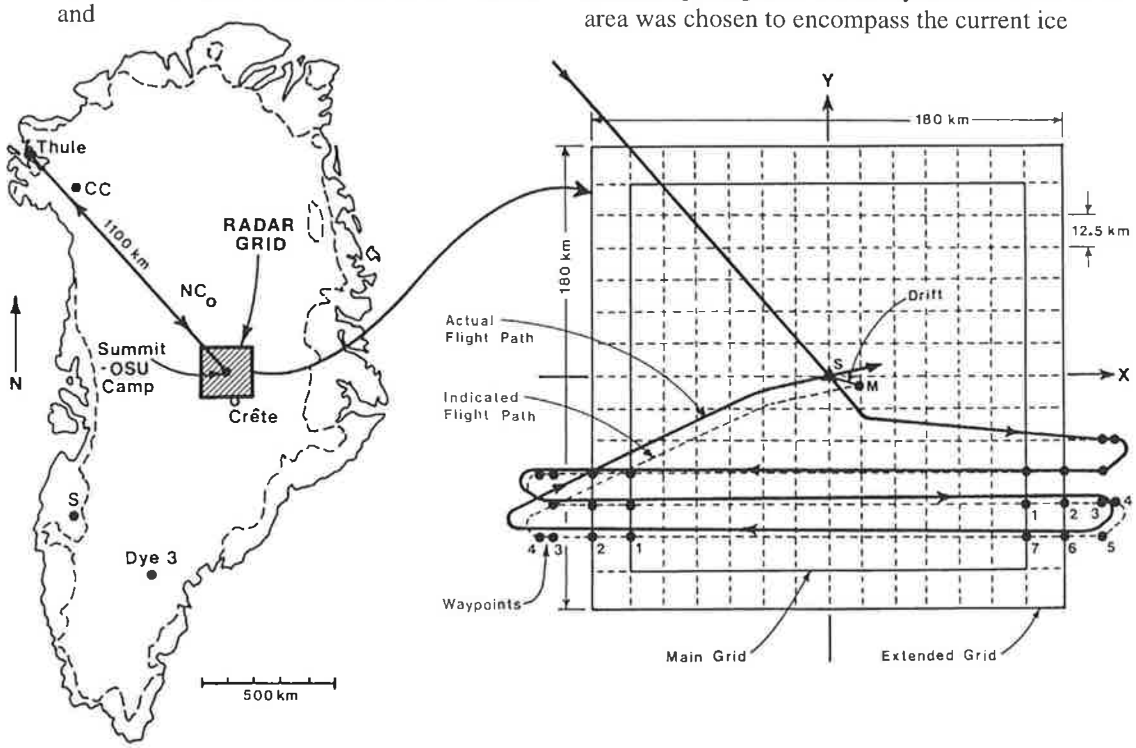
Characteristics that are desirable for a deep ice core site include:

- High-resolution, continuously countable annual stratigraphic layers over the current Holocene interglacial period and earlier;
- Ice at least 100,000 years old;
- Good preservation of the geochemical signals;
- No removal of old ice by basal melting at any time over the past 100,000-year glacial cycle; and
- No disruption or overturning of annual stratigraphy by ice flow.

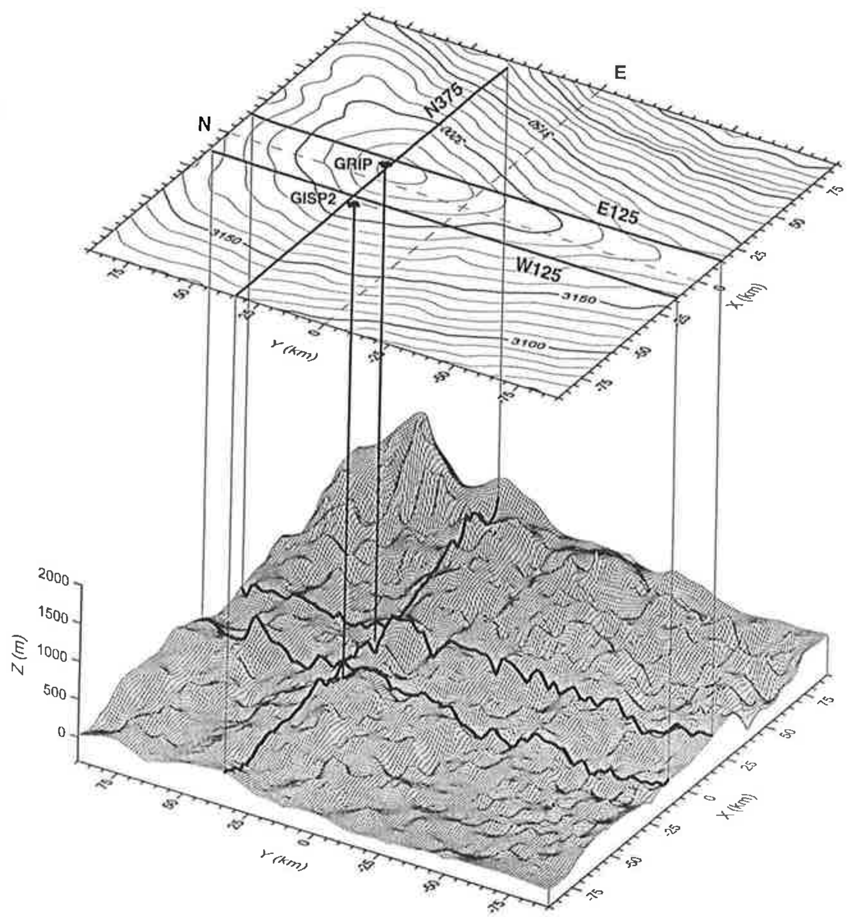
Geophysical investigations are required in order to select optimal ice coring sites. Airborne ice-penetrating radar (for example, Hodge et al. 1990) can identify areas with appropriate ice depth, simple bedrock topography and relatively simple ice flow as revealed by relatively smooth and flat internal radar layers. Snow accumulation measurements obtained by counting annual layers in shallow cores, or by identifying radioactive fallout layers from atmospheric nuclear bomb tests (Picciotto and Wilgain 1963), then permit ice flow models to estimate the age–depth relation and annual layer thickness pattern to be expected at a particular core site.

Finally, if the temperature of the basal ice reached the pressure-melting point at any time in the past, some or all of the oldest basal ice has been lost to melting. If the temperature even came close to the melting point at any time, the chemical and isotopic climate records locked in the ice have suffered. Of the climate records in the ice, the composition of gases (such as carbon dioxide) trapped in the air bubbles is probably the most vulnerable to high ice temperatures. Measurements of shallow ice temperature, when combined with ice flow calculations, allow estimation of the temperature history of potential sites in order to assess the quality of the retained climatic record.

In 1987, prior to the final selection of the GRIP and GISP2 ice core sites, Hodge et al. (1990) flew an airborne ice-penetrating radar survey at 12.5-km line spacing over a 180- by 180-km area. This area was chosen to encompass the current ice




*The area of the airborne ice-penetrating radar survey flown and a typical radar survey flight path. [The figure is taken from Hodge et al. (1990).]*




*Surface and bedrock topography under the airborne ice-penetrating radar survey grid. [This figure is taken from Jacobel and Hodge (1995).]*

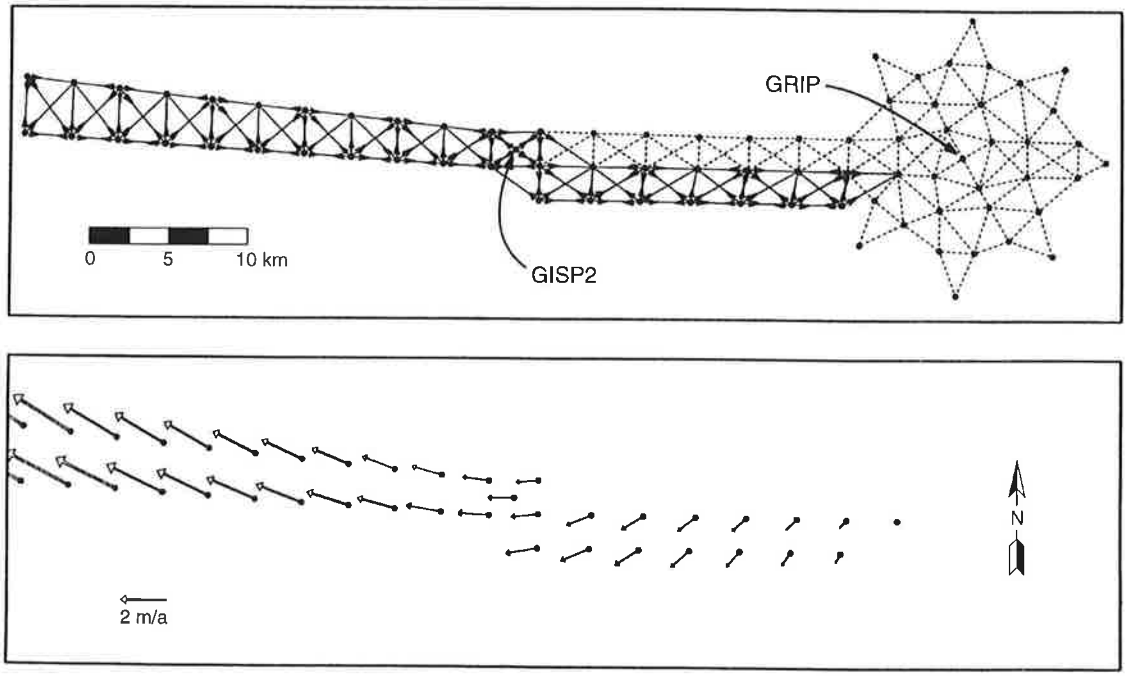
sheet summit and all likely positions of the ice divide during the past 100,000 years. The airborne radar data set then was processed to produce the ice surface and bedrock topographic maps needed to choose the drill sites.

Simultaneously with the airborne radar flights, Bolzan and Strobel (1994) carried out a series of ground traverses within the radar grid to measure accumulation rates by two independent techniques. Using 17-m hand-augered cores, they counted annual layers in $\delta^{18}O$ profiles. They also measured the depths to the layers deposited during the atmospheric nuclear bomb test period (1954–1965), as detected by radioactivity measurements on material filtered from the shallow cores. [Dunphy and Dibb (1994) later also measured snow into boreholes that penetrated the bomb fallout layers.] Those data, combined with data from Danish colleagues (Clausen et al. 1988), showed a strong trend of decreasing accumulation rate from the southwest to the northeast. This is consistent with moisture sources in the southwest and precipitation influenced by air flow up the slope of the ice sheet. Those data provided the accumulation maps essential for estimating the burial rates and the rate of thinning of annual layers by ice flow at Summit.

In 1988 it became clear that two ice cores could be drilled near the summit of the ice sheet. Glacier flow theory (for example, Raymond 1983) predicts that by separating the two sites by a distance of ten ice thickness units, it can be assumed that the two sites have not shared a common history of the stress and strain rate variations that control the shape of the depth–age curves; as a result, the two ice core records can be used together to separate ice dynamical effects from paleoclimate effects. Therefore, glaciologists (Hodge et al. 1988) recommended that the GRIP site be located at the highest point of the ice sheet and that the GISP2 core be drilled down a flowline 30 km to the west. The value of this approach has been demonstrated by the comparisons of the two climate records. In the deep ice older than 100,000 years, ice flow disturbances that appear to have affected the climate records have been discovered (Taylor et al. 1993b, Grootes et al. 1993).

To verify that ice flow calculations are accurate, we must be able to compare the calculated ice velocity and the deformation rate to values measured in boreholes and at the surface. Between 1987 and 1989, Bolzan (1994) measured the surface ice flow velocity at 20 locations within the radar grid, using Doppler satellite techniques. These ice velocity data have been used to estimate the state of balance between surface snow accumulation and the ice flux leaving the Summit area by ice flow. Work in progress by John Bolzan and Ed Waddington suggests that the Summit area is either in steady state or thickening very slowly. Conclusions like this, which cannot be derived from the ice core geochemical data alone, set the glaciological context within which the ice core data must be interpreted.

Scientists in both the GISP2 and the GRIP programs realized that detailed observations of ice velocity and deformation rate around the GRIP site and along the flowline leading to the GISP2 site were essential to accurately calculate the effect of ice flow and dynamical thinning on the stratigraphy observed in the ice cores. Scientists from the Technical University of Braunschweig observed a network of ice motion markers for the GRIP program between 1989 and 1993, and University of Washington scientists observed a similar network for the GISP2 program in 1993 and 1994. Both GRIP and GISP2 strain nets were measured optically by theodolites and electronic distance meters. The GRIP strain net measures the approximately radial deformation pattern around the ice sheet summit. The GISP2 network extends 30 km (ten ice thickness units) downstream from the GISP2 site. This allows the performance of ice flow models to be checked well downstream of the GISP2 site, thereby ensuring good results at and




*Strain nets on the ice sheet surface in the vicinity of the two boreholes. In the top figure, the GISP2 University of Washington surface strain network optically surveyed during 1993–1994 is shown by solid lines, and the companion GRIP strain net surveyed during 1989–1993 is shown by dashed lines. Ultimately the observations and velocities from both networks will be combined. The arrow clusters point to other markers observed from theodolite survey stations. The bottom figure shows preliminary ice velocity vectors determined by a least-squares network adjustment.*

upstream of the GISP2 site. The strain history of ice traveling to the GISP2 site will ultimately be best determined by the data from the combined network. Ice velocities have been calculated from deformations observed within the GISP2 strain net. The results are preliminary; until data from the satellite global positioning system are analyzed, we assume that GISP2 moves due west, that GRIP is motionless and that the easternmost point in the GISP2 network moves westward at the speed necessary to carry away the annual snow accumulation between that point and GRIP. The ease with which glacier ice flows is described by its rheological properties, such as viscosity, which are variable and still poorly known in central Greenland. The ice flow direction changes more gradually than the direction of surface slope that drives the flow, because ice has a high viscosity. Future comparison of the surface slope with the ice flow directions may provide information about ice rheological properties.

Repeated surveys of progressive tilting and closure of the boreholes provide information about ice flow at depth (Gundestrup et al. 1993). As part of a collaborative GRIP–GISP2 borehole logging program to use the same logging tools in both boreholes, Niels Gundestrup measured the tilt and diameter of the GISP2 hole in 1993 immediately following cessation of drilling and again in 1994 and 1995. Plans call for this program to continue as long as necessary to observe and analyze significant deformation.

Because climatic temperature variations at the ice sheet surface diffuse down slowly into the ice, temperature profiles measured in boreholes today retain a memory of the temperature history at the surface of the ice sheet. Alley and Koci (1990) analyzed a 217-m profile from a dry borehole at the GISP2 camp and derived a temperature history over the last several hundred years. They concluded that a recent warming had occurred but that it was not large enough to provide clear evidence of global greenhouse warming. Gary Clow obtained a high-resolution temperature profile in the 3-km-deep GISP2 borehole in 1994 and again in 1995 (Clow et al., this issue). Like the temperature logs from the nearby GRIP hole analyzed by Gundestrup et al. (1993), the data can provide a surface temperature history back into the Wisconsinan ice age (prior to 11,000 years ago). Repeated temperature measurements in the GISP2 hole are also planned for 1996, as the hole recovers from the thermal disturbance of drilling and emplacement of relatively warm drilling fluid. The multiple surveys will improve the interpreted paleotemperature record. Data available after three years of logging should permit the undisturbed ice temperature profile to be estimated to the 0.001°C precision level. The field program also includes collaborative high-resolution temperature logs in the nearby GRIP borehole.

The stable isotope ratios $\delta^{18}O$ and $\delta D$ in ice are widely and successfully used as proxies for paleotemperature. However, calibration is required in each area, because the isotopic ratios can also be influenced by nonthermal effects, such as changing seasonal distribution of snowfall, isotopic fractionation in the snow, or changing moisture source regions. Cuffey et al. (1994) used the measured temperature–depth log in the 217-m dry borehole at GISP2 to calibrate the relationship between temperature and stable isotopes at the site over the past 1300 years. Cuffey et al. (1995) later used the temperature–depth log from the deep borehole to extend the calibration to the past 40,000 years. They deduced that the temperature change in central Greenland during the last deglaciation was at least 15°C, which is significantly larger than previously thought. Two great strengths of this method are that it uses actual thermal data in the calibration and it does not rely entirely on modern spatial correlations.

## *Ice Dynamics Analysis*

Models that span the full ice sheet provide the regional context and long-term ice thickness trends to which ice flow near the summit responds. However, for ice core interpretation, ice dynamics models that incorporate many physical processes on a fine spatial mesh around an ice core site are more useful than whole ice sheet models that necessarily have coarser resolution and parameterized physical processes. Ice dynamics results from both types of models have advanced our understanding of glacier geophysics and paleoclimate in central Greenland.

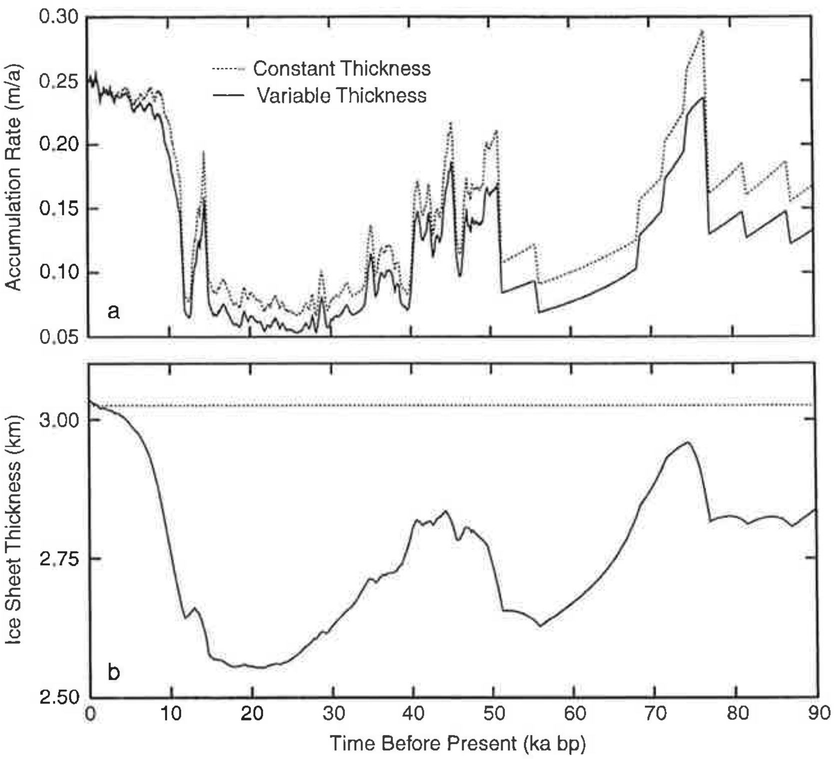
Prior to ice core drilling near the center of the ice sheet, ice flow and temperature calculations were carried out to assess the site. Firestone et al. (1990) calculated the temperature history in the vertical profile through both the GRIP and GISP2 sites. The calculation showed that the old basal ice had not been subjected to basal melting and had probably remained below –10°C throughout the past 100,000-year glacial cycle.

Schøtt et al. (1992) estimated the age–depth distribution at both drill sites prior to drilling. Their finite-element calculation for flow in plane strain along the GRIP–GISP2 profile used the Hodge et al. (1990) surface and bed data together with the accumulation rate data reported by Bolzan and Strobel (1994). They correctly predicted the depth–age scale at GISP2 back through the Holocene interglacial period to the end of the ice age. The model also made reasonable estimates of the total thinning as a function of depth for older ice, but the predicted time scale depended on the accumulation history, which was then poorly known.

Since the GISP2 ice core showed well-defined annual layering well back into the Wisconsinan ice age, the problem could then be turned around, that is, the total thinning predicted by the Schøtt et al. calculations could be used to convert the observed annual layer thicknesses of known age back into the true accumulation rate at the time the layers were deposited. Alley et al. (1993) used the Schøtt et al. (1992) ice dynamics thinning results to demonstrate that the accumulation rate had increased from 9 cm per year (ice equivalent) to 17 cm per year in a period of only several years at the termination of the Younger Dryas cold event at 11,640 B.P. Dahl-Jensen et al. (1993) estimated a similar accumulation history by using annual layer thickness data and stable isotope data from the GRIP ice core with a Dansgaard and Johnsen (1969) ice flow model adapted for conditions at GRIP.

These first estimates of paleoaccumulation in central Greenland (Alley et al. 1993, Dahl-Jensen et al. 1993) assumed that the ice sheet thickness was invariant. Prior to the end of the Wisconsinan ice age about 12,000 years ago, the ice sheet probably did not maintain a constant thickness and strain pattern. Cutler et al. (1995) developed a non-linear, one-dimensional, time-dependent ice sheet model to investigate the effect of ice sheet thickness change on the vertical straining of annual layers. This model used the GISP2 annual layer thickness data and other dated points in the core to infer an accumulation history over the past 90,000 years. The estimated accumulation rates during the ice age were one quarter to one third of their modern values. Uncertainties in the layer thickness data, physical simplifications in the model and poorly known values of model parameters precluded a more precise determination of the accumulation rate history. Subsequently, Cuffey et al. (1995) and Cuffey (in prep.) calculated an accumulation history using a method similar to Cutler et al. but allowing for deviations of the ice sheet geometry from steady-state configurations and including thickness changes of the ice sheet due to temperature changes within the ice. The former reduces the sensitivity of the inferred accumulation rate to the extent of marginal position changes. The average accumulation rate during the coldest 15,000 years of the last ice age was between 5 and 7 cm per year according to these calculations.

Since the accumulation rate was low during the ice age, the ice sheet might have been thinner than it is now. However, the margins expanded in the ice age (Funder and Larsen 1989), causing the ice sheet to tend to thicken. Glaciologists can estimate the thickness changes in the ice sheet by using ice dynamics models (for example, Letreguilly et al. 1991), by using ice core data such as total gas content (for example, Raynaud and Lebel 1979) or by using both ice dynamics and ice core geochemical records. Since changes in ice sheet thickness largely represent a dynamic response to changes in climate, the ice sheet thickness histories inferred with the help of ice dynamics complement the




*Range of past accumulation rates and ice thickness histories considered to be most probable at GISP2, based on a range of plausible histories of various ice sheet parameters described by Cutler et al. (1995), from which this figure is taken.*

geochemically inferred paleoclimate record. Two calculations have been made to estimate the thickness history in central Greenland using both the ice core data and ice dynamics.

The Cutler et al. (1995) one-dimensional paleo-accumulation calculation also produces an ice sheet thickness history consistent with the inferred accumulation history. When they assumed that the ice sheet margins during the ice age occupied the same positions that they occupy now, Cutler et al. predicted an ice age ice sheet that could at times be as much as 450 m thinner than the present ice sheet. However, the ice sheet margins probably moved outward during the ice age. When this was taken into account, Cutler et al. found that the ice sheet could have been only 100–250 m thinner than it is now, depending on how far the margins moved out, and that the ice sheet has thickened at a decreasing rate since the last glacial maximum, such that it is now either in steady state or still thickening slightly. These results suggest that the assumption of constant ice sheet thickness in previous estimates of accumulation rates by Alley et al. (1993) and Dahl-Jensen et al. (1993) was reasonable.

Bolzan et al. (1995) used a very different approach to compute the ice thickness as a function of time over the past 20,000 years. For a given ice thickness history, they calculated the age of ice at various depths in the GISP2 core by reconstructing ice particle trajectories. The ice thickness history was then adjusted iteratively to give the best agreement between measured ages and computed ages. Their results from this inverse theory approach indicate that the ice sheet thickness over the past 10,000 years has changed by less than 10 m. For earlier times, they obtained upper and lower bounds on the thickness changes. They estimated the thickness change at 20,000 years ago to be in the range of plus or minus 85 m. This conclusion is compatible with the Cutler et al. (1995) results, in which they assumed that the ice sheet expanded during the ice age. Work continues on ways to improve the ice thickness history calculations and to reduce their uncertainties. The thickness of the ice sheet changes in response to changing climate, and an ice thickness history inferred through ice flow considerations provides paleoclimatic insight not easily derived from geochemical records alone. In the future, collaborative simultaneous analysis of the annual layer thickness data from both GISP2 and GRIP ice cores using a common ice flow model could help to separate any remaining ice flow effects from real accumulation rate variations.

As ice flow calculations are refined to address new questions about the paleoclimate in central Greenland, more of the assumptions that simplified previous ice dynamics calculations must be relaxed. For example, the depth–age scale and the strain history of ice near the ice core sites may depend on the historical positions of the ice divide. Therefore, estimates of the likelihood, timing and magnitude of ice divide migration are required. Anandakrishnan et al. (1994a) modeled an east–west flowline across the Greenland summit to study the potential range of divide positions. They concluded that in the ice age, the ice divide was likely within 40 km of its current location. They also showed that the divide position was more sensitive to the ice sheet margin position than to the value of ice age accumulation rate.

## *Current and Future Work*

The radar data reported by Hodge et al. (1990) have since been processed further by Jacobel and Hodge (1995) to show the internal layering in the ice sheet. These layers are widely considered to be isochrons, that is, surfaces of constant age. Weertman (1993) showed that if the layering can be dated at one location, as by an ice core, then the layers can be used to infer some features of the ice velocity field and the spatial pattern of snow accumulation in the past. Similar analysis of the Jacobel and Hodge (1995) data could add the time dimension to the mass balance patterns reported by Bolzan and Strobel (1994) and permit even more realistic ice flow modeling.

The radar internal layering data shown by Jacobel and Hodge (1995) and by Hempel and Thyssen (1992) have led to some concern about the appropriateness of the current ice flow models, because efforts to replicate the layering pattern observed by radar under the ice divide have been unsuccessful to date when using Glen's Flow Law, the standard rheological law for ice (for example, Paterson 1994). It is possible that a more general form of flow law will be needed at ice divides. To check the appropriateness of Glen's Flow Law for polar ice at low stresses, measurement of the vertical velocity pattern at both GRIP and GISP2 would be extremely valuable in the future. These measurements could be accomplished by resistive wire strain meters frozen into holes drilled by hot water (Harrison et al. 1993). Vertical strain observations should also be checked for compatibility with the detailed horizontal strain measurements.

Calibration of the stable isotope record (for example, Cuffey et al. 1994, 1995) using the deeper borehole temperature measurements described by Clow et al. (in this volume) will allow more-accurate long-term ice dynamics calculations, since ice flow is affected by the changing temperature distribution in the ice sheet. Finally, the borehole temperature measurements and the annual layer thickness records from both the GRIP and GISP2 holes should provide constraints on ice dynamics analysis of the ice divide migration history.

The GISP2 and GRIP geochemical records are remarkably similar over the upper 90% of their depths (Grootes et al. 1993, Taylor et al. 1993b). This confirms that this section of the paleoclimate record is intact in both cores. However, earlier portions of the records, including much of the previous interglacial period known as the Eemian or Sangamon, show striking differences in the geochemical sequences. It is possible that either overturned folds or boudins have disrupted the normal stratigraphic sequence in one or both ice cores at these depths. (When a relatively stiff layer is stretched by flow, it can develop thin "necks" like pulled toffee. These necks may eventually be totally severed. The resulting structures, resembling a string of link sausages, are called boudins.) Prior to drilling, Cunningham and Waddington (1990) suggested that the complete Eemian layer could be disrupted by boudinage under the ice divide, as a result of known rheological contrasts between ice-age and interglacial ice in the Northern Hemisphere. However, the actual form of the mismatch (Grootes et al. 1993, Taylor et al. 1993b) suggests that disruption has occurred over depths of meters to tens of meters, that is, on a shorter depth scale than the thickness of the complete Eemian sequence. Glaciologists usually think of ice sheets as large homogeneous and isotropic masses dominated by processes that act on scale lengths comparable to the ice thickness. The stratigraphic disruption observed under central Greenland (Alley et al. 1995) stimulates glaciologists to merge this view with a new appreciation of microdeformation and of anisotropy and inhomogeneity in layers or "blobs" of differing viscosities caused by impurities or crystal fabrics (Waddington et al. 1995). More field studies that can measure the spatial variability of ice fabric and other factors affecting rheological properties will be required. Continuous high-resolution ultrasound measurements on the ice core (Anandakrishnan et al. 1994b) and in the borehole (Taylor 1982) are existing techniques that should prove to be useful. New techniques may also be needed. Ice flow models used to investigate the stratigraphic structure near ice core sites will need to incorporate more-complicated rheological laws. This new view of polar ice sheets will be essential to understand where, why and how the regular stratigraphic sequence might be disturbed. This is another valuable contribution that ice dynamics can make to future ice core studies.

An interesting technique that may be used in the future to locate suitable deep drilling sites is the Philberth Probe, originally developed in Europe. NASA is now trying to develop a probe with the ultimate goal of using it on the Martian ice cap. The idea is to launch a thermal probe powered from the surface through a thin coaxial cable. The probe contains instrumentation that makes it possible to transmit information on pH, conductivity and dust to the surface while it melts its way down into the ice cap. The technique is difficult, using instrumentation at pressures up to 2000 bars, and further tests in Greenland will show if it is possible to develop this into a reliable vehicle.

# *Conclusions*

The paleoclimate output from the GISP2 ice core project has been enriched by its geophysical ice dynamics component. Site selection activities allowed the GISP2 and GRIP cores to be drilled in locations that avoid or minimize ice dynamical effects that could complicate interpretation of the climate records. Ice flow modeling, aided by geophysical studies, has allowed correction of annual-layer thicknesses for ice flow effects, producing the first long, high-resolution accumulation-rate records ever obtained and greatly enhancing paleoclimatic interpretations. Temperature measurements in the boreholes have been combined with computer models to show that the late glacial climate in Greenland was much colder than the ice core geochemical data had first suggested, and in the process those geochemical data have been recalibrated to enhance their usefulness in the paleoclimate reconstruction. These geophysical model studies can also separate reconstructed temperature changes into climatic and ice sheet elevation effects. Ongoing studies to characterize flow mixing in the deep ice should improve the interpretation of these and future ice core records. Drilling two ice cores separated by ten times the ice thickness has proved to be a valuable and successful interpretive asset for both GISP2 and GRIP programs. At the same time, the unprecedented quantity and quality of geophysical and climatological data from central Greenland promise to significantly advance our understanding of how cold ice sheets work.

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# *Physical Properties of the GISP2 Ice Core*

## *Research from The Pennsylvania State University*

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Geological or physical studies of ice cores produce a host of useful results. They have helped turn the GISP2 core into a "weather station" for central Greenland, documenting unexpectedly large and rapid changes in climate that would severely challenge humans were they to recur. They have helped us date the ice core, understand variations in the atmosphere that supplied contaminants to the ice sheet, and learn how ice flow can affect and ultimately confuse the climate record. Working in close collaboration with colleagues at the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL; Tony Gow and Debra Meese) and at the U.S. Geological Survey (USGS; Joan Fitzpatrick), we have participated in a variety of such studies of the GISP2 ice core and associated surface phenomena. Here, we briefly summarize progress in each of these, concentrating only on those aspects to which Penn State physical-properties researchers have contributed in some way.

## *Paleothermometry*

The stable isotopic composition of snow that accumulates on an ice sheet is primarily controlled by the temperature when it accumulates, providing a valuable record of past temperature. However, so many other factors can affect the isotopic composition of snow that research remains active.

Borehole temperatures provide a different record of past surface temperature. In the same way that a frozen roast placed in the oven "remembers" its history in the freezer for a while before it thaws fully, the temperature in the ground or in an ice sheet "remembers" the temperature changes in the air above. The "memory" of old events that did not last long is lost to heat diffusion, so the time-resolution of the method is not high, but the events that are "remembered" are present with high accuracy. Through a series of studies, we have used borehole temperatures to show how to interpret the isotopic composition of the ice core, and we have demonstrated that temperature changes in Greenland have been huge—much larger than previously suspected.

In 1989, we assisted Bruce Koci of the Polar Ice Coring Office (PICO) in measuring a 216-m borehole-temperature profile, and we demonstrated that this record contains paleoclimatic information from the most recent centuries. Then Kurt Cuffey led the effort to use the borehole profile and the oxygen-isotopic data of Pieter Grootes and coworkers to calibrate the isotopic paleothermometer. The best calibration yields slightly larger temperature changes than the traditional calibration based on the modern spatial variation of isotopic composition with temperature. Using our calibration and the isotopic data as surface boundary conditions, a time-dependent heat-flow model predicts a borehole temperature profile quite similar to that observed, indicating that stable-isotopic ratios provide good paleothermometers over the most recent centuries when averaged over decades. The snow-pit work of Christopher Shuman, described below, produces a similar result for a scale of months to years.

More recently, a temperature profile from the deep borehole measured by Gary Clow and coworkers has become available (see their paper in this issue). Application of the same techniques to this profile, again led by Kurt Cuffey, shows that the isotopic composition of the accumulated snow faithfully records temperatures on glacial–interglacial time scales. The coldest part of the ice age was more than 20°C colder than today, roughly twice as large a change as estimated using older isotopic calibrations.

These are records of temperatures averaged over years. By examining how often we see rare melt features in the core (ranging from roughly once per century to once per few centuries), we can estimate changes in summer temperatures as well. We find that both summer and non-summer temperatures were higher thousands of years ago than they were hundreds of years ago.

## *Atmospheric Modeling*

The large temperature changes, and the high accumulation rate and other changes described below, challenge our understanding of the climate system. To aid in interpreting these data, Peter Fawcett and Anna Maria Agustsdottir have begun an atmospheric-modeling effort focused especially on the late-glacial Younger Dryas oscillation, using the Genesis general circulation model. The ocean in Genesis requires an "extra" heat source in the Nordic Seas east of Greenland to match the modern climate; this heat source is related to the formation of deep water at the "end" of the Gulf Stream. Paleoceanographic data show that this deep-water formation and the associated heat source were reduced or eliminated during ice ages. Simulation of the climate with and without this heat source then provides insight into the rapid oscillations recorded in the ice core.

Among the results are storm-track shifts consistent with those recorded in the accumulation-rate data, as described below. Also, the model results suggest that changes in the seasonality of temperatures and snowfall have contributed to the differences between the actual isotopic calibration over time and the modern spatial gradient and thus to previous underestimates of the ice-age cooling.

## Origin of Annual Layers

Visible strata have long been used to identify annual layers in ice cores. Summer accumulation contains coarse-grained ice of low density, called depth hoar, sometimes alternating with fine-grained, high-density wind slabs. Winter accumulation is more homogeneous and more like wind slabs than depth hoar. As discussed below, the use of visible strata, when combined with other indicators, allowed accurate dating of the ice core.

Observations show that solar heating of near-surface snow causes mass loss and grain growth in the upper centimeter or so to form depth hoar, with at least some of the lost mass contributing to growth of a surface-hoar layer above. This direct linkage to the sun causes depth-hoar/surface-hoar complexes to be good summer indicators. Strong storms after hoar formation deposit wind slabs over hoar, typically without removing the hoar, producing the characteristic summer signal in the accumulating snow.

The formation of a hoar complex reduces the density and increases the roughness of the surface, changing it from something that appears smooth to something that looks rather like popped corn. This produces changes in the microwave thermal emissions from the snow that can be detected by satellite. When the surface is a wind slab, some of the upwelling microwaves are reflected back downward by the smooth, sharp snow–air interface, with the usual polarization difference caused by reflection. When the surface is a hoar complex, it no longer provides a sharp interface, and there is little reflection of the upwelling microwaves and little polarization difference. Hoar formation thus can be monitored by its distinctive signal of a slow decrease in the polarization difference, followed by a rapid increase when the hoar is buried under new snow.

Use of this signal allows hoar formation to be mapped. It appears that hoar forms primarily from mid-June to late August and that much of central Greenland experiences hoar-forming events at the same time. Comparison of microwave brightness temperatures and automatic weather station (AWS) temperature data establishes the passive microwave data as a useful way to estimate temperature in this area during short times when AWS data are not available. Comparison of combined temperature data to the stable isotopic record from snow pits shows that it snows frequently throughout the year in central Greenland and that the isotopic composition of that snowfall reflects the temperature over months to years.

## Dating, Accumulation and Climate Records

Reliable dating is critical to ice-core studies. In the GISP2 core, many indicators show annual signals. Visible strata proved easiest to measure rapidly and accurately, especially in the brittle-ice region where high bubble pressures caused fracturing of the core that interfered with other high-resolution studies. Our observations thus proved useful in the accurate dating of the core, which is being refined and finalized by Debra Meese and the dating committee. In ice-age ice, we relied mainly on dust layers, which are visible to the naked eye and also appear in electrical-conductivity (Ken Taylor) and laser-light-scattering (Michael Ram) records. Fortunately, in the early Holocene, both indicators were present, and we were able to calibrate the visible dust record to the hoar record.

An accurate time scale can be used to produce an accumulation-rate record if corrections are made for density and ice-flow effects. Measured densities can be applied directly. Fortunately, the ice-flow modeling by Edwin Waddington and co-workers produced accurate predictions of layer thinning, so we were able to calculate accumulation rates easily. These can be refined by further flow modeling (see the paper by Waddington et al. in this issue). The most remarkable result from this study is that the termination of the Younger Dryas cold event was exceptionally rapid—it can be interpreted as almost a step change, with accumulation doubling in one to three years. This confirms the pattern of exceptionally large and rapid climate changes reported by Ken Taylor and co-workers.

Accurate ages are important in a variety of paleoclimatic studies. Accurate accumulation rates allow chemical and particulate data to be transformed into fluxes if desired, and they can be used to improve estimates of atmospheric contaminant loadings from ice-core contaminant loadings.

Accumulation-rate data also allow study of co-variation with other climate variables. In particular, Wanda Kapsner led the effort to show that accumulation rate has been almost independent of temperature in central Greenland over most of the most recent 17,000 years and that the large increase in snow accumulation at the end of the ice age was caused by storm-track changes as well as by the warming, consistent with the atmospheric modeling results. If this weak dependence persists into the future, it would cause sea-level rise in response to global warming to be larger than expected by some workers, who believe that warming would increase snowfall in the central regions of ice sheets.

## Crystalline Structure

One of the most remarkable observations of the GISP2 ice core has been that it and the parallel GRIP ice core are in almost perfect agreement above about 2750 m (105,000 years ago) but that there are important differences between the two below that level. Physical-properties observations of the GRIP and GISP2 cores by CRREL, Penn State and GRIP workers show flow disturbances in both cores increasing with depth, with the shallowest occurrence of disturbances too large to be characterized within the diameters of the cores at approximately (though not exactly) the depths where differences appear in the records of the two cores. Significant similarity of the types of disturbances in the two cores may be related to past migration of the "continental divide" between ice flowing east and west, which would have caused GRIP to have undergone ice-sheet-flank flow similar to that of GISP2 rather than the divide flow expected there today.

Other physical-properties results include the demonstration by Joan Fitzpatrick of an inexpensive, rapid ultrasound technique to measure c-axis fabrics, which Sridhar Anandakrishnan and Joan Fitzpatrick have extended to shear-wave observations. Gregory Woods has developed a grain-size profile for the core and demonstrated the importance of impurities in controlling grain growth. Richard Alley has worked out a framework for interpreting the ice-crystal orientations and developed (with Tony Gow and Debra Meese) a new technique to confirm the contribution of polygonization in controlling grain sizes. M. Fischer has introduced to the glaciological community a new technique for measuring the fracture toughness of firn and ice and is developing an extended data set. Many other data sets are being developed or extended by the CRREL team, with some contribution from Penn State.

This partial catalog barely scratches the surface of the exciting work to be done on the ice core. We can anticipate advances in understanding ice deformation, glacier flow, surface processes and climate history. We feel fortunate in being able to contribute to this high-resolution, sensitive, multivariate record of North Atlantic and global climate. There no longer can be any doubt that the climate in central Greenland has undergone large, abrupt and "flickering" or oscillating climate changes and that these climate changes are synchronous with changes elsewhere in the North Atlantic region and the world within the time resolution of other indicators of climate change. The GISP2 goal now is to understand those changes better and any implications they may have for modern humans.

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# *Physical Properties of the GISP2 Ice Core*

## *Research from the Cold Regions Research and Engineering Laboratory*

*This article was prepared by Anthony Gow and Debra Meese, both of the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), 72 Lyme Road, Hanover, NH 03755.*

The CRREL team has been studying the basic physical properties of the GISP2 ice core (including detailed density and ultrasonic velocity measurements and thin-section studies of crystal size and shape, crystal orientations, and entrapped air bubble characteristics) as a function of depth in the ice sheet. A major part of our effort has also centered on the development of the depth–age scale of the core. This has been accomplished by continuous stratigraphic analysis of the core based on annual layer counting and correlations with other data sets that also provide an annual signal. This project has been carried out with close collaboration with researchers from The Pennsylvania State University (Richard Alley) and the U.S. Geological Survey (Joan Fitzpatrick).

## *General Core Condition*

Core recovery at Summit exceeded 98% of the footage drilled to reach bedrock (3053 m). A number of important transitions in both the physical and mechanical condition of the 13.2-cm-diameter core included:

- The transition from porous firn (compressed snow) to impermeable bubbly ice at 75–80 m;
- A change from substantially bubble-rich ductile ice to crack-prone ice between 400 and 600 m;
- A gradual decrease in the number of bubbles until they had completely disappeared by approximately 1400 m;
- A return to essentially ductile ice below 1400 m, accompanied by major changes in the size and orientation of crystals composing the ice; and
- An abrupt transition from bubble-free glacial ice to silty ice 13.1 m above the ice–rock interface, which was penetrated at 3053 m.

The bed material was drilled to a depth of 1.55 m before drilling was terminated.

## *Depth–Age Scale*

To interpret climatic events, an accurate depth–age scale must first be obtained. The best way to accomplish this is by interpreting annual signals if they exist. We are very fortunate in that several annual signals exist in the GISP2 core, enabling us to compare and contrast signals, eliminating any subjectivity that might occur when using only one. Determination of the annual layers is being completed by Debra Meese and the dating committee.

Our primary signal is visible stratigraphy. (The details of the origin of the stratigraphy are described in the article by Alley and others in this issue.) Each summer at the GISP2 site a depth hoar layer or series of layers forms and is retained in the core, providing a visual stratigraphic record. Annual layer counting based on visual stratigraphy was initiated in the field and completed at the National Ice Core Laboratory (NICL) in Denver. A close analogy to this is counting tree rings, where variations in the width of the ring are associated with variations in the local climate. The thickness of the layer, when corrected for compression and flow, corresponds to the amount of accumulation received over an annual cycle. This work was facilitated by using a focused fiber-optic light source that illuminated the stratigraphic detail, permitting essentially continuous layer counting to 2811 m.

Other annual indicators include oxygen isotopes, electrical conductivity (ECM) and laser-light scattering of dust (LLS). Oxygen isotopes were used to aid in dating in the top 300 m of the core; below this, diffusion occurs and the annual signal is not as clear. ECM is a measure of the acidity in the core. Each spring an acid spike occurs, which provides another annual signal. (See the article by Taylor and others in this issue for a more detailed explanation.) Unfortunately the ECM signal is affected by other factors, including volcanic eruptions and forest fires, that may influence annual counts. However, the signal remained viable throughout most of the core and was a valuable indicator. Each spring an influx of dust also occurs, indicated by LLS. (See the article by Ram and others in this issue for a more detailed description of this technique). Although dust is also affected by other factors, it has proven extremely valuable, especially in the lower portions of the core.

Since some of the parameters used to identify annual signals are affected by other factors, the counting of the annual signal becomes complicated. However, once patterns and the way in which the signal is affected by these factors are realized, an accurate analysis can be completed. Correlation of the various methods provides the most accurate depth–age scale possible, as questionable signals are compared and the strength of the signals can be weighed. Ongoing analyses of annual-layer dust peaks utilizing a laser scattering technique now indicate that the provisional date of 85,000 years at 2811 m, based primarily on visible layer counting (Meese et al. 1994), may need to be revised upwards to 110,000 years. Naturally the GISP2 depth–age scale constitutes the longest and oldest continuously dated stratigraphic sequence ever obtained and has provided the time scale against which the high-resolution GISP2 climatic record is being evaluated.

Below 2811 m, visible stratigraphy proved difficult to decipher. The typically even layering seen in the upper portions of the core was frequently distorted into s-folds and structures resembling boudinage (a deformational structure that looks like a string of sausages, resulting from tensional forces) and was accompanied by intermittent inclined layering, with inclinations often exceeding 20°. It now appears that irregular ice flow below 2811 m, leading to the distortion of the layers, could have disturbed the environmental record that may have existed in the basal 250 m of ice at GISP2. The extent of this disturbance is being evaluated in terms of the distorted layer–crystal structure relationships of the bottom 10–15% of the core.

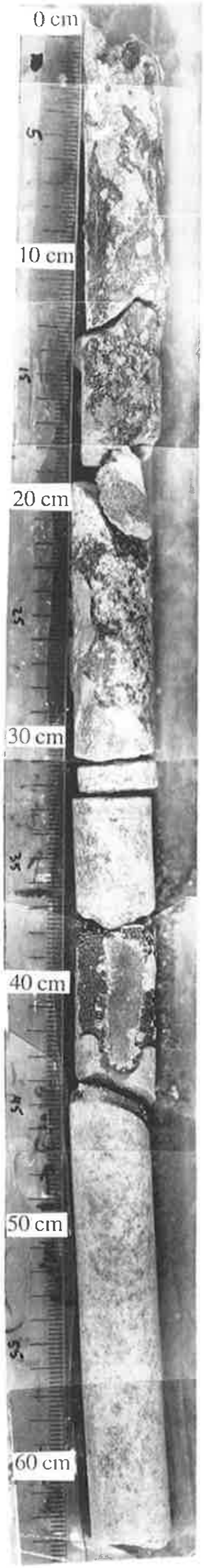
In collaboration with Ed Waddington, John Bolzan and Nadine Cutler, the annual layer thickness data are being converted into accumulation. (See the article by Waddington et al. in this issue.) These data have provided information about how accumulation rates at Summit have varied with time and climatic fluctuations. Based on these data we have ascertained that accumulation rates may be used as a proxy indicator of climate and/or temperature changes at Summit site, Greenland (Meese et al. 1994). Additionally we found that the climate at Summit during the Holocene has varied more than expected and that several possible "Little Ice Age" events have occurred.

## *Silty Ice–Bedrock Relationships*

At GISP2 13.1 m of silty ice was found sandwiched between bedrock and the overlying clear glacial ice. Currently the basal silty ice at Summit is frozen to its bed at –9°C, approximately 6°C lower than the pressure melting point. The top 3 m or so of silty ice contained a number of clear ice layers ranging in thickness from a few millimeters to more than 10 cm. The entrained debris consisted predominantly of fine-grained brown to amber-colored sediment, mainly silt with some sand and larger particles up to 2 cm in diameter. Sediment loads in the GISP2 silty ice ranged from 0.3% to 0.65% by weight based on samples 5 cm and longer.

The GISP2 silty ice also contains significant amounts of entrapped gas similar to those found in basal silty ice cores at the GRIP Summit site. Though gas compositions in the GISP2 silty ice have yet to be analyzed, along with stable isotope measurement of the basal ice, the data obtained so far at GISP2 support the results of the GRIP research team, who concluded that the silty ice at both locations originated as ground ice prior to the growth and establishment of the current ice sheet and is therefore unrelated to direct interaction of the present ice sheet with its bed. The fact that the basal ice at Summit is frozen to the bed also

*The silty ice core. Notice the sharp transition between the clean ice and the silty ice.*




*Core from the top of the bedrock underlying the Greenland Ice Sheet at GISP2. This rock core, 3.4 cm in diameter, features what appears to be cobbles or boulders in the top 38 cm overlying or embedded in unconsolidated (now frozen) breccia or soil, possibly till. A sharp angular transition to gray granitic bedrock occurs at 46–48 cm.*

precludes sliding of ice over the bed or any erosive activity at the bed.

Ongoing measurements of cosmogenic radionuclides to determine the exposure ages of the bedrock core in immediate contact with the basal ice at GISP2 may help to determine the most recent date of glaciation at Summit. The bed at GISP2 was penetrated to a depth of 1.55 m and consisted of cobbles and boulders embedded in till-like material to a depth of 46–48 cm resting on top of gray biotite granite, which is the true bedrock.

## Recent Accumulation Rates

In July 1990, 20 stakes were emplaced at intervals of 0.5 km along a line due south of the GISP2 drilling site in order to measure accumulation rates on an annual basis and also from late spring through early fall during storm and sublimation events. Measurements over the last several years show remarkably uniform snow deposition of about 70 cm annually, equivalent to 24 cm of water. This uniformity of accumulation is consistent with the very low surface relief around the GISP2 site and indicates that the accumulation rates measured in the core are consistent with the local environment. A number of new pits were excavated beside snow stakes to evaluate stable isotope variations and depth hoar occurrence with respect to measured increments of snow accumulation at the stakes. Winter and summer accumulations appear similar in magnitude, but the distribution characteristics of the winter snowfall are not yet known. Current measurements taken by the automatic weather stations may resolve seasonal accumulation rates. Accumulation measurements continue to be collected annually by researchers involved in atmospheric–snow gas exchange work at the GISP2 site.

## Ice Density

Density is a major property used to track the change from snow to firn to ice, calculate the overburden pressures from the integration of depth–density profiles, provide accurate estimates of air bubble pressures in the ice, and monitor the volume increase of cores with time. The firn–ice transition corresponds to the pore-close-off density and was reached at a depth of 75–80 m at GISP2 at an overburden pressure of 5.0–5.1 bars. Thereafter, the bubbly ice densities increased, primarily in response to hydrostatic compression of the entrapped bubbles. This process was accompanied in the deeper ice of the brittle zone by a progressive decrease in the concentration of bubbles until they disappeared entirely from the ice at around 1400 m. This disappearance can be attributed to pressure-induced diffusion of gas into the ice structure to form gas hydrates. A maximum density of 0.9208 $Mg/m^3$ was reached at around 1600 m, very close to the depth of temperature overturn (to higher temperatures) in the ice sheet. Densities then decreased progressively (in response to increasing temperatures) to 0.9172 $Mg/m^3$ at the glacial ice–silty ice transition at 3040 m. Repeated density measurements show that volume expansion has occurred along the entire GISP2 core, with the changes most pronounced in the brittle ice zone due to microcracking, bubble depressurization and cavity formation associated with the decomposition of the gas hydrates.

## Crystal Structure

As snow accumulates and becomes incorporated into the ice sheet, it undergoes recrystallization, and patterns of preferred orientation of the crystals composing the ice (called the fabric) begin to develop in response to stresses induced by the weight of the ice. Determining the fabric profile is important in evaluating the rheological behavior or dynamic state of the ice and its potential impact on the preservation of paleoclimate records in the deeper parts of the ice sheet. (See the article by Waddington and others in this issue for more details on ice deformation.) The evolution of the crystal fabric is also accompanied by significant changes in the size and shapes of the crystals; all three properties, which collectively make up the crystal structure of the ice, were extensively examined optically, in thin sections cut at intervals along the entire length of the GISP2 core.

The mean crystal diameter based on crystal cross-sectional area analysis increased approximately linearly from 2–3 mm at the firn–ice transition (at a depth of 75–80 m) to 7–8 mm at 1000 m. Below 1000 m the crystal size remained fairly constant until the onset of the Younger Dryas event at 1678 m, where the crystals underwent a significant two- to three-fold decrease in size. Progressive development of a preferred orientation of individual crystals, leading to vertical alignment of their crystallographic c-axes, accompanied the crystal size changes. Increased dust levels that characterized Wisconsin ice has contributed to the maintenance of the generally fine-grained crystal texture, which, with its strongly vertical c-axis fabric, persisted to 2990 m. Beginning at about 2800 m, in regions of dust-poor ice, layers of coarse-grained ice, consisting of crystals 50–60 mm in diameter and larger, began to appear. The growth of very large crystals, attributed to recrystallization due to elevated temperatures in the basal ice, was also accompanied by a significant change (degrading) of the c-axis fabric. A transition to much finer-grained ice, 13 m above the bed, occurred coincidentally with the appearance of silt-rich ice.

## *Ultrasonic Velocities*

Compressional p-wave (sound-wave) velocities in ice vary according to the aggregate orientation (fabric) of the crystals. At GISP2 p-wave velocities were measured ultrasonically as a first-order indicator of changes in the crystalline fabrics of the ice. Measurements were made in both the vertical and horizontal direction on 10-cm-long core pieces spaced 10 m apart along the entire length of the GISP2 core. Vertical p-wave velocities increased progressively with depth, with values exceeding 4000 m/s by 2000 m. This and an accompanying increase in the velocity difference between the vertical and horizontal direction both signify the onset and full development of c-axis clustering about the vertical, consistent with the optically determined fabric obtained on thin sections. Ultrasonic measurements also revealed other significant changes in the GISP2 core fabrics, including a significant decrease in p-wave velocities of the basal ice associated with the effects of recrystallization (grain coarsening and degraded crystal fabric).

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# *Electrical Conductivity Measurements on the GISP2 Core*

*This report was prepared by Kendrick Taylor, Desert Research Institute, University and Community College System of Nevada, Reno, NV.*

To predict the timing and magnitude of future climate change, we need to have an understanding of what the climate has been in the past and what the mechanisms were for previous climate changes. The GISP2 ice core contains a continuous sampling of the precipitation, particulate material and atmospheric gases from central Greenland for the last 100,000+ years. The chemical and physical properties of these preserved materials contain a story that will improve our understanding of climate change. The chemistry of the core is being studied by aqueous chemical methods that involve analysis of melted samples. Electrical measurements on the ice can also provide some chemical information.

In the electrical conductivity method (ECM), the direct current flowing between two electrodes with a potential difference of 2100 V is measured (Hammer 1980, Taylor 1992). In ice the $H^+$ ion is the only ion that can conduct the direct current, so the electrical conductivity signal is controlled by the acid/base balance of the ice. This is different than in an aqueous solution, where the total ionic concentration determines the electrical conductivity. The ECM has higher spatial resolution than routine aqueous chemistry work and is particularly well suited for investigating aspects of climate that influence the acid/base balance of the ice for short periods of time. The ECM is frequently used as a "road map" to identify interesting sections of the core that merit more detailed examination by other methods that are more chemically specific. This article presents a sampling of the electrical conductivity features observed in the GISP2 core and discusses how the electrical conductivity record has been used to assist in interpreting the core.

## *Annual Layering*

At the GISP2 site, the precipitation forms layers within the firn that are preserved during the transition of firn to ice. Seasonal physical, chemical and isotopic differences in the snow and particulates result in a signal that can be used to identify annual layers. Reliance on a single parameter to determine the location of annual layers is not advisable because there is no check on the accuracy of the layer identification. Instead, it is important to use multiple independent parameters. This allows discrepancies between the methods to be detected and resolved. Consecutive counting of the annual layers is the main method for determining the depth/age relationship for the upper 40,000 years of the core (Alley et al. 1993, Meese et al. 1994).

Because the ECM has a spatial resolution of less than 5 mm, it is well suited for identifying seasonal changes during the Holocene in the acid/base balance that are related to seasonal variations in the concentration of nitric acid (Taylor 1992). Ice from the Wisconsin glaciation contains more than 40 times more dust than Holocene ice. Much of this dust is calcium carbonate, which makes the ice alkaline and reduces the ECM signal by approximately 40 times. However, during the dusty periods a seasonal variation is still observed in the ECM signal, which has been used to assist in dating the core.

Because the ECM can be performed rapidly, a high-spatial-resolution record was obtained for the entire core. Electrical conductivity records have been used in conjunction with the continuously measured visual stratigraphy (Richard Alley, Tony Gow, Debra Meese) and particles (Michael Ram) to determine the locations of annual layers. High-time-resolution measurements of aqueous chemistry (Paul Mayewski) and isotopic measurements (Pieter Grootes, James White) of selected intervals were also used to assist in determining the locations of annual layers. The Holocene accumulation rate does have significant variability (Meese et al. 1994). During the climate transitions associated with the start of the Holocene, the accumulation rate increased by a factor of approximately two in less than a decade (Alley et al. 1993).

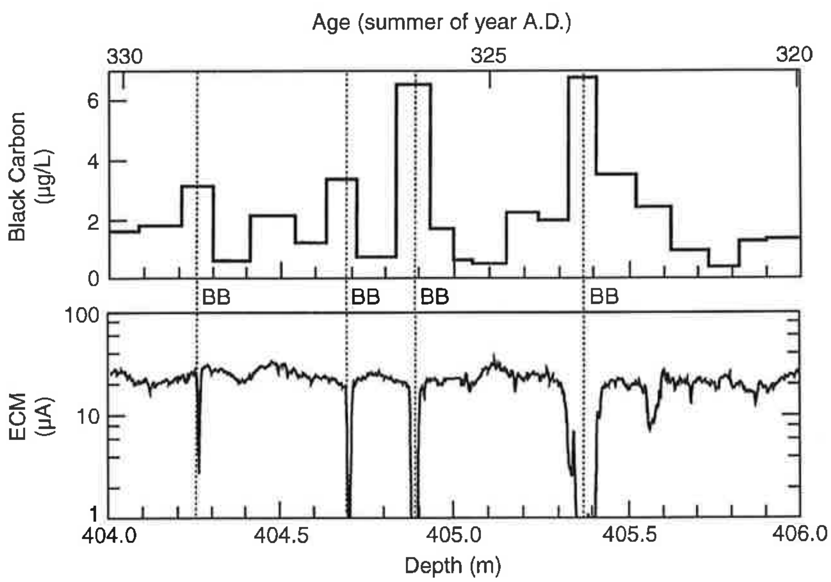
## *Volcanic Events*

Many volcanic eruptions release large quantities of $SO_2$ into the atmosphere, where it reacts with water vapor to form an aerosol of $H_2SO_4$. This can alter the optical properties of the atmosphere and impact global weather patterns for several years, possibly longer. The higher levels of $H_2SO_4$ in the precipitation leave a record that is easily detectable as an increase in electrical conductivity and have been used to identify the location in the core of the byproducts of volcanic eruptions. Historical records of volcanic activity over the last 2000 years have been used in conjunction with electrical conductivity, $SO_4$ and particulate records to correlate specific volcanic eruptions with individual layers of volcanic byproducts that are preserved in the core. These volcanic events of known age serve as checks on the accuracy of the layer-counting dating methods (Meese et al. 1994). The volcanic events also serve as valuable stratigraphic markers to facilitate correlation of the GISP2 core to other records. A joint GRIP/GISP2 record of volcanic activity is being developed, and preliminary work indicates a good correlation between the cores.

## Biomass Burning

Biomass burning introduces many chemical species into the atmosphere. When the correct conditions exist, ammonium is released and can be transported to the ice core site, where it is deposited in precipitation (Legrand 1993, Whitlow 1994). When this occurs, the acid/base balance of the ice is affected and the electrical conductivity is reduced by more than an order of magnitude. The biomass burning byproducts are deposited in discrete layers that are from 5 cm to less than 5 mm thick, which are deposited during a single storm. The short duration and large decrease in the electrical conductivity that is associated with biomass burning is easily recognizable and has been shown to be correlated with soot carbon from fire activity. During the last 6000 years the primary source area for biomass burning byproducts preserved in the core has been eastern Canada. The electrical conductivity records show that the frequency at which biomass burning byproducts are preserved in the core varies through time. A record of the relative amount of biomass burning that has occurred in the eastern Canada source area has been developed for the last 6000 years and shows several periods of high fire activity (0–150 B.P., 350–750 B.P. and 5150–6000 B.P.) that are associated with drier conditions in the source area. Biomass burning byproducts are observed prior to 6000 B.P. but are not interpreted because of uncertainty in the source area (Taylor et al., in press).

*Electrical conductivity records from the GISP2 core that show byproducts of biomass burning (indicated by "BB"). There is an excellent correlation between the low-conductivity spikes and soot carbon from biomass burning.*




## Rapid Climate Transitions

Because the ECM has high spatial (and hence temporal) resolution, it is well suited for investigating changes that occurred rapidly. In Greenland, major climate transitions are associated with changes in the concentration of alkaline particulates (carbonate dust). The alkaline material decreases the electrical conductivity, making it easy to locate the transitions and determine how rapidly they occurred. The ECM record shows that the transition between the Younger Dryas and the Holocene time periods (Taylor et al. 1993) occurred in less than 10 years, indicating that a major reorganization of the atmosphere circulation occurred in less than a decade. The abruptness of this transition is not unique; all the transitions during the Wisconsin glaciation had similarly abrupt transitions.

## Stratigraphic Ties

The ECM was performed on both the GISP2 (Ken Taylor) and the GRIP (Hammer, Clausen and Dahl-Jensen) cores. By comparing the two ECM records, we have been able to use volcanic events and major climate transition to establish stratigraphic ties between the cores (Taylor et al. 1993b). In the upper 90% of the cores, the ice flow is well behaved and the environmental record is reliable. In the lower 10% of the cores, the ice flow is complicated and is likely to have resulted in repeated and missing sections, which will make it difficult to interpret the record. Stratigraphic ties from the ECM are being incorporated into ice flow models of the Summit region (Ed Waddington) to improve our understanding of the deformation of basal ice.

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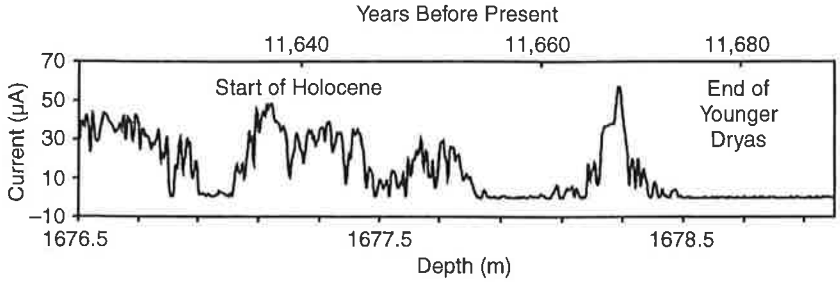


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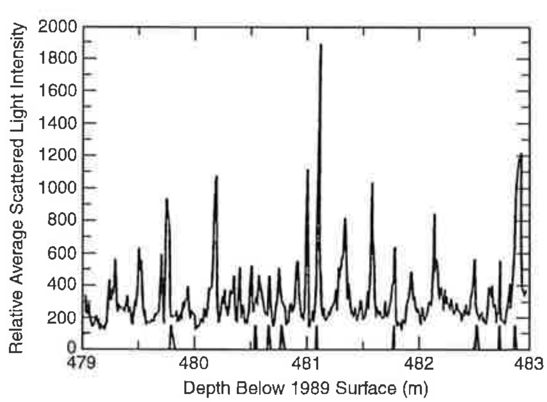
# Dust in the GISP2 Ice Core

*This article was prepared by Michael Ram, of the Department of Physics, University at Buffalo (SUNY), Buffalo, NY 14260.*

Dust is ubiquitous and reaches even the remote heights of the Greenland and Antarctic ice sheets. The largest influxes occur in the spring and summer, providing us with important stratigraphic ice core markers (Hamilton and Langway 1967, Hammer 1989, Ram and Illing 1994, Ram et al. 1995). This seasonal dependence is not surprising and is without doubt related to the seasonality of dust storms, which are most common in the deserts of Asia and in the arid southwestern U.S. in the dry spring and summer months. The dust present in the ice at any depth is representative of the dust that was in the atmosphere at the time of snow deposition. By studying the composition, size distribution and concentration of dust in an ice core, one can form an image of what past atmospheric dust burdens were like. This is of great interest since dust can absorb and reflect solar radiation and can, consequently, affect the Earth's albedo and, as a result, its climate (Rasool and Schneider 1971).

When light shines through impurity-free water, it just passes straight through. If dust is present in the water, however, the dust makes its presence felt by scattering the light in all directions. Similarly, dust is made visible when a ray of sunlight passes through a crack in a curtain and enters a dark room. The amount of light that is scattered depends on, among other things, the number of dust particles in the path of the light beam. The more particles there are, the more light is scattered.

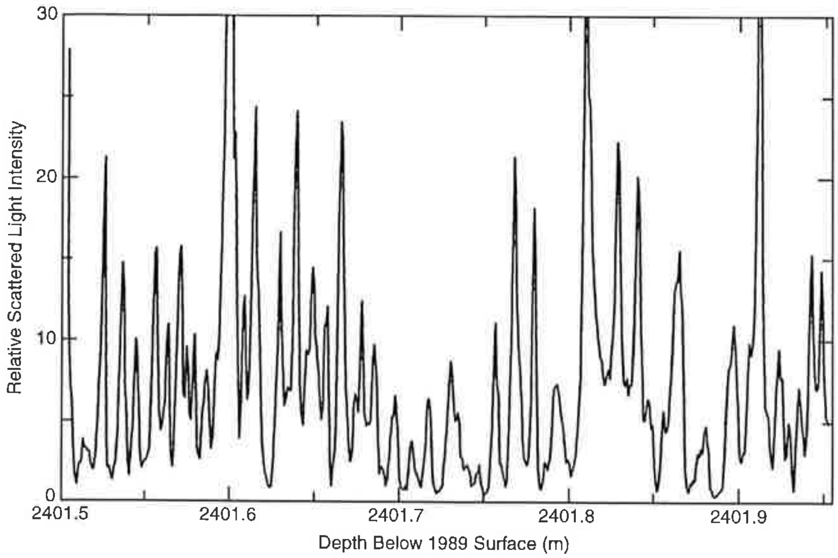
When you melt a chunk of polar ice, dust that was embedded in the ice is released and floats in the meltwater just like dust floating in air. A beam of laser light passing through the water and impinging on this dust is scattered in all directions. We have used laser-light scattering (LLS) from polar ice meltwater to measure variations in dust concentration along the GISP2 ice core down to depths of 2200 m (Ram and Illing 1994). The maxima in scattered light intensity correlate with maximum dust concentrations in the ice and correspond to spring–summer dust maxima. These dust peaks are annual stratigraphic markers and, together with other stratigraphic parameters, have allowed for excellent dating of the GISP2 ice core (Meese et al. 1994).




*Seasonal dust peaks along a representative section of the GISP2 ice core recorded using laser-light scattering from meltwater.*

At depths greater than 1900 m, annual ice layers have thinned down so much that the meltwater measurements become very slow. For example, measuring one meter of ice by this technique at these depths can take over four hours, and measurement time increases with depth. The slowness of the measurements is dictated by melting requirements and by resolution considerations. Measurements would be greatly speeded and resolution could be increased if we did not have to melt the ice. This is not feasible in shallow ice, which has large numbers of air bubbles formed when fluffy snow was converted into ice under the pressure of the overlying snow. Air bubbles are excellent scatterers of light and can easily mask the scattering produced by dust. Fortunately, however, the air disappears into the ice matrix at great depths, and no bubbles are visible in the ice at depths greater than 1400 m. We discovered that at those depths where the ice is bubble-free, laser-light scattering from the solid ice core is an effective and speedy method for measuring changes in dust concentration along the core (Ram et al. 1995). These measurements are similar to those done on meltwater; the peaks in the measurement correspond to maxima in dust concentration and are annual spring–summer markers. Using LLS off solid ice, we have successfully completed the measurements of dust concentration along the GISP2 ice core down to bedrock and have produced the first continuous series of dust concentration measurements along an entire ice core spanning both the Holocene and the Wisconsin (Ram and Koenig, in prep.). Our measurements have the highest resolution (0.5 mm) of any known stratigraphic technique.

In addition to its stratigraphic value, the measurement of dust in ice cores is an indicator of past continental aridity and wind strength. For example, polar ice contains considerably more dust during glacial periods than during the Holocene. This has been related, qualitatively, to the greater continental aridity of cold periods and to the very strong winds that are thought to have been induced by large temperature gradients (Petit et al. 1981). Our measurements of dust concentration confirm these observations and show large and abrupt increases in dust concentration in glacial times that correlate very well with decreasing atmospheric temperatures as determined by oxygen isotope measure-




*Seasonal dust peaks along a representative section of the GISP2 ice core recorded using laser-light scattering from ice.*

ments. Our dust measurements clearly show all the stadials (cold periods) and interstadials in the record. In contrast, dust concentrations during the Holocene were very steady (just like temperature) and show very little change on the average.

As a natural extension of our dust concentration measurements, we are now studying the mineralogy and size distribution of the dust in the GISP2 ice core. In particular, we want to determine similarities and differences in the nature of the dust during the different stadials and interstadials. This should shed some light on the source of the dust and on the atmospheric circulation responsible for carrying the dust to Greenland during the Wisconsin. Size distribution is also an important general parameter determining whether or not nearby or distant dust sources are involved.

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# *Highlights of the GISP2 Glaciochemical Record*

## *Climate Change and Atmospheric Chemistry*

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Understanding the Earth system and, in particular, its climate, remains one of the major intellectual challenges faced by science. The processes influencing climate, the mechanisms through which they act, and the responses they generate are, in general, as complex and poorly understood as they are important. Because observational records of climate processes span only the most recent years of Earth's history and, in many instances, are known to be markedly affected by anthropogenic influences, paleorecords of past climates are exceedingly important to the development of scientific understanding of local, regional and global climate systems. Of the various paleorecords available to science, ice cores from polar ice sheets provide the most direct and highest-resolution view of the paleoatmosphere.

On 1 July 1993 the Greenland Ice Sheet Project Two (GISP2) successfully completed drilling to the base of the Greenland Ice Sheet near Summit (72.6°N; 38.5°W; 3200 m above sea level). In so doing, GISP2 recovered the deepest ice core record in the world (3053.44 m) and, along with its European companion project, GRIP, developed the longest paleoenvironmental record—more than 250,000 years—available from the Northern Hemisphere (Mayewski et al. 1994a, Mayewski and Bender, in press). Based on a comparison of electrical conductivity and oxygen isotope series between the two cores (Taylor et al. 1993, Grootes et al. 1993), at least the upper 90% (approximately 2800 m) display extremely similar, if not absolutely equivalent, records. The current best estimate for the age at this depth is approximately 110,000 years, based on multiparameter annual-layer counting (Alley et al. 1993, Meese et al. 1994) combined with measurements of the $\delta^{18}O$ of atmospheric $O_2$ calibrated with the Vostok ice core in Antarctica (Bender et al. 1994). This agreement between the GISP2 and GRIP cores (separated by 30 km) provides strong support for the climatic origin of even the minor features of the records and implies that investigations of subtle environmental signals (for example, rapid climate change events with 1- to 2-year onset and termination) can be rigorously pursued.

One of the primary sets of measurements developed from the GISP2 ice core is the glaciochemical record. It has set a new standard for ice core research by providing a robust measure of change for both the chemistry of the atmosphere and climate. The GISP2 glaciochemical record is a highly resolved, multivariate, continuously sampled time series of the major chemical species found in glacial ice and snow (sodium, potassium, ammonium, calcium, magnesium, sulfate, nitrate and chloride). Each of the major eight species were collected from the same section of core and sampled at a resolution of approximately 2 years through the Holocene, a mean of 3.48 years through the glacial–interglacial transition, and approximately 3–50 years throughout the remainder of the 110,000-year-long record, yielding a total of 16,395 samples analyzed plus an additional 4,500 blanks or replicate samples. The techniques for processing and analyzing these samples have been described elsewhere (for example, Mayewski et al. 1986, 1987, Buck et al. 1992).

## *Chemical Species in the Ice*

Based on our present knowledge of the chemistry of the atmosphere, polar precipitation is expected to contain various soluble and insoluble impurities, which are either introduced directly into the atmosphere as primary aerosols, such as sea salt (mainly sodium and chloride, with some magnesium, calcium, sulfate and potassium) and continental dust (magnesium, calcium, carbonate, sulfate and aluminosilcates), or are produced within the atmosphere along various oxidation pathways involving numerous trace gases, mainly derived from the sulfur, nitrogen, halogen and carbon cycles. In the latter case, the secondary aerosols and gases ($H^+$, ammonium, chloride, nitrate, sulfate, fluoride, $CH_3SO_3^{2-}$, $HCOO^-$ and other organic compounds) are derived from a variety of biogenic and anthropogenic emissions or volcanic activity.

Some chemical species have multiple sources. For example, sulfate present in snow can be linked to primary marine sea salt (as $Na_2SO_4$) or continental dust (as $CaSO_4$). It can also arise due to the presence of $H_2SO_4$ produced by atmospheric oxidation of $SO_2$ introduced directly into the atmosphere during volcanic eruptions, through anthropogenic activity or by atmospheric oxidation of various other sulfur compounds emitted from the biosphere.

Seasonal chronologies developed from a series of snowpits collected in the Summit region (Mayewski et al. 1990a, Whitlow et al. 1992) were defined by overlapping oxygen isotope and chemical species data series. The total beta activity peak corresponding to inputs from the Chernobyl nuclear accident served as an absolute time stratigraphic marker and as a check on the oxygen isotope chronology. This analysis showed that the peak concentrations of chemical species have a definite pattern. From midwinter to spring, there are maximum peaks in total chloride, sea-salt chloride, sodium, sea-salt potassium, calcium, magnesium, total sulfate, sea-salt sulfate and excess sulfate. Spring to summer brings maximum peaks in excess chloride (greater than the ratio in seawater) and nitrate. In summer there is a maximum peak in ammonium. Since maxima for total and excess potassium occur during both midwinter and summer with no apparent regularity, a unique input timing could not be determined.

The input timing developed from the snowpit data is similar to that identified for sodium, magnesium and calcium in southern and central Greenland; for ammonium, sulfate, chloride, calcium and sodium in southern Greenland; and for excess sulfate, nitrate, chloride and sodium in southern Greenland. Therefore, it is assumed that the input timing for chemical species is probably uniform over the entire inland portion of the Greenland ice sheet.

Major chemical species (sodium, potassium, ammonium, calcium, magnesium, sulfate, nitrate and chloride) sampled from 25 snowpits collected from north, central and south Greenland suggest that the mean annual concentrations of these species are the same over the portions of the Greenland Ice Sheet investigated. Future investigations will address spatial variability on the sub-annual scale.

Yang et al. (in press) investigated the relationship between the concentration and flux (concentration times accumulation rate) of chemical species (sodium, potassium, ammonium, calcium, magnesium, sulfate, nitrate and chloride) versus snow accumulation rate at several sites (GISP2, south Greenland, Yukon Territory and the Indian Himalayas). At all sites only nitrate flux and snow accumulation rate had a significant linear relationship. Of the chemical species, only nitrate concentration data are normally distributed, suggesting that nitrate is affected by post-depositional exchange with the atmosphere over a broad range of environmental conditions.

# Interpreting the Record

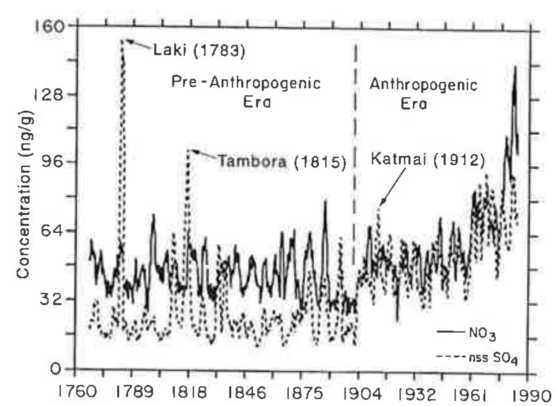
## *Bipolar Chemical Species Comparisons*

Whitlow et al. (1992) compared the high-resolution chemistry record from a site close to the South Pole, covering the period 1955–1989, with the one from Summit, Greenland, for the period 1979–1987 (anthropogenically affected) and 1259–1989 (natural and anthropogenic era). Gaseous species and some species with gaseous precursors (nitrate, ammonium and excess chloride) have similar timings in South Pole and pre-1900 snow. The timing of non-sea-salt (nss) sulfate and species that are generated as marine and crustal aerosols (sodium, nss magnesium and nss calcium) differs between the two sites. The timing of nss sulfate and nitrate is complicated in recent precipitation at Summit by the impact of anthropogenic emissions. Fluxes of sea-salt species, nss sulfate and nitrate (pre-1900 values for Summit) are less than a factor of two higher at Summit. Species with a continental source (nss potassium, nss magnesium, nss calcium and ammonium) are more than five times higher at Summit.

## *Unique Chemical Events*

Anthropogenic influences on climate and atmospheric chemistry have been investigated in the GISP2 record. Previously identified increases in sulfate and nitrate seen in south Greenland ice cores and attributed to anthropogenic activity (Mayewski et al. 1986) have been identified in the GISP2 record and contrasted to the pre-anthropogenic atmosphere (Mayewski et al. 1990b). Increases in excess chloride associated with anthropogenically increased sulfate and nitrate have also been suggested from the GISP2 core (Mayewski et al. 1993a). The role that anthropogenic sulfate may have on the depression of North Atlantic temperatures has also been confirmed by a comparison of GISP2, south Greenland and Yukon Territory ice cores with temperature change records (Mayewski et al. 1993b).

Volcanic event signatures have been identified in the GISP2 core by measurements of electrical conductivity, chemistry and insoluble particles, providing evidence of local eruptions [for example, the A.D. 1783 Laki (Iceland) eruption and the



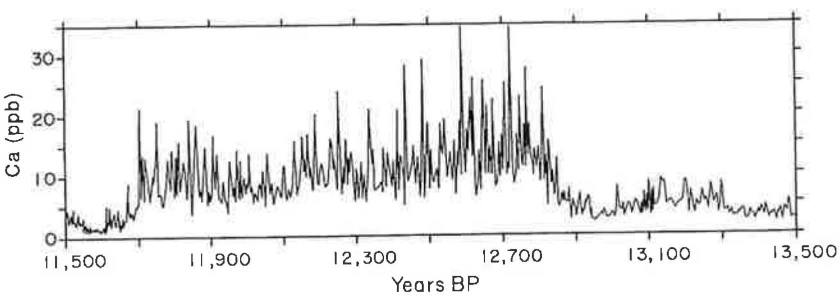

*Time series of the nss sulfate and nitrate concentrations at a site in southern Greenland. The data have been smoothed to remove seasonal signals. Volcanic events are recorded by the nss sulfate spikes.*

A.D. 1362 Oraefajokull (Iceland) eruption (Palais et al. 1991)], intrahemispheric eruptions [for example, the A.D. 1479 Mt. St. Helen's (Washington) eruption (Fiacco et al. 1993)] and interhemispherically distributed eruptions [for example, Tambora (1815)]. The last 300 years of the GISP2 volcanic record has also been compared to volcanic records developed from cores in south Greenland and the Yukon Territory in order to investigate the transport of volcanic aerosols (Mayewski et al. 1993b).

Ammonium increases and accompanying enrichment in $NO_3^-$ and $K^+$ in three ice cores (GISP2, south Greenland and Yukon Territory) covering the period 1750 to the 1980s is believed to reflect biomass-burning events (Whitlow et al. 1994). Most of the $NH_4^+$ spikes at GISP2 and south Greenland occur between 1820 and 1920, when large, intense fires burned in North America.

## *Paleoenvironmental Reconstructions*

Climatic events can be robustly characterized by interpreting the multiparameter GISP2 glaciochemical series. The multivariate nonstationary and nonlinear processes recorded in these glaciochemical series have been analyzed through the innovative use of several existing and newly developed statistical tools (Mayewski et al. 1193a,c, 1994b), many of which were summarized by Meeker (in press).




*Rapid onset and decline of the Younger Dryas as expressed by the calcium series.*

The most recent analogs for conditions cooler and warmer, respectively, than the present century [the Little Ice Age (LIA) and the Medieval Warm Period (MWP)] have been investigated in some detail (Mayewski et al. 1993a). Based on the glaciochemical record the LIA appears to span the period A.D. 1350 or 1450 to approximately A.D. 1900, depending on measurement type (since each may respond to climate change differently). Non-sea-salt sulfate (reflecting primarily volcanic-source sulfur) does not appear to be a major forcing agent on multi-decadal-scale climate. Dust (including particles, calcium, magnesium and potassium) and marine (including sodium, chloride and MSA) sources or transport to the central Greenland increased during the LIA. Nitrate sources (for example, lightning and soil exhalation) decreased during the LIA. Finally, ammonium, primarily reflecting biomass destruction, has peaks that parallel the onset and end of the LIA.

Several periods of air flow reorganization occurred during the Holocene, as determined from the GISP2 glaciochemical record. The timing of these events appears to have some regularity. The circulation patterns described in this study include both large-scale features, such as the polar atmospheric cell, as well as regional-scale atmospheric systems.

A record of volcanism since 7000 B.C. and its relationship to climate has been determined from the GISP2 sulfate series (Zielinski et al. 1994). Three times as many volcanic events occurred from 7000 to 5000 B.C. as over the last 2000 years. As reported in this study, this increased volcanism may have contributed to volcanic cooling in the early Holocene.

One of the most dramatic climate events observed in marine and ice core records is the Younger Dryas (YD), a return to near-glacial conditions that punctuated the last deglaciation. Multi-parameter annual-layer counting of the GISP2 core has provided a high-resolution view of this event (Alley et al. 1993). The end of the YD is characterized by a doubling of accumulation at GISP2 in perhaps one to three years, and the onset of this event is also characterized by a large and abrupt change in accumulation rate. Further, dramatic and rapid changes (10–20 years) in the soluble composition of the atmosphere over central Greenland, attributed to changes in the size of the polar atmospheric cell and changes in source regions (for example, the growth and decay of continental biogenic and terrestrial source regions), mark the Younger Dryas onset and termination (Mayewski et al. 1993c). Massive and frequent, decadal-or-less-scale changes in atmospheric composition also exist throughout the YD.

Multivariate GISP2 chemical records covering the last 41,000 years provide a sensitive measure of climate change (response and forcing) and chemical composition of the atmosphere (Mayewski et al. 1994b). Modeling the common temporal behavior of these chemical series reveals a record of change in the relative size and intensity of the circulation system that transported air masses to Greenland [the polar circulation index (PCI)]. Increases in the PCI were accompanied by increased levels of terrestrial and sea-salt aerosols. Examination of chemical indicators such as excess chloride reveals evidence of changes in the extent of the ocean ice cover.

Massive iceberg discharge events, called Heinrich events, previously defined from the marine record and correlated with certain stadials (cold periods) in the ice core record, are defined in the glaciochemical record as notable expansions of ocean ice cover and the PCI. During the latter type of stadial, the ocean ice cover appears to reach some common maximum level. It is believed (Mayewski et al. 1994b) that the presence of continental ice sheets during the last glaciation and YD provided conditions suitable for relatively unstable conditions (massive and rapid changes in the size and intensity of the PCI and the ocean ice cover) relative to the Holocene. The rapid, massive fluctuations in the extent of the ocean ice cover (sea ice and icebergs) may have played a major role in the radiation balance and thermohaline circulation of the ocean. Changes in the ocean ice cover have the potential to significantly magnify temperature over marine surfaces and consequently affect atmospheric circulation.

Changes in atmospheric circulation and ocean ice cover monitored by the GISP2 glaciochemical record appear to respond rapidly enough to yield direct evidence of the effects of climate forcing, and future studies of such events over the 110,000-year-long record should prove valuable in constraining the significance and character of climate forcing agents.

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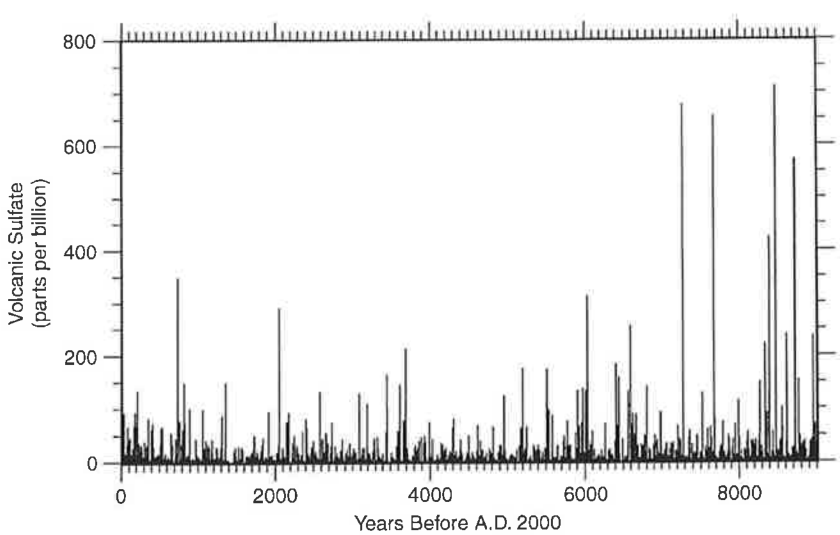
# *Records of Past Volcanism in the GISP2 Ice Core*

*This report was prepared by Gregory Zielinski, Paul Mayewski, David Meeker, Sallie Whitlow, Mark Twickler and Joseph Fiacco, Jr., all of the Glacier Research Group, University of New Hampshire, Durham, NH, 03824; and Mark Germani, of MVA, Inc., Burr Ridge, IL, 60521.*

Explosive volcanic eruptions eject large quantities of debris (both gaseous and mineral matter) into the upper parts of the atmosphere. The gaseous component, in particular, plays an important role in modifying both the physical and the chemical nature of the atmosphere, including modification of the Earth's climate system (Lamb 1970, Self et al. 1981, Angell and Korshover 1985, Rampino et al. 1988). Although recent eruptions (for example, El Chichón in 1982 and Pinatubo in 1991) have provided much information that can be used to evaluate the environmental effects of volcanism, the magnitude and longevity of these effects are still not well understood (Self and Rampino 1988). Part of the reason for not having a more complete grasp of the atmospheric and, in particular, the climatic effects of volcanism is the limited number of explosive eruptions that have occurred in historical time. In fact, many recent eruptions are only moderate when compared to some prehistoric events as known from evidence in the geologic record.

The direct deposition of both volcanically derived soluble chemical species and insoluble species (volcanic ash or tephra) on polar ice sheets offer the potential to develop very high resolution records of past volcanic activity and in particular past volcanic activity that may have had a significant effect on Earth's climate (Hammer et al. 1980, Delmas et al. 1992, Mayewski et al. 1993, Zielinski et al. 1994a). As snow falls on these ice sheets, volcanic material in the atmosphere is removed by deposition onto the ice surface. Continued snow accumulation and the ultimate conversion of this snow to ice as it is buried enables this material to be preserved in the ice sheet and recorded in ice cores. Specific characteristics of the ice enable annual layers to be detected, which allows the exact year of the deposition of the volcanic material to be known (Meese et al. 1994). Because the annual layers of snow and ice in the GISP2 ice core can be detected to about 110,000 years ago, the most complete record of past volcanism, to date, is available from this ice core.

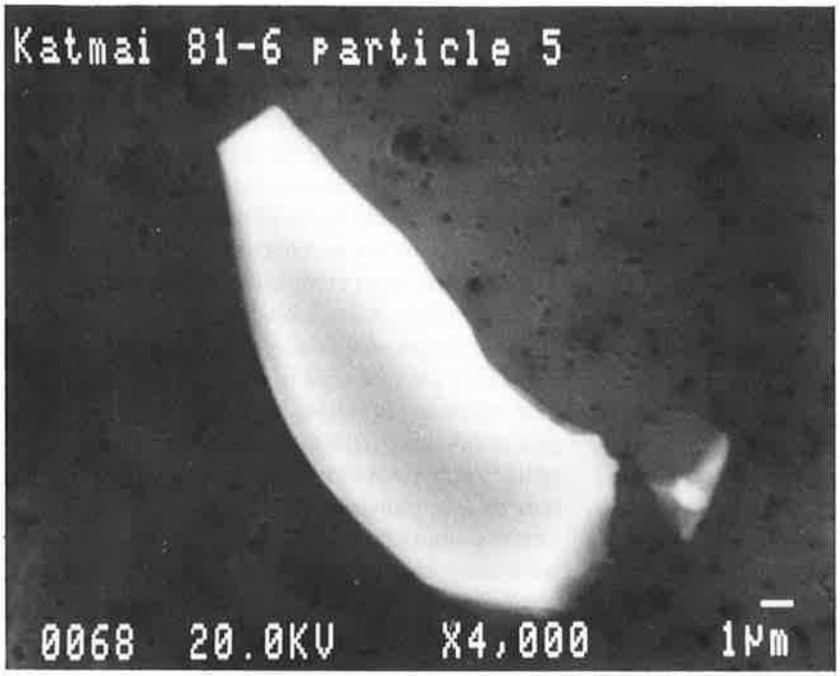



*Record of volcanically produced sulfate deposited on the Greenland Ice Sheet and recorded in the GISP2 ice core for the last 9000 year*

The primary chemical species measured in the GISP2 ice core used to establish a record of past volcanism is sulfate. Sulfur dioxide or hydrogen sulfide gases emitted during an eruption are quickly converted to sulfuric acid in the upper atmosphere, primarily in the stratosphere. The concentration of sulfate in the ice core is a direct measurement of the amount of sulfuric acid deposited on the ice sheet (Mayewski et al. 1993, Legrand and Delmas 1987, Delmas et al. 1992, Zielinski et al. 1994a,b). It is the presence of sulfuric acid in the stratosphere that both absorbs and reflects incoming solar radiation, leading to the cooling of the Earth's climate for several years following a major explosive eruption (Self et al. 1981). The volcanically produced sulfate recorded in the ice core is represented by very high peaks in sulfate concentration that are much above background levels.

Continuous biannual sampling of the GISP2 core has produced a record of volcanism for the past 9000 years, with each large peak representing the deposition of volcanically produced sulfate (Zielinski et al. 1994a). The record over the last 2000 years matches well with the known record of global volcanism (the time period where the volcanic record is better known), thus supporting the use of these data for developing longer records of past volcanic activity. One of the more obvious characteristics of this record is the greater number of large eruptions recorded between 7000 and 9000 years ago. The amount of sulfate deposition associated with many of these events is much greater than the large historical eruptions of Tambora (Indonesia, A.D. 1815) and Laki (Iceland, A.D. 1783). The Tambora eruption is often thought to have played a major role in causing the "year without a summer" (A.D. 1816) in the northeastern U.S. Extending this record over the entire 110,000 years is presently underway.

The second major component of the volcanic record available in the GISP2 ice core is the presence of volcanic glass (tephra). This material is usually not visible to the naked eye, so a scanning electron microscope is used to find individual tephra grains from filtered meltwater samples (Palais et al. 1991, Palais et al. 1992, Fiacco et al.




*Photomicrograph of a typical glass shard found in the GISP2 ice core. The composition of this shard closely matches that of the very explosive A.D. 1912 eruption of Novarupta (Mt. Katmai), Alaska. The shard was found in the ice core at a depth of about 32 m.*

1993, 1994, Zielinski et al. 1995). The chemical composition of the glass is then determined with an electron microprobe to match with the chemical composition of volcanic glass from the suspected eruption. A successful match verifies the volcanic eruption responsible for deposition of debris on the ice sheet. Because volcanic glass is often found in the same layers of ice that have a large sulfate spike or in layers immediately adjacent to the chemical signal, identifying the source of the volcanic glass is an important step in verifying the volcanic record developed by the sulfate data. Accurately identifying the source volcano also is important in evaluating the climatic effects estimated from the magnitude of the sulfate signal for individual eruptions.

Several additional pieces of information may be obtained from the presence of volcanic glass in the ice core. For example, the identification of glass of different compositions in the same layer of ice may indicate the changing composition of magma during the eruption. This was the case for the 10th century eruption of Eldgjá, Iceland (Zielinski et al. 1995). On the other hand, identifying several different compositions of glass shards in the same layer or in adjacent layers can indicate that multiple eruptions occurred at nearly the same time. Such information is again useful in deciphering the chemical signal in the ice core and ultimately the effects of multiple volcanic eruptions on the atmosphere and on climate (Zielinski et al. 1994b). Evidence of circulation patterns at the time of the eruption may be suggested by the size of the shards found in the core and the timing of the deposition of the shards relative to the time of the eruption. We have found that the residence time of volcanic glass in the atmosphere following the Katmai eruption was at least one year (Germani et al., in review).

Records of volcanic aerosol deposition and volcanic glass in the GISP2 ice core have provided exciting new information on volcanic activity in both historical and prehistorical time. This information is beneficial in determining the effects of volcanism on our environment and particularly on the Earth's climate system.

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# Cosmogenic Radionuclides in the GISP2 Ice Core

*This article was prepared by Robert Finkel, of the Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory, and Kunihiko Nishiizumi, of the Space Sciences Laboratory, University of California Berkeley.*

Cosmic rays are charged particles, mostly protons and alpha particles, which originate outside the solar system (galactic cosmic rays) and in our sun (solar cosmic rays). Most cosmogenic radionuclides found in the terrestrial environment are produced by the interaction of galactic cosmic ray particles with terrestrial materials. The cosmogenic radionuclides found in ice cores can yield information about many facets of the terrestrial environment during the late Pleistocene and Holocene.

The cosmic rays penetrate through the atmosphere into the upper levels of the Earth's crust and ocean. In the process they produce a spectrum of radioactive products with half-lives that range from less than a minute up to millions of years. These radionuclides serve geochemistry both as tracers (What pathway does a material follow through the Earth system?) and as chronometers (When did this event happen?). In the context of polar ice core research, cosmogenic radionuclide concentrations are yielding information about those properties of the terrestrial environment that control their concentration in precipitation over Greenland. Thus cosmogenic radionuclides reflect changes in the primary cosmic ray flux (which causes direct changes in their production rate), in solar activity (which modulates the cosmic ray flux in our solar system), in the geomagnetic field (which influences the extent to which the cosmic rays penetrate the Earth's atmosphere) and in atmospheric circulation, precipitation and other climate-related parameters.

The history of these parameters can only be read if a suitable archive can be found that records past changes. The GISP2 ice core comprises one such archive, which spans at least the past 120,000 years. Polar ice sheets are an almost ideal archive, containing a record of past environmental conditions not limited to cosmogenic radionuclides but also including climate change, the global $CO_2$ cycle and ancient atmospheric components. In our work on the GISP2 ice core, we are focusing on the use of $^{10}Be$ (half-life = $1.5 \times 10^6$ years) and $^{36}Cl$ (half-life = $3.0 \times 10^5$ years) for reconstructing the history of solar activity, variations in the geomagnetic field strength and changes in climate. In addition, $^{10}Be$ spikes have been used as stratigraphic markers to cross-correlate both polar ice cores and marine sediment cores from different geographic areas (Yiou et al. 1985, Raisbeck et al. 1987, McHargue et al. 1992). $^{36}Cl$, which follows more complicated atmospheric pathways than $^{10}Be$ (Deck et al. 1990), has been less extensively studied but also promises to be of significance. Since we are in the middle of our analysis of the GISP2 ice core, we can present here only an outline of our work, with some indication of the conclusions we will be able to draw.

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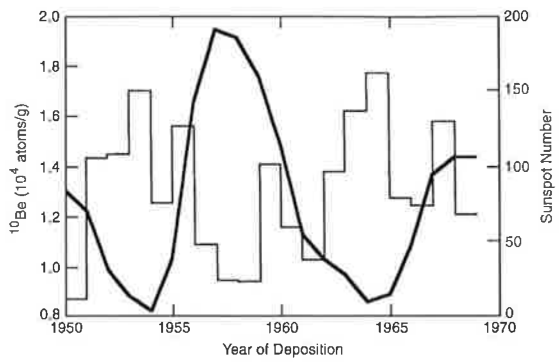
## Solar Variability and Paleoclimate

Concentrations of $^{10}Be$ in the GISP2 ice core at Summit are producing information about the history of solar variability. This knowledge is important because, although it is clear that climate is ultimately driven by the solar energy intercepted by the Earth and by the subsequent redistribution of that energy, we have very little information about the effect of changes in solar irradiance on climate over time scales that are of concern to policy makers. Therefore, predictions of climate change based solely on emission scenarios of greenhouse gases may be misleading if they ignore solar forcing. For example, the IPCC Scientific Assessment (Shine et al. 1990) suggests that changes in radiative forcing due to solar variability may be on the same order of magnitude as greenhouse forcing. Neither solar physics, which determines solar irradiance, nor atmospheric physics and chemistry, which determine global energy flow, can yet directly answer the question of the importance of solar irradiance changes. The paleoclimate record, however, may contain this information by enabling us to detect correlations between solar irradiance and climate.

The $^{10}Be$ record at Summit offers one method for determining solar irradiance before the era of instrumental observations. Two properties of the sun make this possible. First, satellite data show that solar irradiance is correlated with sunspot number. Second, measurements at several sites, including Camp Century (Beer et al. 1990) and Dye 3 (Beer et al. 1993), and preliminary measurements from GISP2, all in Greenland, have demonstrated that $^{10}Be$ concentrations in polar ice cores are inversely correlated with sunspot number. We will interpret our cosmogenic radionuclide record in the GISP2 core to extend the sunspot record to periods before recorded observations. This will allow investigations of the relationship between solar irradiance and climate. There is already circumstantial evidence that solar variability may have an influence on climate. Parts of the 17th and 18th centuries were periods of climate deterioration, also known in parts of Europe and North America as the Little Ice Age. During




*Concentration of $^{10}$Be in the GISP2 core (light line) compared with sunspot activity (heavy line).*

this period, which has come to be known as the Maunder Minimum, the sun was almost devoid of sunspot activity. Measurements at Milcent in central Greenland (Beer et al. 1988) have shown that during the Maunder Minimum (A.D. 1645–1715) $^{10}$Be concentrations were substantially higher than during other periods. Using cosmogenic nuclides to study past solar activity changes can be very helpful in understanding the nature of climate change (Alley et al. 1994).

## *Atmospheric Concentration*

The ultimate goal of much of the ice core work is to determine a time series of atmospheric concentrations of various geochemical species and to relate this to changes in climate or other environmental parameters. The success of this effort depends on the confidence with which an observed change in the concentration of a species in ice can be translated to a change in the concentration of that species in the atmosphere. We have used $^{10}$Be to calibrate a simple model that relates atmospheric and ice concentrations of various anionic and cationic species. By fitting a very simple atmospheric-chemistry model to high-resolution data on ice accumulation and on chemical fluxes in the GISP2 ice core and by assuming that the $^{10}$Be atmospheric concentration changes were small, we have been able to calculate the atmospheric concentrations of sodium, soluble calcium and $^{10}$Be during the transition from glacial to Holocene conditions. The atmosphere over Greenland during the Younger Dryas cold event contained on average of about three times more sea salt and seven times more soluble calcium derived from continental sources, but only slightly more cosmogenic $^{10}$Be, than during the warmer Preboreal period that followed. This indicates stronger winds and probably an enhanced dust source during the Younger Dryas but little change in the mechanisms of chemical transfer to the ice sheet.

## *Geomagnetic Field*

The available geomagnetic data, which are not very complete, support a picture of slow variation of the geomagnetic field over the past 10,000 years, with a peak at roughly 2,000 years ago, followed by a slow decrease in the magnetic moment, which reached about half the present value by 20,000 years ago. Tree ring studies suggest that there is a correlation between the geomagnetic field and atmospheric $^{14}$C concentrations (Bard et al. 1990a), at least in the upper Holocene. Studies of $^{10}$Be in Holocene ice, which shows a different pattern than $^{14}$C, have led to a re-examination of this question (Lal 1987). The nuclide patterns could also be interpreted as indicating that production rates were higher during glacial time (Beer et al. 1984). Recently, Bard et al. (1990b), by comparing Th-U dates of corals with $^{14}$C dates of corals and tree rings, have also deduced that $^{14}$C production may have been higher in the past, as much as 50% higher 30,000 years ago than it is today. The question is complicated by the dipole nature of the geomagnetic field, which has the consequence that production rates at polar latitudes are much less affected by changes in the geomagnetic field than are those at equatorial latitudes. Atmospheric mixing tends to decrease the importance of this effect. Since the solar effects mentioned above show the opposite latitude dependence, comparison of core data from different latitudes will make it possible to assess the sensitivity of sites to both effects and thereby allow the extraction of a geomagnetic signal. The results will have important implications for many fields, including $^{14}$C dating.

## *Dating*

Cosmogenic nuclides can also be used for dating polar ice, which is important not only for understanding the environmental record of the past but also for understanding ice flow dynamics and the history of polar ice sheets. Several dating methods have been applied to ice cores, including counting annual dust layers and measuring annual changes in $\delta^{18}$O values. Dating old ice at depths where annual layer counting is no longer possible relies heavily on ice flow models, the validity of which can be difficult to assess under the different climate regime that occurred during the glacial period. Radioactive nuclides can provide absolute ages based on the half-lives of the nuclides. However, since several factors influence the $^{10}$Be concentration in ice, the age of ice can't be deduced by a simple analysis of the concentration of $^{10}$Be. Nishiizumi et al. (1983) proposed a dating method for polar ice using the $^{36}Cl/^{10}Be$ pair. It was expected that changes in atmospheric production rates and the effects of transport in the atmosphere and precipitation scavenging would affect $^{36}Cl$ and $^{10}Be$ identically and thus cancel. Our results so far indicate that at GISP2 the $^{36}Cl/^{10}Be$ ratio is constant to about 20%. This would allow dating to about ±75,000 years.

$^{10}Be/^{26}Al$ may be another dating pair for old ice because their atmospheric chemistries are expected to be more similar. Although $^{26}Al$ measurements require larger samples than $^{36}Cl$ (approximately 20 kg), by pooling samples we intend to investigate the $^{10}Be/^{26}Al$ pair. The constancy of the ratio has to be tested using the ice core. The limitation of this method is that the relative half-life (1.3 million years) is very long. The technique will be useful only for old ice with high-precision AMS measurements. $^{26}Al$ has another limitation in that the contribution from extraterrestrial sources may be significant.

## *Anomalous Peaks*

Recent work (Raisbeck et al. 1987) has demonstrated the presence of two $^{10}Be$ spikes at about 60,000 years and 35,000 years in ice cores from widely separated regions of Antarctica. The $^{10}Be$ concentration at these times is up to three times higher than either before or after. Careful examination of $\delta^{18}O$ and other parameters has excluded the possibility that this change in $^{10}Be$ concentration could be due to a climate effect such as a change in the snow accumulation rate. At least one of these peaks has also been tentatively identified in marine sediment cores, one from the Gulf of California (McHargue et al. 1992) and one from the Mediterranean (Castagnoli et al. 1995). Several explanations have been proposed, including a geomagnetic excursion and a nearby supernova that temporarily increased the $^{10}Be$ production rate in the atmosphere. Aside from the question of the origin of these peaks, these $^{10}Be$ anomalies are valuable stratigraphic markers for correlating the climate records from widely different areas. We have detected a peak of anomalous $^{10}Be$ concentration in the GISP2 core, which occurs at about 40,000 years. Further study of this peak and a search for the 60,000-year peak are underway.

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# *High-Precision Temperature Measurements in the GISP2 and GRIP Boreholes*

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High-precision temperature measurements are being acquired in the 3-km-deep GISP2 borehole and in the companion European borehole at the GRIP site, 30 km to the east. These data will be used to reconstruct paleotemperatures on the surface of the ice sheet directly from the climate-induced temperature transients still remaining at depth in the ice. The data are also necessary for several other GISP2/GRIP studies, including:

- An improved calibration of the $\delta^{18}O$ isotopic paleothermometer for central Greenland;
- Evaluation of the non-thermal effects present in the stable isotope signals within the ice cores;
- Ice dynamics studies; and
- Detection of shear heating at the base of the ice sheet.

## *Paleoclimate Reconstruction*

Any temperature change on the surface of the ice sheet will cause a temperature transient to slowly diffuse down into the ice and ultimately into the bedrock below. This process has occurred continuously since the ice sheet came into existence. The two deep boreholes drilled at Summit, Greenland (GISP2 and GRIP) provide ideal access holes in which to directly measure the temperature transients still remaining at depth due to past changes in climate. Once the borehole temperatures have been measured, these data can be used to reconstruct the history of temperature change on the surface of the ice sheet using geophysical inverse methods. This type of climate reconstruction has been accomplished at other sites in Greenland (Dahl-Jensen and Johnsen 1986, MacAyeal et al. 1991, Firestone 1995) and at GISP2 using temperature data from a 217-m dry borehole (Alley and Koci 1989).

Summit is an ideal site to conduct this experiment for several reasons:

- The ice sheet geometry is relatively simple at this location.
- Because of the great depth of the two main boreholes (3 km), surface paleotemperatures can potentially be reconstructed well back into the Wisconsin glaciation (tens of thousands of years into the past) directly from the borehole temperature measurements.
- Unlike the situation for boreholes drilled into differing rock strata, the thermal properties of the ice are both simple and well known. This reduces the uncertainty in the inferred paleoclimate.

Temperatures within the ice sheet are strongly affected by the motion of the ice, as well as by past climatic changes. Thus, the climate reconstruction process must incorporate the effects of ice dynamics. At Summit, ice dynamics are being intensively studied by several other projects, providing important constraints on the ice velocity (both vertical and horizontal), the snow accumulation history, and the ice density as a function of depth. Information on all of the significant physical factors that affect our interpretation of the borehole temperature measurements will ultimately be available.

Because of the comprehensive nature of the GISP2 and GRIP programs, several fundamentally different approaches are being used to extract paleoclimatic information from the Summit ice cores and geophysical measurements. These approaches are complementary. Paleotemperatures derived from the borehole temperature measurements have the following characteristics:

- Because the paleotemperatures are determined by directly measuring the temperature transients still remaining at depth from past climatic changes, no calibration constants are involved. As a corollary of this, the borehole temperatures can be used to calibrate the geochemical proxy-temperature signals derived from stable isotopes (Dansgaard et al. 1973) in the ice core.
- Since the ice sheet continually responds to temperature changes on its surface throughout each year, changes in the derived paleotemperatures reflect changes in the mean annual temperature. This information complements that provided by paleoclimate reconstruction methods based on the ice core, which may be more sensitive to particular seasons. For example, stable isotopes only record temperature when it is snowing.
- Analysis of the borehole temperature measurements yields the surface-temperature history in the immediate vicinity of the boreholes (within a few kilometers). In contrast, temperatures determined from geochemical characteristics of the ice core are influenced by climatic changes both at the

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moisture source regions in the north Atlantic Ocean and at the snow deposition site (central Greenland); the moisture source regions may shift with time, adding an additional complication.

Unfortunately, any surface-temperature history derived from a set of borehole temperature measurements will be "smeared" in time (Clow 1992). This is primarily a consequence of heat diffusion. The signals from relatively short-duration climate events disappear as the associated temperature transients diffuse down into the ice. Consequently it would be difficult to detect a decade-long climate event that happened only 100 years ago using present-day temperature measurements in a borehole. Similarly it would be difficult to detect a 1000-year-long event that occurred 10,000 years ago. The presence of instrumental and natural sources of noise further aggravates the problem. Two strategies can be used to improve our ability to resolve past climatic events:

- Reduce the noise due to instrumental and natural sources to the 1-mK (0.001°C) level;* and
- Increase the number of temperature measurements in the borehole. However, significant gains would require at least a 100-fold increase in the number of data points used in the reconstruction process (Clow 1992).

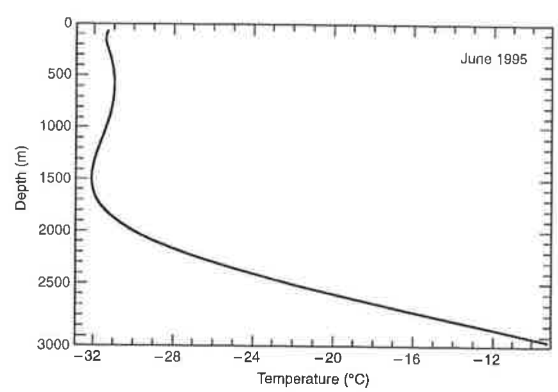
## *Borehole Temperature Measurements at GISP2*

Temperatures in the ice immediately surrounding a borehole can be significantly disturbed by the drilling process. At GISP2 this thermal disturbance, which was quite large, was due to the heat generated by the drill motor, heat radiated by the drilling cable, and the sensible heat associated with the temperature difference between the ice and the drilling fluid (n-butyl acetate), which was periodically added to the hole as it was deepened. To obtain undisturbed ice temperatures, our strategy is to obtain several temperature logs at one-year intervals. Comparison of the repeat logs will establish the magnitude of the drilling disturbance and the rate at which it is dissipating. We can then extrapolate in time to determine the undisturbed temperatures that will ultimately be reached when the drilling disturbance goes away.

Shortly after the GISP2 borehole was completed (July 1993), Niels Gundestrup of the University of Copenhagen obtained a baseline geophysical log in the GISP2 hole. This was part of an exchange program between the GISP2 and GRIP borehole logging teams. During this logging experiment, Gundestrup measured the borehole diameter, inclination, azimuth and temperature using the same tool he used to log the European GRIP hole during 1992, 1993 and 1994 (Gundestrup et al. 1994). These baseline data provide important information regarding the initial temperature disturbance in the borehole and its original geometry. Such data greatly enhance the value of the ongoing temperature and ice deformation measurements in the GISP2 borehole.

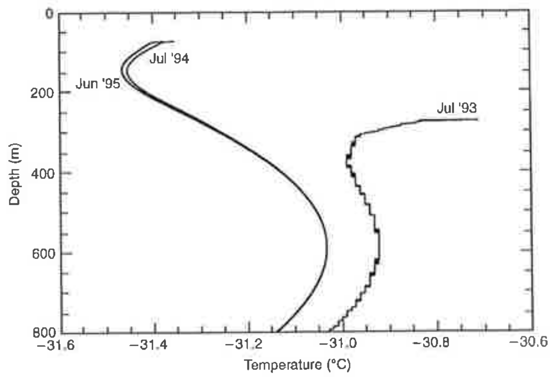
Subsequently Gary Clow used a temperature logging system developed at the U.S. Geological Survey to obtain high-precision temperature measurements to bedrock in the GISP2 borehole. With a sensitivity of 0.14 mK (0.00014°C), this system was specifically designed to provide the data that would improve our ability to detect past climatic changes. The resulting temperature logs (July 1994 and June 1995) consist of over 20,000 measurements, each with a precision of 1 mK. A set of experiments was also conducted to characterize the degree to which the fluid in the lower section of the borehole is convecting; temperature fluctuations associated with fluid convection constitute a natural source of thermal noise.

Comparison of the USGS's 1994 and 1995 logs with Gundestrup's 1993 log reveals that the drilling disturbance upon completion of the borehole was roughly 100–150 mK. Our data suggest that by June 1995 the drilling disturbance had dissipated to about 25 mK in the upper section of the borehole and to about 1 mK at depths greater than 400 m. The final temperature logs in the GISP2 borehole are scheduled to take place during the summer of 1996. The new data, when used in conjunction with a heat-transfer model and the 1993–1995 temperature logs, will allow us to determine the undisturbed temperatures in the ice surrounding the GISP2 borehole. In cooperation with the




*Temperature log obtained in the GISP2 borehole during June 1995 using the U.S. Geological Survey's high-precision system.*

* A one-degree difference on the kelvin (K) temperature scale is equivalent to a one-degree change on the Celsius (°C) scale.




*Detail of the 1993, 1994 and 1995 temperature logs obtained in the GISP2 borehole. The borehole is slowly returning to thermal equilibrium after the thermal disturbance caused by the drilling operations.*

Europeans, the USGS logging system was used to make high-precision temperature measurements in the GRIP borehole during July 1995. Additional temperature measurements are planned for the GRIP borehole during the summer of 1996.

# Additional Studies Utilizing Borehole Temperatures

### *Calibration of the $\delta^{18}O$ Paleothermometer*

$\delta^{18}O$ data obtained from an ice core are often used as a proxy for ice sheet surface temperature in the past (Dansgaard et al. 1973). This climate reconstruction method relies on an empirical relationship between $\delta^{18}O$ and temperature; the calibration constants are generally derived from modern spatial relationships. However, the modern, spatially derived $\delta^{18}O$–temperature relationship may not be valid over long periods of time. One way to test this is to use the surface temperatures derived from $\delta^{18}O$ to predict the present-day temperatures at depth in the borehole. If there is a large discrepancy between the predicted subsurface temperatures and those actually measured in the borehole, then the $\delta^{18}O$ calibration constants may be in error. Cuffey et al. (1995) turned this problem around, using the temperatures measured in the GISP2 borehole and a thermomechanical model of the ice sheet to calculate the average $\delta^{18}O$ calibration constants over the last 100,000 years. They found that the modern, spatially derived calibration constants were not valid in the past at GISP2. Using the new calibration constants, they found that Greenland warmed 15°C when the last ice age (the Wisconsin) ended. This warming is twice as large as previously thought.

### *Evaluation of Non-Thermal Isotopic Effects*

Even with the improved isotope calibration, there remains some discrepancy between the present-day subsurface temperatures predicted from $\delta^{18}O$ and the measured borehole temperature profile. The remaining deviations may be due to deficiencies in the thermomechanical models, which are being improved all the time, and to non-thermal processes that affect the isotopic records. Such non-thermal processes include changes in the source regions for the moisture transporting oxygen isotopes, isotopic fractionation in the snow, and changes in the seasonal distribution of snowfall. Thus, the borehole temperature measurements may prove useful for discriminating the non-thermal component of the $\delta^{18}O$ signal in the GISP2 ice core.

### *Ice Dynamics Studies*

Both climatic change and the vertical velocity distribution within the ice strongly influence the subsurface temperatures we measure in the boreholes. By comparing temperature data from both the GISP2 and the GRIP boreholes, we hope to isolate the effects of ice flow from true climatic signals. This should be possible because GRIP and GISP2 have experienced essentially the same climate history, while the vertical velocity distribution may be very different at the two sites; GRIP is located on the present ice divide, while GISP2 is on the flank. If the ice divide has migrated significantly, as is suggested by the pattern of internal layers within the ice sheet, changing velocity patterns should have influenced both temperature profiles in different but predictable ways. Thus, the borehole temperature data may provide important constraints for the Summit ice flow models.

### *Shear Heating in Basal Ice*

The silty ice at the base of the ice sheet may be much softer than the overlying clean ice and could thus contribute a large fraction of the total shear deformation. In this case, the soft basal ice would have a serious impact on the ice flow modeling projects underway to derive a time scale or to derive paleoprecipitation rates from layer thicknesses in the deep ice. The best way to detect rapid shear in the basal layer is by repeat measurements of the borehole inclination. However, the borehole inclination tool is fairly large, so it may be unable to re-enter the deformed basal zone after a few years. Shear heating associated with deformation in the silty basal ice may be detectable by temperature measurements at the mK level. If so, the USGS temperature sensor, which is much smaller than the inclination tool, may provide an additional means for measuring the basal shear rate.

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# Atmosphere–Snow Exchange at Summit, Greenland

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Climate changes over time scales ranging from intra-annual to glacial–interglacial transitions are recorded in the physical and chemical properties of glacial ice. Changes in ice chemistry are thought to largely reflect changes in atmospheric chemistry and dynamics resulting from variations in biogeochemical cycling due to climatic (and other) perturbations. There is a broad list of parameters in polar ice cores that have been, and will be, widely used to describe the evolution of past climate. Each of these parameters is linked to a specific aspect of the Earth system. All of these signals (for example, temperature, moisture and trace impurities) pass through, and may be modified in, the atmosphere, the surface layer of snow and then the snowpack before they are recorded by the ice. Therefore, variations in the properties measured down an ice core have to be translated first into corresponding variations of the atmospheric properties before they can be used to estimate past climate signals.

In other words, full use of ice core records requires that we be able to identify and account for any compositional changes occurring between air and newly fallen snow, between new snow and aged snow beginning its metamorphism into ice (termed firnification), and finally during the transformation of firn into ice. However, the overall transfer function involves multiple physical and chemical processes. The composition of the atmosphere over any ice coring site is the result of horizontal and vertical transport from a variety of source types and regions. Physical and chemical modifications that occur in each air mass during transport to the ice sheet must also be considered. Another complication involves the effects of temporal averaging; the snowpack and ice usually preserve, at best, monthly or seasonal resolution. On these time scales, the air reaching the ice sheet can originate from widely divergent source regions and follow numerous pathways.

Initial incorporation of atmospheric constituents into surface snow can result in large differences in the proportions of various chemical species between the atmospheric and snow phases. The relative importance of wet and dry deposition of aerosols and gases will differ between species present in the atmosphere and between sites. Re-emission of some species to the atmosphere, mobilization and redistribution within the snowpack, and the potential for wind to redistribute (and perhaps import or export) surface snow will further modify any atmospheric signal that is eventually preserved in glacial ice. Thus the overall goal of understanding air-to-snow transfer involves developing an understanding of:

- Source areas and transport pathways of the air masses reaching a site;
- Processes controlling the incorporation of material from the atmosphere into the snowpack;
- Temporal variations in these processes as related to observable atmospheric processes from the meso- to micro-scale; and
- Post-depositional modification of snow.

Climate change will likely alter the air/snow transfer function of a chemical species at a given site. Moreover, air/snow transfer functions developed for one ice coring site may not be completely transportable to a different site. Therefore, it is imperative that we obtain a fundamental understanding of the processes responsible for the composition of a given layer of glacial ice. In addition to quantifying present-day transfer functions, we must also determine the parameters that affect each of the linked transfer processes. This will entail a series of intensive field experiments, including sampling of a variety of chemical species in the air and snow under a range of atmospheric conditions, and laboratory experiments investigating single processes under controlled conditions (temperature, relative humidity, "atmospheric" loading). These efforts must support modeling at different temporal and spatial scales, ranging from cloud microphysical processes governing scavenging and gas–ice interactions within firn pore spaces, on the small scale, up to general-circulation model (GCM) simulations of the atmosphere over the past several hundred thousand years at the larger end of the scale.

## Recent Results from Summit

Over the past several summer seasons, a multinational atmospheric research program has been underway in the Summit region of the Greenland Ice Sheet. The program began as an integral part of the U.S. and European deep ice coring campaigns (GISP2 and GRIP, respectively) and involves researchers from 20 institutions in the U.S. and Europe. The primary purpose of the surface snow and atmospheric sampling activities at Summit has been to study the transfer functions that relate atmospheric aerosols and gases emitted from source regions to their ultimate fate in the deep ice. Such information is crucial to allow the best possible interpretation of the detailed ice core records that have been recovered from Summit.

Findings from this research are helping to unravel the complexity of physico-chemical processes occurring in the atmosphere over the ice sheet and in the snowpack during the first few weeks to years after snow deposition.

The composition of air along the crest of the Greenland Ice Sheet (Summit and Dye 3) does not reflect that in the better-studied Arctic Basin. In particular, the Arctic haze phenomenon, which blankets the Arctic Basin with pollutants and dust for 3–4 months during late winter, is manifested at Dye 3 only as brief episodes (a few days) of transport from the basin to the higher elevations of the ice sheet interior. Most of these events appear to occur in spring (toward the end of the Arctic haze season), and they can contribute a large fraction of the annual deposition of anthropogenic and crustally derived species to the snow surface. The Greenland Ice Sheet's orientation (a tall obstruction perpendicular to the prevailing westerly winds) and boundary layer dynamics mediated by the presence of the ice are responsible for this decoupling between low-elevation Arctic sites and those on the ice sheet (Dibb 1990, Davidson et al. 1993; see also the special issue of *Atmospheric Environment* on "Arctic Air, Snow and Ice Chemistry," December 1993).

In the surface layer of snow (the top 1–3 cm), replicate samples separated by at most a few tens of centimeters typically show 10–30% variability in concentration of soluble ions. In general, the variability of "reversibly deposited" species (for example, $H_2O_2$, $Cl^-$, $NO_3^-$) is significantly less than that of aerosol-associated species (for example, $Na^+$, $Ca^{2+}$, $Mg^{2+}$), with $H_2O_2$ concentrations usually varying only a few percent on these spatial scales. The variability in surface snow composition of a given surface layer appears to increase only slightly (no more than three-fold) when the spatial scale of replicate sampling is expanded to tens or hundreds of meters.

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Concentrations of some aerosol-associated species showed variation of over 100% at a given depth in snowpits over horizontal distances of a few meters. The increased variability observed in these pits reflects sampling of different layers at the same level in the snow. (In contrast to the surface snow samples, where distinct stratigraphic layers are selected, any fixed-depth sampling scheme can mix different events.) Departures of snowpack stratigraphy from uniform, planar layers are largely due to the formation of dunes and other bedforms caused by wind (drifting of loose surface material). Such variability is probably inherent in any ice core sampling scheme that attempts to resolve sub-seasonal events (Dibb et al. 1992).

With increasing degrees of reversibility, the concentrations of gases seem to be determined by post-depositional adjustment of the upper snow layer to the air ventilated through the firn. In the case of $H_2O_2$, which is considered the archetypal "reversibly deposited" species, the time scale to reach equilibrium appears to be at least weeks, as the snow responds to seasonal patterns of temperature, water accumulation, and photochemically controlled variations in the atmospheric concentration of $H_2O_2$. In general, $H_2O_2$ concentrations in the air a few meters above the snow at Summit during the summer are too high to be explained by homogeneous photochemistry yet too low to be in Henry's law equilibrium with surface snow. Outgassing must continue into fall and winter even after burial, with grain-scale processes dominating the kinetics of equilibration at Summit (Conklin et al. 1993, Drummey 1993, Neftel et al. 1995, Bales et al. 1995a,b).

During the summer, snowfall is the dominant process delivering soluble species to the ice sheet. However, fog carries down a significant fraction (up to 40% of the total) of the summer flux of some species, even though it is a negligible fraction of the water budget. The contribution of dry deposition is insignificant for the summer in recent years but might be more important in spring, when aerosol loading increases or during periods of reduced snowfall (Borys et al. 1992, Bergin et al. 1994, 1995a,b).

Depth profiles of several chemical tracers suggest that the winter is underrepresented in the snowpack at Summit (Dibb et al. 1992, Jaffrezo et al. 1994). The combination of detailed stable isotope records from snowpits and satellite-borne microwave images yields snow accumulation estimates with winter–spring minima (Shuman et al. 1995) that are consistent with preliminary results from an acoustic snow-depth gauge mounted on an automatic weather station at Summit. Variable accumulation of snow through the year may create substantial biases in the reconstruction of atmospheric concentrations, particularly if the phase relationships between annual cycles in snow accumulation and airborne concentrations vary over time (that is, small changes in the relative amount of snow falling and accumulating during a given season could have disproportionate impacts on the annual flux to the snow of those species whose airborne concentrations are at minima or maxima during that season).

# *Ongoing Research*

Penetration of the entire thickness of ice and collection of samples of the underlying rock in the summer of 1993 marked the successful completion of GISP2 drilling activities. However, the investigations of air–snow relationships have continued, and even expanded, in the past several summers. Some preliminary results from ongoing, collaborative investigations are briefly highlighted below.

Inorganic nitrate (aerosol-associated $NO_3^-$ and gas-phase $HNO_3$) are thought to be the major sinks for the complex tropospheric chemical cycles involving reactive nitrogen. The atmospheric chemistry of nitrogen is, in turn, central to the larger issue of atmospheric photochemical cycles. For example, recent intensive atmospheric sampling campaigns in the North American Arctic troposphere suggest that documented increasing concentrations of $O_3$ are at least partly due to greater availability of $NO_x$.

Nitrate is the dominant ion in summer snow at Summit, presumably reflecting contributions from both forms of inorganic nitrate. On an annual basis, $NO_3^-$ remains one of the two dominant species (with $SO_3^{2-}$) for both recent (anthropogenically impacted) times as well as in the snow that has accumulated at Summit over the 10,000 years preceding the rapid spread of industrial pollution. Variations in the concentrations of $NO_3^-$ preserved in Greenland ice cores must contain valuable information about atmospheric photochemistry and the biogeochemical cycling of nitrogen, if we can decipher the atmospheric signals trapped in the snow and ice.

We are focusing on improving our understanding of reactive nitrogen chemistry over Summit and establishing the relationship between $NO_3^-$ in snow and atmospheric nitrogen. Measurements of "total reactive nitrogen" ($NO_y$), made in conjunction with very highly resolved micrometeorological measurements, allow us to estimate fluxes of $NO_y$ into or out of the surface snow by a technique known as the eddy-correlation method. These are complemented by measurements of $HNO_3$ at several heights above the surface (gradient-flux method) and $NO_3^-$ concentrations in the surface snow. Concentrations of $NO_y$ have been found to be quite high, with an indication of marked decreases from the spring into midsummer. Flux estimates from these data indicate that several-hour-long periods of flux out of the snow generally alternate with similar periods of flux to the surface, resulting in a season-long mean flux very close to zero. By inference from similar studies in other environments, we would expect the inorganic nitrate species to constitute the bulk of the $NO_y$ depositing to the snow surface. However, concentrations of $HNO_3$ during the same period, while much higher than those of aerosol-associated $NO_3^-$ (Dibb et al. 1994), could generally account for only a few percent or less of measured $NO_y$. These unexpectedly low values of $HNO_3/NO_y$, and surprisingly high concentrations of gas-phase organic acids, suggest that poorly understood organic nitrate species in the $NO_y$ pool may make a significant contribution to the high concentrations of $NO_3^-$ measured in Greenland snow. Gradients of $HNO_3$ concentration suggesting both deposition to, and emission from, the snow were also observed, and comparisons between the timing and magnitudes of the apparent fluxes of $NO_y$ and $HNO_3$ are in progress; these should confirm or refute our hypothesis about the need to also consider organic nitrates.

These preliminary results for $NO_3^-$, and the investigations of $H_2O_2$ described above, indicate that post-depositional interactions between air and snow have the potential to significantly modify the composition of snow before it is buried. These two examples are concerned with species that are mainly, or entirely, in the gas phase in the atmosphere. We might hope that post-depositional modifications of the concentration of aerosol-associated species are smaller or nonexistent. However, recent experiments to characterize the composition of snow drifting over the surface (after deposition but prior to burial) have shown that the concentrations of all soluble ionic species are subject to changes by this process. Careful examination of the stratigraphic features preserved in the snowpack indicate that essentially all of the snow accumulating at Summit is redistributed by wind at some point before it is covered by subsequent layers.

Burial alone is not sufficient to "lock in" the composition of a given layer of snow. The concentrations of $H_2O_2$ and $NO_3^-$ in summer snow have been shown to decrease substantially between the end of one summer season and the following one (Drummey 1993, Bales et al. 1995a,b, Dibb et al. 1994). These findings suggest that the snow continues to equilibrate with the air in pore spaces for some time. Earlier theoretical work indicated that the subdued topography at Summit should limit the flow of air into and through the snowpack, such that equilibrium between snow and pore air would be expected to be rapidly established. However, we have made the first bidirectional measurements of permeability in the snowpack at Summit and found the values to be high enough to permit air flow through the snow and firn, even under moderate wind forcing conditions (Albert 1995, Albert et al. 1995). The permeability actually increases with depth in the top 3 m of the snowpack, and there are very large differences in horizontal and vertical permeability created by the layering in the profile. This greatly increases the potential for significant flow of air in and through the top several meters of the snowpack.

As part of the same investigation, the distribution of surface pressure variations caused by the turbulent flow of air (at the relatively slow wind speed of 4 m/s) over the natural small-relief bedforms at Summit was also measured. When these pressure fluctuations are used as the forcing term for advective transfer of air through a modeled snowpack with the observed permeability profile, we find the highest air flow velocities in the surface snow, but velocities on the order of 1 mm/s still occur at depths of 1.5 m and deeper in the firn. Such exchange of the pore air would disrupt any rapid equilibration between the snow and pore air. Analysis of bidirectional permeability data down to 20 m, and additional ventilation modeling, is underway. Merging chemical reaction and exchange processes with the models of snowpack ventilation is the obvious next step in our ongoing attempts to quantify the processes controlling air–snow exchange.

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# The ARCSS Data Coordination Center at the National Snow and Ice Data Center

*This article was prepared by Claire S. Hanson, David L. McGinnis, Matthew D. Cross and Mary J. Brodzik, all from the Cooperative Institute for Research in Environmental Sciences, University of Colorado at Boulder.*

## Data Management for Integration

Since September 1994 the National Snow and Ice Data Center (NSIDC), at the University of Colorado at Boulder, has been funded as the ARCSS Data Coordination Center for all components of the ARCSS program. This unified project follows separate grants for ARCSS data management pilot projects for Ocean–Atmosphere–Ice Interactions (OAII) and Land–Atmosphere–Ice Interactions (LAII), and for the Greenland Ice Sheet Project Two (GISP2) archive. Current NSIDC efforts focus on identifying ways to integrate the ARCSS component communities and on providing access to existing, unarchived data of interest for ARCSS research. In parallel, archiving planning for ARCSS-funded data sets continues in concert with the OAII, LAII, GISP2 and PALE (Paleoclimates of Arctic Lakes and Estuaries) Science Management Offices. Close contact is maintained with the Surface Heat Budget of the Arctic Ocean (SHEBA) experiment planning process and the emerging Human Dimensions of the Arctic System (HARC) and Synthesis, Integration and Modeling Studies (SIMS) components. The concept of system science, or integration, depends heavily on the accessibility and sharing of data and results among all those involved. NSIDC is seeking to develop the ways and means to ensure that accessibility.

## Exploiting the World Wide Web

Because communication is a fundamental building block for integration, we provide an ARCSS World Wide Web information server at http://nsidc.colorado.edu/ARCSS. A "Home Page" and an electronic mail listserver were established in early 1995, providing access to such information as a listing of all ARCSS-funded investigators with their contact information, the ARCSS Data Catalog, and links to the NSIDC "anonymous ftp" area, where small data sets will be available for on-line retrieval, and to other information sources at NSIDC. As the service develops, links to other ARCSS and ARCSS-related sites are added. PALE, SHEBA, OAII, NSF/Office of Polar Programs, and Arctic Tundra LTER (Long-Term Ecological Research site, Toolik Lake, Alaska) links are already established.

## Data Requirements: Setting Priorities

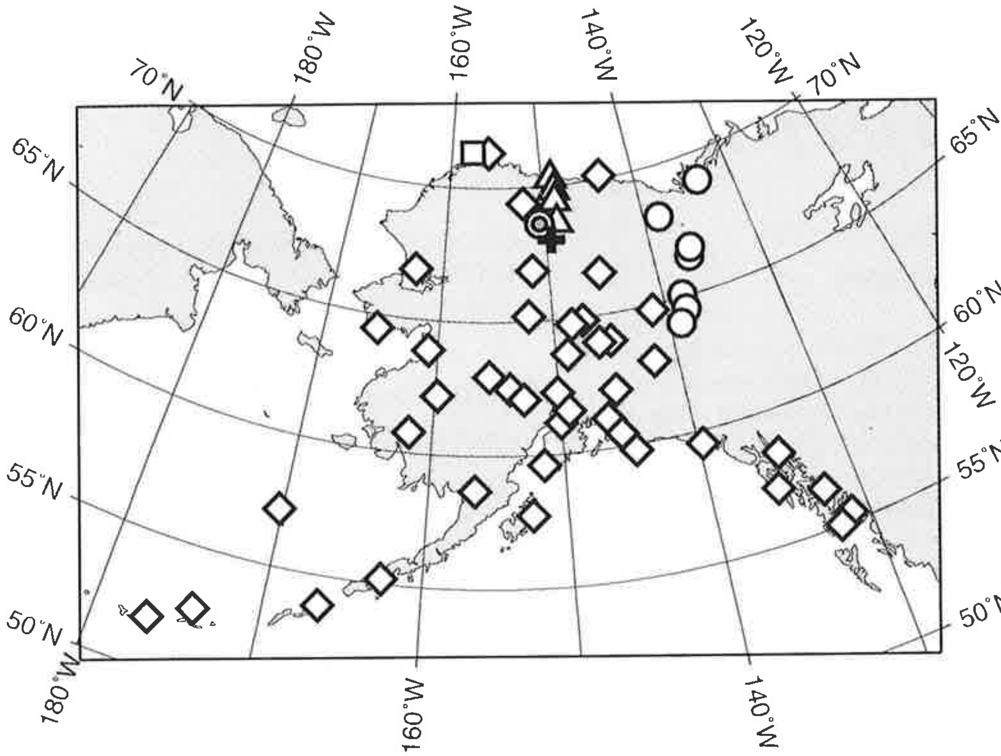
Another fundamental building block for integration is discussion, in an established forum, of data issues and priorities across all ARCSS components. The ARCSS Data Management Working Group and the ARCSS Modeling Working Group held their inaugural meetings in August 1995, in conjunction with the first meeting of the ARCSS Advisory Committee. Each ARCSS component is represented on the Data Management Working Group (DMWG) to provide input and feedback for data management and coordination planning within the ARCSS program. Priorities for data product development and delivery mechanisms are set by this group, with additional guidance from the ARCSS Advisory Committee. The Modeling Working Group brings together representatives of the ARCSS modeling projects and related non-ARCSS efforts to develop a coherent plan for an integrated approach to ARCSS modeling strategies.

A primary purpose of the DMWG is to determine the data needs of ARCSS-funded projects. Each component, and the Modeling Working Group, must be involved in this task, and the ARCSS Advisory Committee assists the Working Groups in determining whether the ARCSS science questions can be answered by the available and ARCSS-generated data. There is a general need for "griddable data" that are:

- Spatially and temporally registered;
- In original spatial and temporal resolutions;
- In a consistent format per data type; and
- Accompanied by tools to allow easy subsetting and gridding to various map projections and grid sizes.

## Current ARCSS Data Products

In late November 1994 NSIDC announced its first ARCSS CD-ROM product, the ARCSS/LAII




*Coverage of the Alaska North Slope Data Sampler.*

Data Series, Volume 1: Alaska North Slope Data Sampler. This volume contains a group of data sets identified by the LAII/Flux Study investigators as needing improved access and as useful to them in the progress of their field work and data analysis. Included on the disk are:

- The Imnavait Creek watershed climate database, from Douglas Kane, University of Alaska;
- Climate, plant biomass, soils, nutrient and related data from the Toolik Lake Long-Term Ecological Research Field Station, from John Hobbie, Marine Biological Laboratory at Woods Hole;
- The GIS and permanent plot data for the Toolik Lake area, from Donald Walker, University of Colorado; and
- Active layer temperature, thickness, soil moisture and snow depth data at Barrow, from Frederick Nelson, SUNY-Albany, and Jerry Brown, Arctic Connections, Inc.

Also included are several Alaska subsets of generally available global data:

- Monthly temperature and precipitation for Alaska, from the NOAA/National Climatic Data Center's Global Historical Climatology Network;
- ETOPO5 elevation data for all areas north of 50°N, from the NOAA/National Geophysical Data Center;
- Northwestern Canada soil survey data (Barrow data will follow), from the USDA/Soil Conservation Service in Lincoln, Nebraska;
- Runoff data from several Canadian and Russian rivers in the Arctic drainage, from the Department of Oceanography, University of Washington; and
- Global FAO soil data and the Matthews Vegetation Data Set, from NASA/Goddard Institute of Space Studies.

This disk was sent to each LAII/Flux Study scientist. Each ARCSS investigator was notified of its availability, and several requests have resulted. ARCSS-funded investigators receive the disk at no charge; others are charged to cover the cost of production and distribution of the copies. (This charging policy will be the same for all CD-ROMs funded by ARCSS at NSIDC.)

The next data product scheduled is the OAII/Northeast Water Polynya Project (NEW) CD-ROM. This prototype database will contain access software and the suite of NEW data from the 1993 and 1994 operations at the NEW field site northeast of Greenland, centered at 80.5°N, 14°W. The data will cover meteorology, hydrography, nutrients and phytoplanktons.

In parallel with the NEW CD-ROM development, we are locating and obtaining Arctic subsets of solar radiation data from U.S. and foreign sources. As these data are obtained, they are made available via anonymous ftp. These data will be distributed on CD-ROM, either alone or in comforce for this task is the expressed need for such data, voiced at the February 1992 ARCSS/OAII Interagency Workshop on Surface Energy Budget, Radiation and Clouds over the Arctic Ocean, held in Orlando, Florida, and subsequently by the SHEBA Steering Committee. The Global Energy Balance Archive (GEBA) is available at the Eidgenössische Technische Hochschule in Zurich, but the Arctic solar radiation data in GEBA include only monthly average values. NSIDC is seeking Arctic time series with high temporal resolution to supplement the GEBA data. Any data that are obtained will be made available to GEBA.

## *GISP2 Data: Moving Toward Accessibility*

GISP2 ice core data until now have been managed internally by the GISP2 Science Management Office (SMO) at the University of New Hampshire. NSIDC has held a complete copy of those data since 1993; frequent updates are obtained via ftp. The primary reasons for this arrangement were the instability of the data sets at the early stages of preparation and analysis, and assurance of data quality and compatible formatting for ease of data comparison. Since the SMO intended to develop an on-line server, NSIDC agreed to leave the responsibility for this GISP2 internal access to the SMO until NSIDC could provide a similar on-line server.

Now NSIDC is implementing a server for ARCSS, and discussions with the GISP2 SMO are taking place regarding the transfer of archive and distribution responsibility to NSIDC. Because of the close relationship between NSIDC and the World Data Center A (WDC-A) for Paleoclimatology at the NOAA/National Geophysical Data Center (NGDC), we have developed an ice core data access strategy that minimizes duplicative activities between our two centers. NSIDC holds the official archive of GISP2 data and distributes the GISP2 data via ftp and the World Wide Web. WDC-A for Paleoclimatology archives and distributes non-GISP2 ice core data, as well as analyzed paleoclimatology products using PaleoVue and other software developed by NGDC specifically for the visualization and use of paleoclimate data. Since both centers maintain most of their data on-line or near-line, users are able to obtain needed data from either site easily and quickly. Each site points to the other's holdings on the World Wide Web, facilitating links between these related data resources.

In addition, a GISP2/GRIP (Greenland Icecore Project, the European deep-drilling program) CD-ROM is in development. It will be released to coincide with a *Journal of Geophysical Research* Atmospheres/Oceans joint issue (Fall 1996) dedicated to the Greenland ice coring projects.

## *Integration of PALE Data Management*

In mid-1994 the PALE SMO (Institute of Arctic and Alpine Research, University of Colorado, and College of Forest Resources, University of Washington) added a full-time PALE data manager at Boulder to coordinate the various and widespread PALE data collection and analysis projects. Developing a close working relationship, NSIDC and the PALE SMO are establishing an integrated archive and access plan for the PALE data based on integration of the PALE data into WDC-A for Paleoclimatology's on-line data server at NGDC. The data will be distributed by the WDC-A for Paleoclimatology, and a "deep archive" copy will be maintained by NSIDC as part of the complete ARCSS database. Access strategies are a continuing topic among these three groups, as we meet regularly on both working and planning levels.

## *Long-Term Access to ARCSS Data*

In keeping with NSF data policy, and to ensure that data collected as part of the ARCSS program are cared for on a long-term basis, NSIDC retains a complete copy of each ARCSS data set and data product. Where an existing national data center is identified as an appropriate additional dissemination site for particular types of data (NOAA's National Oceanographic Data Center for hydrographic data and the National Geophysical Data Center for many types of ice core data, for example), those data will be deposited at that national center, with a copy at NSIDC either on a "CD-ROM of record" or on another appropriate archival medium.

NSIDC's coordinating role is to provide a complete catalog of the ARCSS data, with pointers to locations where copies of the data may be obtained for research use. We have begun construction of this catalog, containing brief descriptions of each ARCSS data set and contacts to order the data. It is available on the NSIDC ARCSS World Wide Web site, URL http://nsidc.colorado.edu/ARCSS. The catalog will also be published in hard copy when there are sufficient entries. The primary intent of the catalog is to provide a permanent, published record of the ARCSS program, viewed through its data output. Long-term access to the data, with permanent tagging as part of ARCSS, will be ensured by the complete archive copy at NSIDC; the catalog provides the table of contents.

# Proceedings of the Japan-Russia-United States Study Group on Dumped Nuclear Waste in the Sea of Japan, Sea of Okhotsk, and the North Pacific Ocean

January 12-13, 1995
Biloxi, Mississippi

Edited by Bruce F. Molnia
U.S. Geological Survey

## Proceedings of the Japan-Russia-United States Study Group on Dumped Nuclear Waste in the Sea of Japan, Sea of Okhotsk, and the North Pacific Ocean

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# Background, Framework, Results and Recommendations

## An Overview of the *Japan–Russia–United States Study Group on Dumped Nuclear Waste in the Sea of Japan, the Sea of Okhotsk, and the North Pacific Ocean*

*Janos Radvanyi and L. Brett Brinegar*
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**Project Background**

Although the former Soviet Union had long been suspected of dumping radioactive and other hazardous wastes in surrounding coastal waters, Washington, D.C., and Tokyo did not become aware of the scope of the problem until 1991. Russian environmentalists and nuclear scientists revealed that not only had a number of nuclear accidents gone unreported, but also that toxic and nuclear waste had been discharged into the sea. An estimated 18 nuclear reactors, some still containing fuel, had been dumped at sea—some within the holds of nuclear submarines—and more than 2.5 million curies of radioactive wastes were also discharged into the ocean. These figures, compiled by a committee chaired by Dr. Aleksei V. Yablokov, former environmental advisor to Russian President Boris Yeltsin, now Environmental Advisor to the Russian National Security Council, are double what was previously believed to have been dumped at sea globally during the Cold War.

Since some of this waste was dumped into the Sea of Japan, the Sea of Okhotsk and the North Pacific Ocean, Tokyo called for an immediate halt to all dumping at sea. Russia's Minister for Environmental Protection, Viktor Danilov-Danilyan, promised that the Navy would temporarily stop dumping waste but stressed that lack of proper disposal sites and technologies might force Russia to resume dumping at sea. According to Danilov-Danilyan, funding and technological support—especially Japanese and American—were absolutely crucial to the appropriate disposal of Russian radioactive and toxic waste. In subsequent Russo–Japanese meetings, the 1994 Clinton–Yeltsin summit, and Gore–Chernomyrdin discussions, Russian representatives repetitively cited lack of adequate waste storage facilities, funding and technology as stumbling blocks to solving the waste disposal disaster.

As a result the U.S. and Japanese governments are currently engaged in a joint effort to alleviate the dumping problem, as outlined in the Common Agenda for Cooperation in Global Perspective—an agreement reached at the Clinton–Hosokowa summit last year.

In order to better understand this nuclear waste disposal conflict, and to find innovative methods for alleviating the situation, the Center for International Security and Strategic Studies (CISS) at Mississippi State University, in conjunction with the United States Geological Survey (USGS) of the Department of Interior (representing the Interagency Arctic Research Policy Committee), and the Center of United States–Japan Studies and Cooperation (CUSJSC) at Vanderbilt University, formed the Japan–Russia–United States Study Group on Dumped Nuclear Waste in the Sea of Japan, the Sea of Okhotsk, and the North Pacific Ocean.

The Study Group's purpose was to provide a neutral forum in which participants could freely exchange views and open new channels of communication. The results of this forum are presented here as the following proceedings.

The Study Group's focus was two-fold:

- The collection and compilation of data, as well as evaluation of the present conditions of existing dumping sites in the Sea of Japan, the Sea of Okhotsk and the North Pacific Ocean; and
- The discussion and identification of alternative disposal methods for radioactive wastes agreeable to all parties.

The areas of risk assessment, data collection, site analysis, public health and disposal alternatives were also thoroughly explored by panelists in a round-table format—a proven strategy that provided spirited discussions and frank exchange of viewpoints and ideas.

Obviously, trilateral cooperation was necessary to develop a satisfactory program for dealing with this waste disposal problem. Waste discharged into the seas that lie between Russia and Japan may be swept toward Alaska by ocean transport and ice. Scientists are currently concerned about the possibility that radionuclides may be transported through air masses. The dumped nuclear waste in the Sea of Japan, the Sea of Okhotsk and the North Pacific Ocean may affect the public health and safety of Japan, Russia and the United States.

Therefore, our purpose in establishing this study group was dual in nature:

- To promote the open discussion and information exchange necessary to understand the risks and scope of their critically important issue; and
- To synthesize all aspects of the dumping question within the framework of the Common Agenda for Cooperation in Global Perspective, the Gore–Chernomyrdin Committee's activities, and bilateral Russo–Japanese cooperation.

**Framework**

The three sponsoring institutions' respective representatives, Dr. Janos Radvanyi (CISS) and Dr. James Auer (CUSJSC), as well as Chief of International Environmental Studies Dr. Bruce Molnia (USGS), established a Preparatory Committee in order to finalize workshop details such as a workshop agenda and a list of participants. This committee first focused on evaluating the present condition of dump sites and identifying any significant environmental damage or risks, carefully considering necessary information in order to conduct a successful workshop.

On January 12 and 13, 1995, the workshop, *The Japan–Russia–United States Study Group on Dumped Nuclear Waste in the Sea of Japan, the Sea of Okhotsk, and the North Pacific Ocean,* was held at Biloxi, on the Mississippi Gulf Coast. This ground-breaking meeting created a foundation for a highly productive Japan–Russia–United States dialogue, which in turn established a basis for cooperation among these three nations in order to develop a satisfactory program for dealing with nuclear waste disposal problems. This foundation allowed representatives of these three nations, along with a Korean observer, to come together in an area where they shared one common concern—nuclear waste disposal. Clearly the assembled representatives provided a striking reminder that the Cold War is indeed behind us. This type of intellectual exchange, interaction and information sharing would have been difficult two years ago, unthinkable five years ago.

This project was the first academically organized meeting in the United States to successfully promote trilateral Japanese–Russian–United States exchange at the private sector, scientific and governmental levels on this issue. Furthermore the workshop marked the first time that delegates from the Russian Navy and the Russian Foreign Ministry attended a university-sponsored meeting, revealing important new data on the dumping issue. By all accounts, the interaction of our workshop participants was not only vital in providing a firm grasp of empirical reality, but also served as a necessary confidence-building step on the road to more concrete cooperation.

The two-day workshop utilized a round-table format that provided lively discussion and interaction among participants and ensured frank exchange of diverse viewpoints and ideas. Morning and afternoon session were held each day. These sessions promoted intellectual exchange on the dumping issue in the areas of:

- Physical setting, extent of nuclear contamination, and the results of recent surveys of some of the dump sites;
- International cooperation; and
- Sharing of technical information.

The preparatory committee was successful in building U.S. Congressional participation and support with the help of Congressman Kurt Weldon of Pennsylvania and Senator Frank Murkowski of Alaska. In addition, many participants were pleased by the apparent willingness of the Russian Navy representatives to disclose new information and discuss the situation with Japanese and U.S. participants.

Workshop participants were briefed on potential financial support from international institutions for preventing nuclear waste dumping. This concept was explained in a paper by Mr. Koji Yamazaki, Deputy Chairman of the Board of Counselors, the Japan Research Institute, Limited. During the closing session of the workshop, panelists commented on the overall positive information exchange that had taken place; however, all participants stressed the need for future meetings in order to promote long-term efforts to confront this serious issue of global concern.

**Results**

This workshop produced unique discussion among participants drawn from academia, business, environmental organizations and government. Yet it became clear that more information is needed for officials and private citizens of Japan and the United States, along with Russia and Korea, to deal with disposal of nuclear waste and to be in a position for assessing the level of environmental risk. According to data compiled at this workshop, spent nuclear fuel seems to be a growing problem both on land and at sea.

Workshop presentations indicated that little is known about the status of the dumped nuclear fuel in the three seas. However, no immediate risks had been identified. Another more potentially dangerous situation came to light. Russia is currently holding twenty years' worth of spent nuclear fuel waiting for proper disposal—a situation worsened by the collapse of the Russian defense industry. Without serious negotiations and exchange of information between the four nations, a potential danger still exists that Russia could dump more spent nuclear fuel and waste at sea.

In order to successfully process and fully understand the impact of this new information, gather further information and actively continue the confidence-building and intellectual exchange established at this workshop, it is critical that this multinational project continue on a long-term basis.

**Recommendations**

During the closing session, workshop participants requested that the preparatory committee compile a list of recommendations based upon suggestions offered by participants throughout the course of the workshop. Consequently the preparatory committee recommends that a Multi-National Study Group be formed, consisting of representative from Japan, the United States, Korea and Russia. This Study Group would hold a series of three workshops in order to:

- Attempt to obtain further information concerning dump sites in all three seas, gather information on short-term and long-term environmental consequences, and perform contamination risk assessments concerning local populations, marine ecosystems and the overall global environment;
- Suggest ways and means for policymakers to assist in alleviating Russia's current spent nuclear fuel storage crisis;
- Discuss the possibility of forming an expert group to visit Russian Pacific Fleet waste-storage facilities in Vladivostok, as well as U.S. facilities at Hanford, and similar storage sites in Japan;
- Facilitate quadrilateral (U.S., Japan, Russia, Korea) technology and information sharing in order to alleviate the nuclear waste problem;

- Investigate potential financial support for preventing marine nuclear waste dumping, including the remediation of retired Russian nuclear submarines and other hazardous materials by inviting international financial institutions such as the International Monetary Fund, the Japan Overseas Economic Cooperation Fund, the Asian Development Fund, and the United States Export–Import Bank to these workshops;
- Concentrate on quadrilateral private-sector cost-and-time-effective plans for obtaining rapid and effective results in dealing with stabilization of threats at sea and on land in the Pacific area;
- Incorporate the experience and collaboration of Global Legislatures for a Balanced Environment (GLOBE), an international parliamentary environmental organization, consisting of member of United States Congress, the Japanese Diet, the Korean Parliament, the Russian Duma, and other legislative bodies in order to develop ties not only with our multinational Study Group, but also to develop close bonds and trusting relationships with members of these respective parliaments and the scientific community of all four nations;
- Improve understanding in the area of integration of existing knowledge concerning the dumping of radioactive wastes at sea in order to improve public awareness of this issue, as well as provide new data to interested scientists, corporations, government officials and organizations, NGOs and other environmentally oriented groups;
- Distribute summarized findings and reports to the public at large, as well as members of the scientific community, NGOs, government officials, and private sector representatives; and
- Create a quadrilateral database on environmental contamination and radioactive waste, possibly along the lines of the Arctic Data Directory developed by U.S.–Russian–Norwegian cooperative efforts. This will allow information gathered from Japan, the United States, Russia and Korea to reach researchers, scientists, policymakers and environmental groups via the Internet and Bitnet, as well as hard-copy distribution to libraries in all four nations.

# Welcoming Remarks

*Billy C. Ward*
Vice-President for Institutional Advancement
Mississippi State University, Mississippi State, Mississippi

Good morning. My name is Billy Ward and I am Vice President for Advancement at Mississippi State University. It's a pleasure for me to welcome you on behalf of Mississippi State University to this *Japan–United States–Russia Study Group on Dumped Nuclear Waste in the Sea of Japan, the Sea of Okhotsk, and the North Pacific Ocean.*

In developing this unique workshop, Mississippi State University's Center for International Security and Strategic Studies joined forces with Vanderbilt University's Center for United States–Japan Studies and Cooperation and the United States Geological Survey of the United States Department of the Interior. I, along with the workshop's preparatory committee, Dr. Janos Radvanyi, Dr. James Auer and Dr. Bruce Molnia, hope that this study group will provide a neutral forum in which all of you gathered here today can freely exchange views and open new channels of communication. This study group will study the obviously serious problem of nuclear waste disposal practices. The current state of the disposal situation is especially critical now in light of two recent earthquakes which shook the floor of the Sea of Japan.

We are especially honored to have with us Mr. Naotoshi Sugiuchi, Deputy General for Arms Control and Scientific Affairs of Japan; Dr. Michail Kokeev of the Ministry of Foreign Affairs; Mr. William Nitze, Assistant Administrator for International Activities of the United States Environmental Protection Agency and U.S. Representative Curt Weldon from Pennsylvania. The preparatory committee has assembled a truly impressive team of scientists, government officials and private sector representatives for this workshop and we are pleased to have all of you in attendance.

Before I relinquish the floor, I would like to give you an idea of what to expect in the next two days. Today's session will open with a briefing on the purpose of the workshop, an overview of cooperative efforts for building a tripartite international working group and open dialogue scheduled to be conducted by Bruce Molnia followed by presentations on management of data and descriptive physical oceanography on the Sea of Japan, the Sea of Okhotsk and the North Pacific Ocean. These presentations will be followed by others on the potential impact of radioactive waste and nuclear contamination on the ecosystem.

In the afternoon, presentations by representatives of Japan, Russia and the United States will deal with current information and studies of the extent of contamination of existing ecosystems including sampling, condition of containment vessels and mapping of dump sites. The day will end with a discussion of experience in dealing with radioactive contamination in the Arctic and potential application of such methods to the Pacific region.

Friday's presentations and discussions will focus on alternatives to the disposal of radioactive waste at sea, possible remediation methods, special models to assess the potential impact of the disposal activity and experiences in radioactive waste disposal as potential models for multilateral cooperation. This round of meetings will begin with short presentations on current experiences in waste disposal by Japanese, Russian and United States participants. Presentations will follow on development of multilateral programs to gather data on the sites and discuss appropriate remediation methods. Multilateral cooperation on the overall problem will be discussed in detail. The purpose of these discussions is to lay a sound foundation for trilateral cooperation which will develop a satisfactory program for dealing with this waste disposal problem.

We at Mississippi State University sincerely hope that this workshop will be the first of several which will promote an ongoing effective relationship between the United States, Japan and Russia concerning the problem of nuclear waste disposal in the Far East. Thank you.

# Welcoming Remarks
## A Videotaped Greeting

*Senator Frank Murkowski (R-AK)*
United States Senate
Washington, D.C.

Good morning. I'm Senator Frank Murkowski of Alaska. I regret that I cannot join you in Biloxi today, but with the start of a new Congress, indeed a new era in American politics, I was not able to personally join you in your very important work. Nevertheless, I did want to offer my welcome and encouragement that you will be able to assess the potential impacts of radioactive waste in the Sea of Japan, the Sea of Okhotsk and the North Pacific Ocean. I also wanted to extend a special welcome to the Honorable Naotoshi Sugiuchi of the Japanese Ministry of Foreign Affairs and Minister Danilov-Danilyan of the Russian Ministry of the Environment Protection and Natural Resources.

I am pleased that you could join this conference and I want to thank you for all the past and present efforts to help us understand and evaluate the problem of ocean-dumped nuclear waste. In looking over your agenda, I noticed the participation of a number of U.S. officials and experts that my staff and I have closely consulted since we first became aware of the problem. I know that there are now new names and I am encouraged by that extended participation. I am also encouraged by the fact that your conference will take positive steps towards the survey of some potential solutions. If it is determined that the remediation or removal of the waste is needed, this is not solely a Russian problem, or for that matter an Alaskan problem, or a Japanese problem. This is a problem that is best addressed to an application of our combined resources and talents.

We owe a debt of gratitude to the Center for International Security and Strategic Studies at Mississippi State University, the Center for United States–Japan Studies and Cooperation, the U.S. Geological Survey, and the Japan–United States Friendship Commission and most of all, to all of you for your talent and dedication. I will look forward to reviewing the proceedings of your meeting and I wish a good day and one last thought. I do hope that the recommendations that are made will come out of sound science and not emotion, which is often the case with recommendations that come out of Washington, D.C. Good day.

# Welcoming Remarks

*Congressman Curt Weldon (R-PA)*
United States House of Representatives
Washington, D.C.

Good morning. Let me begin by thanking the Center for International Security and Strategic Studies at Mississippi State University and specifically Drs. Radvanyi, Molnia and Auer for their leadership in putting this forum, this process, together. Let me begin by welcoming all of our foreign visitors to the U.S., at a time when we are going through a transition in our federal government. Let me warn our foreign visitors as they walk through the streets of Biloxi, and perhaps visit the restaurants and perhaps even the casinos, to not misinterpret the smiles on the faces of the people. It is not because of the weather and it's not because I'm here, it's because they know that our Congress is out of session and as long as our Congress is not in session, they know that we are not trying to find new ways of solving problems that don't exist. I also want to bring you greetings from our new Speaker of the House, Newt Gingrich. I briefed Newt on my visit to this forum before I left and asked him for some words of advice to give to our foreign friends. He told me that he is very supportive of this process and has offered to be our new leader. But he told me to relate to our visitors from Japan and Russia, as I understand we have visitors from Korea and perhaps Norway, that if your spouses are with you please do not let them talk to Connie Chung and especially if they do to make sure you are controlling what it is they say.

There is much change happening in Washington right now. We are reviewing entirely the process of governing at the federal level. There are some things that have not changed. I can say on behalf of my Republican colleagues and my Democratic friends and colleagues, we are committed to work in a bilateral, trilateral process on the issue of dumped nuclear waste and how we can work together. I will elaborate later on some of the things that we are doing, but I would say to you that we see this opportunity far beyond dealing with a problem of nuclear waste. We see this process as an opportunity to develop trust and cooperation between the members of our legislative bodies. My own personal interest stems from my involvement as the Vice-Chairman of the Oceanography Committee in the last Congress, and in the new Congress as the Chairman of the Research and Development Committee for our National Defense. And that committee, by the way, has jurisdiction over 37 billion dollars each year for research to support our military. My interest also in being here relates to my involvement as a member of the Science and Technology Committee, where we work with our civilian scientists and leading researchers on problems of mutual concern to everyone on the planet. We need to develop not just the ties with our scientific community and our academic community, but we need to develop close bonds and trusting friendships and relationships with the members of our respective parliaments.

To that end, many of you probably know that I am very active in an organization known as GLOBE (Global Legislators for a Balanced Environment). Initiated by the late Senator John Hines from my state of Pennsylvania less than a decade ago, this organization has memberships from the parliaments of the European community, Russia, Japan and the U.S. The International Chairman of GLOBE is Tom Spencer from the European Parliament. Nikolia Voranzo chairs GLOBE of Russia, Carlos Pimento chairs GLOBE European Community, and Akiko Dimoto chairs GLOBE Japan. In the U.S., Senator Kerry chairs GLOBE U.S.A. We meet at least twice a year and focus on common concerns that we have as legislators in the environmental area. Obviously, one of our top priorities is the topic that you will be discussing today. At lunch today, I will relate how our GLOBE network assisted us in this country in dealing with the issue from the U.S. perspective. But I will say to you that we are all extremely excited, in each of our countries involved with GLOBE, in looking for new areas to cooperate and share technology as well as break down some of the old barriers and to build trust and friendship so that we can work together on some of the more difficult problems where perhaps we are not so much in agreement.

So the thrust of this forum, in my mind and the minds of many of my colleagues in the U.S. Congress, is not just this issue but the foundation that you are laying and have been laying to allow us to come together in an area where we share one concern where we have the technology, where we have the resources, and all we need is cooperation. Because what has happened up until now, in terms of nuclear waste and the success that we have had to date which will be documented in a few days, I think can provide for us a model that can be used to deal with any environmental problem that could affect the GLOBE. And beyond that, any problem that affects the people of our various countries. So, I am very happy to be here. I look forward to working with each of you and I bring you greetings from our Congress and our leadership, and I know that our administration in Washington and in the White House shares our concern for mutual cooperation, trust and building long-term, stable relationships where we can come together in forums such as this and find ways to solve problems that in the past have seemed insurmountable.

## Welcoming Remarks

*Michail E. Kokeev*
Directorate of International Scientific and Technical Cooperation
Ministry of Foreign Affairs
Moscow, Russian Federation

Thank you very much for the possibility to address this very important forum. We are very grateful to everybody here who promoted this great event. We are grateful to the Center for International Security and Strategic Studies at Mississippi State University, the United States Geological Survey of the Department of Interior, and the Center for United States Defense Studies and Cooperation of Vanderbilt University. We are glad to say and to see that real trilateral cooperation is underway, resolving this very, very important problem.

Three years ago, this problem did exist, but nobody took note of it. The only exception was the London Convention effort to regulate the issue. The situation has been changed dramatically. I would say that the main change is that this problem is now at the center of our national efforts, which is an extremely difficult task in Russia, I should admit. To keep the environment problem so visible requires additional efforts. Although the problem of radioactive safety is the number one problem in our environmental policy, it's also very difficult to keep it on the agenda, because the priorities are being changed.

Mr. Danilov-Danilyan, who was not able to come here, asked me to tell all of you that he is not here because of emergencies in his work. He used the word "emergencies," because it's more understandable than "occupational circumstances."

He was going to say that Russia is open to bilateral, trilateral and multilateral cooperation in resolving these very, very important issues. He told me also that honorable Curt Weldon will understand him very much, because he, Mr. Danilov-Danilyan, is not only a Minister, but he is a Congressman at the same time. He was sure that you will understand him very well. And he wished to be here to change the view that ministers aren't also people.

It has been said here that we probably should look for alternatives to dumping. I am sure that there is an alternative to dumping. That we should stop it, step by step, forever, for our future generations! I'm going to dwell on it a little bit later. But I would like to tell you, and this is a good sign, that in our Ministry of Foreign Affairs we are going to have the organizational division, like the division in Japanese Ministry of Foreign Affairs, combining disarmament and environmental efforts. The problem of how not to dump will be the focus of the activities of this new unit of the Ministry.

I am glad to be here for one additional reason, when we began this bilateral efforts with my very good friend Mr. Amano of Japan, to arrange a bilateral ending of dumping in Japanese seas, it was extremely difficult. And we were trying at that time to tell our American friends that it's your priority also, it also includes the northern part of the North Pacific Ocean. It would be extremely useful to cooperate. I am not going to use any tough words, but it was anyway. And I am glad that this widening trilateral, or even more four-, five-lateral, cooperation is underway now and with the active participation of the United States. It's crucial from every point of view, from political, from economic, and from a practical point of view, as well.

It was said also here that the extension of our cooperation will depend on our national efforts. I would like to inform you that after the single dumping on October 23, 1993, in the Sea of Japan, we have had no dumping at all, even though we didn't agree to the new provisions of the London Convention. But in practice we do obey the ban for disposal of liquid nuclear waste. And I think that anyone who knows the present Russian circumstances will estimate this decision highly.

Even more, we now have a program dealing with the liquid nuclear waste issue, with a budget of 45 billion rubles. It is not properly financed as yet, because of our financial turmoil, but five billion of the sum went directly to the Far Eastern region to settle the problem there. And one of the results that I can report about here is the reduction of liquid nuclear waste on board of our ships and the presence of two tankers in the Far Eastern region of the country. And the encouraging fact that our government is dealing now very actively with two crucial issues. They are:

- The treatment of radioactive wastes in Russia, and they are very determined not to allow anything in that field; and
- They are dealing with nuclear power reduction in the Russian Federation.

Here the situation is mixed because some people are going to allow everything, and some people are not going to allow anything. So we shall see the results, but the whole issue is in the front of efforts and on the minds of our parliament.

So I am grateful to be here with you. Many of you I know from our previous work. I wish to everybody here, and to myself naturally also, to combine our efforts as much as possible, because in that case we shall see the results. We ourselves, not only as the UN charter says "the forthcoming generations." Thank you.

# Welcoming Remarks

*Natoshi Sugiuchi*
Deputy Director General for Arms Control and Scientific Affairs
Ministry of Foreign Affairs, Tokyo

Ladies and gentlemen, I offer this short speech, a very short speech, as a token of my deep gratitude to all participants of the meeting. I want to share with you some of the thoughts that came to my mind in connection with the theme of the workshop, *Japan–Russia–U.S. Study Group on Dumped Nuclear Waste in the Sea of Japan, the Sea of Okhotsk, and the North Pacific Ocean.*

First, about the sea, Japan is a country made only of islands. It is surrounded by seas in all directions. From the earliest time the life of Japanese people has been closely connected with the sea. The sea gives food, the essential of life. The sea is the beauty and greatness of nature, so we used to say "Japan was the nation of the sea." The Japanese were the people of the seas. They loved the seas and lived with the seas. I hope our children, grandchildren and generations to come will continue to be allowed to appreciate the beauty, greatness and benefits of the seas.

Secondly, about the seas again, but from a different angle. Japan is a country of islands and is surrounded by the sea. It is cut off by the sea from the outside world. So for the Japanese people, foreign countries and the international community means "overseas." The seas isolate Japan and its people but at the same time connect them with overseas countries and international society. The sea is the road leading into the international community. Therefore, the sea means overcoming isolation for the Japanese people. That is a key to international cooperation. In the spirit of our Constitution, international cooperation is the guiding principle with which the Japanese people would seek peace and prosperity. The seas provide important resources and main traffic roads to other countries and regions, not only for Japan but also for other countries as well. The high seas are a common property of mankind. As such, every country must take a responsible attitude so as not to spoil this wealth.

Thirdly, about the composition of the interested parties of this study group, Japan, Russia and the United States are immediate neighbor countries across the sea, across the ocean. So it was natural that in the middle of the nineteenth century, the United States and Russia came to Japan and knocked on the door. This was at a time when Japan was still under seclusion, with a shut-the-door policy to the outside world. The United States and Russia succeeded, and we opened the door to the United States, first, and then Russia, second.

During the Cold War period, cooperation of the three countries was unthinkable. The end of east–west conflict brought about a totally new international context. The dialog among the three parties, like the one now taking place during this workshop, is surely new. But it is an encouraging attempt that may open up a new dimension to future cooperation.

Fourth and lastly, about the broad participation in this workshop from different sectors, academic, official and private. Maybe not in as dramatic a way as in Russia and other countries, but Japanese society is also undertaking a big change. Our new political situation, new since last year, is well known. With enforcement of a new election law, it may change further. The economic and social situations are changing similarly. Under such circumstances, deregulation and unrestricted reform are on the agenda. In connection with our efforts for deregulation and unrestricted reform, strong criticism of the bureaucrats is now getting voiced.

In the past, Japanese bureaucrats were said to have contributed to modernization of the society, of the country and to the stability of the policies. They are now attacked as being arrogant and are playing a negative role in their opposition to deregulation and unrestricted reform that is said to be essential to further change and further internationalization. Whether Japanese bureaucrats can manage to change themselves or not may be instrumental to further changes of our society. And if arrogance is really the core of the problem, the key to that, in my view, is how flexible and receptive we bureaucrats can become in thinking. Intensified dialog with people belonging to other sectors, that is, political people, journalists, academicians, businessmen, etc., will surely accelerate such a process.

All these personal considerations that I have presented convince me of the value and usefulness of this workshop. Therefore, I want to thank the organizers once again and thank each one of you participating in this workshop for having given me a very good, useful opportunity.

I thank you very much for your kind attention.

# Welcoming Remarks

*William Nitze*
Assistant Administrator
U.S. Environmental Protection Agency, Washington, D.C.

This is a very, very important activity from the standpoint of the EPA and the U.S. government as a whole. Before giving you just a little bit of background as to exactly why it is such an important activity, I want to first thank all of the sponsors of this conference and the preparatory committee, particularly Mississippi State University and particularly Dr. Janos Radvanyi. This has been a tremendous effort of entrepreneurial skill in putting together a multilateral workshop, and all of the sponsors are to be congratulated at continuing this very important process.

Now, just a few words on why this particular issue of low-level liquid radioactive waste disposal in the Arctic Ocean and the Northern Seas is of such importance to EPA. EPA, aside from its overall regulatory responsibilities within the United States, including Alaska, which regulatory responsibilities do include, in various aspects, low-level radioactive materials, has a key role in the Gore–Chernomyrdin process with Russia. We chair the environment committee under the Gore–Chernomyrdin Commission with Minister Danilov. This particular issue has been given very high priority, not only within the environment committee but by the commission as a whole. It has received considerable attention from both the Vice President and Prime Minister Chernomyrdin and is the subject of a statement by Presidents Clinton and Yeltsin, who referred to the Murmansk activity as a very important cooperative activity between Russia and the United States.

It is also a very important issue in the context of our dialogue with Japan. When I was in Tokyo with EPA Administrator Browner in November 1994, we spoke with Minister Miashta about this problem and about our cooperation in addressing it, not only in a Murmansk context, of course, but also in a context of the North Pacific. It is an important item in our common agenda with Japan, which is on the U.S. side being coordinated by Undersecretary of State Tim Worth. We work very closely with his office. It is also a very important item in our relations on environmental issues with other Arctic states, particularly Norway, Canada, other Scandinavian countries, the United Kingdom and others. In a policy sense, it is extremely important because this issue is the tip of the iceberg of a broader set of contamination issues involving the Arctic. It was in recognition of that broader set of issues that we have entered into a separate bilateral agreement with Russia on Arctic contamination which goes well beyond the subject of this workshop. If we can succeed here, we will have laid the foundation for that broader cooperation.

Now let me turn to this morning's session. We should all note that the session is a striking reminder that the Cold War is indeed behind us. We have here in this room representatives of the scientific and defense communities of our three countries who will seek to provide a factual and analytic foundation for future policy making. This kind of factual exploration will of necessity involve the discussion and disclosure of facts which would have been unthinkable to discuss and disclose in a Cold War context. And, indeed, it is really quite wonderful that we have moved so far in so few years in terms of real trust and collaboration.

Now a very important goal of this morning's discussion is to bridge the gap between highly technical discussions and sensible policy making at the national and binational and trinational and multilateral levels. This is a very, very important gap for us to address. I, as someone who does not have a technical background, have tried to read about these issues. Like so many other American officials, I'm trained as a lawyer, which at time has its disadvantages. It is very important to me to learn from this workshop and other similar activities the technical bases for addressing various policy options.

# Statement of Workshop Purpose

*Bruce F. Molnia*
Office of the Chief Geologist
U.S. Geological Survey, Reston, Virginia

Nineteen months ago this week, we had just completed the Anchorage Workshop on Arctic Contamination, a workshop attended by many of you in this room. That 1993 International Workshop, coordinated by the U.S. Geological Survey and involving representatives from a number of other federal agencies, was instrumental in providing U.S. government decision-makers with the first credible information about the extent of radioactive waste and other contaminants disposed of in the Arctic and about potential environmental consequences and risks to human health.

Today's workshop is designed to follow on the success of that first contamination workshop and expand the geographic area of concern to include the Sea of Japan, the Sea of Okhotsk and the North Pacific Ocean. It is very gratifying to see the continuing, friendly, cooperative involvement of U.S. and Russian scientists in this critical international environmental issue. It is also very gratifying to have distinguished representatives from the Japaneses government and private sector involved.

The 1993 Arctic Workshop was instrumental in opening avenues of communication, information exchange and cooperation involving Russian scientists and government officials on the one hand, with their counterparts in the United States. During the year-and-one-half following the first workshop, international cooperation has resulted in many visits to the Arctic disposal sites and a much better understanding about the types of radioactive waste that has been disposed of, and the location of the disposal sites. Preliminary results from the analysis of these data suggest that while no immediate environmental risk has been identified, additional monitoring and investigations are needed to assess future consequences. We would very much like to make the same statements for the Sea of Japan, the Sea of Okhotsk and the North Pacific Ocean. Today's Study Group is a very important first step in reaching this level of information for these three regions.

Our efforts here build on the trust and cooperation that resulted from the first workshop. As you can see, not only do we have continued U.S. and Russian cooperation, we now have expanded our group of principal participants to include representatives from Japan. Not only do we have governmental participation, but we now also have academia and industry taking a lead role in these proceedings.

We have come a long way in both cooperation and scientific understanding since the March 1993 release of the Yablokov White Paper describing the disposal of radioactive waste at sea. Today's meeting may well be the catalyst necessary to complete our understanding of the marine waste disposal problem for the area of the Russian Far East.

I hope that this workshop will continue, multilaterally, the remarkable bilateral interaction that resulted from the Workshop on Arctic Contamination. As this Study Group in Biloxi represents the first of three planned meetings, I hope to have the opportunity to welcome you to the next meeting and to regale you with the successes of the next two days. I urge you to keep up the international cooperation and the sharing of ideas and information.

Although the Sea of Japan, the Sea of Okhotsk and the North Pacific Ocean are thousands of miles distant from Biloxi, we are all part of the same global environment.

## Management of Data

*Douglas Posson*
U.S. Geological Survey, Denver, Colorado

At the 1993 Workshop on Arctic Contamination, held in Anchorage, data management was one of the last topics discussed, and that effort led to what I am going to speak about today.

I work with what is known as the Arctic Data Directory (ADD), and this is my topic today. The ADD is intended to be the source for who has what data in the Arctic. Now I understand that our topic at this conference, at this study group, is not specifically the Arctic alone. It is in the North Pacific and the adjoining seas as well, but I think that you will see that the approach taken with the Arctic Data Directory might fit very closely with needs that will develop from this workshop. The ADD is multinational. It started in 1987, with an effort in the United States. After the conference in Anchorage, the Nordic countries began to participate with a comparable directory of Arctic data for the Nordic areas and portions of northwestern Russia. This year, 1995, the Russians, through the Ministry of Environment Protection and Natural Resources, are proposing to establish a data directory node in Moscow. Next year, the Canadians are considering establishing a fourth node in Canada to cover Canadian Arctic activities.

The ADD includes information about data from many disciplines. Initially most of the data were from the earth sciences, atmospheric sciences and oceanography. More recently we have branched off into human health issues. The node in Norway, which is operated by the United Nations Environmental Program, Global Resources Information Data Base (UNEP GRID) in Arendal, is especially focused on contamination data that is associated with the Arctic Monitoring and Assessment Program (AMAP).

I would like to mention how the ADD is distributed. We have nodes in Anchorage, Alaska, and Arendal, Norway, right now. We will have a node in Moscow later this year. We use the Internet to link these nodes to each other and to make all of the information accessible as if it is in one place. A scientist or a researcher can get on the network and make an inquiry using software tools that we have developed and it accesses the different databases as if they were in one place. The advantage, we feel, in having these national nodes, or these regional nodes, is that there are people at each of these locations who are very interested in what is going on in those locations and those areas. We don't have one group in one place trying to do all things for all people. We have small groups in different places who have a special concern about the activities and the environment of their area. In addition, using the Internet, we have links to other data directories and programs, such as the IGBP (International Geosphere Biosphere Program) and Global Change programs elsewhere.

The approximate coverage of the nodes is not to be taken literally or precisely, but the basic idea is that each node will focus on Arctic data, environmental data, from their areas of interest. There are overlaps. For example, the node in Arendal, Norway, for Nordic areas in northwestern Russia, obviously overlaps with some of the proposed coverage for the Russian node in Moscow. The reason is that the node in Arendal is operational right now, and there is vital interest in a bilateral agreement between Norway and Russia, in accumulating information about data for that portion of Russia as well. It is not intended that information will be duplicated at each location, but rather that each location have data about areas of their own interest.

At the Arctic Contamination Workshop, we developed an action plan consisting of three steps. The first step was to identify data that now exist. We have been working on that. This is the purpose of the International Arctic Data Directory. There are really few sources of information that exist about Arctic contamination. Second was to identify priority data needs. Because money is scarce, we decided to focus on data rescue; looking at data sets that were thought to be important but that might be at risk of being lost for various reasons, either because of retirements, because of deaths, because of changing programs. But the important thing was to take some first steps to rescue data. The third, which seems maybe obvious but also invisible, was to build quality data set descriptions. It was clear from our experience with the early days of the Arctic Data Directory that if the data directory is to be used, is to be relied upon by people around the world, then the contents of it must be reliable, must be correct.

So I propose, now, at the start of this conference, that we consider certain recommendations at the end of this conference. First, I would recommend that this group might choose to adopt the Arctic Data Directory as the mechanism to share information quickly. It already exists. It takes several years to get an effort like the ADD off the ground, and ADD exists in a manner that can be used directly by the folks in this room. The Arctic Data Directory, of course, is primarily Arctic in its orientation. This work group has other interests as well, including the North Pacific and the adjoining seas. I think this is not necessarily a problem because what we are talking about is environmental data in the higher latitudes.

Second, I think that it is important this year that we move quickly to be certain to establish the Russian node. This has been discussed as a result of the workshop in Anchorage, and we are ready to begin. The first step to do this would be to have a workshop in Russia, perhaps in Moscow or St. Petersburg, and to invite those people and those organizations within Russia who have the environmental data of interest to participate. Then we need to populate that node with information about those data. This works. The United Nations Environment Program has expressed interest in helping to support this endeavor as well.

Thirdly, consider establishing a Japanese node with the purpose of joining forces with the other portions of the ADD. This would give a national focus within the country of Japan for data and information on these environmental issues. Such an organization would have a certain appeal in the sense of circumpolar Arctic data activities. With the Internet it would be possible, of course, to link all of the nodes, as we do right now, and to establish tools using international standards that we already use to facilitate access to the information that resides in these different locations. As I mentioned, next year the Canadians are considering a consolidation of several different data directories that they now maintain into a single activity that will be compatible with the Arctic Data Directory. I should note that the Nordic node of the data directory is especially focused on geographic information systems (GIS) data, on pictorial data if you will, of the spatial coverage of the Nordic areas. So, in addition to having a directory that identifies who has what data, they also accumulate large quantities of environmental data and manage those data in their facility in Arendal, Norway. That is one possibility.

With this proposal, I think, this is what you might expect. We would have an immediate improvement of knowledge on who has what by taking advantage of the fact that ADD already exists. We will have a jump start on the process of sharing information about nuclear contamination. Secondly, it is clear that the ADD is an example of sharing among the international community, of being open, or more open, with information about the data that we have. The Internet is now heavily used for such activities. The research community is routinely using the Internet to access a large variety and large quantities of data and information about the environment. We can expect that by adopting the recommendation similar to what I suggested, that we will have this increased sharing among the international community. And finally, it is something that can happen quickly.

It is possible for data management to get tangible results, very quickly, within months, not years. That is not a very time consuming thing in the grand scheme of endeavors, to gather information about who has what data. These things already exist. The data already exist. It is a matter of describing who has what in a manner that is consistent so that people can believe what they are reading.

So, that is my message, which is that we have an important data management activity that has been going on now for a few years. It has become international in scope. It seems to work. People like to use it, and we have standards and processes in place to help with the sharing of information about who has what data in the Arctic. I would encourage the group to consider these recommendations.

# Descriptive Physical Oceanography of the North Pacific, Sea of Japan (East Sea) and Sea of Okhotsk

*Janice D. Boyd*
Naval Research Laboratory
Stennis Space Center, Mississippi

The region of interest for this Study Group and the known radioactive waste disposal areas are shown in Figure 1. Known waste sites occur in the Sea of Japan (also known as the East Sea), the Sea of Okhotsk and the North Pacific off the Kamchatka Peninsula. Other sites may be located later as additional information on the radioactive waste disposal problem becomes known.

Important oceanographic considerations in this region as applied to the problems of nuclear waste disposal and disposed nuclear waste remediation include:

- Bathymetry, or water depth;
- Sea bottom composition;
- Currents;
- Fronts;
- Wave fields; and
- Ice cover

as well as biological and biochemical factors whose complex impacts can only be generally mentioned here.

The first consideration, water depth, is of particular importance if bottom-resting wastes are to be inspected or if remediation efforts such as recovery or enclosure are to be undertaken. Present engineering capabilities for inspection and handling extend to depths of up to 3 km (A. Watt, SubSea International, personal communication, 1995), but such activities are much cheaper and easier in shallower water. Shallow disposal locations may present certain negative complications, however. Shallow water provides less local dilution capability in the case of liquid wastes or leaking bottom-resting wastes, and storm waves may penetrate deep enough to dislodge or damage bottom-resting wastes in very shallow regions. Water depth also influences the local biota. Deep open ocean areas typically are relatively sparsely populated by living organisms, both in the water column and on the bottom, while shallow nearshore regions are usually much more productive and often are heavily fished or otherwise exploited by people, opening up the possibility of contamination of human food sources.

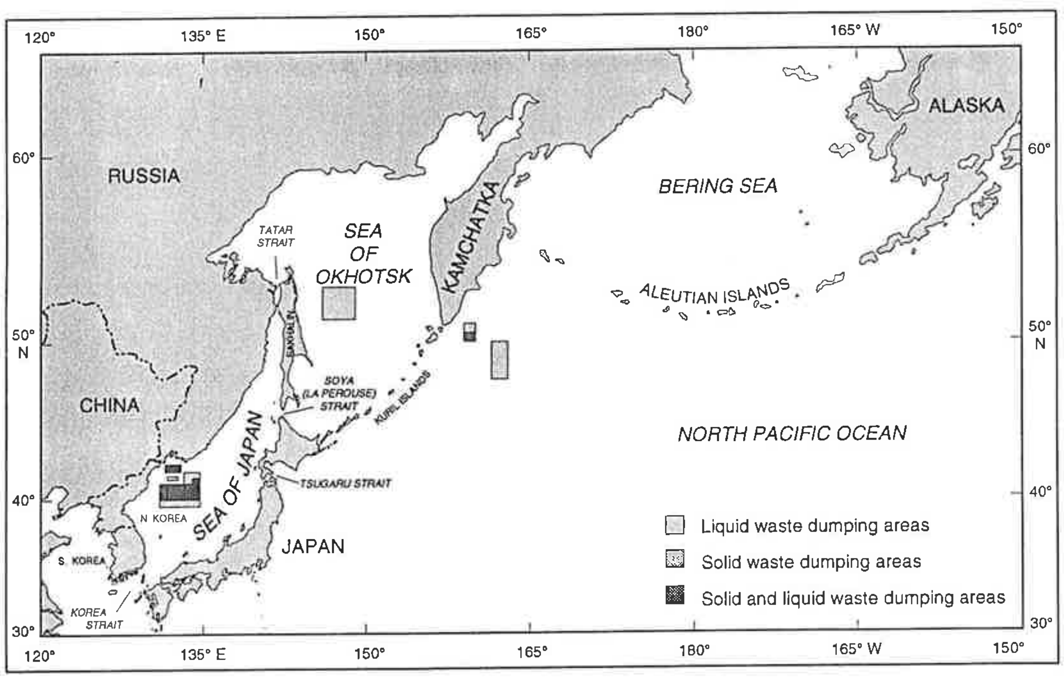



*Figure 1. Geography of the area of interest in the North Pacific, Sea of Japan (East Sea) and Sea of Okhotsk and the known radioactive waste disposal areas. (From Yablokov et al. 1993.)*

The area bathymetry, with details for the Sea of Japan and the Sea of Okhotsk, are presented in Figures 2–4. Known solid radioactive waste dumping sites lie in water up to several kilometers deep in the Sea of Japan and off the Kamchatka Peninsula, although some of the Sea of Japan wastes may have been deposited on the shallower shelf off North Korea. If deep disposal did take place, the deep sites may prove difficult and expensive for monitoring or retrieval or other remediation

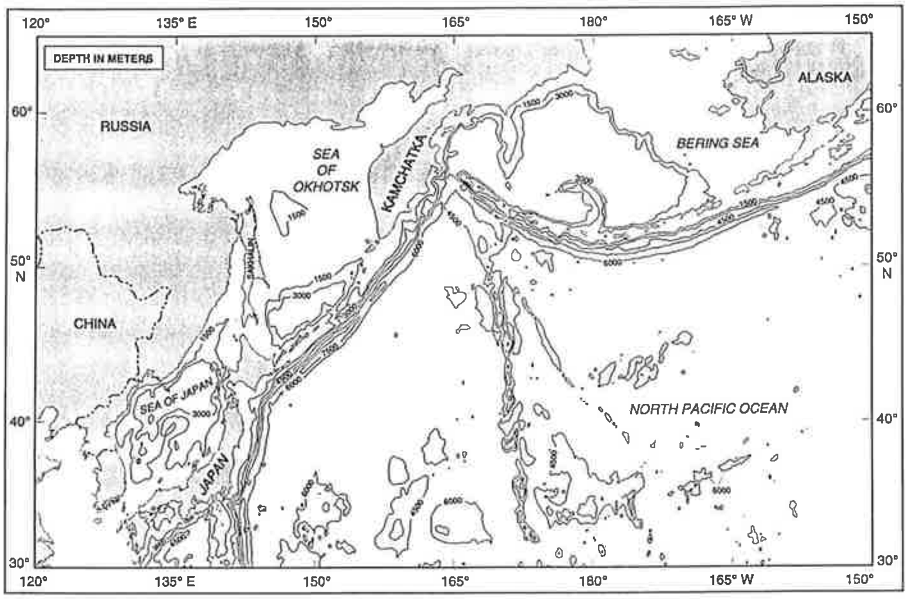



*Figure 2. General bathymetry of North Pacific and adjacent seas. Depths are in meters. (From U.S. Naval Oceanographic Office bathymetry database "DBDB5.")*

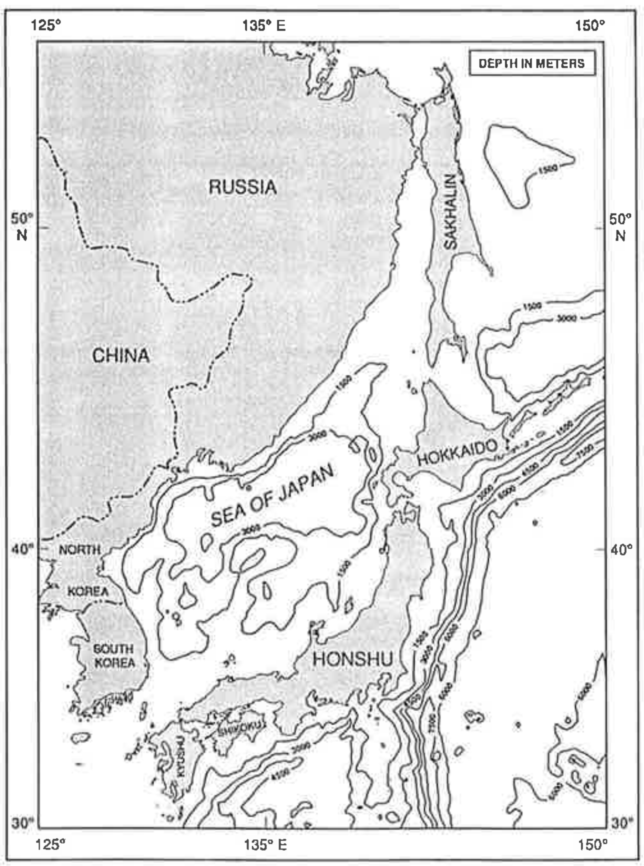



*Figure 3. Detailed bathymetry in the Sea of Japan. Depths are in meters. (From U.S. Naval Oceanographic Office bathymetry database "DBDB5.")*


*Figure 4. Detailed bathymetry in the Sea of Okhotsk. Depths are in meters. (From U.S. Naval Oceanographic Office bathymetry database "DBDB5.")*

efforts. However, in the case of bottom-resting wastes in the Japan Basin of the Sea of Japan, the expected very slow vertical mixing and transport out of the deep basin would suggest any leakage would be confined to the Basin itself. In the North Pacific off the Kamchatka Peninsula, the disposal site appears close to the tectonically active subduction zone of the Kuril Trench. While earthquakes, submarine landslides and turbidity currents in such an area could potentially damage containers that enclose radioactive wastes, much of any resulting leakage might also be expected to remain localized in the deep trench. Because any leakage from bottom-resting nuclear wastes in these deep areas would be anticipated to remain confined to the deep basins, the wastes probably present a low-level near-term hazard. However, if the disposal locations are inaccurately known and the wastes are actually situated on the shallower shelf or slope regions, transport outside of the local region may indeed readily occur.

The second consideration, sea bottom composition, affects the type and quantity of biota present, thus affecting the impact of wastes on the local ecology and the paths and rates of transfer of nuclides through the food chain. The chemical interactions that take place between various waste products and different sediment types such as organic material, fine clay, mud, sand, gravel, etc., are known to affect physical transport mechanisms and the rates and paths of chemical species through the food chain. Different sediment types also impact natural burial of bottom-resting wastes and the ease or difficulty with which in-situ remediation efforts may take place. Natural burial would occur more readily, for example, in deep, soft mud than in sandy gravel. General surface sediment types in the Greater North Pacific region are shown in Figure 5. From this figure, solid radioactive wastes appear to have been dumped in regions of mud and of mud and sand. Actual inspection and sampling at individual disposal sites would be required for more specific and accurate knowledge of the relevant bottom composition and the implications of that composition.

Disposal of liquid wastes and leakage of contained bottom-resting wastes have chemical and ecological consequences in the immediate area. Effects outside of the immediate disposal area will depend largely on physical transport by ocean currents. Both the direction and, particularly in the case of short-lived isotopes, the speed of transport are important. For liquid wastes disposed of near the surface, surface currents are the most important factor, while near-bottom currents will disperse bottom-resting wastes.

Oceanic fronts are boundary zones between water masses of different characteristics, often separating different current regimes. Across these zones, certain characteristics of the water, such as temperature, salinity or nutrients, change significantly over short horizontal distances. Frontal regions typically are areas of increased biological productivity and hence often sites of concentrated human fishing activity. Disposal of pollutants near frontal regions or transport into frontal regions can thus potentially have serious ecological and human health implications.

Estimates of dispersal of near-surface wastes from the dumping sites may be obtained by examining the average near-surface current regimes of the region. To a first approximation, wastes would be expected to be transported at a speed and in a direction given by these currents. The physical transport of pollutants disposed at the locations of Figure 1 may be estimated through examination of Figures 6–9, the climatological surface currents for the area and their approximate speeds for both summer and winter. Care must be exercised in using conclusions

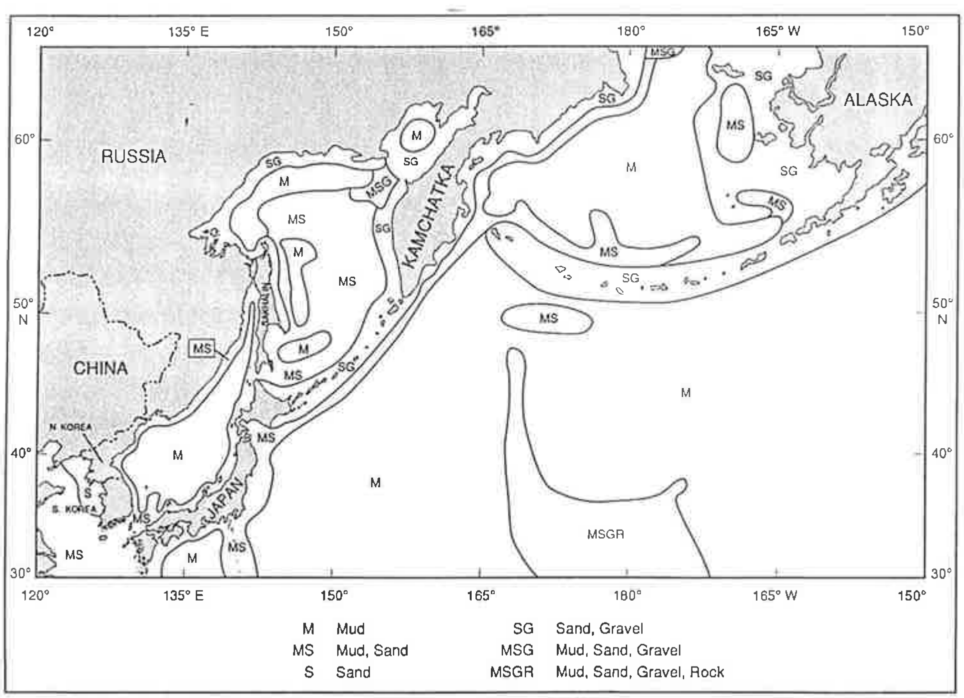



*Figure 5. General surface sediment types in the North Pacific and adjacent seas. (From U.S. Navy Hydrographic Office 1951, Naval Oceanographic Office 1978.)*

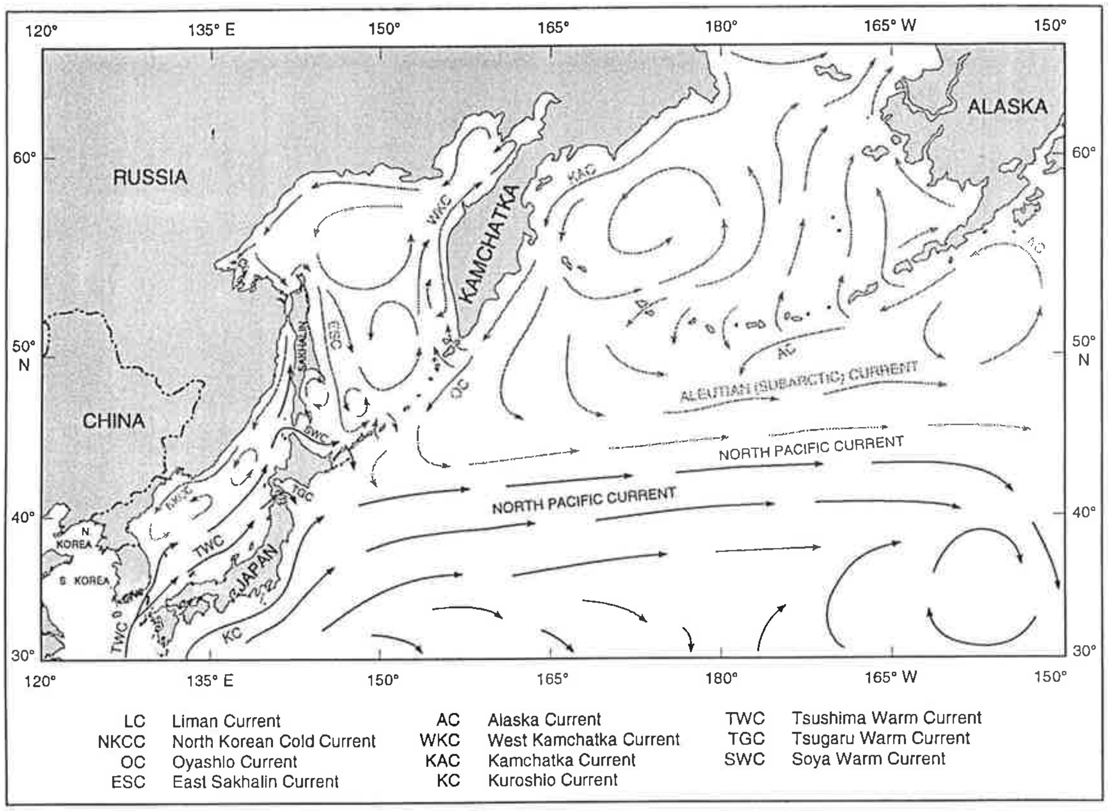
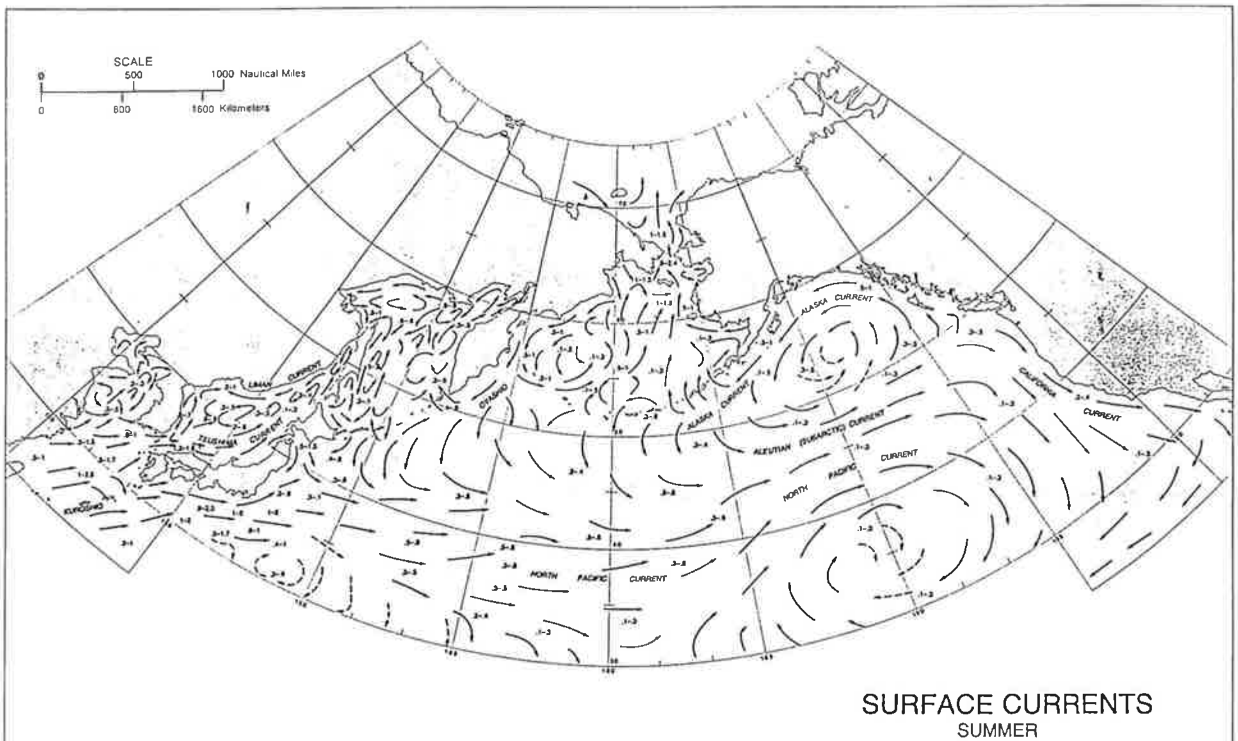



*Figure 6. General large-scale ocean circulation in summer in the North Pacific and adjacent seas. (From Defense Mapping Agency 1989, U.S. Department of Commerce 1961.)*




Prevailing Current Direction
Weak and Variable Current
Mean Speed Range Given In Knots

*Figure 7. Approximate mean speed (kt) and direction of main ocean surface currents in the North Pacific and adjacent seas in summer. (From U.S. Department of Commerce 1961.)*

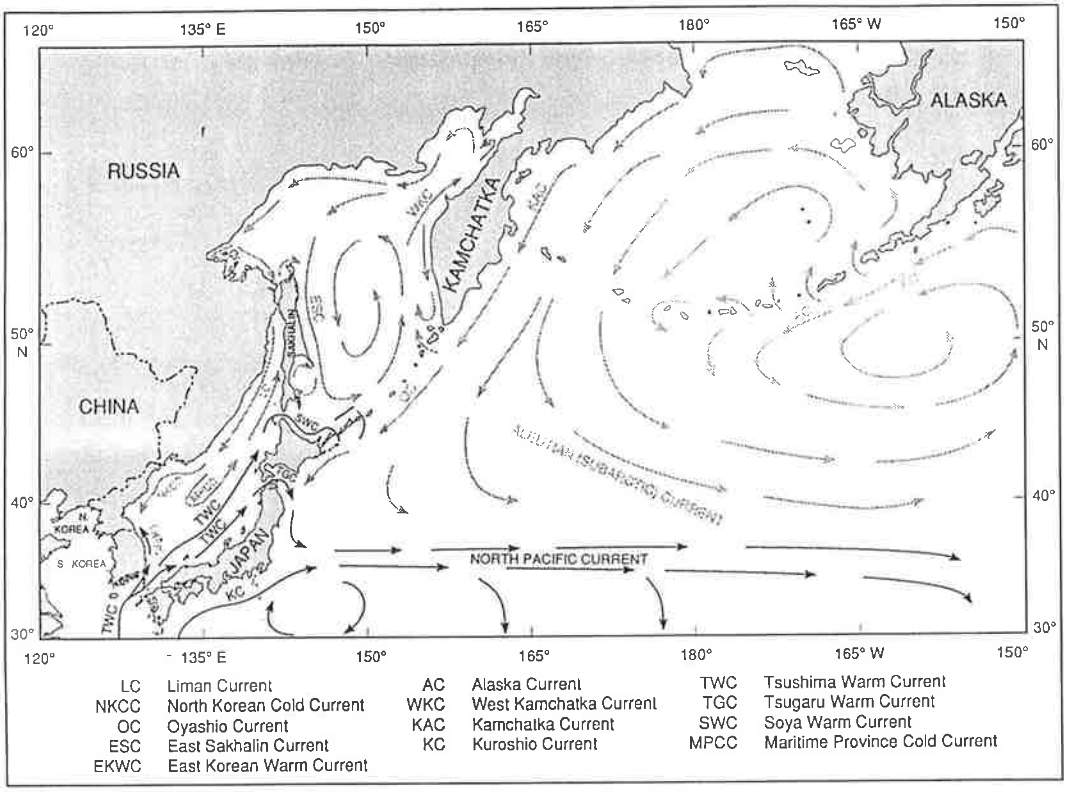



*Figure 8. Approximate mean speed (kt) and direction of main ocean surface currents in the North Pacific and adjacent seas in winter. (From U.S. Department of Commerce 1961.)*

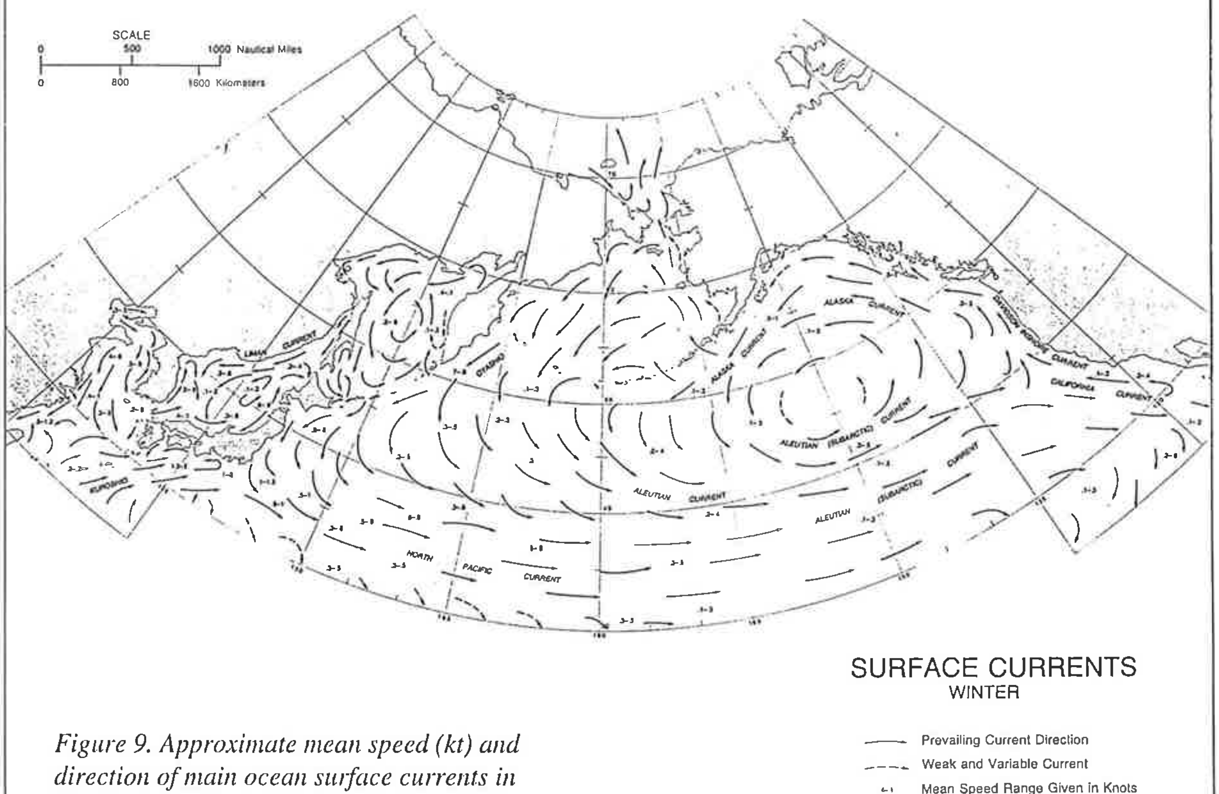



*Figure 9. Approximate mean speed (kt) and direction of main ocean surface currents in the North Pacific and adjacent seas in winter. (From U.S. Department of Commerce 1961.)*

drawn from these climatologies, however, as the currents are highly smoothed averages in time and space of what would be expected at any particular instant or location. Any conclusions are likely to be more accurate over the longer terms of months and years than over the shorter terms of hours, days or weeks.

The potential for radioactive concentration in the biota of frontal zones may also be estimated by correlating expected physical transport of wastes from various sites with the locations of frontal regions. The climatological positions of the frontal zones in the study area are given in Figures 10 and 11. The same caveat holds for climatological frontal positions as for climatological current patterns: climatologies are not necessarily accurate descriptions of instantaneous conditions.

Examination of these figures leads to the following expectations for physical transport and frontal concentration of surface-disposed nuclear wastes in this region over the longer term. Some liquid wastes dumped in the Sea of Japan are likely to be caught up in the North Korean Coastal Current and carried to the coast of North Korea. Others may be caught up in the Tsushima Warm Current and be carried to the coasts of Honshu and Hokkaido. Concentration in the biota of the Japan Sea Polar Front or the Tsushima Front is possible. In the Sea of Okhotsk, liquid wastes will potentially be transported by the East Sakhalin Current to the eastern coast of Sakhalin and down to the Kuril Islands and possibly into the Oyashio and out into the North Pacific via the North Pacific Current. Concentration of radioactive nuclides in the biota of the Soya, Kuril and perhaps West Kamchatka Fronts is possible. Liquid wastes disposed of off the southern coast of Kamchatka are likely to be carried into the North Pacific via the Oyashio and the North Pacific Currents. Having drawn these conclusions from oceanographic conditions, it must also be noted that the ecological and human health significance of these expectations will depend upon the magnitude of the dumping and the half-lives of the constituent isotopes and their chemical and biological pathways.

Very little relevant information was found for the region regarding near-bottom currents, which will govern the dispersal of leaking bottom-disposed wastes. Inspection or remediation of bottom-disposed wastes will be impacted by local currents, including tidal currents, which may be quite different in both direction and magnitude from the larger-scale climatological currents, which will control the long-term transport characteristics. Additional measurements of near-bottom currents on both short and long time scales will be necessary to properly assess the difficulties associated with monitoring and remediation or the significance of any leakage.

Finally, the feasibility of inspection or recurrent monitoring of disposal sites will be dependent upon the accessibility of the sites to inspection vessels. Wave heights and sea ice extent are important considerations. Temporary wave conditions in a local area which are unsuited for particular operations may be generated at any time by the passage of storms and atmospheric fronts, which can usually be predicted shortly in advance by weather reports. Winter will usually be the time of most frequent and most extreme unsuitable wave conditions, and a feel for the

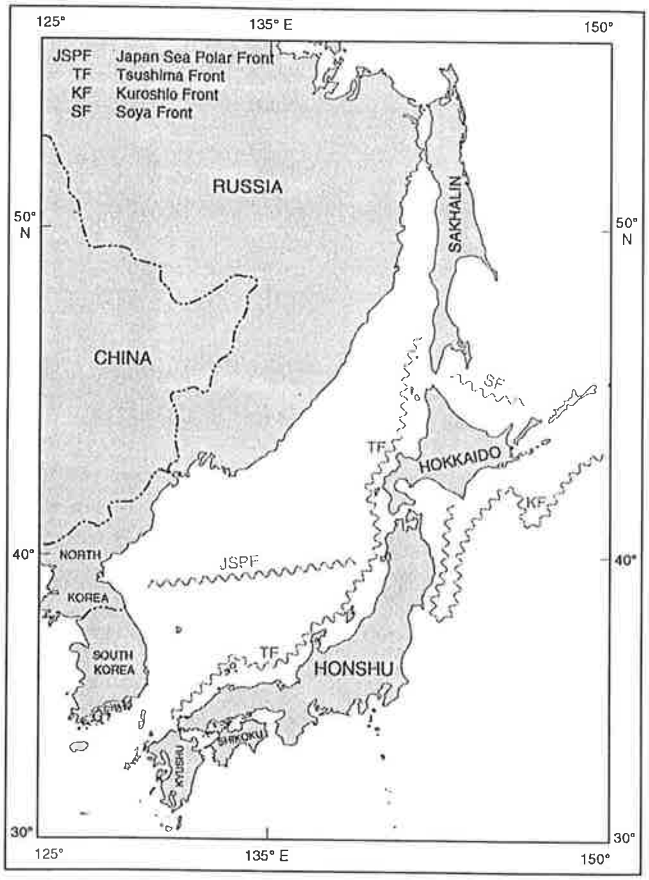



*Figure 10. Approximate positions of the main ocean frontal regions in the Sea of Japan (East Sea). (From Tomczak and Godfrey 1994.)*

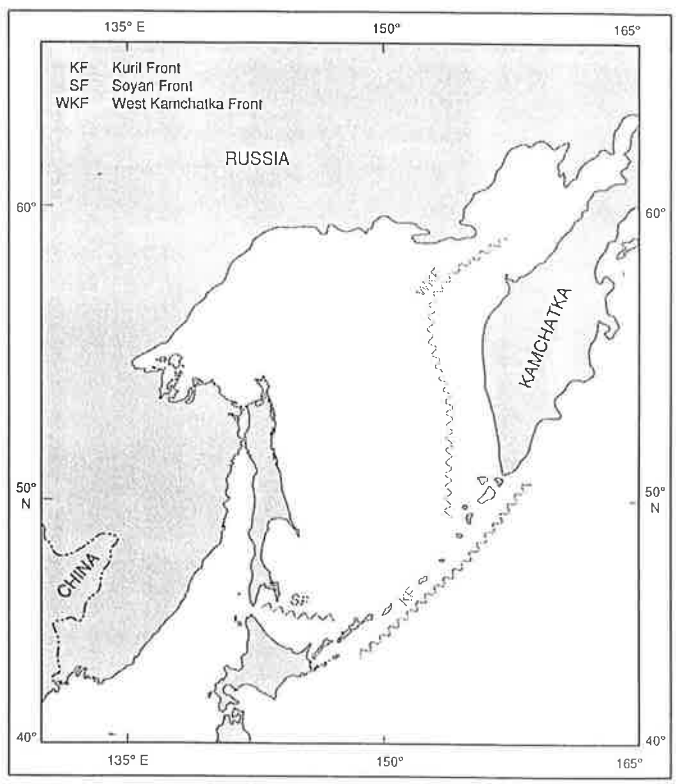



*Figure 11. Approximate positions of the main ocean frontal regions in the Sea of Okhotsk. (From Tomczak and Godfrey 1994.)*

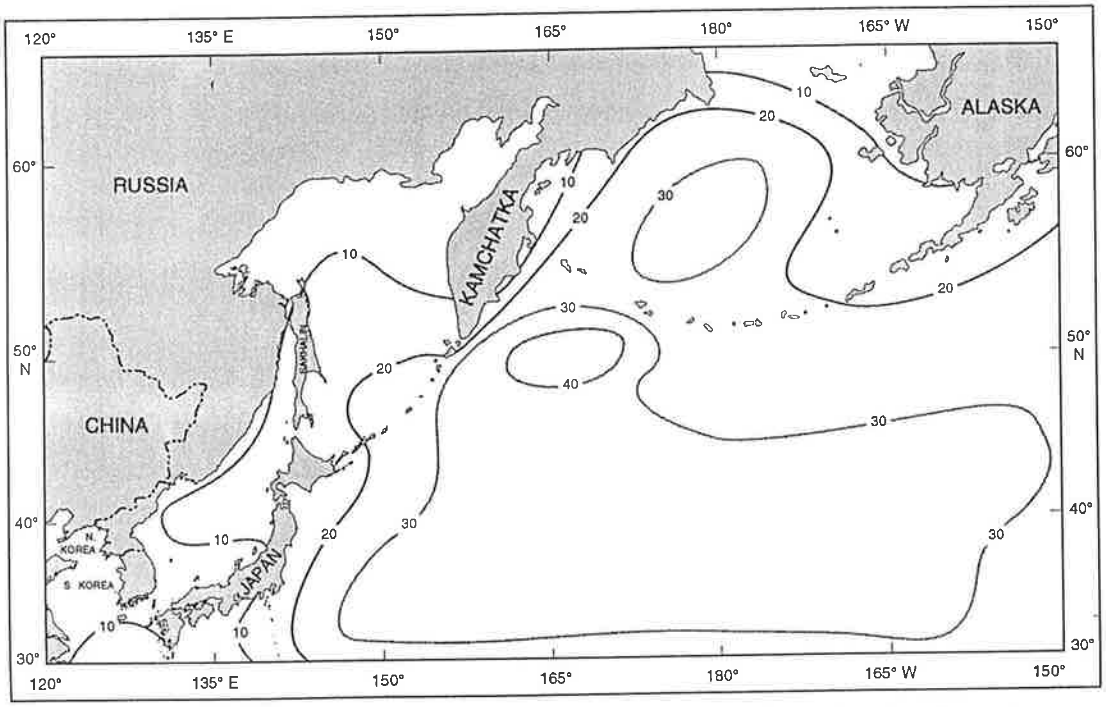



*Figure 12. Percent of the time waves reach or exceed 3.5 m (12 ft) in height in winter in the North Pacific and adjacent seas. (From Defense Mapping Agency 1989.)*

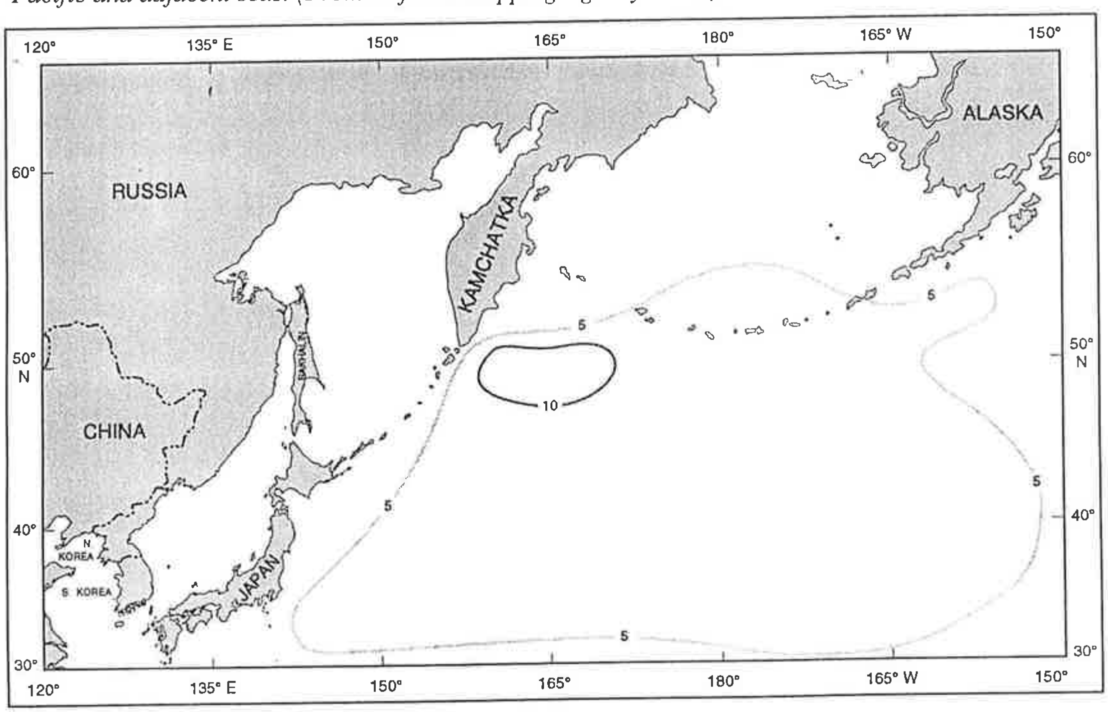



*Figure 13. Percent of the time waves reach or exceed 6 m (20 ft) in height in winter in the North Pacific and adjacent seas. (From Defense Mapping Agency 1989.)*

regions most likely to experience high wave conditions can be obtained by examining climatological charts of how often winter waves exceed some height, such as 12 feet or 20 feet (Fig. 12 and 13). From these figures can be seen that the most frequent high wave conditions are expected in the unprotected North Pacific off Kamchatka, where between 20% and 40% of the time waves higher than 12 feet are likely. Such waves are only expected 10–20% of the time in the Sea of Japan and the Sea of Okhotsk.

Maximum sea ice extent is shown in Figure 14. Sea ice is expected to be extensive in the Sea of Okhotsk and off Kamchatka. On-site inspection is likely to be hazardous in the areas in winter (as would be any disposal operations). Sea ice also presents another transport mechanism for suspended or dis-

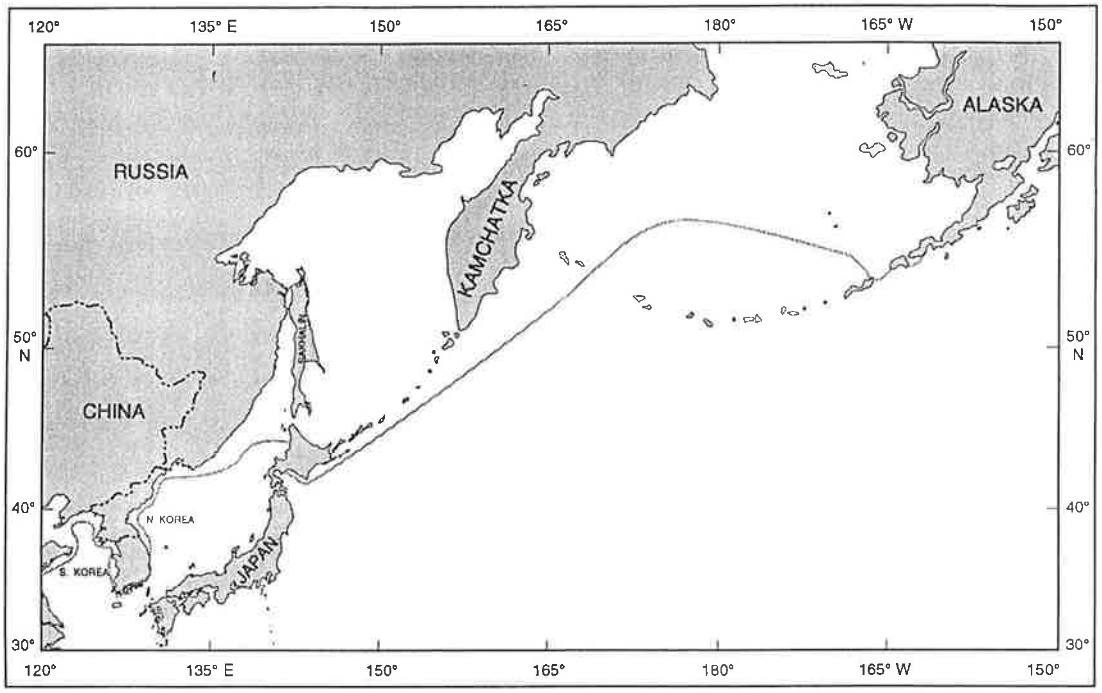



*Figure 14. Maximum extent of sea ice in the North Pacific and adjacent seas in winter. (From U.S. Department of Commerce 1961.)*

solved wastes, with the transport paths likely to be governed roughly by the winter climatological surface current patterns.

In summary, the oceanography of the Greater North Pacific region will strongly affect both the impact of pollutants on the natural and human ecology of the area and the difficulties inherent in monitoring, retrieving or minimizing the impact of disposed wastes, including nuclear wastes. Our knowledge of this area is sufficient to make some general statements about expected longer-term transport pathways, possible impacts, and difficulties in inspection and remediation, but there is no assurance these general statements will be accurate over the short term and in specific, localized cases. Each dump site would have to be examined in greater detail before policymakers could be supplied truly reliable information upon which to base decisions. However, it cannot be too strongly emphasized that these after-the-fact studies and efforts are far less desirable than reasoned before-the-fact studies and efforts. Before any disposal of hazardous materials takes place in the ocean, a realistic and thorough assessment should be made to select a suitable site and to gain a knowledge of such factors as likely current transports, bottom composition, and biological and geophysical pathways. Plans should be made before-the-fact for post-disposal monitoring and, in the case of contained wastes, for responses to both slow and catastrophic releases. It may sometimes be impossible to formulate satisfactory after-the-fact plans.

## Acknowledgments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# The Application of a Numerical Ocean Model to Study the Dispersion of Radioactive Contaminants in the Arctic

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Information released by the former Soviet Union in a publication called the Yablokov report or the Russian White Book (1993) on the disposal of radioactive waste in the shallow waters of the Kara and the Barents Sea has attracted strong international attention. Many countries are concerned that the radioactive material, released into such shallow water, may be incorporated into the food chain and have a serious impact on important fishing grounds such as those located in the Barents Sea. Concern has also been expressed by the United States that some of this material might be transported as far as the northern coast of Alaska and have a detrimental effect on the Alaskan fishing industry.

The Yablokov report states that low-level liquid waste was dumped into the Kara and Barents Seas, with lesser amounts dumped into the White Sea and the Baltic. Low- to intermediate-level waste was dumped into the Kara and Barents Seas. Higher-level solid radioactive waste with spent nuclear fuel, dumped into the Kara Sea, was considered the most environmentally hazardous. Nuclear reactors containing the spent nuclear fuel were deposited along the eastern coast of Novaya Zemlya island in water with average depths of 20–40 m. The major river/estuary systems of the Kara and Barents Seas are also sources for both radioactive and chemical waste in the Kara Sea. Finally the disposal of liquid radioactive waste at the Sellafield site in the Irish Sea has also been suggested as a source of radioactivity for the Barents and the Kara Seas.

Numerical models have been used as tools for studying the problem of the dispersion of radioactive contaminants that have entered the water column. The Naval Research Laboratory has applied their coupled ice–ocean model, developed for sea ice forecasting (Cheng and Preller 1995), to the problem. For this particular study the ice and ocean model have been decoupled, and only the ocean model will be used. Later studies, which include sea ice as a mechanism for transport of contaminants, will use the coupled model. The ocean model is the Cox (1984) ocean model, which has been adapted to a region of the northern hemisphere that extends from the North Pole to approximately 30°N latitude. The horizontal grid resolution of the model is 0.28°, and there are 15 vertical levels, which increase in thickness with depth. The model is driven by annual mean winds, which are representative of climatic winds. The ocean temperature and salinity values are initialized from Levitus (1982) climatology.

Several ten-year ocean model simulations have been made, each using a different source of radionuclides. Radionuclides are released at a constant rate into the water column. These release rates are based on the total amount of material dumped at a site and the time over which these dumpings occurred. For example, if 100 kCi were dumped at a site over a period of 30 years, the release rate would be defined as 100 kCi/30 years. At the end of the 30 years, all of the radionuclides would be released into the water column. In the case of the Sellafield dumping, the amount of waste dumped each year has been documented, and constant release rates for each year are calculated from those values.

Model simulations indicate that if only the low- to intermediate-level sources of radioactive waste are used, the resulting levels of radioactivity in the Kara are lower than what has been recently observed. If the high-level radioactive waste source is used, the resulting levels of radioactivity in the Kara Sea are nearly two orders of magnitude higher than recent observations indicate. This would agree with the statement in the Yablokov report that the high-level waste is protected from interaction with the water column at this time by being encased in a substance called furfurol. The lifetime of this material is on the order of one hundred years. At the time the furfurol decays, there may be a sudden release of radioactivity into the water column. However, at this time, no such high levels of radioactivity have been observed near these sources. When rivers are used as the source of radioactivity, model results produce the best agreement with observations. Levels of radioactivity fall within the same order of magnitude as those observed. In each of these cases, model results indicate that the level of radioactivity along the north Alaskan coast is four to five orders of magnitude less than values near the source. Therefore, the Kara Sea sources do not seem to have a major impact on the north Alaskan coast. Finally, when a simulation is run using the Sellafield source, levels of radioactivity in the Kara are nearly an order of magnitude less than those observed. The Sellafield source does have a serious impact on levels of radioactivity in the Norwegian and Greenland Seas, as well as in the Barents Sea.

Future work on this project will address several issues. The first will be the verification of model results against data. This is a difficult issue to address, since not only are observations scarce, but actual source release rates are not known. The case that can provide the most useful model-to-data comparison is the Sellafield case, where we have both annual dumping data as well as a substantial number of observations of the radioactivity in and around the Irish, the Norwegian and the Greenland Seas.

Validation of the model for this case will give us confidence in its ability to simulate accurate dispersion patterns in other scenarios. The second issue will be the importance of sea ice as a mechanism for transport of contaminated material carried in sediments. The coupling of the ice to the ocean model should provide us with a useful tool for investigating this topic.

Finally, we will also use this model to investigate the dispersion of radioactive materials dumped in the Pacific Seas, since the model domain covers the northwestern Pacific, including the Sea of Japan and the Yellow Sea.

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# Practice of Nuclear Waste Treatment in the Russian Pacific Fleet

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While preparing for this meeting, V.A. Vysotsky and I looked through all the information that we possess concerning liquid waste dumping in the study area. Our report, which follows this short introduction, also contains a description of the history of dumping by both the Russian and American sides. I will read some information it contains. Stemming from the principles and recommendations developed in the Former U.S.S.R. by MAGATE, 10 regions in the Sea of Japan, the Okhotsk Sea and near the southeastern cost of Kamchatka were selected as dump sites for nuclear waste. Regions 1 and 2 in the Sea of Japan, Region 3 in Sea of Okhotsk and Region 4 near Kamchatka were not used for waste disposal.

For the past 30 years, nuclear waste disposal took place only in Regions 6, 9 and 10 in the Sea of Japan, and Region 8 near the Kamchatka Peninsula. The maximum multiyear load of these regions did not exceed 7% of the permissible limits for liquid waste disposal (Region 9 in the Sea of Japan) and 5% for solid waste (Region 8 near the Kamchatka Peninsula).

The total radioactivity of low and medium radioactive nuclear waste disposed by the U.S.S.R. Navy in the Pacific Ocean comprises 6,979 curies. This radiation is contained in 6,868 flooded containers, 38 ships and more than 100 separate large objects. The amount of the liquid waste is 12,298 curies. The total sum of all waste dumped into the Pacific Ocean is 19,265 curies. It should be mentioned that while selecting nuclear waste dumping regions, that 9 out of 10 regions do not meet the MAGATE and London Convention requirements in depths, internal seas or latitude. The only exception is region 4 near the Kamchatka Peninsula.

Also radio-ecological studies performed every 3–5 years by Pacific Ocean Fleet Chemical and Medical Services specialists, in collaboration with colleagues from the Navy Central Medical Laboratory and the State Hydrometeorological Committee, showed that the concentration of major artificial radionuclides in the seas' waters does not exceed background values. A joint Japanese–Korean–Russian expedition to the Russian regions of nuclear waste disposal in the Sea of Japan has also arrived at similar conclusions.

Long-term radio-ecological observations have shown that low-activity waste disposal from special laundries and shower-baths at atomic fleet maintenance stations does not lead to environmental radioactive pollution that exceeds permissible levels. The concentration of artificial radionuclei in adjacent regions does not exceed background values.

# Nuclear Waste Disposal Practices in Russia's Pacific Ocean Region

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Using and repairing nuclear-powered ships inevitably leads to the formation of solid and liquid nuclear waste. The problem of safe nuclear waste disposal is an intrinsic part of the nuclear energy problem. The countries that possessed nuclear industries from 1950 to 1980 used to solve the problems of nuclear waste disposal by dumping it into seas and oceans, or into the rivers that flowed into them. This approach, in part, is at present in practice in the United Kingdom, France and in other countries.

From the very beginning of the development of a nuclear industry in the Soviet Union, nuclear wastes were subjected to detoxification or disposal into special land-based containers. The only exception to this rule was processing waste from nuclear vessels and from nuclear repair plants. Those nuclear wastes were collected and disposed of in special regions of adjacent seas and oceans.

The selection of regions for nuclear waste disposal has taken place in accordance with the appropriate standards that provided required safety standards for public health. The absence of international agreements concerning requirements for nuclear waste disposal has resulted in various approaches to this problem.

The following principles were obeyed while selecting regions for waste disposal in the U.S.S.R.:

- Liquid and solid wastes were allowed to be dumped and disposed of inside strictly defined regions that met special requirements (situated beyond fishing regions, far away from fish migration paths and spawning regions, far enough from traditional communications lanes; sea bottom structures, local stream and depths were also taken into account).
- A selective approach was used to estimate the danger of contamination to coastal waters, the continental shelf and to the open sea. Only liquid, low-active nuclear wastes from immovable sources (laundries, showerbaths, etc., in ships) were dumped as an exception. Only liquid low-active wastes were allowed to be dumped in selected regions inside 10–30 miles from the coastal zone. The major portion of nuclear wastes was disposed of in special regions in the open sea, farther than 50 miles from the coast.
- Solid wastes were disposed of only in containers. The only exceptions were large-scale constructions.
- Waste disposal was limited by the quantity of radionuclei in them, as well as by total radioactivity.
- Periodic radiobiological control procedures were performed in regions of nuclear waste disposal.

When submarines with nuclear engines were first used in the U.S., all nuclear wastes that were produced by them were dumped into the sea. In the very beginning, they were disposed of in ports and bays. But, with the increasing quantity of waste, uncontrolled waste dumping was canceled.

In 1958 the U.S. Naval Ship Construction Department issued a mandate to control the process of nuclear waste disposal. This mandate established waste radioactivity limits for ports, bays and estuaries as not exceeding 0.2–6.0 curies (or 7.4–220 GBq). Nuclear vessels were permitted to dump up to 1000 curies (37 TBq) in each separate case 1–12 miles outside of port. Waste disposal was not limited for depths more than 400 m beyond territorial waters. Dumping without containers was permitted outside of fishing waters of up to 500 curies (16.5 TBq).

These approaches were in practice for many years and were confirmed in 1959, by a U.S. National Academy of Science committee report on the influence of radiation on oceanography and fishing. Similarly all ship nuclear waste disposal activities in the U.S.S.R. and Russia have been performed under the control of competent specialists in accordance with permissible biosphere radioactive pollution levels that were in existence at the time. In addition, a reserve component was used that ensured the safety of seafood consumed by the population. However, a uniform approach to the consequences of radioactive pollution has not yet been formulated. In particular, it was recommended to allow 1/25 of the permissible genetic dose by nuclear wastes disposal, which comprises about 0.2 Bq during 30 years. In the United Kingdom, U.S., Japan and India, it comprised 1/10 or more. In accordance with this the maximum permissible radionuclei concentration in seafood permissible for critical organs irradiation estimation appeared to be 3–10 times as much in foreign countries as in the former U.S.S.R.

The solution to these problems is very important because, most probably, it will be impossible to completely avoid nuclear waste disposal into the seas of the Pacific Ocean region for a considerable period of time. The problem should be considered at present from the point of view that would allow us to optimize nuclear waste handling with the goal of minimizing, to the most possible extent, the radiation effect on sea waters.

Stemming from principles and recommendations developed in the former U.S.S.R. by MAGATE, ten regions in the Sea of Japan, the Okhotsk Sea, and near the southeastern cost of Kamchatka were selected as dump sites for nuclear wastes

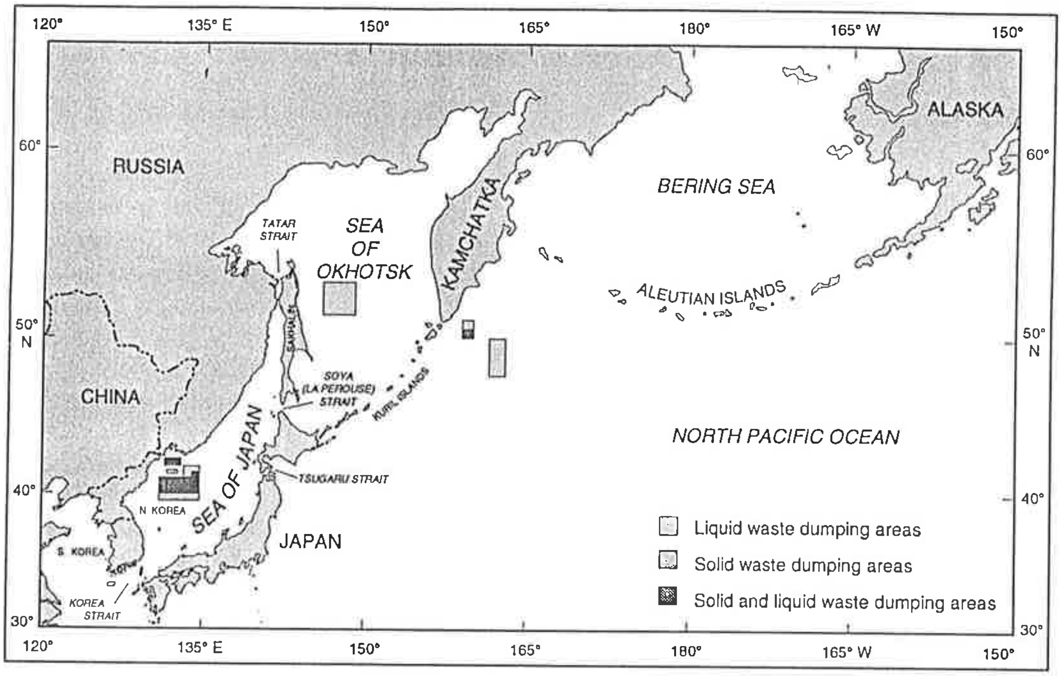


*Figure 1. Geography of the area of interest in the North Pacific, Sea of Japan (East Sea) and Sea of Okhotsk and the known radioactive waste disposal areas. (From Yablokov et al. 1993.)*

**Table 1. The characteristics of nuclear waste disposal regions by the Navy of Russia and former U.S.S.R. in Pacific Ocean region.**

| | | | | | *Nuclear waste type/quantity* | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | *LNW* | | *SNW* | |
| *Region* | *Sea* | *Distance from coast (miles)* | *Depth (m)* | *Time of utilization (yr)* | *dumped (curies)* | *Allowed (curies/yr)* | *dumped (curies)* | *Allowed (curies/yr)* |
| 1 | Japan | 90 | 3000–3400 | have not been utilized | — | — | — | — |
| 2 | Japan | 160 | 2800–3400 | have not been utilized | — | — | — | — |
| 5 | Japan | 25 | 1100–1500 | 1962–1992 | 117 | 500 | — | — |
| 6 | Japan | 50 | 1900–3300 | 1967–1990 | — | — | 869 | 200 |
| 9 | Japan | 120 | 3300–3400 | 1974–1993 | 10,840 | 5,000 | 2,234 | 2,000 |
| 10 | Japan | 120 | 2900–3300 | 1974–1984 | 536 | 1,000 | 721 | 2,000 |
| 3 | Okhotsk | 160 | 1200–1300 | have not been utilized | — | — | — | — |
| 4 | Kamchatka | 160 | 4700–5300 | have not been utilized | — | — | — | — |
| 7 | Kamchatka | 20 | 1400–1500 | 1962–1992 | 361 | 500 | — | — |
| 8 | Kamchatka | 25 | 2000–2600 | 1969–1992 | — | — | 2,993 | 2,000 |

(Fig. 1, Table 1). It follows from data in the table that Regions 1 and 2 in the Sea of Japan, Region 3 in Okhotsk Sea, and Region 4 near Kamchatka were not used for waste disposal.

For the past 30 years, solid nuclear waste disposal took place only in Regions 6, 9 and 10 in the Sea of Japan, and in Region 8 near the Kamchatka Peninsula. The maximum multi-year load of those regions did not exceed 7% of the permissible limits for liquid waste disposal (Region 9 in Japan Sea) and 5% for solid waste (Region 8 near the Kamchatka peninsula). There was no nuclear waste dumping that exceeded permissible limits.

The total radioactivity of low and medium radioactive active nuclear waste disposed of by the U.S.S.R. Navy in the Pacific Ocean comprises 6,979 curies (258 TBq). This radiation is contained in 6,868 flooded containers, 38 ships and more than 100 separate large objects. The amount of liquid waste is 12,298 curies (455 TBq). The total sum of all waste dumped into the Pacific Ocean is 19,265 curies (714 TBq).

It should be mentioned, that while selecting nuclear waste dumping regions, that 9 of the 10 regions do not meet the MAGATE and London Convention requirements (depth, internal seas, latitude) except for Region 4 near the Kamchatka peninsula.

Also, radio-ecological studies performed every 3–5 years by Pacific Ocean Fleet Chemical and Medical Services specialists, in collaboration with their colleagues from the Navy Central Medical Laboratory and the State Hydro-Meteorological Committee, showed that the concentration of major artificial radionuclei in the seas' waters does not exceed background values. A joint Japanese–Korean–Russian expedition to the Russian regions of nuclear waste disposal in the Sea of Japan has also arrived at similar conclusions.

Long-term radiological observations have shown that low-active waste disposal from special laundries and showerbaths of atomic fleet maintenance stations does not lead to environmental radioactive pollution that exceeds permissible levels. The concentration of artificial radionuclei in adjacent regions does not exceed background values.

The only exception is the local area of radioactive contamination by cobalt-60 radionuclei of coastal waters and a portion of the seawater in the shoal of Chazhma, the Gulf of Strelok and Ussuriysky Gulf, which was the result of a nuclear accident on the 10th of August, 1985, in the shoal of Chazhma. It can be considered an open area of radioactive waste storage. Long-term observations of the cobalt-60 expansion external boundaries has shown that the radioactive, polluted region is practically stable, and the dynamic equilibrium between the processes of radionuclei migration and their decay is taking place (T 1/2 = 5.27 years). This suggests, as a temporary solution, to leave those polluted regions for natural deactivation to minimize the risk of polluting new territories while transporting radioactive wastes.

The loss of a radioisotope thermo-electro-generator (RITEG) as a result of an accidental dump in the Okhotsk Sea near the Sakhalin Island coast in 1987 should be treated as an unplanned act of natural radioactive waste disposal by the Pacific Fleet. The hermetically sealed solid construction contains 350,000 curies of strontium-90 (13,000 TBq). According to assessments made by the developers of the generator, the hermetization system is ecologically safe. Extensive annual studies that have been made by Pacific Fleet specialists in 1987–1990 in the region of the generator loss have not led to its detection nor to the detection of any local radioactive pollution.

The last Pacific Fleet liquid nuclear waste disposal took place in Region 9 in the Sea of Japan in October, 1993. The disposal was sanctioned by the Russian Ministry of Nature. Appropriate MAGATE specialists were informed. The disposal was carried out under the control of Ministry of Nature officials and under the technical observation of Pacific Fleet specialists. Some 0.38 curies (14.1 GBq) of liquid waste (cesium-137: 76%, strontium-90: 21%, cobalt-60: 1.5% and cesium-134: 1.5% of total quantity) were dumped into the sea.

The portion of the polluted region (wastes were dumped on the surface and at a depth of 2 m) was 30 miles in length and 200–400 m in width. Measurements showed that the concentration of cesium-137 in radioactive anomalies was 0.4–1.2 Bq/L and did not exceed values permitted by the Russian Navy in 10–20 minutes after disposal. Assessments made by Pacific Fleet specialists based on a turbulent diffusion theory showed that concentrations of all nuclei in the seawater, in the instance discussed above, reach background values in 15–25 hours after disposal.

As seen from above, the negative effects of radiation in the seawaters after liquid waste disposal is local and temporary. The considerable depths of the Pacific Fleet waste disposal regions and considerable underwater streams quickly disperse the concentration of waste. As a result, there is no significant radio-ecological danger to hydrobionts or any bottom accumulations.

Radioactive pollution to seafloor fauna may take place under the influence of highly toxic solid nuclear waste. However, this process does not currently affect human activity if it takes place at great depths. In the meantime, it should still be a topic for further scientific research. It should be noted that the Russian Pacific Fleet has not disposed of solid nuclear waste into the ocean since 1992.

According to Russian Hydro-Meteorologic Center data and research performed from 1988 to 1994, global and regional nuclear waste pollution to Far Eastern seas is mostly determined by radioactive precipitations caused by nuclear tests. The amount of radionuclei that go into the environment as part of nuclear waste comprises just a small percentage of the total anthropogenic sea pollution.

Just and urgent demands made by Japan for Russia to obey the international rules concerning handling nuclear waste are a positive step, but cause some practical difficulties in its realization by the Russian Pacific Fleet. Pledges made by Russia concerning terminating nuclear waste disposal in the Pacific Ocean region have not received financial support by Russia.

The essence of the problem is the absence of a sufficient amount of solid and liquid nuclear waste depositories, waste processing plants, means of transportation and radiological control equipment that meet appropriate requirements. The Russian Pacific Fleet has 16,000 cubic meters of solid nuclear waste and 5,000 cubic meters of liquid waste collected at present. Some 70–90% of the wastes are accumulated in the Primorsky Territory. Taking into account the fleet utilization schedule (3–4 PLA annually), approximately 2,000 cubic meters of liquid and 5,000 cubic meters of solid waste will be accumulated annually during the next 10–15 years.

Efforts undertaken by Russian Pacific Fleet Headquarters to decrease regional problems caused by existing waste depository overflows are insufficient in solving the total problem. The very important task of terminating nuclear waste disposal in the Sea of Japan is difficult to resolve due to the half-year lead time needed to put the technical tanker *Pinega* into service. It will be able to process nuclear waste. The realization of the program of Japanese assistance to Russia probably will not be completed earlier than the end of 1995.

At present the fleet must deal with the problem with its own means, trying to decrease the volume of accumulated nuclear waste by concentrating it to a liquid brine condition. Extensive progress in this direction has been made by specialists of the Russian scientific-research enterprise Exaton, who have designed two experimental devices called Sharya-04, with which they have rectified 461 cubic meters of liquid wastes to acceptable levels. One unit is located in Primorsky Territory and the second is on the Kamchatka Peninsula.

Despite their high level of effectiveness in rectifying briny solutions, they have many shortcomings tied to low-volume capability (0.5 cubic meter per hour) and to the formation of highly radioactive liquid nuclear waste with a high salt content.

It is apparent that these tasks, due to their immensity, are still very formidable. The Pacific Fleet's problem of disposing of nuclear waste takes on some new features. The program must include creating the technical means for storage, utilization and processing radioactive waste throughout the Russian Far East that meet international standards.

As a transitional stage in the implementation of the given program, there arises the necessity for continuing low-level radioactive waste discharge (the content of radionuclides must correspond to the maximum permissible concentrations in sea water).

A distinguishing peculiarity of the northern coast of the Sea of Japan is the large area of shelf that extends dozens of kilometers from the Pacific Fleet's technical centers. Also, these regions are located near wildlife refuge zones, vacation areas, resorts and industrial fishing waters. In conjunction with Russian legislation concerning the environment, there exists even stricter requirements concerning all forms of waste disposal including radioactive waste.

Under such circumstances, it is very important to develop standards concerning the disposal of low-level nuclear waste in the seas of the Pacific Basin, along with methods to control, assess and predict changes in the ecological conditions in the area that meet the requirements of all countries concerned.

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# Investigation of Marine Environment Radioactivity in the Dumping Areas and Coastal Zone of the Sea of Japan

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I would like to describe results from a few 1993 and 1994 expeditions in the Sea of Japan and Peter the Great Bay. The first expedition was conducted in March and April 1994 aboard the Far Eastern Regional Hydrometerological Research Institute's (FERHRI) research vessel *Ocean*. It was the first Japanese, Korean and Russian joint expedition to study the radioactive waste dumping sites. About 40 specialists from Japan, Russia, Korea and the IAEA participated in this expedition.

In September and October 1994, a Russian expedition, without foreign experts, was conducted aboard the FERHRI research vessel *Akademik Shokalsky* to Peter the Great Bay, an area south of Vladivostok, located between Vladivostok and Nakhodka. The area is bounded by Amursky Bay, Ussuriysky Bay, Chazhma Bay and Bolshoy Kamen Bay. Navy facilities to reprocess or service nuclear submarines are situated in Chazhma Bay. This was the location of the nuclear submarine incident which took place in 1985.

A third expedition is a joint Japanese, Korean, Russian project titled: Circulation Research of the East Asian Marginal Seas, or CREAMS. It deals mainly with the Sea of Japan. Analysis of samples from the first expedition to the Sea of Japan dumping areas during the spring of 1994 are already available, at least in Russia. In the near future, these results will be exchanged with our Korean and Japanese colleagues and after joint evaluation, a final report will be prepared.

Measurements of $^{137}Cs$ in surface seawater (data of sorbent measurements), range from 2.9 – 4.3 Bq/m$^3$ and was less than 4 Bq/m$^3$ for bottom water. Levels of activities in bottom sediment and biota are at the background level, typical for the North Pacific. These activity levels can be explained mainly by fallout of radionuclides from the atmosphere. For bottom seawater and for bottom sediments, the figures were below the detection limit of the spectrometric devices which were aboard the ship. In general, the results of detailed measurements made in onshore laboratories confirmed these figures.

I would like to present the results of our Korean colleagues from the CREAMS–93 cruise aboard FERHRI *R/V Professor Khromov*. $^{137}Cs$ in 18 surface seawater samples from the Sea of Japan, including the areas of waste dumping, ranged from 2.6 to 3.4 Bq/m$^3$, within the same range as the 1994 samples from the *Ocean*.

The main goal of the CREAMS project is to study water circulation in the Sea of Japan. As Dr. Boyd told us this morning, there are very limited data on deep water currents in the Sea of Japan. During the summer cruise of 1993, three moorings were deployed, with one of these moorings situated close to the dumping area. Moorings had current meters at 1000-, 2000-, and 3000-m depths. According to the results for approximately a one-year period from August 1993 to July 1994 for current measurements close to the dumping areas, current velocities at the 2000-m depth may be up to 20 cm/s during some periods in winter, for example, December. At 3000-m depths, current speeds may be as high as 10 cm/s. Current direction was changing throughout the entire period of measurement. So in the case of any leakage of radionuclides from dumped containers, these radionuclides could be transported and distributed throughout the whole Sea of Japan.

Preliminary results of radionuclide activities from onboard measurements in Peter the Great Bay show that distribution of $^{40}K$ and $^{214}Bi$ in sea water are mainly related to fresh water and suspended material discharges due to heavy rains in Primorie Territory. $^{137}Cs$ and $^{60}Co$ levels are no more than 0.05–0.10% of natural radionuclide activity. $^{137}Cs$ measurements in surface sea water are <12 Bq/m$^3$, while in bottom sea water they range from <1.5 to 11.0 Bq/kg. Levels in bottom sediment are the same as in bottom water.

$^{60}Co$ was detected in bottom sediments only near Chazma Bay. In the western strait of Strelok Bay, $^{60}Co$ levels in bottom sediment were 18–66 Bq/kg, a level still below the maximum permissible concentration in the Russian Federation of 150 Bq/kg. In Ussuriysky Bay, $^{60}Co$ concentrations in bottom sediment collected 1–1.5 km from the coast were 2–3 Bq/kg, and <2 Bq/kg 2–2.5 km from the coast. Everywhere else, $^{60}Co$ activity was below 2 Bq/kg.

Slightly elevated concentrations of $^{137}Cs$ (up to 11 Bq/kg) were detected in the northern part of Amursky Bay and close to Bolshoy Kamen Bay, where the shipyard to scrap nuclear submarines is situated. In other areas of Amursky, Ussuriysky, Strekol, and Nakhodka Bays, $^{137}Cs$ activity in bottom sediments was below 4–6 Bq/kg. In the open parts of the Peter the Great Bay $^{137}Cs$ levels were below 1.5 Bq/kg.

Radionuclides from Chazhma Bay are transported rapidly to the open sea. But nevertheless, even these activity levels are below the permissible levels in Russia of radioactivity in bottom sediments.

In conclusion, I am very glad that our workshop, which is called the Japan, Russia, U.S. Study Group, also includes our colleague from Korea, Dr. Hong. I really think that it is impossible to study the North Pacific marine environment radioactivity on the basis of bilateral or even trilateral cooperation. It is possible only using multilateral cooperation. We should take into account not only the Russian dumping sites, but also some discharges of nuclear waste from Japan and from Korea. We should include the dumping sites of Japan and of Korea, and in the near future we should take into account nuclear power plants which probably will be constructed in North Korea and in southern China, near the East China Sea.

As Dr. Boyd demonstrated, the ocean currents move from west to east, to the coast of the United States, and even to Mexico. We should work together. We should not forget Canada either.

Thank you for your attention.

# Process of Studying Radionuclides in the Arctic and the North Pacific
## Limited Availability of Scientific Data on Radionuclide Level in the Pacific/Bering Sea

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My presentation is going to have an Alaska flavor to it. This is always of some interest to our Russian and other international cooperating scientists, because Alaska is so remote from areas of significant radioisotope contamination. The interest of the American program has been focused on problems in Alaska, or potential problems in Alaska, because of the areas along the west and north coast of Alaska, where there are subsistence communities of people depending on local food resources. The concern of those people, when these revelations of wide-scale dumping came out, has really been the emphasis for the whole program of Arctic radioisotope contamination research funded through the United States.

An article in the *New York Times*, which people who are interested might read in order to learn about this problem, was buried in the back of the paper. In Alaska, it was front page news in the Sunday *Anchorage Daily News*. So it is something that people in Alaska are very concerned and well informed about. The Alaskan Natives have been hassling the American Government about radioactive waste that was left at Point Hope, some thirty years ago. It is actually a relatively small amount of material. But they are very well informed, and whenever I've been up there, we are always being asked, "What have you found; what can you tell us?"

I want to start with the Laptev Sea, north of central Siberia, to discuss some iodine-129 ($^{129}I$) data (Fig. 1). $^{129}I$ is of interest because it has a very long half-life, 15.7 million years. It is a common byproduct of nuclear fission, so there was some contributed by nuclear testing. It is also a common component of nuclear waste. The advantage to measuring it is that it travels thousands of kilometers in seawater because it is soluble. It is concentrated by biological organisms, so we do see some elevation of $^{129}I$ in surface layers, but what I want to call your attention to is the increase in deep water at about a thousand meters. The units in Figure 1 are in hundred million atoms per kilo of seawater. This, because it has such a long half-life, can't be counted. It is a rather expensive process of analysis. We are grateful, at my lab, to Tom Beasley, Department of Energy, Environmental Measurements Lab, New York, for helping get these numbers. These water samples that were collected at this step, from the Laptev Sea, have a salinity that is characteristic of water in the Barents and North Atlantic, suggesting that this $^{129}I$ came from North Atlantic sources, whether Sellafield or French, it is hard to define the answer. But the content of $^{129}I$ in these samples suggested a North Atlantic Ocean origin in terms of the salinity structure. In Figure 1, the amount of $^{129}I$ at the depth 0 m is around 6 or 8, or close to a billion atoms of $^{129}I$ per kilo of seawater.

Figure 2 shows some data from four different locations. Included are Laptev Sea data from Gi Hong of the Korea Ocean Research and Development Institute. There are data from the Beaufort and Chukchi Seas (close to Alaska), then the Bering and Chukchi Seas from very shallow water. These are continental shelf sediments. Because of the biological concentration of iodine in surface sediment, I am not sure what to make of these numbers. It might be interesting to everyone, actually, that this sample with the highest $^{129}I$ that we have been able to identify

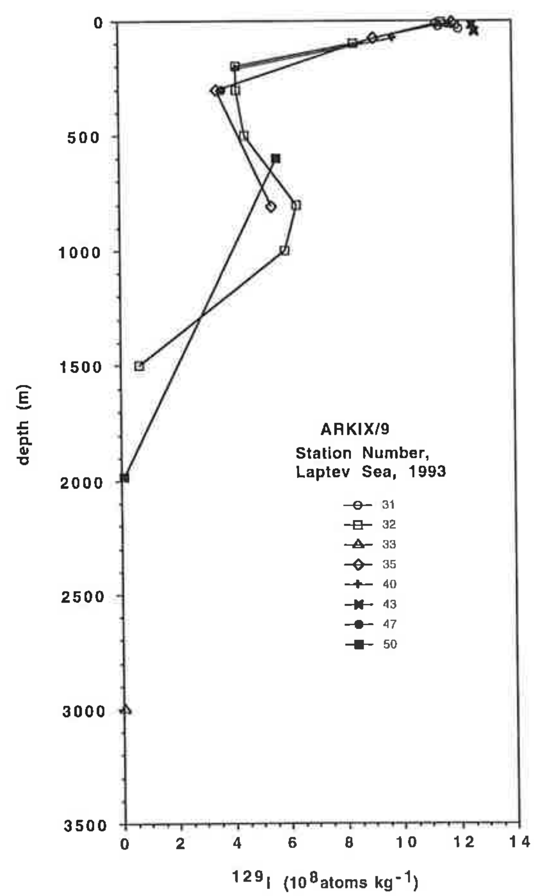


*Figure 1. Iodine-129 in the Laptev Sea.*

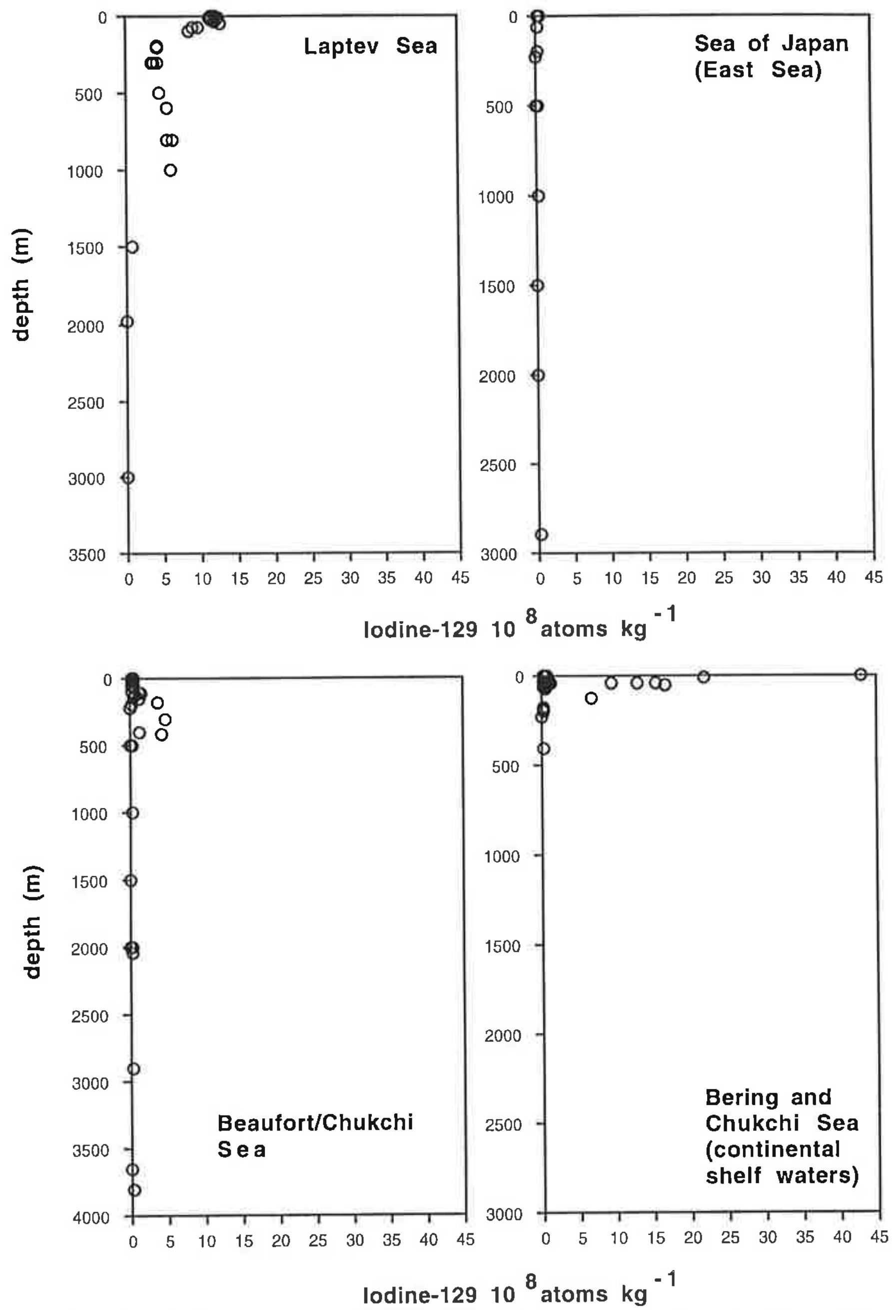


*Figure 2. Iodine-129 in the Laptev Sea, the Sea of Japan and the Beaufort/Chukchi Sea.*

was collected at Adak Island, which is a U.S. Navy base. We think that the reason for this is that there is a lot of marine algae at this location that concentrate iodine out of the seawater and, in turn, release it.

Anyway, very interesting data, but what has been interesting to us is that the high level from the Laptev Sea, in what is essentially Atlantic Ocean water, and in the Beaufort and Chukchi Seas, within a hundred kilometers of the coast of Alaska, appears to have what we think is a Sellafield signal. So $^{129}$I that originated in the Irish Sea has gotten all the way to Alaska, although you can see it has been very well diluted by the time it gets there.

Let me switch gears and talk about cesium. I am going to use units of becquerels (Bk). For the nonspecialists here, a Bk is decay per second, and it is the new unit versus the curie that has been used in the past. But it makes a little more sense than a curie, and I give you a conversion there in terms of number of Bk per curie. I might mention that Dr. Hong has been very cooperative in sharing data with me, also, and so I have the same data that Dr. Tkalin presented. What I want to call your attention to are the numbers in the Bering Sea and their comparison to the Sea of Japan, or East Sea as the Koreans prefer to call it. Figure 3 shows values there, in mBq/kg of cesium-137 ($^{137}$Cs), are all less than about 5. In the Bering Sea, numbers range from about 1 to 3 mBq/kg. So the Bering Sea has slightly lower cesium than the Sea of Japan, only slightly lower.

The probable explanation for this slightly lower concentration is simply that atmospheric bomb fallout was lower at the far northern latitudes of the Bering Sea than it was at temperate latitudes, say at the Sea of Japan. Additional data that Dr. Hong

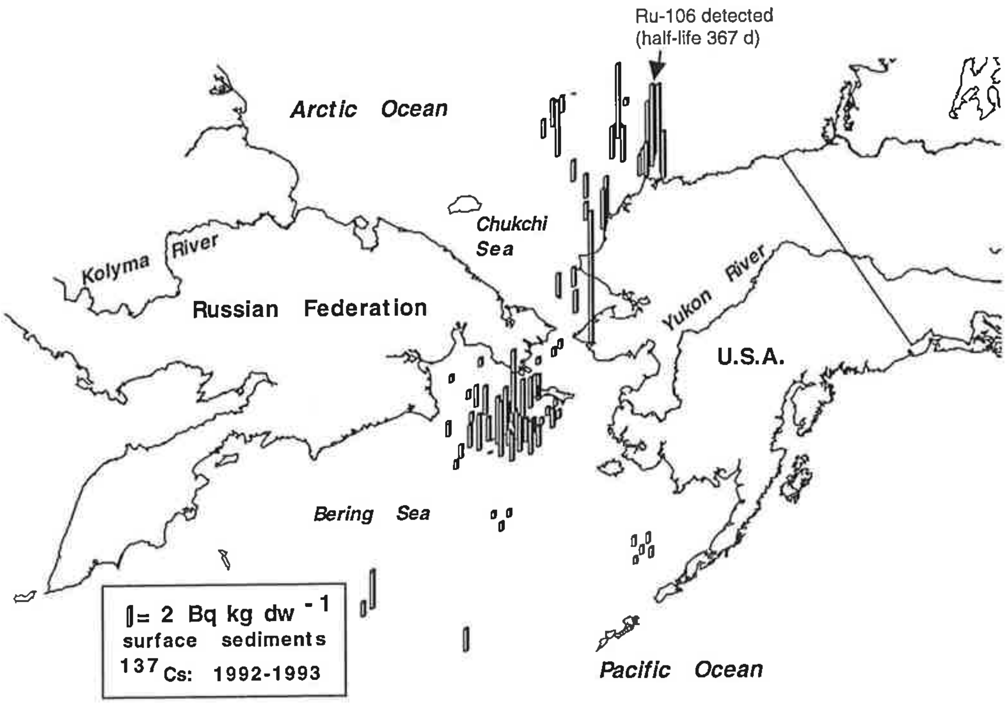


*Figure 3. Cesium-137 in the Sea of Japan.*

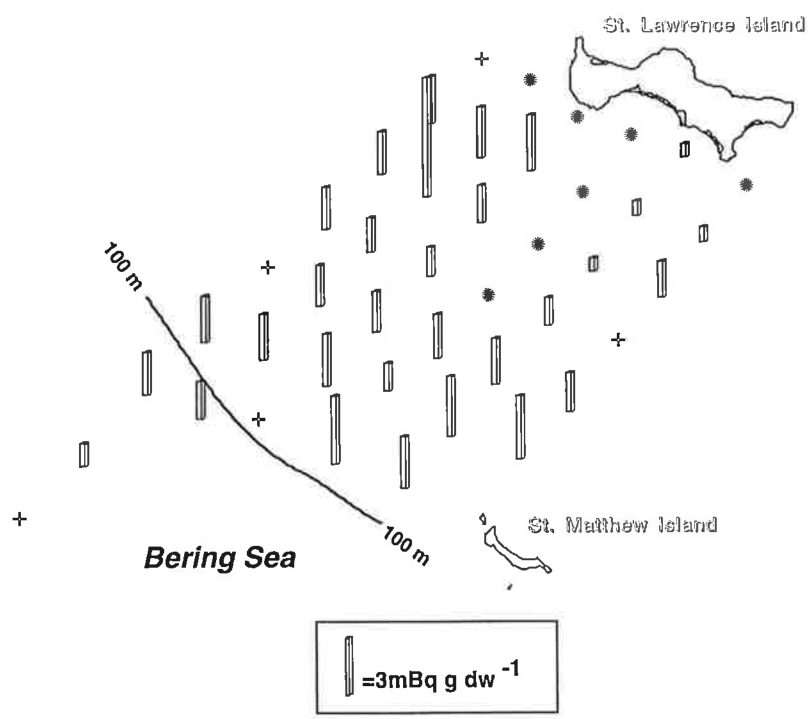


*Figure 4. Cesium-137 concentrations in surface sediments, Bering Sea, June 1993 (mBq g $dw^{-1}$). + = not detected. * = sandy or rocky bottom, unable to core.*

has shared show plutonium values. The numbers, just like cesium, are not enormously high. At sites in the Sea of Japan, values are only a few mBq/L.

Cesium concentrations in sediments in Alaska show some interesting patterns (Fig. 4). The highest concentration, west of St. Lawrence Island, is about 12 mBq/gm dry weight, which is almost exactly the same as the eleven reported in a fluvial environment by Tkalin in the last presentation. The reason for this is that a lot of clay minerals come down the rivers. In this particular location, a real quiet lagoon, where cesium is apparently concentrated, not a lot of biological activity occurs that causes mixing. In the case of all of these other samples, organisms do cause a lot of mixing. We do not have very good coverage of the Western Bering Sea and North Pacific. Biological

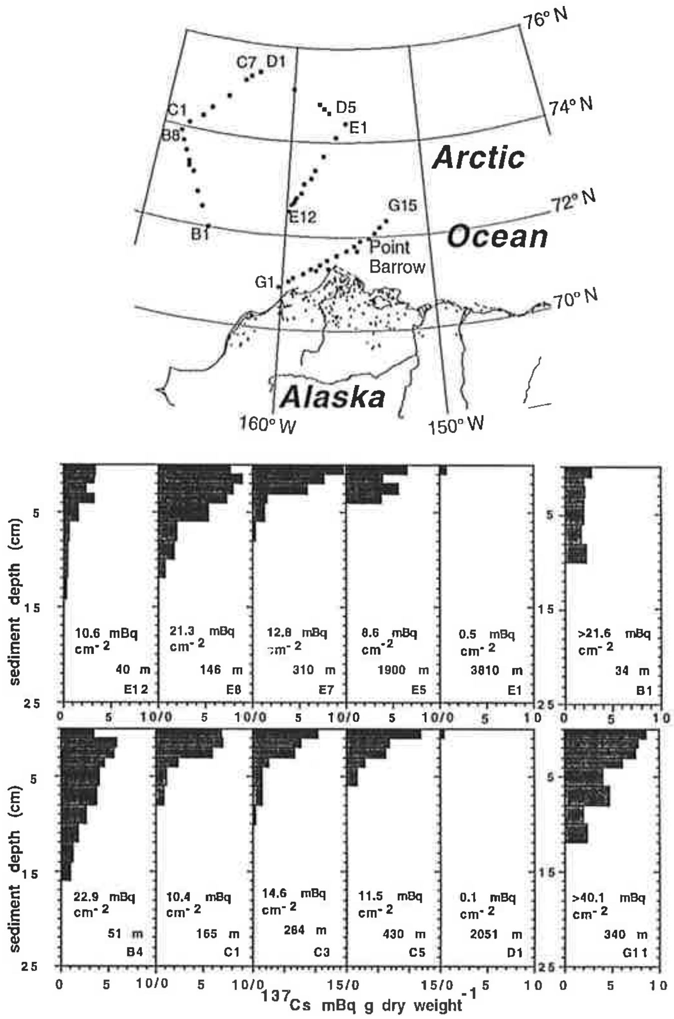


*Figure 5. Cesium-137 in* Polar Star *sediment core samples, August 1993.*

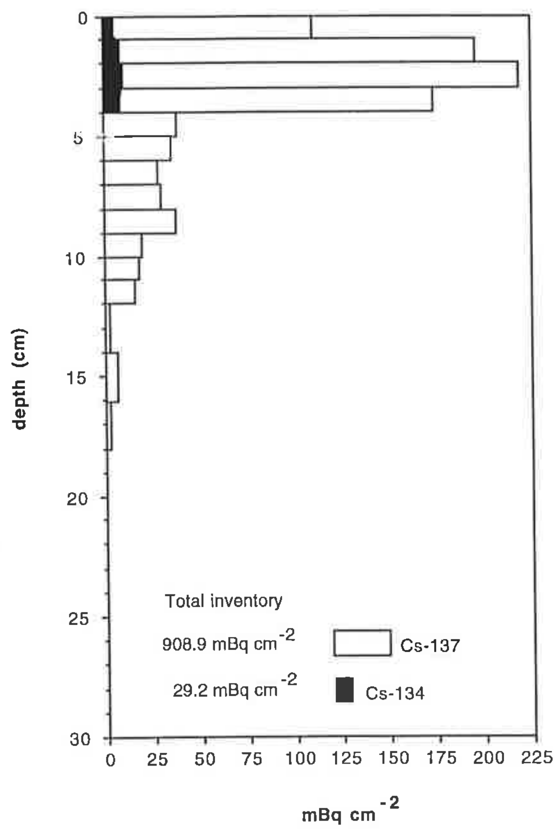


*Figure 6. Cesium in shallow sediments in the Black Sea, March 1993.*

productivity, water currents and possibly contributions from sea ice affect the patterns of all of the cesium in surface sediments.

At a couple of locations south of St. Lawrence Island, locations we have visited in 1990, 1993 and 1994, places where we have a time history of how much cesium has been out there each year, somewhat to my surprise, cesium values are going down faster than you would predict, based on the radioactive decay of this material. It has a 30-year half-life. So you shouldn't be able to resolve a 1993 to a 1994 change, but there is fresh sedimentation of clean sediments coming in. This is an area of high biological productivity, so the material is being mixed up, and that may probably be the explanation for the significant decline. Since we are scientists, we like to prove this, so we did some statistics that show statistically that there has been a decline in cesium in this particular area of the Bering Sea between 1993 and 1994.

To conclude, Figure 5 shows the total amount of cesium that was measured in *Polar Star* sediment core samples collected in August 1993. We find really low levels of cesium in these sediments. Values range from almost nothing at 3800 m at station E-1, which is in real deep water, to 10–12 mBq/cm$^2$. So there is not a large amount, it is a continental shelf, to slope, to deep sea transition. That is what the declining core lengths indicate. There are two other stations, one an area of accumulation in Barrow Canyon, that show a decline, that show most of the cesium is on the continental shelf. Those values are about ten to twelve.

Figure 6 shows data from the Black Sea collected in 1993. There, instead of working with 10–12 mBq/cm$^2$, we are working with 90–100 mBq/cm$^2$, and there is also still $^{134}$Cs left in these sediments, which has a two-year half-life. So these isotopes can be dated directly back to Chernobyl. This is probably a good example of a site where there are two orders of magnitude more cesium in the sediment.

Finally, Table 1 shows data on organisms in Alaskan waters. In no case are they extremely high. We do see some subtle indications that there are sources other than bomb fallout that are providing radioisotopes and are generating contamination close to Alaska, but it is all very clean relative to most of the rest of the world.

Thank you.

**Table 1. Anthropogenic radioactivity in selected marine invertebrates from Alaska waters.**

| *Organism* | *Region of collection* | *Year of collection* | *Isotope detected* | *Activity ($mBq\ g\ dw^{-1}$)* |
|---|---|---|---|---|
| Mixed bivalves | St. Lawrence Is. | 1990 | $^{137}Cs$ | 0.1 |
| *Macoma calcarea* | Gulf of Anadyr | 1988 | $^{137}Cs$ | 0.5 |
| Walrus (liver) | Bering Sea | 1991 | $^{137}Cs$ | 0.6 |
| Mixed bivalves | St. Lawrence Is. | 1990 | $^{137}Cs$ | 0.9 |
| *Macoma calcarea* | southeast Chukchi Sea | 1988 | $^{137}Cs$ | 2.4 |
| *Macoma calcarea* | southeast Chukchi Sea | 1988 | $^{241}Am$ | 2.9 |
| Ampeliscid amphipods | north of St. Lawrence Is. | 1986 | $^{137}Cs$ | 3.3 |
| *Macoma calcarea* | southeast Chukchi Sea | 1988 | $^{137}Cs$ | 4.4 |
| *Macoma calcarea* | St. Lawrence Is. | 1990 | $^{155}Eu$ | 9.4 |
| Oweniid polychaetes | St. Lawrence Is. | 1990 | $^{137}Cs$ | 18.5 |
| Ampeliscid amphipods | southeast Chukchi Sea | 1988 | $^{137}Cs$ | 29.1 |
| Mixed bivalves | St. Lawrence Is. | 1990 | $^{106}Ru$ | 33.1 |

# Extent of Dumped Nuclear Waste Contamination in the Sea of Japan

*Minister Yukiya Amano*
Japanese Delegation to the Conference on Disarmament
Geneva, Switzerland

In 1993 the revelation that Russia was dumping radioactive waste in the Sea of Japan became a very serious problem to Japan. I very much wanted this sense of importance of this problem to be shared by other countries, such as Russia, the United States and Korea. Therefore, this study group provides an excellent opportunity to enhance the understanding of this issue among these countries.

From August 1993 to September 1994, I was the Director of the Science and Nuclear Energy Division and was deeply involved in this issue. As I am not a scientist, I would like briefly to touch upon the negotiations side.

Since the Yablokov White Paper was made public in April 1993, the extent of contamination in the sea around Japan has been a great concern for the Japanese government and Japanese people. Just after the Yablokov report was published, the Japanese government made a three-point proposal to the Russian government. A joint expedition was one of the three important elements, together with the immediate ending of dumping, and the supplying and sharing of information about past dumping activities.

During the period from April to October 1993, Japanese government efforts were focused on the implementation of the joint expedition, but the negotiations did not enjoy quick progress. The major difficulties were the choice of sites, choice of expedition vessel, whether it would be a Russian vessel or Japanese vessel, and cost sharing. But among these three points, the first one, namely the choice of sampling sites, was the most serious problem. The Russian side insisted that there be reciprocity. The Japanese side did not accept that principle because we thought that the nature of our dumping was different. However, a breakthrough was achieved during early October 1993 negotiations, which took place in Moscow. The result was finalized on the occasion of the visit of President Yeltsin to Japan.

On October 17, 1993, unfortunately, another dumping event occurred. After the dumping the immediate task that we needed to do was crisis management. I said "we," meaning both the Russian and Japanese governments. After we passed through the most difficult period, the priority was placed on development of cooperation and on construction of waste treatment facilities, rather than on a joint expedition. Still, negotiations on a joint expedition went on quietly. Both sides reached final agreement for a joint expedition in early 1994.

The first joint expedition was implemented from March to April 1994 with the participation of Russia, Korea, IAEA and, of course, Japan. By the way, I am very glad that our Korean colleagues participated in this joint expedition, and I have to note that our Korean colleagues had a very high degree of expertise and were very cooperative.

Coming back to the expedition itself, they took samples of seawater, bottom sediments, zooplankton and other organisms. Preliminary spectrometric measurements showed that in all samples, the concentration of $^{137}Cs$ was very low and did not differ from the global fallout background level. Although this joint expedition did not have high visibility, I think it was very important because it served to create confidence among the participating nations.

In conclusion, I would like to address three points. First, this is naturally a question of science and environment. The Russian monitoring that was done at the time of the dumping in October 1993 showed that there was a slight increase of radioactivity in the dumping area. Fortunately the joint expedition did not find any abnormally high levels. But research and study were not done at every dumping site. We do not know the long-lasting effects.

However, I must stress that the scientific aspect is an important aspect, but not the only one. Secondly, I would like to say that this is a social and political question, and probably a security question too. Japanese fisherman worried very much because they could not sell the fish they caught. The Japanese public opinion of Russia became less friendly because they saw the dumping scene everyday on the TV. I do not think that Russia intended to cause a division between the two countries, but the October 1993 dumping badly damaged the confidence in the region, which was already precarious.

In that sense, it was not merely a question of dumping of one curie. It was a question of confidence among nations that was so miserably damaged by the dumping of one curie. I would like very much for the United States to share our view, because confidence and security in the North Pacific region is naturally in the interest of the United States.

Thirdly, I will not go into details, but this is a legal question. The credibility of the London Convention was at stake. This was a global question, and that is why we wanted to enhance the interest level of all the nations, particularly the members of the London Convention, to this issue.

I would like to explain a little bit about the approach that I made. First, I negotiated with Russia, bilaterally. It involved other countries, but it was very clear that the relationship between Russia and Japan was very important on this issue.

At the same time, when we took action, we wanted it to be done regionally. I mean, the cooperation between Russia, Korea, Japan and hopefully the United States was very important. And thirdly, I took the global or multilateral approach. We raised this issue at the Summit. We raised this issue at the occasion of the meeting of the London Convention, and we tried to solve this question through this three-dimension approach. Having said all of this, I would like to say again how much I appreciate your taking the initiative to convene this meeting.

Thank you very much.

# Preliminary Assessments of the Radiological Significance of Radwaste Dumped in the Seas Adjacent to the Territory of the Russian Federation and Some Problems of Nuclear Waste Management

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Kurchatov Institute, Moscow, Russian Federation

## Introduction

Arms race and nuclear energy producing installations (NEPI) development have resulted in the problem of the management of large quantities of radioactive wastes (RW). Nuclear icebreaker and submarine fleets developed in the former U.S.S.R. required that RW disposal facilities be developed. During the Cold War, that problem was not considered as one of paramount importance. The simplest way to dispose RW was in the ambient seas. Such practice was carried out not only in the U.S.S.R. but in the majority of the countries having nuclear industries.

In the U.S.S.R., dumping in the seas was conducted from 1959 to 1991. In most cases the Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Matter (signed in London in 1972) was violated. Dumping resulted as a result of unpreparedness to develop a special industry for RW management. Design and construction of the facilities for refining of liquid RW (LRW) and compactification of solid RW (SRW) were stopped due to pseudo-economical reasons and the lack of direct danger from seabed dumping.

Clause 50.3 of the Law of the Russian Federation (RF) "On the protection of the environment" (Dec 1991) says: "...Import of radioactive wastes and materials for storage and burial from other countries, flooding, launch for disposal into outer space of radioactive wastes and materials are prohibited."

To study this problem, on January 24, 1992, a Government Commission was created by the Order of President No. 613-rp. The work of the Commission is presented in the report "Facts and problems concerning radwaste disposal in the seas adjacent to the territory of the Russian Federation" (so called "White Paper" [1]).

The objectives of the present report are to:

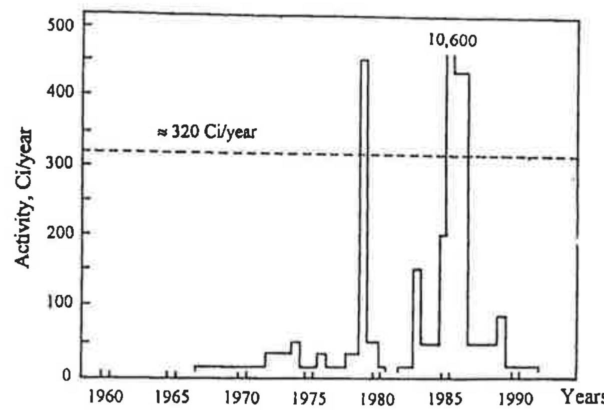
- On the basis of the data of the "White Book," try to assess quantitatively the radiological significance of RW dumped in the seas; and
- Consider some problems concerning future RW management and their solution.

## Waste Dumping in the Seas of RF

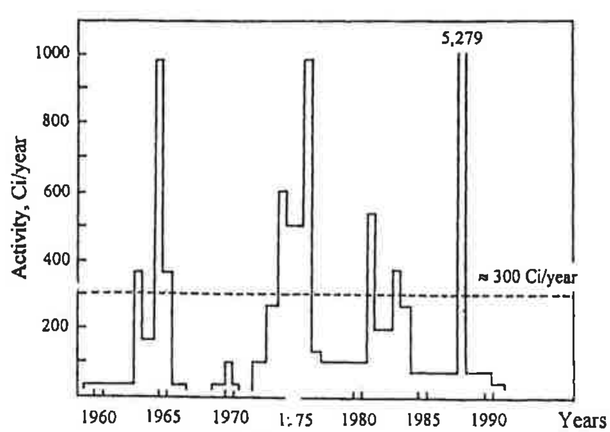
Dumping of LRW was carried out between 1959 and 1991 in five areas of the Northern seas and in ten areas of the Far Eastern seas. Only one of the areas meets the London Convention requirements.

For the period 1959–1991, the activity of LRW dumped in the Northern and Far Eastern seas is shown in Figure 1. The figure shows that the dumping was very uneven. The annual mean values are 300 ci/y for the Northern seas and 320 ci/y for the Far Eastern seas. For the same period of time, it should be noted that the Sellafield recovery plant has dumped 66,000 ci of $^{137}Cs$ LRW per year into the Irish sea.

The activity of typical SRW, consisting of contaminated film coatings, instruments, individual protective means, overalls, fittings, pipelines, activity filters, pumps, steam generators, and other contaminated objects due to ships recovery activities, is shown in Figure 2. As a rule, low- and intermediate-level

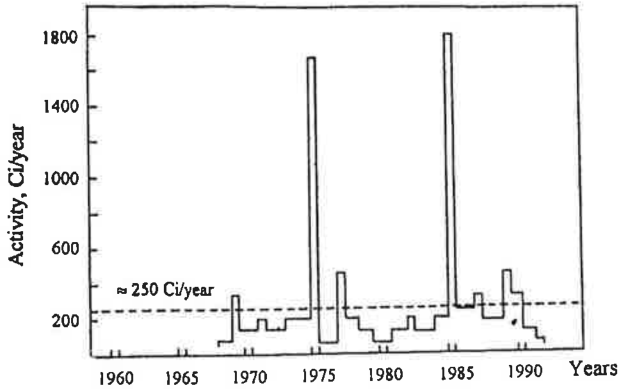



*a. Far Eastern seas.*

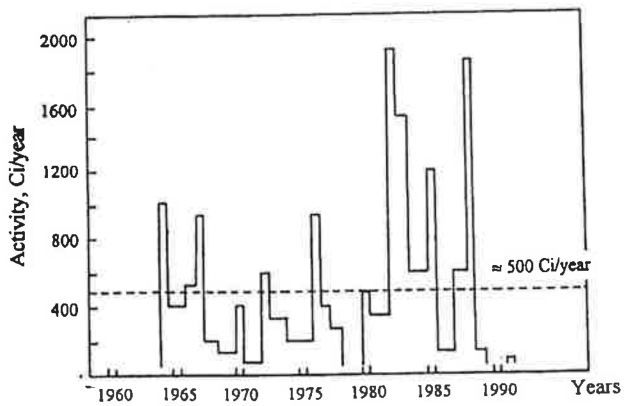



*b. Northern seas.*

*Figure 1. Dumping of liquid radwastes.*



*a. Far Eastern seas.*



*b. Northern seas.*

*Figure 2. Dumping of solid radwastses.*

SRW were enclosed in metal containers (steel - 3, walls 3–4 mm thick). Large-scale RW was flooded separately or stored inside special ships.

The mean annual activity of SRW was 500 ci/y for the Northern seas and 250 Ci/y for the Far Eastern seas. The activity of SRW in the White Paper is presented in terms of "equivalent of $^{90}$Sr." Since the $^{90}$Sr activity in typical SRW of light-water reactors is about 5%, the conventional activities presented above should be multiplied by 20. Therefore, the mean annual SRW dumpings are 10 kci/y for the Northern seas and 5 kci/y for the Far Eastern seas. These activities are much smaller than permissible ones (1 Mci/y [2]). This amount of SRW was dumped in the Kara Sea at the eastern coastline of Novaya Zemlya.

However, the objects containing reactor spent fuel (SF) were dumped in the Kara Sea and are considered to be the most dangerous. As noted in the White Paper [1], one submarine with two loaded reactors, a reactor compartment containing two reactors with the fuel, a reactor compartment containing one loaded and one unloaded reactor, and one submarine reactor containing nuclear fuel were disposed of in the bays of Novaya Zemlya. Also disposed of was the steam-producing installation, OK-150, from the icebreaker *Lenin*. OK-150 contains 125 assemblies with irradiated nuclear fuel. Reactor unloading was impossible in all cases due to accidental active zone conditions. In some cases, the reactor compartments are without fuel but have high inventories of activation products $^{59,63}$Ni and $^{60}$Co, which were dumped too.

In 1994 scientists of the RRC Kurchatov Institute carried out the calculations of the inventory of flooded reactor compartments for fission products, activation products and actinides [3]. These calculations allowed us to make the data of the White Paper [1] more accurate. Until recently the materials concerning detailed submarine construction were secret, so the following approach was applied. The inventory of the icebreaker compartment OK-150, for which all necessary information is accessible, was calculated precisely. The construction of submarine reactor compartments was similarly taken into account for fuel loading and enrichment. Corrections to the fission products activities were linear to submarine fuel real burn-up. Actinoids calculations took into account the inverse dependance of their production rate from specific energy production (excluding $^{238}$Pu), assumed to be a linear function of fuel enrichment (5% of $^{235}$U for OK-150 and 20% for submarines). Such an approach seems to be real enough.

Table 1 summarizes the inventories of long-lived radionuclides in flooded reactor compartments, both containing fuel and without it, up to the present time (1994). The data of Table 1 show that previously published data [1,4] are an order of magnitude higher. This is mainly due to the unrealistic values of burn-up that had been used in previous works. Real burn-up values were 4–10 times smaller.

**Table 1. Long-lived radionuclides activities in nuclear reactors dumped at Novaya Zemlya, 1994.***

| | | *Activity (kCi)* | |
|---|---|---|---|
| *Submarine no.* | *Fission products* | *Activation products* | *Actinoids* |
| | **Six reactors without spent fuel** | | |
| 285 | 17.10 | 0.345 | 0.220 |
| 421 | 7.75 | 0.078 | 0.077 |
| 901 | 19.40 | 0.161 | 0.093 |
| Total | 44.25 | 0.584 | 0.390 |
| | **Six reactors without spent fuel** | | |
| 254 | | 0.256 | |
| 260 | | 0.137 | |
| 538 | | 0.122 | |
| Total | | 0.51 | |
| | **Icebreaker *Lenin*** | | |
| OK-150 | 50.9 | 6.6 | 2.3 |

*Except for submarine no. 601.

The total activity of long-lived radionuclides in the compartments flooded with fuel is almost two orders of magnitude smaller than the activity of loaded reactors.

The comparison of inventories of flooded submarine reactors and OK-150 of the icebreaker shows that the latter has the largest activity among the objects disposed of at Novaya Zemlya. The fission products activity of OK-150 is more than the activity of all the submarine compartments considered. The same is true for the activation products and actinoids.

As it was noted in the Governmental Commission report, there is an estimated 500 years before leaking results in contact beginning between sea water and fuel in compartments treated with furfural-based mixtures. The fuel–water contact will begin in 2400–2500 under such a supposition. At that time, only four radionuclides will still have considerable activity. Those are three actinoids—$^{239,240}Pu$ and $^{241}Am$—and activation product—$^{63}Ni$. Their activities for the icebreaker compartment are 310 and 150 ci, correspondingly.

It should be kept in mind that there is no information about whether the reactor of submarine no. 421 was filled with the furfural-based mixture. If it was, the container enclosing this reactor may become the main source of radionuclides released in the Kara Sea in the future.

To assess the radiological danger of the burials in the seas, the following information is necessary:

- Radionuclides inventories of all objects flooded;
- Corrosion and radiation destruction rates of solidified furfural-based mixtures that were used to prevent the early contact of radionuclides with the water;
- Release rate of radionuclides from flooded reactors under real conditions at the place of dumping;
- Hydrogeological and geochemical features of marine environment: bottom sediments thickness, height and velocities of the rise and fall of the tides, streams directions and velocities, etc.; and
- Bioproductivity of the Kara sea areas, marine products intake by coastal population.

It is clear that in every case the determination of the parameters is a difficult and prolonged task.

There is a model developed by the IAEA [2], where permissible activities for basic radionuclides dumped into a hypothetical ocean of 1017 $m^3$ volume are assessed. The main features of the model are:

- The place of dumping satisfies the requirements of the London Convention;
- Release rates are constant for 4000 years;
- The container with RW is tight for 10 years. Radionuclide consumption begins 3 years after the release outside the container;
- Bottom sediment absorption is ignored;
- A concentration coefficients model is used instead of a dynamic one; and
- All radionuclides are assumed to be soluble and aerosols being formed are the most dangerous due to inhalation.

Hydrologic characteristics, food chains and marine products intake were taken as average statistically. Release rate limits under such conservative suppositions are for $^{239}Pu$: 92,000 ci/y, for $^{240}Pu$: 300,000 ci/y, for $^{63}Ni$: $2.3 \times 10^7$ ci/y, etc.

Burials described above do not seem to be dangerous concerning human irradiation by standard ways: contaminated products intake, evaporated aerosols inhalation and external irradiation. Most likely, accidental contact with individual high-radioactive items may be due to diving activities or storm transportation. These would be the most dangerous, as the bays near Novaya Zemlya are shallow. For example, an unknown metal object, having a surface dose rate of about 100 rem/h, was found on the shore of Ambrosimov Bay in 1984.

At present it is not possible to assess the influence of disposed waste on the marine ecosystem and biocenoses, although this problem seems to be urgent.

**Rate of RW Origination**

Every year 20,000 $m^3$ of LRW and 6,000 t of SRW originate due to the exploitation of submarines and ships having nuclear reactors [1].

LRW consists of:

- 70% of low-salinity releases of loop waters and waters from loops washing; specific activity $10^{-6}$ ci/L;
- 15% of waters from special sewage systems of the sanitary sluices, laundries, decontamination stations and radiation protection laboratories. The waters are saline and contain detergents; specific activity $10^{-9}$ ci/L;
- 15% of wastes from loop decontamination, waters of spent fuel ponds and others. Those are the most active LRW; specific activity $10^{-3}$–$10^{-2}$ ci/L;

Therefore the rate of LRW origination may be up to 30 kci/y.

Ion-exchange resins being used to purify loop waters, residues of filtration and concentrates in the evaporators have the largest activities among SRW. Such wastes result from reactors and spent fuel pond exploitation. These are wastes with an intermediate level of activity (10 ci/$m^3$).

The next correlation between the wastes of low and intermediate levels of activity (LLW/ILW) are typical for light-water reactors [5]:

LLW/ILW 4 in weight;

LLW/ILW 0.01 in specific activities.

Metal wastes (LLW) are about 30% by weight of all SRW. Therefore, ILW activity (assuming an average density of 1 t/$m^3$) may be up to:

$6000 \text{ t/y} \times 0.7 \times 1/4 \times m^3/t \times 10 \text{ ci}/m^3 = 10 \text{ kci/y}.$

Similarly the value for LLW may be assessed as 500 ci/y.

Certainly such estimations should be considered as only order-of-magnitude assessments.

**Problems of Decommissioned Submarine Management**

If a submarine is decommissioned, nuclear fuel must be unloaded from the reactor, decontamination done, equipment dismantled for future utilization, and reactor compartments cut out from the submarine body and disposed of in specially equipped ecologically safe places for storage or burial. The most urgent problem is unloading of spent fuel from the reactors and its subsequent disposal. This question causes much anxiety but it is solved in principle; the problem is the special container production and dispatch to the recovery plants by the railways.

Let's dwell upon the question of reactor compartments management. Maximal time of submarine operation is 20–30 years. Currently the terms of operation have expired for 121 submarines. By the end of the year 2000, this number is expected to be about 150. Having been decommissioned, a submarine is stored for 3–5 years. The core is unloaded and the primary circuit coolant and content of coolant filters are removed. After those operations the activity of some elements of the reactor compartment is $10^{13}$–$10^{15}$ Bq, 90% of long-life radionuclides are found inside the reactor body [7]. Transuranic elements in the primary circuit may have activity up to $4 \times 10^{10}$ Bq.

Figure 3 shows the area of dose rates at the external surface of the reactor compartment versus time. The use of the reactor

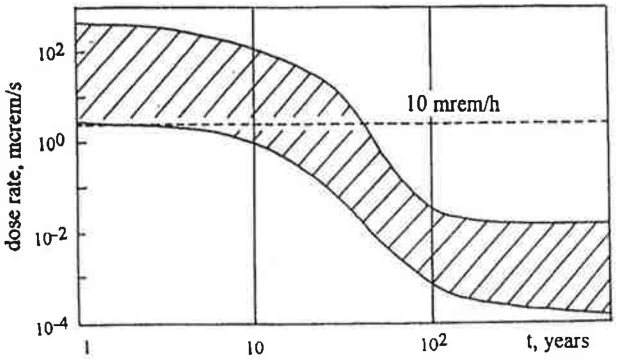



*Figure 3. Area of expectable dose rates at the external surfaces of the reactor compartment.*

compartment as a transport container requires a dose rate at the external surface of 10 mrem/h [8]. At that rate the time of exposure will be 30–40 years. It has to be taken into account that the weight of the reactor compartment is about 1000 t and the typical size will be 6 m. Extraordinary containers are needed to transport such large things. Besides, the average specific activity of the metal of the compartment is 105 Bq/g and does not allow its recycling.

## Conclusions

The analysis of conditions, volumes and activity of the RW dumped in the seas of the RF shows an insignificant radiological influence on the population. The question of influence on the marine ecosystem requires further consideration.

Taking into account volumes and activities of existing RW and RW being originated from submarines decommission, and the legal prohibition by the laws of the Russian Federation against the further dumping of waste in the seas, new problems of waste disposal will arise. The quest for new forms and extraordinary solutions is needed preferably for the safe disposal and/or on-site burial of waste.

Now that the Kurchatov Institute is actively seeking ways of waste disposal and methods of remediation for nuclear facilities. We are interested in international cooperation in which the potential of the Kurchatov Institute could be united with the modern west technologies. At the present time, for example, the Institute studies the possibility of the PTC (Plasma Technology Corporation, USA) technology of plasma treatment of the waste in-situ implementation [9,10], after appropriate testing has been done.

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# Building and Operating Atomic Vessel Units in the Former Soviet Union

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Department of Naval Reactors, Minatom
Moscow, Russian Federation

The theme of my report may sound a little unexpected to you. I would like to tell you of my experience in building and operating atomic vessel units. The units that I am talking about are responsible for the problems that we are considering today at our meeting.

Russia has amassed a vast and unique experience in operating and building atomic vessel units. Actually, Russia has monopolized the field of civil atomic shipbuilding. There are two major types of Russian atomic surface vessels: container ships (lifter carriers) and icebreakers.

During the 35-year history of operation of our atomic ice breakers, there was not a single situation when their operation had to be stopped. The second point is that up until now we have built more than 450 atomic vessel units of different capacity and designation. The experience of operating and building these vessels have allowed us to collect rich material on them and to provide recommendations for their exploitation. The main recommendations are that we think it is quite enough to have one reactor on a ship. We have developed such broad rules of exploitation that now it is quite safe to have only one reactor. The major requirements are concerned with the atomic vessel unit, its reliability and nuclear and radioactive security. Nuclear and radioactive security must be subordinated with the security of the vessel.

Because the usual causes of the accidents such as fire, explosions, and others are much more dangerous than the situations that occurred with the reactors, an atomic vessel unit has to have a hood that will isolate and protect the radioactive waste that can exist in emergency situations. The project has to cover the whole life of the atomic vessel unit. This means that it has to be decided beforehand not only all the rules about the operation, building, and maintenance of the process, but also the procedure that will be taken after it will be decommissioned. We have achieved positive results where we can project everything for the atomic vessel unit up to its decommissioning.

The most dangerous operation is the process of recharging the fuel. That's why this process has to have detailed prescriptions, and equipment has to be absolutely secure and the personnel operating the vessel have to be of the highest qualification. The modern atomic vessel unit has to be equipped with a technical monitoring system to inform the personnel about any situations that differ from the normal in pressure, temperature, in everything that is connected with the operation of the atomic vessel unit. The atomic vessel unit has to be equipped with training equipment that allows the personnel to train in their operations and work on the vessel. In the exploitation of atomic vessel units, the public has to be informed about the reliability of this kind of ship, and a special information center has to be created and established in the area of exploitation of atomic vessel units. More detailed information about how the first atomic vessel units were built in Russia and are currently in operation can be obtained from previously published reports.

The world has changed greatly and I think that in the future, neither we nor the United States of America is going to build large quantities of submarines. So we have to use our experience in constructing a civilian atomic fleet that can include floating atomic power plants that transfer seawater into drinking water and so on. We have big plans in Russia in this direction and we are open for cooperation in this area. Thank you very much.

# Radioactive Waste Disposals in the Ocean and Their Environment Effect

*Frank L. Parker*
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I feel somewhat like the Wicked Witch of the West, because I may have come to spoil the party, because I am going to present a relatively radical point of view. Since I don't want you to think this comes from purely academic experience, though I don't think that it is a pejorative word, I did run the first integrated assessment of radioactive waste discharges into a river from a large site, that is, the Oak Ridge National Laboratory. I also did the first study of the disposal of high-level radioactive waste into geological disposals.

More particular to this session, I did the study on the startup of the nuclear ship *Savannah*, whether or not it would be safe to start that up on the Delaware River, where it was being outfitted, or whether it should be taken out to sea before the startup. So, my experience is not just at the University.

To give you some indication of the extent of some of the ocean disposal literature, I want to point out that this problem has been with us for a very long period of time. The very first international conference devoted to disposal in the sea, among other problems, was held in 1959. It is amazing at this date to look at who the sponsors were. It was not only the International Atomic Energy Agency (IAEA), but it was also UNESCO and the FAO. I also want to call your attention to the fact that I published a paper in 1960 on this very topic. So, I have been involved for some time. I want to point out that in 1961, the IAEA already had issued a booklet on radioactive waste disposal into the sea. I will not read all of these citations. But it might be also useful to look down to more recent data, and the report that has been referenced already, the Yablokov Report. We must also notice that both the European community and the Nuclear Energy Agency have both done very sophisticated feasibility studies of disposal of radioactive materials into the subseabed and to make the literature complete, if any of you have not seen it, I would highly recommend that you look at it, Dr. Werner Burkhart's edited volume on radiation exposure in the Southern Urals, which deals with the radiation effects of the early discharges into the Techa River and into Lake Karitchi from the Myac Reprocessing Plant.

I think that it is also important to have that kind of historical point of view, but also to have a more general environmental point of view and to point out that we are not putting radioactive waste into a virgin ocean. The ocean itself has very large quantities of radioactive material. There are naturally occurring radioactive materials that are already in the ocean, and basically the sea is awash with radioactivity. I am going to take the liberty, later on, of summing this all up in curies, recognizing full well that all radioactive materials do not behave the same no matter what their radioactive content.

An inventory of the radioactive wastes that have been discharged into the ocean includes the worldwide fallout beginning in the early 1970s, which basically was all of it, and then the discharges, the dumping into the North Atlantic Ocean, plus the Windscale discharges, plus the European Community, the Nuclear Energy Agency Community. To put these numbers somewhat into perspective, if I have made the calculations properly, the Yablokov report indicates something on the order of $3 \times 10^6$ curies, whereas if you take tritium from the fallout alone, you have $10^9$ curies. Of course tritium is a weak beta emitter and is immensely diluted. It is not the same but I want to point out that there are some very big differences between what is naturally occurring in the ocean, what has been discharged by man in the ocean, and what we have from fallout.

I think perhaps to put this into further perspective we should look at the most recent United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) report. UNSCEAR is the most authoritative source that we have right now. If you look at the tables of collective dosage, the effects upon humans, and we can extend that with some trepidation to the effects on the environment, we can see that the things that we have been talking about here and will continue to talk about the rest of today and tomorrow, the severe accidents, nuclear power, and occupational exposures, are trivial in comparison to the natural sources, the medical sources, and the weapons. I might say that the weapons category is somewhat misleading because most of it is going to be due to $^{14}C$. Most of this will only impact us in the far distant future because it will be recycled so often.

We need to look at what does one do with this kind of data. I want to just say a word about risk assessment methodology. This is familiar to many of you here in this room, but at the risk of repeating it to people who know, but I think there are some people here who may not be familiar with this. I am using the risk here in the very narrowest technical sense, that is, the ability of an event, times the consequences of an event, and in this case for ease, we will use only mortality, not look at morbidity. To do that we need to know certain things. The first one, of course, is the source term. How much waste is there, where is it placed, and what it is its chemical form?

Secondly, we need to look at the fate and transport mechanisms. What happens to that waste once it gets into the ocean? Once it gets into the oceans we have to look at how it impacts man and the environment. And then finally, we have to recognize the enormous uncertainty in each of these steps for all of the reasons shown. So, to look at numbers beyond one significant figure is sort of ludicrous because it doesn't mean anything. Our basic knowledge is so poor, both on a conceptual basis and our ability to model our conceptions, and the data available to us, as well as exogenous events which we have no ability to predict.

I want to point out that there are things that confound our ability to do these kinds of risk assessments. And the first, of course, is the solubility. Since I did not have easy access to solubility in salt water, I used the fresh water ones, which will make some difference, of course. We also need to recognize that they will not all be soluble. But when you recognize that the ocean has something on the order of $10^{21}$ liters of water, the dilution of these wastes are going to be very, very large. We also recognize that these wastes, depending upon their chemical form, and the types of sediments available, will partition. Some of the wastes will be attached to the sediments and will not be easily available for transport to man or throughout the environment. But also recognize that these wastes will concentrate in fish and in the invertebrates. So we need to take all these into account in recognizing again that these numbers are very squishy, that these numbers depend upon a wide variety of circumstances, and that when one does risk assessment, one really should be talking about doing probabilistic systems rather than deterministic systems.

There are a lot of mitigating factors. I have tried to point out some of them here which will reduce the kinds of dosages, the kinds of effects, that one will find when these wastes are discharged into the ocean. The first, of course, is this enormous dispersion that will take place. The dispersion both horizontally and vertically, recognizing of course that the vertical dispersion is in general much slower than the horizontal dispersion. But there will be, eventually, uniformity if one looks far enough in the future, one can recognize that all of the waste that we have talked about today, including the solid waste buried on land, will eventually wind up in the oceans as well. But perhaps more importantly is the second item, and that is the chemical dilution that will take place.

With respect to the radioactive wastes that have been discharged into the oceans, if we assume that they are in the same chemical form, that means that we are going to have dilution of radioactive wastes in tens of orders of magnitude. So, the amount that we will ingest of that waste is going to be extremely limited. Not only do we have the stable elements of these radioactive materials, we also have stable elements that compete chemically with those, such as calcium competing chemically with strontium, potassium with cesium, and bromide with iodide. So these all will have the effect of limiting the concentrations that will take place in the biota.

Then finally we need to look at the biological discrimination that will take place. It has been estimated that of all the isotopes, all the atoms in the ocean, that only one in $10^9$ will wind its way up to human food and that at the present time, for a U.S. diet, that approximately 1/1000 of our total intake of radioisotopes comes from marine foods. For a Japanese diet that might be a factor of five higher but not much more than that. So we see that there are a lot of things that are going to prevent the kinds of dosages that one gets from land disposal, from sea disposal.

I think it then is useful to look at the experience that we already have. It is foolish to devise theoretical concepts if we don't have any check with reality. Because of time limitations I obviously have limited this only to curie content, which I recognize is not a very good surrogate for what is really taking place, but I think it does give some feeling for what is going on.

If we look at river disposals, we note at the Hanford site in Washington in the United States, during the height of nuclear weapons plutonium production at that site, as much as 350,000 curies per year were released down the Columbia River. Some of it was transported out into the Pacific Ocean. As a matter of fact, I remember in a 1959 meeting, the Russian scientists had carefully monitored that and could tell us better than many American scientists, exactly what we were discharging into the Pacific Ocean.

I also want to call your attention to the Techa River. The amounts of radioactivity dumped into the Techa River are approximately of the same order of magnitude as that disposed at Hanford. But the composition of those wastes, which was medium- and high-level waste, was very different than the induced activity dumped at Hanford. As a result, as you are well aware, there was mass evacuation along the Techa River, and the direct discharges to the Techa River ceased only with the appearance of these wastes in the Arctic Oceans. We also look at coastal disposal, both at Windscale and La Hague, and as we have heard earlier, most likely the isotopes detected in the Arctic came from Windscale, but again, these are on the order of about $10^5$ curies.

We can look at sea package disposal both from the U.S. and basically the European community. Again in total curie content, this totals about $10^5$ curies. Then we can look at fallout into the ocean, approximately $10^9$ curies. We can compare this with the Yablokov Report of U.S.S.R. disposals, about $10^6$, and then finally compare that with natural radioactivity in the ocean of $10^{11}$ curies. So, you can see very easily that the natural and the fallout curies dwarf all other disposals to the oceans.

I would like to then say what don't we know? Well, first thing, we don't know the future. If I did, of course, I would be across the street gambling rather than being here. We don't know the total Russian releases. But I don't think that is a major factor. We know, basically, the size of their fleet, the size of our fleet, and you don't have to be very much of a genius to back calculate, based on the number of ships, the sizes of the ships, the amount of horsepower required, what the amount of fuel elements that they had to burn to get those ships to go where they want to go, and we could certainly use that as a guide as to what could possibly be there. And then finally, we don't have good data on the environmental impact.

Now, having said all that, what do I conclude? Again, these are my own conclusions and they are based upon general concepts. We need, as I pointed out to you, we need experimental data to verify these conclusions. But having done a lot of work on U.S. rivers and having visited the Techa River and Lake Karitchi, I think they are valid. Again, they are based upon radioactive content alone. As I have pointed out, that is a bad surrogate, but for these purposes it is most likely the easiest one. If we do that, if we take all that information that I have presented so quickly this afternoon, if we take that all into account, one could say that these conclusions are technical conclusions.

I recognize as our Japanese colleagues said earlier today, that there are things other than technology involved. There are political and social aspects of this as well. And based upon that, I think one could say that dumping in the ocean as has been practiced to date, so far from a technical point of view, from an environmental point of view, from a human point of view, is a minor irritant. Secondly, that all the data available, all that I have seen, all the models available, show the dosages to be negligible from ocean disposal. This is not surprising. If one looks, as I have tried to show here, one of the major sources of exposure from terrestrial wastes, wastes that have been discharged on land, solid waste as well as liquid wastes, and as you can see, one of the advantages and why scientists have been intrigued with the concept of using the subseabed for high-level radioactive waste disposal is that there is not human habitation there. Secondly, nobody gets their drinking water there. Third, one doesn't have to worry about inadvertent intrusion. Four, that there is very little food taken from the ocean in comparison to all the foods that we take. And finally, that there is limited external irradiation, some fishing gear, some swimming, etc., but these are all relatively minor.

Finally, from a philosophical point of view, I think it is a mistake to spend scarce money on what I would consider minor technical problems. Speaking again only from a technical point of view, when there are areas within Russia where there is still a considerable radiation impact on the Russian workers, and civilians, and the environment. Not only at Myac, but at Chelyabinsk and Tomsk, and some of the other sites where the radiation effects are palatable, one can actually measure what the effect is on human beings. To spend it on ocean disposal, from my point of view, from a technical point of view, is not very sound. Thank you.

# The Radioactive Waste Crisis in the Pacific Area

*Joshua Handler*
Nuclear Free Seas Campaign, Greenpeace
Washington, D.C.

My comments follow on quite nicely from the earlier presentations. What I would like to do is summarize the situation on land in the Russian Far East, where there are severe radioactive contamination problems and severe waste storage problems which may present a larger problem than the materials dumped in the ocean.

My presentation is based on a trip report I did a month or two ago after spending four or five months working in Russia, and based on several years of working in Russia on these naval nuclear waste problems, both in the Far North and Far East. So what I would like to do with my presentation in a way is give you a geographical tour of the areas that could be problems on land and which may represent a threat to local environments, people in the region, or even the whole region as a whole, if there were some catastrophic event which could lead to serious release of radiation.


*Figure 1. Far East.*

Figure 1 is a map of the Far East. Shore-based sites for the storage of radioactive waste for the Pacific Fleet are located near Bolshoi Kamen in the south. Farther up the coast there are decommissioned submarines near Olga and also around Rybachiy (which is near Petropavlovsk). The Kamchatka Peninsula is the second waste storage site for the Pacific Fleet submarine bases and nuclear shipyards.

Figure 2 is a more detailed map of the area. Spent fuel is stored at various areas, particularly in the Shkotovo region, and near Bolshoi Kamen, which are full. There are several service ships with damaged fuel on board, which the Navy doesn't quite know what to do with yet. Also at these waste sites, there are several burial trenches for solid radioactive wastes, which are in bad condition. And then there are any number of these decommissioned nuclear submarines that have their nuclear fuel still on board. If some accident was to occur it could have some disastrous consequences.

In the Shkotovo region, which is southeast of Vladivostok, are located the main nuclear waste storage site and radioactive waste storage site for the Pacific Fleet, here at the tip of this peninsula, north of Chazma Bay. Here spent nuclear fuel is located before it is transported to Chelyabinsk. There are several burial trenches for solid radioactive waste that contain low-level solid radioactive waste, ion-exchange resins from submarines, and some of the damaged materials from the submarine that had the explosion in Chazhma Bay in 1985.

At the Pavlovsk Submarine Base are two TNTs; these are the liquid radioactive waste tankers from which the Navy is working on offloading liquid radioactive waste. Also located there is one of the nuclear submarine service ships, which is involved in offloading the spent nuclear fuel from submarines. There are 118 damaged nuclear fuel assemblies on this service ship. They have been there since the mid-1980s, and the Navy again faces the problem of how to offload this fuel and what to do with it.

As previously stated, the other radioactive waste storage site for the Pacific Fleet is located in the Kamchatka area. There is no permanent or temporary spent nuclear storage there, but there are several trenches with solid radioactive waste that contain, again, ion-exchange resins, other solid radioactive waste. There is a concern, again, that there is water in some of these trenches and radiation could be leaking out. Also located at this facility is another one of these service ships that are used for offloading nuclear fuel from submarines. It has 37 damaged fuel assemblies on board. And again,

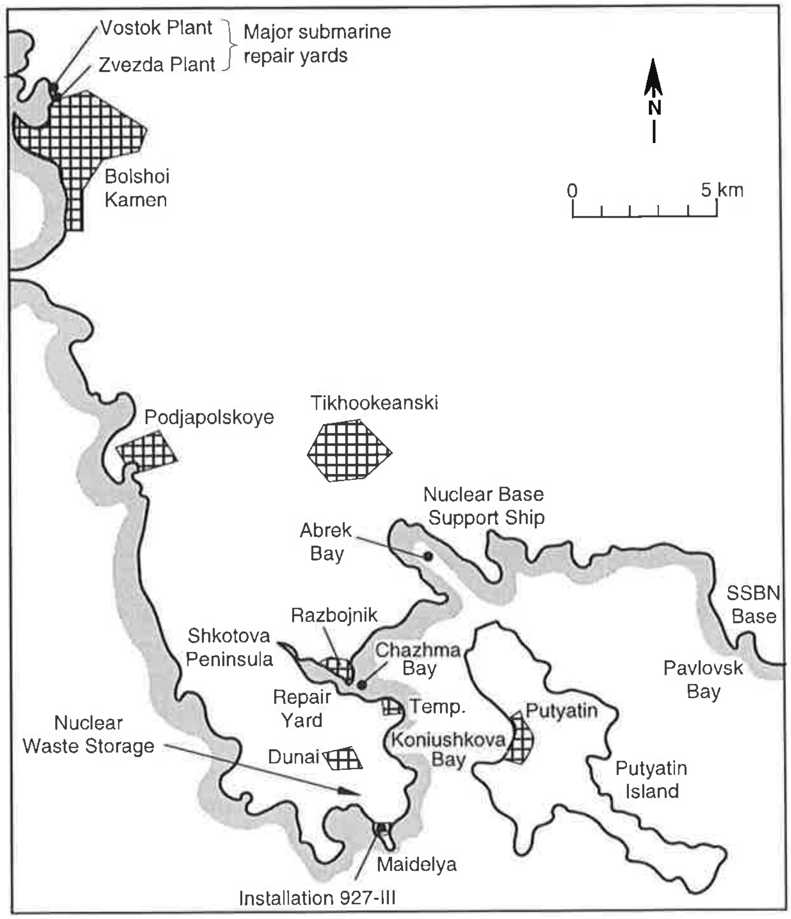


*Figure 2. Bolshoi Kamen area.*

it has been that way since the mid-1980s, is in poor shape, and represents an environmental problem.

One of the things that is of particular concern in the Kamchatka area is that it is a very volcanically active area. As was mentioned in the Conference's opening remarks, there is quite a bit of volcanic activity in the whole Far East, the ring of fire, as it is known. A serious earthquake could crack the burials, leading to a release of radiation into the ocean, since they are right along the shoreline. Already there has been some detection of radiation contamination outside the burial site. In the summer of 1994, in the runoff from the melting snow, some radiation was detected in Seldevaya Bay (Fig. 3) from one of the cracked burials that was leaking.

Returning to the Shkotovo area (Fig. 4), another problem in this region is also at Pavlovsk, where there are three damaged submarines that had severe reactor accidents. The Pacific Fleet isn't quite sure how to offload the fuel from them as well, and they also represent an environmental problem.

Another concern in the area are the decommissioned nuclear submarines which I previously mentioned. There are approximately 50 decommissioned nuclear submarines in the Pacific Fleet. Roughly one-third have had their fuel offloaded. They are found in the Rybachiy area of the Kamchatka Peninsula; in Zavety Ilyicha, which is near Sovetskaya Gavan, north of Olga; at a smaller base called Rakushka on the Shkotovo Peninsula; at Pavlovsk Bay; Chazhma Bay; and at Bolshoi Kamen, which was mentioned earlier, where there is the major refit, overhauling, and scraping plant for the Pacific Fleet.

A particular concern with respect to the decommissioned submarines is the fuel still onboard. It is not necessarily well maintained. There is a possibility that some of these submarines could sink at dockside. Again that would represent some local environmental problems and possibly regional ones.

Another concern about the lack of resources and money when it comes to decommissioned submarines came to the floor recently. In the case of Rakushka (Fig. 4), the lack of funds has meant that the radioecological monitoring station had to be abandoned. So if something serious were to occur, there is not necessarily any specialist on hand that could help rectify the problem and understand what is going on.

In regards with what is being done with the decommissioned subs in the Pacific Fleet, those that aren't lined up along the shore, after the fuel has been offloaded, are slowly being scrapped at the Bolshoi Kamen facility. For example, this is how a reactor compartment from a decommissioned submarine is processed. The reactor compartment is separated out, two submarine compartments on either side are separated out with it, and it is stored afloat.

Some are stored at Pavlovsk in this fashion because the Pacific Fleet doesn't have any land-based facility there. Plans were laid in the mid to late 1980s but they never materialized. So this is the current plan to deal with the decommissioned

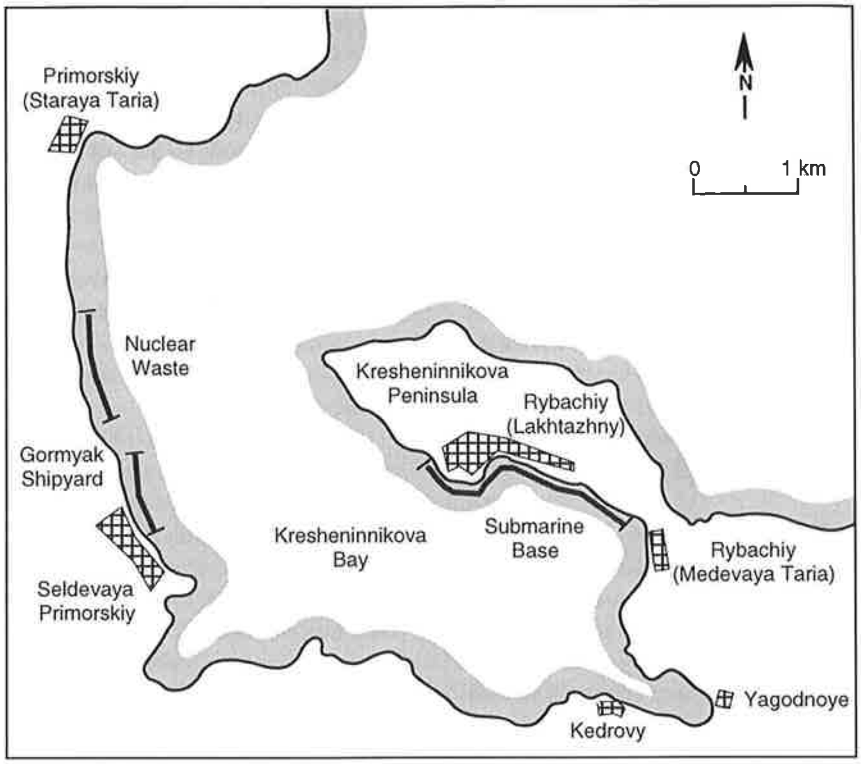


*Figure 3. Seldevaya area.*

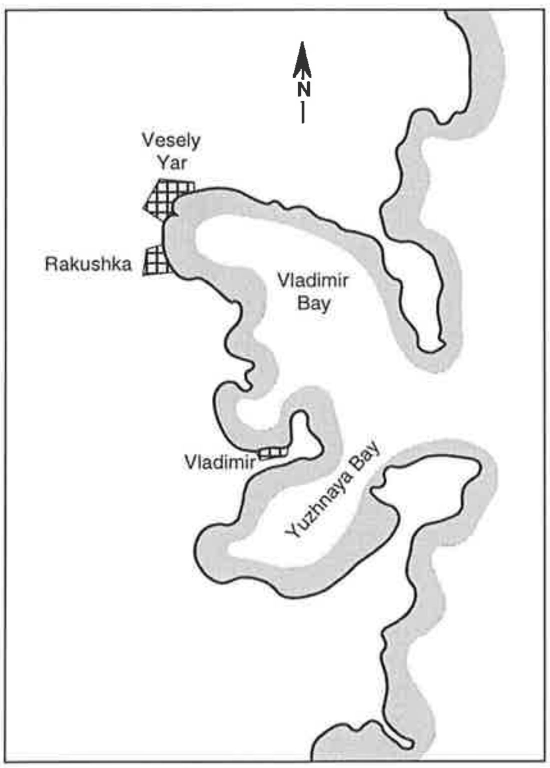


*Figure 4. Shkotovo area.*

submarines until such a land-based facility is constructed. Although those reactor vessels don't have any spent fuel onboard, they are also a matter of concern since the reactor compartments themselves are highly radioactive. This whole area is susceptible to flooding and tsunamis. It becomes a question of whether they are adequately secured or could be washed farther afield.

I won't go into great detail about the Chazhma Bay accident. But again, in terms of catastrophic events that are of concern, that is another issue. During the offloading of spent nuclear fuel, you could have a serious accident that leads to the release of radiation. One of the reasons why spent nuclear fuel offloading is going so slowly is the lack of service ships. As I mentioned, in the Pacific Fleet, two of them have been damaged and two more are basically non-operational. So due to the absence of these ships, fuel cannot be offloaded. If they were offloaded, since the storage sites for spent fuel are full, it wouldn't do much good anyway. There is this tremendous backlog in all aspects of getting the spent nuclear fuel from the submarines.

Some of the problems that need to be dealt with in the land-based side of this problem relate to dealing with spent nuclear fuels, solid radioactive waste, and determining the extent of contamination at these sites.

There are several proposals which I would like to present to insure radiological safety. They are:

- There needs to be some rapid construction of new dry storage facilities for spent fuel, preferably somewhere in the Far East region. Shipping the material to Mayak won't necessarily help out the environmental situation, since if it is stored at Mayak or reprocessed at Mayak, it will only add to the problems in the central Urals region.
- There need to be emergency measures to deal with the two nuclear submarine service ships which have the dam-

aged spent nuclear fuel aboard. This is a major problem if there was to be a sinking of these ships. It would be rather difficult and troublesome to raise them.

- Emergency measures to offload spent nuclear fuel from decommissioned vessels needs to be taken. Perhaps constructing offloading facilities at the shipyards might be the best way to proceed rather than to construct more submarine service ships. The transfer of spent nuclear fuel from the submarines to the service ships is fraught with its own dangers since both platforms are somewhat unstable.
- Emergency measures need to be taken to improve training and the radiation monitoring capability of the Pacific Fleet. Returning to my comments about the situation at Rakushka, clearly the Pacific Fleet is suffering from a lack of resources when it comes to radiation monitoring and training.
- Since it has been very difficult to understand this situation at land-based sites, and there is some evidence and reports of contamination at these sites, as well as at the shipyards and the submarine bases, there needs to be rapid implementation of irradiation environmental survey of these sites, perhaps in the vein of international cooperation that was discussed earlier.
- There clearly needs to be some effort to upgrade the social infrastructure in the region. Living conditions are very difficult. Good specialists are leaving and that is something to be considered, I think, in any degree of any aid package or cooperation.
- There needs to be the construction of a land-based storage site for reactor compartments. Storage afloat is the second-best solution.
- Reduce or eliminate nuclear submarine operations. I mention this in a serious fashion since it is occurring already. Further reductions could also occur which obviously would help elevate the waste crisis in the long term. Reduce or eliminate submarine operations since this obviously would also help reduce the amount of waste being produced.

Question from M. Kokeev: For all the world, or only in Russia?

Handler: Oh yes, all... Let me finish and I will deal with that question, because my final comment is that I view assistance in some of these other questions quite feasible. I think the monetary amount that you mentioned earlier, in your presentation, Mr. Kokeev, was very illustrative. Some 45 billion rubles are needed, that is not so much money, around 15 million dollars (January 1995 conversion rate), to deal with this radioactive waste problem this year. That is well within the bounds of current assistance programs, cooperation programs. But the problem is quite large, and unless more money and better organization is forthcoming, I think the radioactive waste crisis in the Pacific Fleet will be continuing through the end of the century and if not, beyond. So please, in regard to your question, yes, we are in favor of such a global ban.

# The Circulation in the Sea of Japan
## Observations and Modeling Studies

*Lakshmi Kantha*
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University of Colorado, Boulder, Colorado

I am pleased to talk about the oceanography of a region which is of so much importance to the three countries (Russia, Japan and Korea) that are joined in the Sea of Japan, or the East Sea as it is called in Korea. Because of the interchange of water masses between the Sea of Japan and the rest of the Pacific, it is also of interest to the rest of the world as well. I will present a thumbnail sketch of the circulation in the Sea of Japan, simply because it is the circulation that will eventually determine where these disposed radioactive nuclides will end up and in what concentration. So it is of paramount importance to be able to understand the circulation before we make any decisions on what to do with the waste and how to deal with any potential contamination.

There are a variety of data sources that I will briefly describe that can help us understand the circulation. Since data are expensive and by nature rather sparse, it is wise to use numerical models to simulate the fate of radionuclides, as well as to assist in operations that may be undertaken to deal with the problem of any potential contamination.

The Sea of Japan (Fig. 1) is a semi-enclosed sea with three wide ports to the outside world. The southern one is the Tsushima Korea Straits. The others are the Tsugaro Strait and Sawyer Strait. The deep basin itself can be divided into three sections. These are the Japan Basin, the Yamato Basin, and the Ulleung Basin. Shallow areas are rather limited in the Sea of Japan.

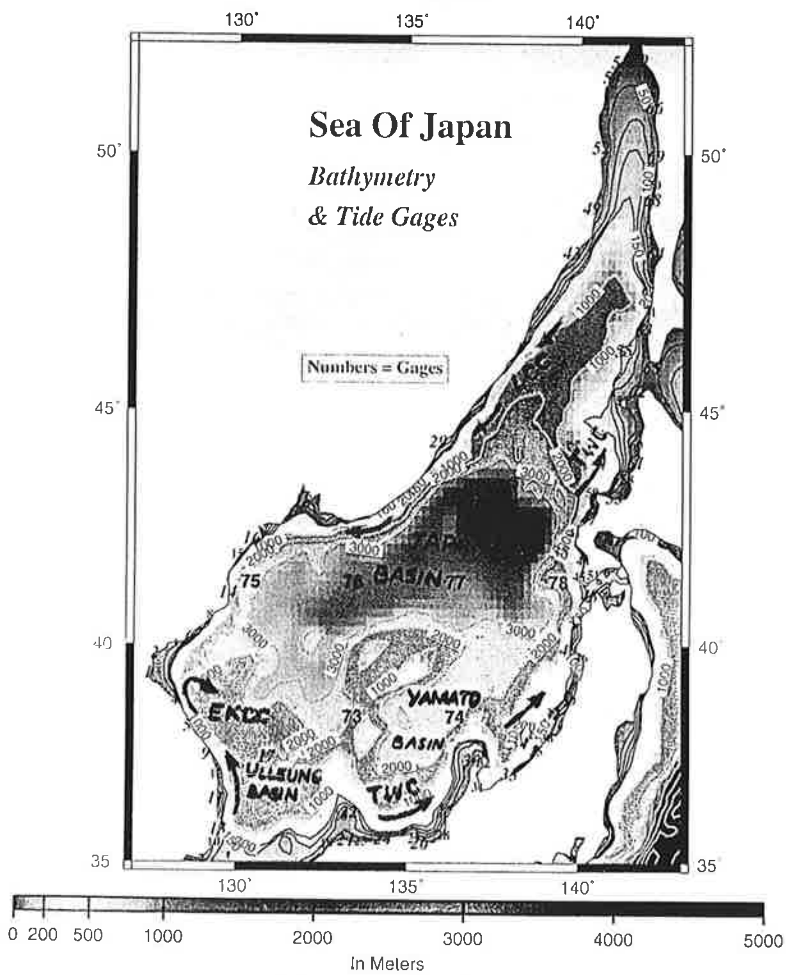


*Figure 1. Bathymetry of the Sea of Japan.*

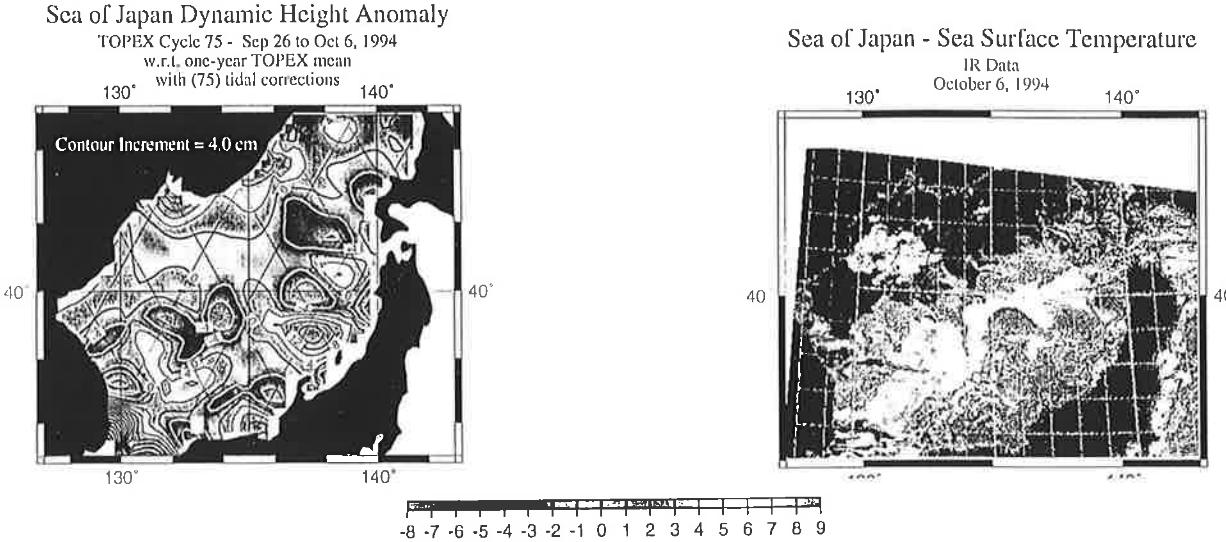


*Figure 2. Dynamic height anomaly and surface temperature for the Sea of Japan.*

When you talk about the circulation in any particular sea, the first thing that occurs to you is what drives it. Of course, winds, heat exchanges, and so on, but there is also astronomical forcing that generates by far the most tidal currents. In the case of the Sea of Japan, the tides are rather small. So, for all practical purposes, we don't have to worry about tidal currents in the Sea of Japan.

The circulation in the Sea of Japan is highly variable. Thermal pattern data from the Advanced Very High Resolution Radiometer (AVHRR) used to map the sea surface show that the structure is very, very complicated. This also confirms that the circulation, in this case the surface circulation, is quite complex as well. If you look at what drives the surface circulation, there is a large amount of water coming through the Tsushima Straits. Additionally, between two to four million cubic meters per second of water comes into the Sea of Japan, and most of it goes out through the Tsugaro Strait, but before going out the current branches into the East Korea warm current and Tsushima warm current which loops around the basin. The circulation is very, very dynamic in nature.

These currents as well as currents off the coast of Russia and Korea all have a role in determining where radionuclides would go if they are ever disposed at the surface. A large quantity of data is needed in order to understand the basic elements of circulation. For example, Figure 2 shows two kinds of data. At the left is a thermal image, while the right shows sea surface bumps and hollows that are obtained from a new type of instrument called an altimeter.

The altimeter essentially measures sea surface height fluctuations. This can be used to tell us essential information about sea surface circulation. These data can be used to understand not just the surface circulation, but also circulation in the water column. Another type of sensor that will be going into orbit soon, funded by NASA, is the color scanner, which essentially detects changes of color of the ocean. This not only tells you what the biological productivity is, but also what circulation patterns look like. So all these remote sensing data will be, or can be, brought to bear on the problem of dumped nuclear waste.

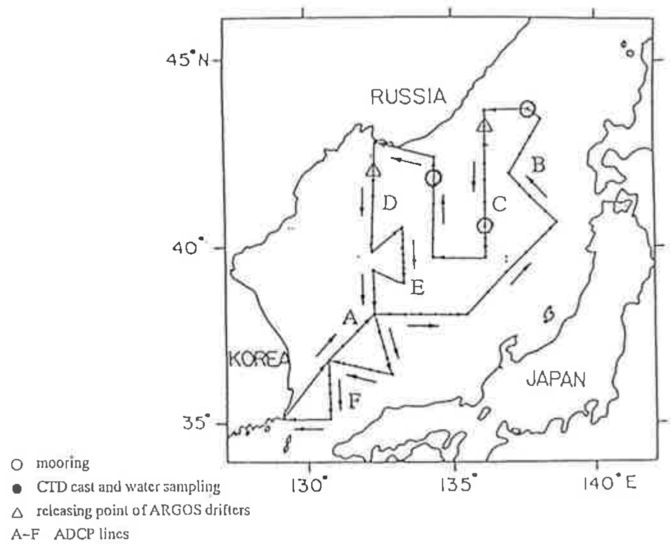


*Figure 3. Cruise track for CREAMS 93.*

Perhaps the most important developments that have taken place in the past few years are the so-called CREAMS programs previously discussed by Dr. Tkalin. CREAMS 93, for example, conducted an extensive cruise in the Sea of Japan. On the cruise track shown in Figure 3, circles represent locations where current meter moorings were deployed. During CREAMS 94, these moorings were retrieved. Figure 4 shows that the CREAMS 94 cruise also conducted extensive investigations throughout the Sea of Japan.

What these CREAMS cruises tell us is that the circulation, even in the deeper depths of the Sea of Japan, is not weak. There is vigorous circulation in these deep water areas. Conditions have been changing in the deep quite a bit from the last cruise that was conducted in the early 1980s.

Figure 5 shows a temperature profile from CREAMS 94 expedition. This plot shows essentially uniform temperatures down in the deep. Another feature of the area is the vigor of the currents. Figure 6 shows current measurements from one

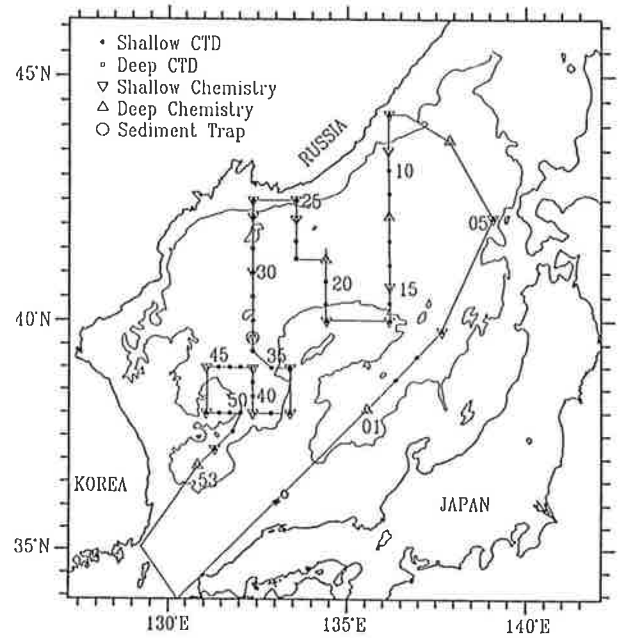


*Figure 4. Cruise track and stations for CTD and hydrocast during CREAMS 94.*

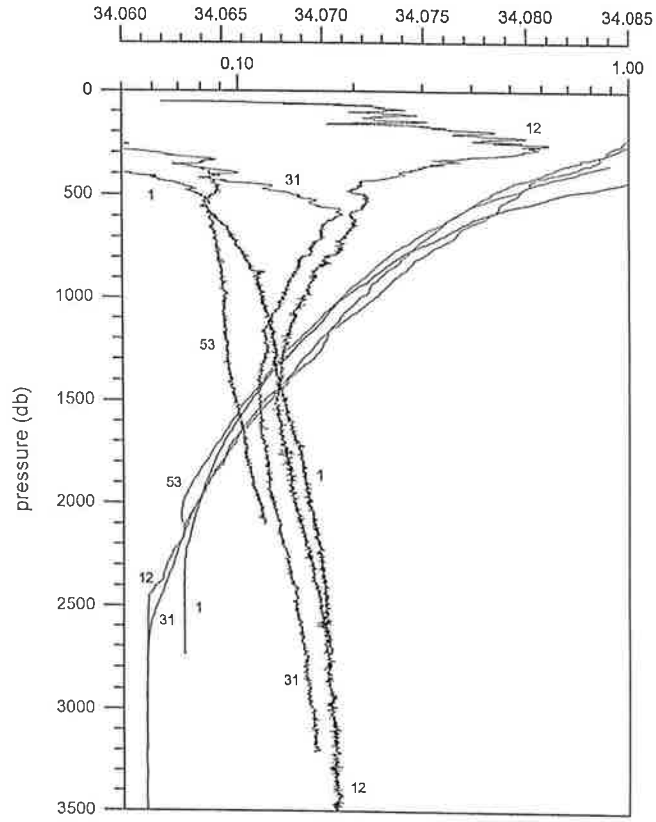


*Figure 5. Temperature profile from the CREAMS 94 cruise (Kim et al., 1994).*

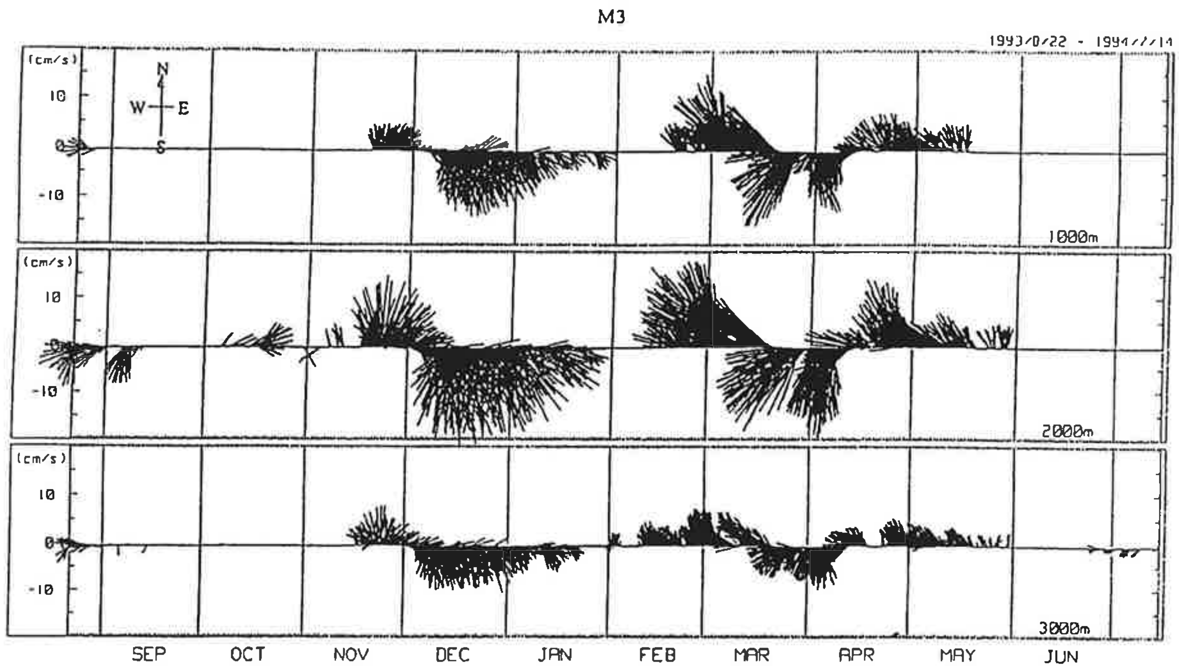


*Figure 6. Time series of current velocities from CREAMS 94.*

of the moorings that was deployed near one of the dump sites. Velocities of this magnitude are somewhat rare in the deep ocean. At 2000 and 3000 m, velocities approach 20 cm/s. This area is one where very vigorous circulation is taking place.

Data collection is extremely expensive, even with remote sensors on satellites. As surface information doesn't tell much about what is happening at depth, it is often essential to supplement this kind of data with something else. I submit that numerical models can be of some help. Reasonable sophisticated data simulation models that model currents can be run with data that has been collected, both in situ and remotely sensed data.

In a manner, that is analogous to weather prediction models.

Their results are closer to reality by assimilation or incorporation of observed data. The same sort of thing is happening in the sphere of the oceans as well, and ocean models have been run with assimilation of data to provide more realistic results. Figure 7 shows Sea of Japan model data for winter currents and temperature at different depths, when the winds are blowing from the west or Russian side at 0.25 m/s towards Japan. At the deeper water depths, vigorous currents occur. This example is only for a maximum depth of 300 m, but I have shown you similar real data for 1000 and 2000 m (Fig. 6). Essentially, this is the sort of information that a model can provide, especially with data assimilation using numerical weather prediction-type methodology. You can now forecast using these types of experiments or simulations. They are useful for operations that might be undertaken to understand potential transport of nuclear waste.

For a long time our knowledge of the circulation in the Sea of Japan was rather primitive. We knew a lot about what was happening at the surface, but not much about what was happening at depth. With the recent initiatives, cooperative ventures of the Koreans, Japanese, U.S. and Russians, undertaking regular cruises in the Sea of Japan, our knowledge of the circulation, especially in deep water, which is very, very germane to the problem of dumped nuclear waste, is increasing rapidly. It is possible to bring both observations and modeling studies, at least, to understand the fate of these radionuclides.

It is very important to pay close attention to the dense water formation for this particular problem. If you are interested just in fronts, for marine tracking and so on, surface circulation might be adequate, but for this particular problem, the deep circulation is crucial. Therefore you need to look at the dense water formation.

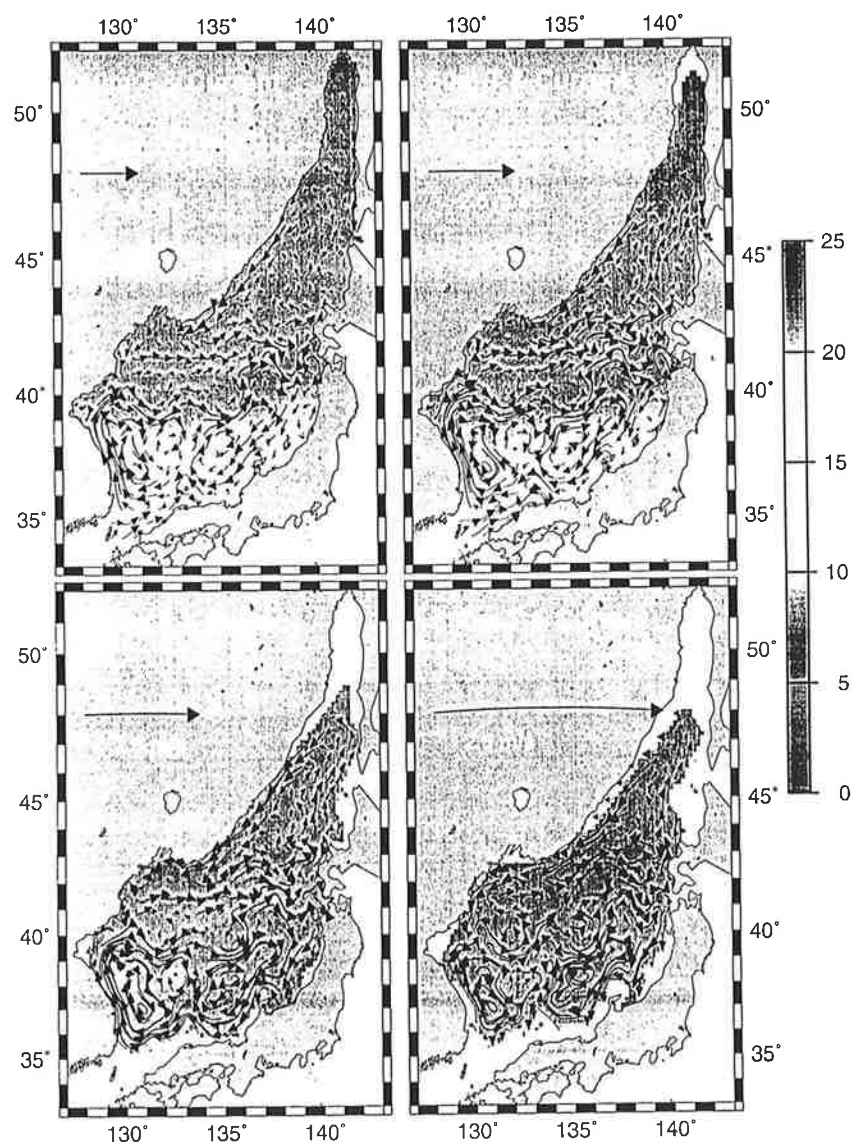


*Figure 7. Sea of Japan model data for winter currents and temperature at different depths.*

# Bilateral United States–Russian Cooperation
## The Activities of the Gore–Chernomyrdin Commission

*Gary R. Waxmonsky*
Environment Committee, Gore–Chernomyrdin Commission
U.S. Environmental Protection Agency, Washington, D.C.

I would like to briefly describe for you the process that has gone forward over the past 14 months that has brought us to where we are today in connection with the trilateral U.S., Norwegian, Russian efforts to upgrade and expand the low-level radioactive waste treatment capacity of the Atomflot facility in Murmansk. I will also discuss very briefly the new Arctic pollution agreement that was signed by the Vice President and Prime Minister Chernomyrdin last month.

A word about the Gore–Chernomyrdin Commission. This structure was formed in the middle of 1993. Vice President Gore was specifically requested by President Clinton to take under his personal wing, if you will, the emerging cooperative agenda with Russia. The Commission originally had, two, perhaps three, committees working primarily in space, energy, and business development. It has then expanded to its current size, seven committees. In addition to the three just mentioned, we now have environment, which is the committee which I represent at the staff level in Washington, science and technology, and health, which is the newest of the committees, and there is also an agriculture committee.

The purpose of the Commission is to identify and address particularly complex issues involving bilateral cooperation—complex in the sense that they are either inherently multidisciplinary and or they involve the cooperation either between public and private sector or within the public sector, cooperation on the part of agencies and organizations that perhaps don't normally work together very well, or sometimes at all. Virtually all problems of environmental policy fall into that category because the environment is inherently a messy concept requiring participation from a number of technical disciplines, scientific disciplines, and ultimately government entities.

The chronology with respect to trilateral U.S., Norwegian, Russian efforts concerning low-level radioactive waste treatment begins in October 1993 with the release of 900 $m^3$ of rad waste by Russia in the Sea of Japan. In November 1993, at the meeting of the parties of the London Convention, the government of Russia stated, I believe in the person of Environment Minister Danilov-Danilyan, that without Western assistance Russia would be unable to formally adhere to the provisions of the London Convention recently adopted at that session banning the ocean disposal of radioactive waste of all levels of activity.

In December 1993, this question of the treatment of low-level liquid radioactive waste in the North of Russia was explicitly inserted into the agenda of the Gore–Chernomyrdin Environment Committee at the third session of the Gore–Chernomyrdin Commission in Moscow. At about the same time, Russia proposed at that Commission session a bilateral agreement focused specifically on the prevention of radioactive pollution in the Arctic. This predated a January 1994 visit to Moscow by President Clinton. At about that time, the U.S. government was presented with the Russian draft. In December 1993, in a concerted effort, the Department of State considered this text in the space of a few weeks and then offered a counter-text of an agreement on radioactive pollution.

The following month, the U.S. received a report from the Russian Ministry of Environmental Protection which basically outlined the nature of problems with regard to low-level liquid radioactive waste in the Arctic and gave some of the empirical parameters of that problem and described in general terms the facility that existed in Murmansk. This report had been discussed at the London Convention session in November 1993. I emphasized that the plant, the Atomflot facility in Murmansk, is the only existing facility in Russia capable of treating low-level liquid radioactive waste, at least in any substantial volume.

In March 1994 the U.S. government decided that a more general Arctic pollution agreement was called for under the circumstances, and the revised draft text was conveyed to Moscow at the time of a Gore–Chernomyrdin Commission executive staff visit to plan the larger environment discussions within Gore–Chernomyrdin. In April 1994 a session of the Environment Committee was held in Washington D.C., where these questions were again discussed, specifically, what it would take for Russia to consider formally adhering to the London Convention, and also some of the technical issues involving the treatment process. At that point the U.S. side, involving Drs. Newstead and Dyer, proposed the convening of trilateral discussions on this question in Murmansk.

That proposal was accepted in fairly short order, and at the end of May 1994 several of us from Washington, as well as two technical representatives from the private sector, traveled to Oslo, joined together with some Norwegian experts, and proceeded to Murmansk. There we had the pleasure of spending several days aboard the nuclear-powered icebreakers and visiting the treatment facility. We also had a number of related discussions. Our visit was certainly an essential and critical first step in this entire process. In April and May 1994 the discussions between Moscow and Tokyo on the processing facility in the Russian Far East also passed a critical point. So the spring of 1994 was a time of considerable activity in this whole area.

In June 1994 the third Gore–Chernomyrdin session was held. At this meeting, an agreement was reached between the Vice President and the Prime Minister that this initiative was sufficiently interesting and important to be included on the agenda for the upcoming summit meeting between President Clinton and President Yeltsin in Washington. At that time we also received a nice letter from a number of American Congressmen, including Congressman Weldon, supporting the initiative.

The following month a meeting was held in Oslo involving Russian, Norwegian, and American specialists, as well as representatives from some other Scandinavian countries. It dealt with questions of radioactive waste management in the Arctic. At that time, we had our first encounter, if you will, on this issue with representatives from a number of important ministries in Moscow that would necessarily be involved if this initiative went forward. The discussions in Murmansk were also interesting in that they involved both representatives of the Murmansk Shipping Company, representatives of the Russian Navy's Northern Fleet, and individuals from the local environmental authorities in the region. Until this July meeting in Oslo, we had not really had an opportunity to engage, in a fairly substantive way, several of the Moscow-based ministries which would subsequently be involved in this effort.

In September 1994, things accelerated rapidly. A team of Russian experts from both Moscow and Murmansk visited the Department of Energy facility located in Hanford, Washington, in the company of the Norwegian specialists. Subsequent discussions were also held in Washington. At that time I had the privilege of being in Moscow negotiating a small statement for inclusion in the Summit discussions with my colleague Chairman Kokeev. That statement was, as he just mentioned, subsequently presented at the Summit meeting. The statement focused on the Murmansk liquid radioactive waste initiative and the larger problem of preventing Arctic contamination from all sources. At the end of September, also through State Department channels, a new U.S. government policy on the Arctic and the various cooperative issues involved in maintaining Arctic environmental quality was announced in Washington.

In October 1994 the Russian government responded to the draft of the Arctic Pollution Agreement which we had presented in the spring. That negotiation continued until early November. At the next session of the Gore–Chernomyrdin Environment Committee in Moscow in November, agreement was reached on the text of this Arctic Pollution Agreement.

This brings us to December 1994 and the fourth session of the Gore–Chernomyrdin Commission in Moscow. There, three documents were actually signed by the Vice President and the Prime Minister. The Arctic Pollution Agreement was one of the three.

In a subsequent visit to Oslo, EPA Assistant Administrator Nitze and I were able to meet with representatives of a number of Norwegian government agencies, including their Deputy Foreign Minister. At that point an oral agreement, and I emphasize oral agreement, was reached that the two countries would jointly fund their share of the cost of the expansion of the Murmansk facility if, and I emphasize if, the study phase produced a positive report in that regard. The study phase has been going on now since the visit. The study phase will be concluded effectively in early February, and we hope a final exploratory meeting involving the three countries will be held among technical experts in Murmansk. Several months afterwards, the study will be finalized and a report will be submitted to the competent authorities in Oslo and Washington. The decision will be reached at consultation with our Russian colleagues on the financing of the upgrade facility. We hope that this will occur by the June 1995 meeting of the Gore–Chernomyrdin Commission, which will again take place in Moscow.

As regards the Arctic Pollution Agreement, I would only say that it is a framework agreement, and those of us in Washington understand that this term means the agreement *allows* us to do X, Y, and Z. It doesn't *order* us to do X, Y, and Z. X, Y, and Z are always dependent upon the availability of funds. But having said that, it does specify for consultation, exchange of data on research and monitoring of contaminant fate and transport in the Arctic, and it also includes a provision to the effect that the parties will consult with regard to technical solutions for the elimination of radioactive and other types of contamination impacts. I would like to think that is what we are about in this Conference this week.

# Russian–Japanese Cooperation in the Safe Disposal of Liquid Radioactive Wastes in the Far East

*Michael Kokeev*
Ministry of Environmental Protection and Natural Resources
Moscow, Russian Federation

Cooperation between Russia and Japan in this radically new area of bilateral relations dates back only one and a half years. Its significance, however, is such that one may safely claim a breakthrough of sorts, leading to a real community of efforts of both countries in resolving problems that affect the vital interest of their populations. Incidentally the genesis of this interrelationship and its progress do indicate a breakthrough. Let us take a glance at the facts.

A White Paper was published in Moscow on April 2, 1993, on the *Facts and Problems Relating to Radioactive Waste Disposal in Seas Adjacent to the Territory of the Russian Federation*. This is the only publication of this sort, unfortunately, to date. The White Paper outlines an objective picture of Russian liquid radioactive waste disposal at sea, in particular the Far East. It declares as unacceptable perennial Soviet practices in this field, and proclaims a strategy toward a complete stoppage of such disposal at sea, in close cooperation with other interested countries.

Remarkably, Japan was to be the first country which espoused a practical, rather than a declarative, solution to the problem. On April 9, 1993, a week after the White Paper appeared, the Japanese suggested the creation of a new mechanism for a Russo–Japanese side partnership, a joint bilateral working group on safe nuclear waste disposal. Within six days the Foreign Ministers of Russia and Japan officially approved the establishment of such a group, and by May 1993 it held its first session in Moscow. An announcement was made there that Russia a) ceased dumping solid radioactive waste at sea, and b) was elaborating a State program for radioactive waste disposal. At that moment an idea was launched also to send a joint scientific expedition to liquid radioactive disposal sites in the Far East.

These very first steps showed that, given political will on both sides, even the most complicated issues were susceptible to resolution, if they were not burdened with politicking but rather approached with professional collaboration in mind. This strategy was affirmed by top leadership of Russia and Japan in the Tokyo Declaration of 13 October, 1993. An intergovernmental agreement was signed at that time on cooperation in eliminating nuclear weapons in the Russian Federation (earmarked for cuts), and on the establishment of a Cooperation Committee for that purpose. Russia's Deputy Minister of Atomic Energy, Mr. N. Ygorov, and the Japanese Ambassador in Moscow were appointed Chairmen of the Committee.

Since then, five meetings of the Committee were held. Among the issues taken up were measures to address the critical situation of liquid radioactive waste in the Primorsky Region and the construction of facilities for waste disposal. An implementing arrangement has been developed and approved between the Committee and the Russian Ministry of Atomic Energy on the implementation of contracts for storage and disposal sites for liquid radioactive wastes. Consequently an international tender was issued, and its results were approved at the very beginning of this month.

The next stage is constructing the facility in the Primorsky Region; its inauguration will make it possible to put a complete stop to Russian disposal of liquid radioactive waste in the sea in this area. It is worth noting that from the very beginning these practical issues were addressed with the participation of all interested Russian agencies and representatives of the Primorsky Region. This allowed for a concentration, albeit a hard one, of varying federal and local interests, and of other organizations involved. This new approach was not easy for the Russian side, but in the end it produced results.

The Russian side did not put all its bets on international support, but simultaneously undertook domestic steps to resolve the problem. The start of the 1994 saw the elaboration of the Program of Priority Measures for Establishing Facilities for Disposal of Liquid Radioactive Wastes in Order to Cease Sea Dumping in Russia's Far Eastern Region. Domestic resources were found with some effort to implement the measures.

In May 1994 the two sides started a feasibility study of a floating facility for processing liquid radioactive wastes in the Primorsky Region, with a capacity of 1.5 $m^3$/hr. At the same time the Russian Pacific Fleet launched a pilot facility for processing liquid radioactive wastes and started the processing of accumulated waste, a contribution to reducing the ecological pressures in the Primorsky Region, and promoting international cooperation.

Thanks to this spirit of partnership with Japan, Russia was able to restrict dumping at sea to a single instance on 17 October 1993, and after the adoption of the reviewed provisions of the London Convention made no discharges of radioactive wastes in the sea whatsoever. As a result, both our countries and the international community stood to benefit.

Russo–Japanese collaboration in this field was never contemplated as a "members only" affair. This was testified by the preparation and execution in the summer of 1994 of the first stage of the Russo–Japanese–South Korean expedition to the Russian radioactive dumping sites, joined by an IAEA official. Its second stage will start tentatively in the spring of 1995, to encompass Russian, Japanese and South Korean dumping sites of radioactive wastes. Such tripartite efforts will continue.

Discussions are being held with the Republic of Korea on assistance in the creation of an infrastructure in the Far East to store and process liquid radioactive wastes. This problem was the topic for consultations with the Republic of Korea (twice), and once with the Peoples Democratic Republic of Korea (PDRK).

A new trend has emerged in the Far East and Northern Pacific for practical cooperation with a view to renouncing the dumping of liquid radioactive waste in the region's seas. One would wish that the non-participation of the U.S., a major Pacific power, is transitory, and it will join a cooperation framework, which has a Pacific, and to a certain extent, an Arctic feature. This cooperation to prevent radioactive dumping in the Far Eastern seas is by no means an isolated example of joint international efforts to resolve the problem. Cooperative action is underway between Russia and Norway, which together with IAEA officials participated in a tri-scientific expedition to radioactive dumping sites in the Northern seas. Collaboration is continuing regarding *Komsomolets*, the sunken submarine, and several environmental projects for the Russian North are being studied.

We should mention another recent event: a cooperative effort by Russia, Norway and the U.S. started several months ago to extend the capacity of a facility to process liquid radioactive wastes near Murmansk. This led to the approval in November and December of totally radically new documents, such as the Russian–American agreement to combat radioactive pollution in the Arctic, bilateral statements with the U.S. and Canada with special attention to cooperation in modernizing an infrastructure in the Russian North for safe storage and processing of liquid radioactive waste to prevent discharges at sea.

These are initial results. They instill hope, though a major cooperative action is still to come. But at least we can say now that the day is not far off when we will witness the total stoppage of sea dumping of radioactive wastes. This will be a day when common sense triumphs, as well as a partnership for a common human cause to realize the right of every person on Earth to live in a safe and healthy environment.

**Additional Comments**

My task is far reaching and very useful. It's not only to present a summary, but to concentrate on ways and means of developing a possible further effort. I think that would be the exchange of data.

Some people spoke about our White Paper. I would stress, especially bearing in mind the expression here, that it is only the tip of an iceberg. But I would like to stress that it's a single iceberg in the northern hemisphere for the time being. There is unfortunately no other such publications which would follow this example, despite some provisions which could be and which are under the process of different additions and details and so on and so on.

I am sure that in the future such a white paper will be the normal procedure for our government. It will not be a single example of doing the things concerning not only exchange of data but the real situation and not only within the border of Russia but internationally.

I think that our second priority is to create by common effort the infrastructure for this in the Russian Far Eastern region and in the northern part of Russia. I would like to concentrate now on the Far Eastern Facility which is underway now. Its capacity will be about 7000 $m^3$.

Now, in full agreement with the Japanese government, we've decided to speed up the development. I would also like to tell you that there is a strong and very good, goodwill participation on the part of the Republic of Korea. We have submitted the list of equipment and measuring instruments to our cooperators, and they promise to give a very specific positive answer to the establishment of the facility.

In February 1995 there will be a session of our joint Russian–Korean environmental committee, held in Moscow. By that I think that the situation shows the fact that the Republic of Korea is joining us in our frantic efforts to establish that facility. I'm sure that this is not only a financial problem. It is a problem of real cooperation, because somebody could give equipment, somebody could give know-how, somebody could give technology, and so on and so on. The arguments of some countries that they couldn't be involved in financial dealings in the Russian region is very difficult to accept.

Secondly we are concentrating on planning our next expedition. The first stage of the expedition wasn't expensive at all. We are now working very hard on the second stage, bearing in mind that it will consist of Russian, Japanese, and South Korean experts as the did the first one, and representatives from the IAEA. It will survey not only Russian dumping sites, but Japanese and South Korean dumping sites as well. In addition to that, we are going to include new Russian dumping sites, which will be explored in much greater detail. We have agreed not to go to areas where there has been no dumping at all, for many years.

Third is technology. In the United States, in Japan, and in every country present here, there is a possibility to involve U.S. technology into the process. Now I am addressing Dr. Waxmonsky, U.S. Executive Secretary for Gore–Chernomyrdin Commission (GCC), that I think this specific project is a very promising one. I believe that processing new nuclear waste with plasma technology probably could be discussed during the forthcoming GCC session. It will help to separate quickly our main problems, both in the Far Eastern region and in the northern part of our country in the most efficient and inexpensive way.

Under our present tasks I would mention also the development of cooperation between our fleets. It would and it could help a lot by training, by exchange of experience, by confidence building. By the way, the confidence building is one of the lessons we learned from our cooperation with Japan and Republic of Korea. It should be, it could be developed step by step, not by jumps, and it in reality it does go ahead.

But I would like to stress one very positive step is the better involvement of the private sector. Because in these fields without private sector efforts, we can go nowhere.

I would like to mention very briefly some protective tasks, among them to broaden further the composition of cooperators dealing with the liquid nuclear waste problem. I mean not people, but countries like France, and like Great Britain in conjunction with the North Sea waste situation we discussed yesterday. Greenpeace also needs to take part in the education of people according to the GLOBE program adopted now by the Russian general assembly and in our cooperation with the U.S.A. and in other bilateral cooperation.

Then, the perspective task, following our joint Russian–American statement adopted during the previous session of the GCC, is to reflect on the possibility of stopping dumping from all sources.

Please think over what this means. Because somebody could say that the dumping from nuclear power plants, for example, is not bad at all. But nobody could prove that it's a healthy and a very good solution for our future generations. And then, I think that it would create in the near future a big territory for our joint efforts to clean up the Arctic region. With the Arctic region as a beginning, we could go further, to clean up the Earth. This clean Earth would be a very good picture to give to further generations. So probably next time during our meeting we could elaborate a little bit more not only on the present situation, but on the near, the far near, and far future developments in this field. Thank you very much.

# The Common Agenda for Cooperation and Global Perspective
## The U.S. Perspective

*Kathy Walz*
Office of Oceans and International Environmental and Scientific Affairs
U.S. Department of State, Washington, D.C.

The Common Agenda for Cooperation and Global Perspective was formed in July 1993. It is part of the Japan–United States framework for a new economic partnership. Under the Common Agenda, Japan and the United States are joining together to respond to some of the world's most pressing global challenges. In the Common Agenda's eighteen-month lifetime, our two governments have begun to make its promise a reality, designing and implementing nineteen Common Agenda initiatives.

I'd like to take a few moments to describe the Common Agenda's process more fully, particularity as it relates to Russian liquid radioactive waste dumping. The Common Agenda is a bilateral mechanism and was formed in recognition of the fact that Japan and the United States share a breadth of issues beyond those that are merely economic in their basic nature. These are interests that we believe are significantly advanced by enhanced regularized policy dialog.

The process initiated under the Common Agenda is quite innovative as it relates to the environment. It establishes regular meetings for the very purpose of policy coordination and cooperation without identifying any particular project necessarily or any joint accomplishment. On a practical level, the Common Agenda establishes meetings involving a greater policy working level depth then might otherwise be the case. It also affords us a new mechanism for raising an issue within our respective bureaucracies and driving that issue to a decision.

The issues considered under the Common Agenda span a very wide range of regional and global issue, although in some cases they are strictly technical in nature and are limited by lateral matters. Now after only one and a half years' experience, the Common Agenda is continuing to grow and demonstrate its vigor. Two of the initiatives under the Common Agenda are of particular interest in this connection. The first is the environment policy dialog, which, as its name suggests, is formed for the very purpose of extensive bilateral discussions on environmental policy. A few such issues include climate, biodiversity and the 1992 Rio Convention (otherwise known as Agenda 21). The Environment Committee meets twice a year.

The second initiative I would like to highlight concerns the Ocean Committee, which has become the umbrella forum for discussing the radioactive waste issue. That forum is fairly broad also. It involves things like fisheries issues, reduction of marine pollution, and cooperation on scientific and technical activities, whether of a global, regional or strictly a bilateral concern.

From the very beginning of the Common Agenda process, the Russia radioactive liquid waste issue was identified as a discrete issue, although placed under the Ocean Committee umbrella. It was also one of high priority. For this reason, we did not wait for a formal meeting of the Ocean Committee, but instead held an informal meeting in January 1994 in Washington, D.C., which was very quickly followed by another in Tokyo at a higher level.

It became apparent from these meetings that there was a natural division of effort between Japan and the United States regarding this issue: that is that a bilateral dialogue between Russia and Japan should be instituted with respect to the Pacific Ocean, with the close cooperation between Japan and the United States focused on our policies with regard to this subject. At the same time the United States began to focus its efforts on the Arctic, as Gary Waxmonsky had discussed, and that became a very intensive effort with almost monthly events.

In this regard the U.S. and Russia also established a similar channel for communication at a high policy level, namely, the Gore–Chernomyrdin process. At the same time that these intensive bilateral discussions were underway, in a sense forming a trilateral dialog, we were holding very intensive discussions in various international fora; I know many of you participated in those meetings over the last two years. In particular, there have been regular discussions in the London Convention, which is the Convention that deals with the dumping of waste at sea, including radioactive waste.

Also, there was an initiative led by Japan for discussions between the most concerned states in the G7 "plus two" ad hoc group of experts meetings in London. The "plus two" refers to the Republic of Korea and Norway. Also, we were discussing this general issue within the IAEA and in various meetings related to the eight Arctic states.

We view the bilateral discussions under the Common Agenda umbrella with Japan regarding radioactive wastes as an example of success under the Common Agenda. We hope that it will become an example for enhanced, in-depth bilateral policy coordination on environmental issues. Thank you very much.

# The Common Agenda for Cooperation in Global Perspective

## The Japanese Perspective– Issues of Global Concern: Development Assistance for the Environment–Oceans

*Hideaki Domichi*
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Thank you for the opportunity to speak, Mr. Chairman. I want to speak about international cooperation, as did Kathy Walz, but from a different perspective. What is the best way to make international cooperation possible? Of course there are various ways: initiatives may start from government-to-government talks, or start from the seminars or informal groupings like this. What I want to stress here is the importance and significance of the grouping like this.

I believe, groupings like this, particularly organized by Professor Radvanyi, have produced very significant results on cooperation on East European environmental affairs. We started the European study group some years back when we saw the change occurring in East Europe. We first talked in this kind of gathering about how we can meaningfully expand our cooperation bilaterally with the United States and then how to involve the Eastern European countries. So it was actually a trilateral cooperation and very unique in nature.

In looking back, I think that perhaps this kind of trilateral cooperation would have never been possible if we started the talks on the governmental level. The Japanese government had very close cooperation with the United States and talked thoroughly on all matters. But at that time, our channel with the Eastern European countries was just beginning to start. There were government changes, and we had very little contact. But putting representative of all these countries together, all with the same common objectives, really started in a program like this. So I want to emphasize the importance of this seminar.

As Kathy Walz explained, we have a Common Agenda with the United States government—that is, a sort of global cooperation encompassing various areas including the environment. I want to caution you a little bit; international cooperation has very beautiful names but it is not always easy to implement. When we speak about the ideas, of course, it is very good, but when it comes to implementation involving the experts and so forth, occasionally we are faced with dilemmas. There are conflicts of the opinions of the experts about how things should be done more effectively. What is the best way? Who will bear the cost? And other things like this.

It is not easy. It is perhaps easier to implement the project alone. In the case of Japan, Japanese expert have found it much easier to implement things at their own cost, rather than to involve Americans and other nations in putting things together cooperatively. However, what we want to stress is that we are getting over these kinds of difficulties.

Particularly, the purpose of the Common Agenda is designed in such a way that we will expand the cooperation doing things together with Americans and other nations. So, together, these things have their own importance. Of course, as I said, there are always misunderstandings, even with a common agenda. I have been involved with this process from the start. But I have to confess, it was not always welcomed by the American government. In the past, when we talked about this informally, there were misunderstandings. This initiative was taken by many high-ranking American government officials as a political cover for more difficult issues, specifically, economic issues. So most American officials first took this initiative as a sort of political cover and were not serious enough. But with thanks to particularly Under Secretary of State Timothy Worth and also Ms. Walz, this Common Agenda was actually launched.

At the February 1994 Summit Talks, our Prime Minister came to Washington and had a talk with President Clinton. The meetings did not go as well as we had planned, and the economic negotiations were broken off. However, that evening Mr. Worth went to President Clinton and Vice President Gore, and explained fully and personally how important it is to launch this kind of environmental cooperation between the United States and Japan. It took this personal effort to bring to existence the Common Agenda.

As was the case in my earlier explanation about how we launched the Eastern European cooperation with the United States and the Eastern European countries, it took personal devotion and efforts to do something new and to actually implement it. So from these two points of view, I want to express the importance of this kind of gathering. People gathering with the same thoughts and talking informally about how things can be done. People exploring ideas on how to implement cooperation. International cooperation may not be realized then, but it is worthwhile and perhaps in most cases, with good will, a large part of the program will actually be implemented and we will have a new scope.

# Current Conditions and Ways of Solving the Radioactive Waste Treatment Problem of the Russian Pacific Fleet

*V. M. Zaharov*
Captain 1st Rank, Russian Navy

At the end of the 1950s, the Navy of the Former Soviet Union started to dispose of its radioactive waste at sea. Taking into consideration the experience of the major nuclear power countries, the marine dumping of waste was designed to minimize the possibility of an accident in a populated area that could impact the environment.

In the Far East Seas, we have never disposed of high-level radioactive waste, specifically reactors still loaded with fuel. The disposal of low-level radioactive waste in the Far East Seas by the Former Soviet Union and the Russian Federation was conducted in violation of the London Convention. Violations include the choice of the location for waste dumping and lack of invitation of observers from competent international organizations to oversee the dumping of waste. Violations of the Convention occurred because the rules of our country, titled *Rules of Dumping of Radioactive Waste into the Seas (PS82),* did not provide sites for waste dumping beyond the continental shelf in the deep seas, did not contain provisions for burying or dumping in high latitudes, and did not provide a mechanism for regularly providing information about the burial of radioactive waste in the seas.

At the present time, special services are provided to the atomic vessels of the Pacific Fleet at technical bases in Primorie Territory and Kamchatka. Radioactive security services are provided in Pavlovsk, Vladimir, Postavaya, and Rybachii Bays, and at ship repair plants in Bolshoi Kamen and Chazhma Bays.

Lately we have started to experience difficulties with providing radioactive and nuclear security. The causes of this situation are the decommissioning, in a short period of time, of a large number of atomic submarines; the lack of availability of sufficient facilities; the production and storage of large amounts of radioactive waste as a result of the decommissioning of such a large number of submarines; the lack, up to the present, of sufficient technical means for treatment of liquid and solid waste; as well as the absence of a facility for the long-term storage of radioactive waste; very limited financial support from the government for problems concerning radioactive waste and the utilization of nuclear submarines.

We create liquid and solid radioactive waste at the Pacific Fleet as a result of operating, repairing, and decommission of submarines, surface ships and other units. The liquid radioactive waste is divided into three major categories:

- First, waste produced by the technical operation of nuclear units, primary discharge systems, secondary discharge systems, and cooling mechanisms; it also includes water from the cleaning of reactors;
- Second, disactivated water from the reactors and its related equipment; and
- Third, water from special baths and laundries from the location of disactivation, and wastewater from laboratories of radioactive security.

The first category of waste is characterized by low concentration of salts, complex radionuclide composition and a relatively high volume of activity. Waste of the second category has a high concentration of salt and other chemical substances. The third waste category is characterized by low volume activity. It also contains other surface substances. The salts concentration in this liquid waste is the same as in the waste of the second category. Additional detailed information about these three categories of low radioactive waste can be provided, as can a description of the radionuclide structure of this waste.

Solid waste results from materials used in construction of nuclear reactors, from submarine emergencies, ion exchange filters, and radioactive soils produced by accidents at power plants. Storage of liquid and solid radioactive waste is conducted at many facilities.

Regulation of storage and treatment of radioactive waste has the attention of the Navy and its staff. Questions related to solving the problems of treatment of radioactive waste and used nuclear materials in the Russian Federation, including the Russia Navy, are reflected in a number of governmental decisions. The government has adopted a number of rules connected with the problem of utilization of radioactive waste. In addition, a government commission to address complex solutions concerning the problem of radioactive waste was established. The ministries and departments currently involved in these problems discussed a draft Russian Federation project to deal with radioactive waste and used nuclear materials. They have produced a schedule for major events that will take place in future years, up to the year 2005, and that had already take place from 1992 to 1995.

The Russian Duma has adopted a federal law of the Russian Federation titled *Concerning Governmental Policy in the Sphere of Radioactive Waste*. These legislative acts are designed:

- To develop a common concept and ruling laws that will

state one procedure for all situations in dealing with radioactive waste;
- To establish a database that will provide information according to the quantity, characteristics and sources of radioactive waste, as well as the locations of dumping;
- To organize a complex monitoring of ecological situations caused by the radioactive waste;
- To provide financial support for all these measures concerning the treatment of radioactive waste; and
- To provide complex monitoring and ecological monitoring of all sites of radioactive dumping.

A draft of a law called *About the Governmental Policy in Dealing with Radioactive Waste* stated that the establishment of a federal organization responsible for the treatment of radioactive waste is in great need and is important. The questions of treatment of radioactive waste; and radiological and ecological monitoring of the environment, including marine regions of storage and dumping of radioactive waste, have been considered as international. They need joint involvement of scientists, especially in the areas of economy and technology. The Russian Navy and its representative, Marshall Gromov, are ready for this kind of cooperation. Thank you.

# Development of a Source Term and Release Rate Model for Former Soviet Union Reactors Dumped in the Kara Sea
## A Historical Perspective

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My intent is primarily to summarize what has been going on in the area of international cooperation. To that end, I am only going to address my comments specifically to the work that is being done with respect to the reactors that were dumped in the Kara Sea and specifically in the development of the source term and the release rate models.

Historically, this is the situation. The International Arctic Seas Assessment Project was started in February 1993 in Oslo. I want to point out that there are four working groups that were established. Dr. Dyer and I belong to the source term group. It has been involved with an effort to prepare a source term and develop a release rate model. After the formation of that committee, the Yablokov Commission published the White Book.

Table 1 summarizes what was in the White Book, specifically dealing with the Kara Sea. We have 13 from submarines and three in the OK–150 reactor compartment for the *Lenin*. As you can see there were a total of 16 reactors that were discarded, and six of them still have fuel, plus a portion of the fuel from the *Lenin*, contained in the reactors. This is simply a breakdown of what was presented in the White Book for the total amount of activity.

**Table 1. Disposal in the Kara Sea.**

| *Disposal site* | *Disposal date* | *Naval reactors discarded** | *Reactors containing SNF* | *Activity (kCi)*† |
|---|---|---|---|---|
| Abrosimov Inlet | 1965 | 2 (No. 285) | 1 | 807 |
| | | 2 (No. 901) | 2 | 400 |
| | | 2 (No. 254) | — | 14 |
| | 1966 | 2 (No. 260) | — | 14 |
| Tsivolka Inlet | 1967 | 3 (OK-150) | 0.6** | 150†† |
| Novaya Zemlya Depression | 1972 | 1 (No. 421) | 1 | 800 |
| Stepovoy Inlet | 1981 | 2 (No. 601) | 2 | 200 |
| Techeniye Inlet | 1988 | 2 (No. 538) | — | 14 |
| Total | | 16 | 6.6 | 2400 |

* Entries in parentheses represent associated factory identification number.

† Fission products from White Book. Activation products estimated from White Book as follows: total content of activation products in reactors without SNF not more than 100 kCi, 50kCi of which was in three reactors of OK-150.

** SNF not contained in naval reactor, but in reinforced concrete and stainless steel shell container.

†† Limited to approximately 50 kCi each of $^{90}Sr$ and $^{137}Cs$; 2 kCi total of $^{238}Pu$, $^{241}Am$ and $^{244}Cm$; and 50 kCi of $^{60}Co$.

At the same time that this was released, or shortly thereafter, there was a meeting held in Anchorage. This was the Interagency Arctic Research Policy Committee meeting that was held, and at this point in time the White Book was actually formally released, or at least the English translation was released. There were also some presentations made at the Anchorage meeting, and again I will move through these quickly. There was one that summarized essentially what was in the White Book. Another one that focused primarily on information was there, but dealt primarily in the Kola and the Murmansk areas. At that time I also made a presentation with some calculations (Table 2). I won't go into any more detail other than to show you that what we had attempted to do at Livermore was to make an assessment of the radioactivity based upon information that we could gather from essentially unclassified sources on the characteristics of the submarines that were discarded. I will just point out that we made some estimates, what we have here are some high and low values and these just simply represent variations in fuel enrichment and also the decay time. The point being that certainly we can bracket initially what was produced by the Yablokov commission.

**Table 2. Calculations of total activity.**

| *Disposal site* | *Disposal date* | *Naval reactors discarded** | *White Book activity (kCi)*† | *LLNL total activity (kCi)*** |
|---|---|---|---|---|
| Abrosimov Inlet | 1965 | 2 (No. 285) | 807 | 341–845 |
| | | 2 (No. 901) | 400 | 511–1795 |
| | | 2 (No. 254) | 14 | 158 |
| | 1966 | 2 (No. 260) | 14 | 158 |
| Tsivolka Inlet | 1967 | 3 (OK-150) | 150†† | 840–1745 |
| Novaya Zemlya Depression | 1972 | 1 (No. 421) | 800 | 256–899 |
| Stepovoy Inlet | 1981 | 2 (No. 601) | 200 | 208–219 |
| Techeniye Inlet | 1988 | 2 (No. 538) | 14 | 158 |
| Total | | 16 | 2400 | 2630–5977 |

* Entries in parentheses represent associated factory identification number.

† Fission products from White Book. Activation products estimated from White Book as follows: total content of activation products in reactors without SNF not more than 100 kCi, 50 kCi of which was in three reactors of OK-150.

** SNF not contained in naval reactor, but in reinforced concrete and stainless steel shell container.

†† Limited to approximately 50 kCi each of $^{90}Sr$ and $^{137}Cs$; 2 kCi total of $^{238}Pu$, $^{241}Am$ and $^{244}Cm$; and 50 kCi of $^{60}Co$.

Following that, about a month later, there was a meeting held at Woods Hole in June 1993, where essentially there was more information put out but there was really no additional information that was made available at that time. In August 1993 there was a meeting held at Kirkenes, Norway. At this point in time, there was the first information that was actually published as far as I know on the *Lenin*, provided by Dr. Sivintsev from Kurchatov. Dr. Sivintsev happens to also be a member of the Source Term Working Group. And at that point in time we got some very detailed information on the *Lenin* and again, without going into these, you can see that we got some very specific information on some of the radionuclides. One of the things that I would point out just as a point here is that of the information that he gave at that point in time, the information is about half of what was in the White Book on the *Lenin*.

The first consultants meeting dealing with the actual evaluation of the source term was held in January 1994. At that point in time, we got a much more detailed report on the *Lenin* from Dr. Sivintsev, and we proceeded to move forward in developing a model for release rates. We essentially put together five scenarios for the *Lenin*.

Basically they dealt with the way the *Lenin* was discarded. About 60% of the fuel from the one reactor that had the accident was placed into a special container of concrete that was essentially clad with stainless steel. This was placed on top of the reactor compartment, and the entire compartment was then jettisoned into Savoka Inlet. So we decided to put together a number of scenarios.

The first one was very simple. We just simply had all the fuel rods and the pressure vessels in contact with the water. The second one became more involved. We assumed they were sealed in the reactor compartment. Basically what we were doing here was building a scenario that went from the most conservative case of immediate release to one that would be most realistic. The third one then has us placing a resin compound called furfurol in the reactor pressure vessels (the RPVs), as well as the box that had the spent fuel. So again, we are moving toward more and more involved scenarios. The final two that we examined were basically about the scenario in which it was actually discarded. I should say the fourth one, the fifth one then involved the situation where we were concerned with the cause of just simple corrosion, that the support structure could collapse and possibly allow the box which contained the spent fuel to break open. So, these were the scenarios that were evaluated. We have prepared some release rate models.

In this past summer, in Vladivostok, I and another member of our working group presented these results. We did present essentially the results from those calculations. Our second meeting was held this past November. At that point in time we were given additional information. Specifically we got more information from Dr. Sivintsev on the pressurized water reactors that were part of the submarines that had been discarded. These basically were calculations that had been performed and had been ratioed to the results that had been provided for the *Lenin*.

In addition, there was also a submarine number 601 (Table 2) that had been discarded. We had some additional information for this submarine. This reactor was a liquid metal reactor, and we were able to obtain some very detailed information on the configuration of the reactor compartment, and information on the fuel configurations at the time that the submarine itself was sunk. With this information we are now in the process of preparing a series of models as well.

So we are going to look at the following three scenarios. We are going to look at the one which would be the corrosion of the hull, the pressure vessels, and the reactor compartments that contain spent fuel. We will also look at those essentially that do not contain spent fuel. Then for one of the submarines, number 421, this particular pressure vessel was removed and placed into a special metal container. So we will be looking at that one in a little bit of a different light.

With respect to the 601, we are going to look at the following possible paths. We are going to take them in order. We will look at hull corrosion, then move to corrosion and release that will come down through the top of the reactor through the horizontal plane of the core, corrosion through the bottom through the guide tubes, and then that portion of the steam generator which contains some of the lost fuel from the reactor accident.

I will just finalize and show you Table 3. This essentially is where we stand right now. This is just summary information, but I did want to indicate that what we essential have is significantly different from what was in the White Book that came out in 1993. This is where we stand as of our final meeting about a month and a half ago. I would point out that we have already heard this to some extent. Two things that are of interest; the *Lenin* certainly is the most significant of all of the radioactive material sources, and in relation to what was in the White Book, we are now less than a factor of two with regard to the total radioactivity that was dumped into the Kara and the Barents Seas.

**Table 3. Summary of current model results.**

| *Disposal site* | *Disposal date* | *Naval reactors discarded** | *White Book activity (kCi)†* | *Revised total activity (kCi)*** |
|---|---|---|---|---|
| Abrosimov Inlet | 1965 | 2 (No. 285) | 807 | 314 |
| | | 2 (No. 901) | 400 | 79.6 |
| | | 2 (No. 254) | 14 | 2.5 |
| | 1966 | 2 (No. 260) | 14 | 1.2 |
| Tsivolka Inlet | 1967 | 3 (OK-150) | 150†† | 528 |
| Novaya Zemlya Depression | 1972 | 1 (No. 421) | 800 | 28.3 |
| Stepovoy Inlet | 1981 | 2 (No. 601) | 200 | 37 |
| Techeniye Inlet | 1988 | 2 (No. 538) | 14 | 0.2 |
| Total | | 16 | 2400 | 990.8 |

* Entries in parentheses represent associated factory identification number.

† Fission products from White Book. Activation products estimated from White Book as follows: total content of activation products in reactors without SNF not more than 100 kCi, 50 kCi of which was in three reactors of OK-150.

** SNF not contained in naval reactor, but in reinforced concrete and stainless steel shell container.

†† Limited to approximately 50 kCi each of $^{90}Sr$ and $^{137}Cs$; 2 kCi total of $^{238}Pu$, $^{241}Am$ and $^{244}Cm$; and 50 kCi of $^{60}Co$.

# A New Approach to Financing: The International Monetary Fund and the Special Drawing Right (SDR) Facilities

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**Introduction**

Ocean dumping of nuclear wastes is one of the single most deplorable deeds of mankind. It must be completely stopped through a joint effort of international society. I am presenting this paper with the hope that we will work vigorously together to harness world opinion as well as that of political leaders of our respective governments, with the end result that such dumping shall be forever banned, and indeed, will vanish from the face of our universe.

The scope of my paper is a proposal on a possible new approach to providing the financing needed to take the measures necessary to prevent ocean dumping of nuclear wastes from occurring again. This approach would provide financing to remove certain dumped wastes which can feasibly be removed. It does not try to cover all the financing possibilities. It does not try to indicate the exact cost which needs to be borne according to diversified ways of handling this issue. It does not cover what the governments of the industrial countries, including that of Japan, are doing now, or can do in the future, jointly or independently.

Having been an External Auditor of the International Monetary Fund (IMF), I repeatedly discussed this subject and also my proposal for using the Special Drawing Rights (SDR) mechanism with the Managing Director, Michael Camdessus. In addition to what I wrote in Japanese newspapers and journals, I wrote an open letter to Vice President Al Gore, titled: *The IMF-Soviet Submarine Connection,* in *International Economy,* a Washington-based journal. At the end of February 1994, this issue was discussed by Senator David Durenberger at the U.S. Senate, where he gave it his full support. He even recommended that the text of my article be included in the Record of the Senate, and that all the U.S. Senators should read it.

**Proposal**

1. The SDR would be allocated, first, to Russia and Eastern Europe, and second, to the less-developed countries (LDCs), the industrial countries (ICs), and others (Fig. 1). The proportion of allocation measured by quota share can be higher in the case of Russia and Eastern Europe compared to the rest of the countries. This is justifiable by dominant political need. At the same time, justification on equity grounds can also be used. However, this should not be interpreted in such a way that the legitimate opinion of the LDCs can be totally ignored. It has to be within reason, and acceptable to the LDCs.

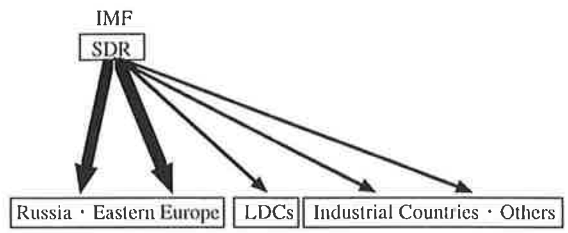


*Figure 1. SDR allocation. The bold lines (of SDR) to Russia and Eastern Europe indicate that a larger share of quotas shall be allocated to Russia and Eastern Europe on equity grounds. As new members, they have not yet received any SDR allocations.*

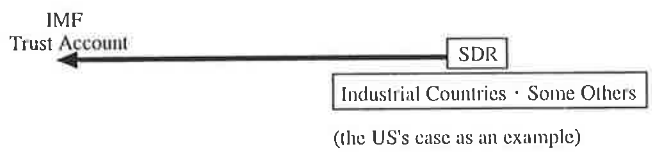


*Figure 2. Transfer of SDR to Trust Account. This scenario is based on the assumption that all industrial countries participate in the scheme. "Some Others" could include some less developed countries (LDCs), such as oil-producing countries.*

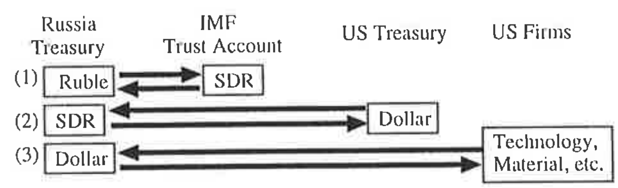


*Figure 3. Utilization of SDR (using the U.S. as an example). The three transactions have to occur instantaneously, although the transmittal of technologies, materials and related items may take time.*

2. The proportion of SDRs as allocated to the ICs (and some other countries, if there are such other countries that are prepared to transfer their allocated share of the SDRs to a trust account), should be transferred to a trust account to be established in the IMF (Fig. 2).
3. When a financial need arises, and the IMF judges that it would not be likely to cause inflation, the following transactions need to be conducted in this order, but immediately (theoretically instantaneously, simultaneously). The timing

of the actual delivery of goods and services from the firms of the ICs to Russia is the only exception (Fig. 3).

a. SDRs of a certain IC be exchanged with the Russian ruble. Exchange risk in this transaction has to be borne by Russia. The IMF cannot be involved in this exchange risk, by definition.
b. The SDRs thus acquired by the Russian Treasury be exchanged with the convertible currency of that particular IC. This is a treasury-to-treasury transaction. In the case of the United States, it means the exchange of SDRs for the U.S. dollars. This requires a request by Russia to convert its SDRs to dollars. Naturally, any obligation as to interest payment and repurchase accrues to the Russian Government.
c. The convertible currency thus acquired by the Russian Treasury can then be paid for the purchase and procurement of technologies, materials, etc., of the firms of the IC. The latter should be transmitted to Russia for the necessary work, but limited to the very work needed to prevent the ocean dumping and/or to remove those detrimental nuclear wastes already dumped into the ocean, which, by technological survey, were proved to be recoverable.

There would be diversified ways to construct the legal setup for the above transaction. To simplify the analysis, let us look into the matter of interest payment obligation. The easiest way would be to treat the above transaction as a simple loan from the trustor (the Respective Government) to Russia. In this case, no notion of the exchange of SDRs with rubles would be needed. The interest payment obligation of Russia to the lender accrues at the time of such a loan of SDRs to Russia. In this case, further exchange of SDRs with dollars should not be construed to add any further obligation to Russia. This is because Russia already has an obligation to the lender and because in this case, this SDR transaction should be treated differently from the case of the use of normally allocated SDRs.

If, in the transaction of 3(a) above, the involvement of the IMF is assumed (and possible), the above transaction can be construed to imply that the interest payment obligation of Russia to the IMF accrues at the time of the exchange of SDRs with rubles. And, following the exchange of SDRs with dollars, such interest goes from the IMF to the U.S. Treasury.

Whatever the assumptions and/or the legal setup of the case, the end result would always be that Russia bears the interest payment as well as the repayment obligation. So, for the sake of simplification of the arguments, the above assumption would probably be most appropriate. The notion that the request for the exchange of SDRs with the convertible currency carries with it interest payment obligation fits well with the general practice of the SDRs in the IMF, although the legal provisions there are somewhat different from what has been discussed here so far. In the legal setup of the Trust Account, the IMF has a very good precedent in the case of the Extended Structural Adjustment Facility (ESAF).

**Order of Magnitude**

The total amount of the SDR allocation is to be determined by the IMF from the viewpoint of the global liquidity need of the world. The order of magnitude of the SDR allocation in total would be somewhere between 50 billion dollars (the Managing Director's proposal) and 23 billion dollars (1994 G-7 proposal).

The order of magnitude of the portion of the allocated SDR to be put in the Trust Account of the IMF would depend upon the total amount of allocation, the method of distribution, and the proportion of countries who put their newly allocated SDRs into the Trust Account. Even though the quota share of Russia and Eastern Europe itself is very, very small, and there would be uneven distribution in favor of Russia and Eastern Europe, this would not affect the amount of SDRs to be put in the Trust Account very much.

On the assumptions (1) that the total allocation is 50 billion U.S. dollars, (2) allocated under the present Rules and Regulations of the IMF, and (3) the whole of the ICs agree to put their newly allocated SDRs in the Trust Account, then the amount of SDRs to be made available at the Trust Account would be roughly of the order of 30 billion dollars. If only G-7 countries agree to put their newly allocated SDRs to the Trust Account, the available amount will be reduced to 23 billion dollars.

**Caveat 1 – With Inflation**

1. The SDR mechanism should never be used as an instrument that leads to inflation. This is the reason why the SDR allocation should not be linked with economic aid to the LDCs. This is because the need to aid the LDCs is practically limitless.
2. Not only the total amount, but also the manner with which the operation of the SDR transactions are conducted has to come under strict scrutiny by the IMF authorities. They will look into the matter solely from the point of preventing inflation. This indeed is the source of soundness of this proposal. There is a clear distinction in this argument of utilizing a limited amount of SDRs for this very limited task, as compared to unhealthy financing practices, or even abuses of power by the Central Banks to print money for the sake of deficit financing.

**Caveat 2 – With Respect to the Utilization of SDR for Specific Purposes**

To utilize SDRs for specific purposes such as these is clearly a deviation from the SDR as it was originally introduced. So this use would not be enforceable unless political leaders become convinced of its importance. Even when we get consensus in this specific use of the SDR mechanism, it must be strictly controlled. The only exception might be to deal with the 25 (or more) Chernobyl-type and/or similarly extremely dangerous first-generation nuclear power plants which exist in Russia and Eastern Europe. Unless political leaders of the world can commit themselves to assure us that they should, in future years, never attempt to loosen and enlarge the utilization of the SDR allocation mechanism for other party political issues, we should not take the course I have just proposed.

**Caveat 3 – Distinction from Military Engagements**

The function of the IMF should be limited to matters of peace and not war. It cannot handle the task of dismantling missiles attached to the nuclear submarines. However, once the missiles are removed, such submarines can be treated simply as moving nuclear reactors. At this stage, those tasks such as removal of the spent fuel from obsolete submarines by robotics, transport of such fuel, temporary storage for conditioning, burial in permanent storage facilities to be constructed underground, etc., would come as an object of the use of funds made available by my scheme.

**Clarification 1 – Relation with other International Organizations**

At this stage of development of the IMF and the World Bank it would not be efficient or economical to let the IMF become a rival to the World Bank in putting manpower and limited resources into a wide range of environmental problems. What is really needed is that collaborative efforts be increased and further strengthened between the IMF and the World Bank. The experience, expertise, and know-how of the World Bank as well as other specialized agencies such as the International Atomic Energy Agency (IAEA) should be fully respected.

**Clarification 2 – Distinction from other Environmental Issues**

It would be highly risky to try to expand the scope of the IMF's involvement too much. My suggestion is to extract this crucially important issue of ocean dumping of nuclear wastes from all other environmental issues, and let it be dealt with by the IMF, even allowing the utilization of its SDR allocation mechanisms. The only possible inclusion in the future is that which has to do with the most dangerous nuclear power reactors.

**Clarification 3 – With Reference to the Scope of the Function**

There are two distinct actions that need to be followed. The first is to establish sufficient storage facilities with processing and related technologies. Such facilities have to be fully comprehensive and sufficient enough to cover present as well as future needs. The second is to recover certain dangerous materials already dumped in the ocean. Dumped nuclear submarines with nuclear reactors with spent fuel intact are some of the most typical examples of such a need. The right approach should be, start from the first action and then proceed on to the second, and not vice versa.

**General Description of other Alternative Financing Means**

There are many other alternative ways to finance the costs under discussion. Some of them, indeed, are, by far, more healthy as financing methods and more orthodox. The real issue, however, is whether these are really workable to the extent necessary to fully meet such need.

1. Russia saves money needed from its own economy, through further curtailment of other expenditures, or increases in tax and/or other source of fiscal revenue. This is the first principle of self help. However, the point of question lies in whether this is a practical proposition, when the present economic and social conditions in Russia are taken into consideration.
2. The ICs should find necessary additional aid money for this. This, in a similar vein, can be achieved through further expenditure cuts, and/or tax increases.
3. Other international organizations increase their aid shares, by shifting expenditures, or by increasing their quotas. Whether or not the proposition is practical depends, in the first case, on whether it is reasonable to assume that there exists such international organizations which are endowed with such extra funds to utilize, or which can exert efforts to save to finance such a grand sum. To me, the answers to both these possibilities seems negative. Quota increases in the international organizations usually come only once every five years. In fact, there had been a strong tendency to oppose any quota increase of any international organizations in the U.S. Congress, particularly by the Republicans.

**Other Alternative Financing Means Within the Mechanism of the IMF**

1. The first possible device would be a Special Allocation of quota applicable to Russia only. But it would be extremely difficult to justify a huge allocation of quota to Russia alone.
2. The second alternative would be the creation of Russian facilities with specific restrictions in the usage of the fund. This could probably take the form of a very special increase in the Systemic Transformation Facility (STF). Here again, there are many problems. Both alternatives would be more difficult to manage that my own proposal.

**Further Clarification**

1. With respect to Russian obligations, if my proposal is put into practice, it naturally follows that:
    a. Russia is responsible for the payment of interest. This fits well with the discipline associated with this specific arrangement.
    b. Russia, naturally, has to buy back SDRs held in the treasuries of other ICs (and some others, if any), in exchange for the U.S. dollars, the Japanese Yen, DM, etc., as soon as its foreign exchange reserve condition improves in the future.
    c. When such repayment is complete, the SDRs thus re-exchanged shall remain in the IMF's Trust Account. Whether to transfer these SDRs back to its own Treasury Account or not would depend upon the trust intention of the respective government concerned. If the ICs prefer to leave the SDRs in the Trust Account of the IMF, a time may come in the future when they will be needed to deal with a new global risk.
2. Why Costs Related to the Prevention of Ocean Dumping of

Nuclear Wastes can be Treated Specially. The existence of many obsolete Russian nuclear submarines lies at the heart of this ocean dumping issue. Handling of the issue of preventing ocean dumping can be interpreted as being one of a post-war settling arrangements. In a war settlement, special arrangements can, in any international practices, be normally admitted as emergency measures.

3. Why the IMF? The reason why the IMF is brought into my proposal is because in the whole system of international organizations, the IMF is the only institution equipped with the ability to create international liquidity with respect to the global liquidity need of the moment of such activities. This is quite appropriate in view of the need for international society to maintain stable growth without inflation. The role of the IMF with respect to this specific issue is very limited. So long as inflation is avoided in these sets of transactions, the role of the IMF probably will be almost wholly achieved. It is other agencies and governments that need really to work.
4. Who can decide the Alteration of SDR Allocation Policies in the Manner I Proposed? The SDR allocation is decided, after adopted at the Interim Committee, by the 85% majority of the voting share of the whole Contracting Countries of the IMF. The U.S. is the only country who has a single vetoing power in important policy decisions, such as the SDR allocation. So, in practice, only those who can have real impact on the decision making of the U.S. Treasury can affect the course of the SDR allocation. The President, Vice President, influential Senators and Congressmen are some of those very few persons who can really influence the course of events.
5. Further Explanations About the Mechanism of an SDR Transaction.
   a. Some might raise doubts about the practicality of the transfer of SDRs in the treasury of the respective countries to the Trust Account of the IMF. The legal setup might change from country to country, but I have no doubt at all that it is possible. To exchange such SDRs with the Russian ruble would, by all means, be possible. The legal framework can be built to make my proposal legally possible.
   b. Some might raise doubts as to the willingness of the ICs to put their newly allocated SDRs into the Trust Account of the IMF. This is a matter of consultation, persuasion and negotiation. Collaboration in the IMF's ESAF provides a good example (in assurances and otherwise).
   c. In reality, the format of these transactions shall be determined, among others, by factors such as legal constraints of the respective governments as well as of the IMF, and also concessions and compromises to be derived from such consultations and negotiations among those international bureaucrats.
6. Relations with Existing Collaborative Efforts. A variety of collaborative efforts exist. Among others are the World Bank, the European Bank of Reconstruction and Development (EBRD), the IAEA and also activities between respective governments. What I have proposed is to supplement, and not to limit, such efforts. It is based on the very understanding that although international efforts are exerted, they do not suffice as compared to the seriousness of the issue. This is due to the financial constraints on the international organizations as well as respective governments, particularly of the ICs.

**Concluding Remarks**

Like Columbus, I have proposed a method to make an egg stand by itself. Just break the bottom! There will inevitably always be some who will say it is against the rules, regulations, and practices that we are accustomed to. I say, "Change the rules and regulations. Change the practices and live anew." Just think which is better: to live in a safe and healthy world with clean oceans and changed rules and regulations, or to live with contaminated seas and oceans, with suffering unhealthy children, yet with the rules and regulations remaining the same as they used to be. The judgement, indeed the whole answer, lies in your hands.

# The Murmansk Initiative and Ecosystem Impacts

*Robert S. Dyer*
Representative to IAEA
U.S. Environmental Protection Agency, Washington, D.C.

**The Murmansk Initiative**

With respect to international cooperation, our experience has been of two kinds. One is direct experience, the other is more or less indirect through our monitoring. The direct experience has been what we call the Murmansk Initiative. It really only started about a year ago. There were two components, the civilian component and the military component.

We started simply with the civilian component because the Murmansk Shipping Company operates what is the only low-level liquid radioactive waste facility in the area. It was designed, and it was stressed many times, primarily to deal with its own nuclear icebreaker wastes, so its experience was with a certain form of waste strain.

So we worked with them first of all to understand the process. Congressman Weldon yesterday said three fundamental points for these deliberations would be cooperation, frankness and honesty, and I stress that from my earliest dealings with the Murmansk Shipping Company and the Northern Fleet in the Murmansk Region Oblast, these three particular attributes have been very strong. As with all activities like this, funding has been a critical issue, and if the discussions on funding start out frankly and honestly we found that the technologies and scientific challenges fall into place.

So, running through this procedure very quickly, what we wanted to understand were the technologies. We want to understand the science, and we want to understand the magnitude of the problem.

We used a mechanism, a very simple mechanism, called the Record of Discussion. This we set up mutually in the very beginning. In the Murmansk Initiative, we had three very important meetings. In each case we developed a Record of Discussion. One page identified what we wanted to do next and what we think we just accomplished. A second page consisted of signatures and it started out a very step-wise procedure that was critical. The first step was going to Murmansk in May 1994, where we had a meeting with the Murmansk Shipping Company. The meeting was arranged through the good graces of Norway, and that meeting included the Russian Navy and the regional Oblast representatives.

From that point, there was a simple agreement that we would take two more steps. One was to look for technical solutions to the problem, which meant understanding the current process and what needed to be done. This included a return visit of the Norwegian and Russian scientists to the United States to look at our technologies and procedures.

The second step was to broaden the participation, which Norway did by hosting a meeting in July 1994. At that meeting, the Russian ministries were involved, as were representatives of the Oblast, as well as representatives of other countries. From that discussion it was agreed again to have a return visit, a reciprocal visit, to the United States to continue to look at the technical issues and to discuss possible reciprocal technologies. That is, are there technologies in Russia that might help the United States do its job better? Also, are there technologies in the United States that would help the Northern Fleet and the Murmansk Shipping Company do its job better?

In September 1994 we hosted a return visit for Norwegian and Russian scientists. We put together a technical team composed of a limited number of participant from Russia, Norway and the United States. We did a tour of the Hanford–Westinghouse Low Level Liquid Waste Facility, in Washington. It was in its acceptance testing stage. The advantage to that was that it was 95–97% complete but did not require the radiation safety measures it would if it were operating. We were able to look at the processes without worrying about any radioactive materials, since none were being processed.

The Murmansk Shipping Company and the Northern Fleet laid out a plan for us. This was a big advantage. The plan was very concise and consisted again of one page. It said, these are the five steps, funded steps, that we need to expand our facility and this is the timetable. It consisted of two stages, a design phase and a construction phase. The design phase outlines five particular steps. As I said earlier, we were now moving into the military waste problem, and the military waste problem identified additional waste strains. The largest volume is what we refer to as "laundry waste," contamination waste, and the additional difficult waste strain which was mentioned by Captain Danilyan, waste brine. One of the tasks is to design a brine solidification system. From our formal discussions, we learned that there is a similar problem in the Far East. So it would seem like an opportunity would exist here to share our experiences in these designs.

Without getting into details about all the technical issues involved here, I will just leave with one point, and that is, we fully expect that within a year, this system will have gone through the design and construction phase. If the timetable presented to us by the Northern Fleet and the Murmansk Shipping Company are accurate, we would expect to have this fairly well along in the construction phase by next year at this time, if not completed.

The key issue now will be solid wastes, low-level solidified waste. Two of the tasks that Norway, Russia, and the United States are cooperating on are a special portable container for solidified, low-level waste and a storage facility for these wastes.

**Ecosystem Impacts**

The key issue here is the word "ecosystem." I think the evolution of the question has been more one of potential ecological impacts. Back around 1970 when the first regulations on ocean disposal came out, there was an assumption that if man was protected, the marine environment was protected.

In the last decade or less, that philosophy is changing. Particularly with sensitive Arctic ecosystems, there is a concern about sublethal effects and what sort of measurement techniques you would use to look at these effects; sublethally, for long-term chronic exposures that we might be seeing in something like an Arctic environment.

One recent activity that came up in the recent Gore–Chernomyrdin meeting was the Arctic Pollution Prevention Agreement. What's interesting about this agreement to me, having looked at lots of these pieces of paper in the past, is one particular article, Article II. It says "the parties shall cooperate in the conduct of joint scientific research to predict ecological impacts" (I stress the words "ecological impacts") "of the existing disposal of radioactive wastes."

That's an interesting concept because historically we've looked at human health impacts, rats notwithstanding, and we've tried to assume that as long as the human health was protected, that's fine. But again, there seems to be a body of scientific evidence developing that suggests that we should look a little bit lower in the food chain and see if we can identify what we would call sentinel organisms or bioindicator organisms that might represent an opportunity, an early warning opportunity, to suggest that there are some processes in the environment that we should pay closer attention to.

With respect to the bioindicators that we've been looking at, are there quantifiable bioindicators? Do they yield biological dosemeters for radioactivity that could give us an early warning or sentinel monitoring capability particularly in such an area as the dump sites in the Kara Sea?

# Arctic Nuclear Waste Assessment Program

*Lt. Commander Robert Edson*
Scientific Officer
Office of Naval Research, Arlington, Virginia

I am, as you know, one of the only two naval officers from the U.S. Navy that were able to participate in this meeting. I would like to make a couple of points concerning that. Why am I here? I manage the Arctic Nuclear Waste Assessment Program. It is a rather large program, both in its scope of topics it covers as well as the number of principal investigators which are doing research in the program, and we also were fortunate to be able to co-sponsor this particular workshop, this particular group of individuals.

I do only represent the Arctic Nuclear Waste Assessment Program (ANWAP). I would like to make that point. The views and statements that I make are not those of the U.S. Navy. I don't in any way try to represent them in this forum, but rather only ANWAP, which I manage. Also, I am an oceanographer, not a nuclear engineer, not a politician. So with those caveats, that's where my areas of expertise lie.

In reference to the comments we've heard over the last two days concerning the U.S. Navy's participation as well as the Department of Defense's participation in nuclear waste studies, it should be noted that the Department of Defense's ANWAP program is the only active program currently investigating Arctic nuclear waste contamination in the United States as a concerted, organized activity. We do have a portion of funds from the Nunn–Lugar money, from the Cooperative Production Funds and that's what's being applied towards this particular research effort. A large number of the investigators whom you have seen, for instance, Mark Mount; Clair Brown and her simulation; Lee Cooper; as well as Ruth Prowler and her simulation were funded by our program and do represent the effort that we're trying to make in investigating the Arctic contamination problem.

The one area that we have not moved into, the one area that we do not feel the necessity to move into, is the area that we are investigating currently with this particular workshop. We do not feel the necessity to move into Japanese waters, into the Sea of Japan, into the Sea of Okhotsk and that region. This is because our colleagues in Japan and Korea, and our Russian colleagues, are doing a very thorough job of investigating those geographic areas now without our additional efforts and assistance.

The one point I would like to make, however, is that I feel that any collaboration between our efforts would be beneficial. I welcome collaboration in a scientific realm in the area of looking at exchanging data and working together in scientific assessments. Again, I emphasize this is a scientific invitation, if you will. But I feel that collaboration between our programs, looking at mutual problems in the respective areas, would be very beneficial. As a first step towards that, Dr. Hong from Korea is collaborating very closely with some of our investigators and has exchanged data, ideas and scientific discussions. We will also be inviting our colleagues to some of our workshops, both the Japanese as well as the Koreans. Certainly a large number of our Russian colleagues will also be invited in the future to foster better collaborative efforts.

The final point I would make is that this discussion that we have presented over the last couple of days is basically centered around two topics. I would like to define those. In the area of contamination, whether it be in the Arctic or in the Pacific, there are two basic topics you can address. The first is the assessment of that which has already been dumped or that which has already been discharged or that which has already polluted the environment. The other is prevention of future problems.

We have addressed both topics within this forum. Again, I would like to emphasize that my particular area has not been in the prevention arena. That I have left to my colleagues, Dr. Dyer, the State Department initiatives, etc. Rather, my expertise is concentrated on trying to assess the problems that currently are visiting in our environment.

# Arctic Ocean Section 1994
## A Transpolar U.S./Canadian Multidisciplinary Arctic Science Cruise

*Lawrence Jendro*
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This presentation is pertinent to this group for several reasons. The Arctic Ocean Section 1994 (AOS 94) was motivated, at least in part, by a concern about radioactive contamination in the Arctic. In response to this concern, international cooperation supported a pioneering cruise. In cooperation, both partners reached previously unachieved goals. AOS 94 demonstrates the capability of the U.S. Coast Guard polar icebreakers to support international multidisciplinary oceanographic expeditions in ice-covered seas.

U.S. Coast Guard icebreakers are national science assets. Their first priority mission is the support of polar science. I want to take a moment to say that the U.S. Coast Guard, while in nature a military organization, is a part of the Department of Transportation.

AOS 94 was a historic science cruise, the first to cross the Arctic from west to east, passing through the North Pole. This was a joint U.S./Canadian cruise that utilized two icebreakers, one from Canada and one from the United States. The U.S. icebreaker, *Polar Sea*, was commanded by Captain Lawson Brigham. The Canadian icebreaker, *Louis S. St. Laurent*, was commanded by Captain Philip Grandy. Both icebreakers are similar in size. The *Polar Sea* is the most powerful, conventional icebreaker in the world, with the *Polar Star*, at 60,000 shaft horsepower.

The motivation for this cruise has several elements. These include the growing concern for pollution in the Arctic, the need to understand the role of the Arctic in global climate change, and the fact that the Arctic is the least well known of the world's oceans. The method of the cruise was to make multidisciplinary observations that were planned to support the analysis and modeling of the biological, chemical, and physical systems related to the Arctic and to global change. Scientific activities included:

- 17 combined biological productivity and biomass stations;
- 5 biomass stations;
- 35 contaminant stations;
- 59 ice stations;
- 45 box cores;
- 17 piston cores;
- 1300 nautical miles of ice survey lines;
- 72 CTD stations;
- numerous contaminant analyses;
- radiation studies; and
- 7 polar bear studies.

The cruise track line and the location of the 39 oceanographic stations are shown on Figure 1.

In any multidisciplinary effort some organization is needed. The scientists were organized under one Chief Scientist for the expedition, Dr. Knut Aagaard of the University of Washington. Dr. Art Grantz of the U.S. Geological Survey led the team on the *Polar Sea*, which consisted of 33 scientists. Dr. Ed Carmack of the Oceanographic Institute in Sidney, Canada, led the group on *Louis S. St. Laurent*. Seventy scientists from 20 organizations participated in this cruise. For the distribution of contaminants, it was not only radioactive contaminants that were studied, but also organic contaminants.

After the initial planning, two additional areas emerged. One was marine mammal studies that looked at polar bears and seals, and the other was icebreaker ship technology that looked at the forces involved with breaking ice.

I am going to just cover the high points. The cruise departed Vancouver on July 17, 1994. Both of the icebreakers have a facility of embarking and disembarking scientists via helicopter, so many came aboard in Nome, Alaska. This precludes them from having to make the entire trip from port to port. The ships passed through the Bering Strait on July 25th. From the July 25th until the 30th they operated relatively independently, going about their separate missions. On July 30th they joined forces when ice became extremely thick, and they stayed together for the rest of the trip.

On July 30th they had their last clear day, and so they proceeded in poor visibility for the rest of the time. This hampered the use of a satellite receiver that provides ice images for navigation. They were still able to use a special sensor microwave imager for strategic planning. On August 8th the Canadians supported a reconnaissance flight. The Canadian Atmospheric Environmental Service provided this flight that went a thousand kilometers along the projected track. As a result of the flight, it was determined that very thick ice lay on their projected track. The track was shifted to the west without compromising the science.

On August 15th one of the significant discoveries of the cruise occurred. Using a CTD that was deployed onto the ice by helicopters at a point that was charted at 3000 m, the scientists found the bottom at a depth of 850 m. Each of the surrounding casts was greater than the 1500-m length of the wire, so the scientists had discovered an undersea mountain.

Another discovery was an unknown gap in the Lomonosov

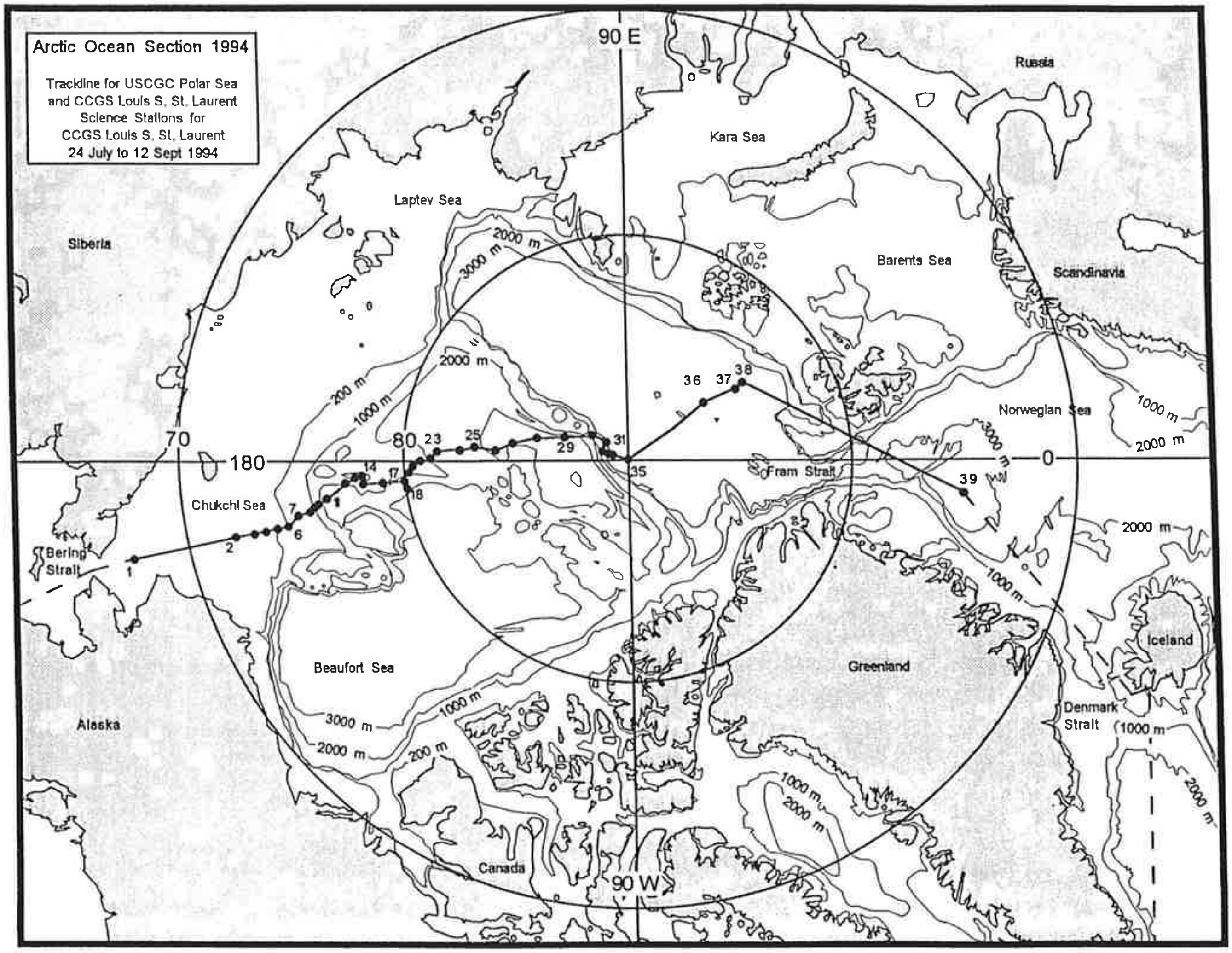


*Figure 1. Track of the AOS 94 cruise.*

Ridge that was indicated by a hydrographic cast. On August 21st the *Polar Sea* sustained an engineering casualty and lost a blade on its starboard propeller. The *Polar Sea* has variable pitch propellers, so this interfered with their ability to use the starboard shaft. On August 22nd the two ships arrived at the North Pole.

A very interesting event occurred at the North Pole. These two ships, struggling together to cross the Arctic, met the *Yamal*, a Russian nuclear icebreaker which was visiting the North Pole, conducting the business of transporting tourists to the North Pole, I understand at a price of $17,000 a person. There was a very congenial meeting between the icebreakers, between the crews and the scientists. The three icebreakers joined to leave the Arctic to the east. The *Polar Sea* and the *Louis S. St. Laurent* resumed their scientific work in the Eastern Arctic and then exited the ice on August 30th.

The Arctic Ocean has proven itself not to be the pristine environment it once was thought to be. We have detected radionuclide contamination. It is turning out that the Arctic Ocean tends to be this invisible dumping ground. A lot of countries have an out-of-sight, out-of-mind attitude. The water that washes across the top of the Arctic Ocean eventually ends up in the North Atlantic, which is where a lot of our fish come from. So we definitely have interest out there. We need to know what is going on with the waters out there.

We, as a country, have some pretty substantial interest in the Arctic Ocean, and we need to be able to access the Arctic Ocean, whether it be for scientific reasons or just the fact that we want to exercise our ability to go pretty much anywhere on Earth, when we want, if we need to. I would think that it is important in terms of both countries' national interests that a statement be made about capabilities and influence in the high Arctic. We have a contribution to make and a role to play.

When organochlorine pesticides begin showing up not only in the top of the food chain, but also in the mother's milk of Inuit people, we began to worry not only about local spills and dumps, but also how were pesticides getting into this pristine environment when people didn't use pesticides.

The real results of the cruise won't be known for quite a while, as these data are collected and analyzed, and reports are written. There is indication that several significant finds have been made. I understand that in an emerging issue of *Nature*, there will be discussion of the transport of radioactive material, via ice, across the Arctic, playing a major role in the distribution of radioactivity.

# Implementation of Plasma Technology

*S.L. Camacho*
President and CEO, Plasma Technology Corporation, Raleigh, North Carolina

*Vladimir Kmelnik*
Scientist, Plasma Technology, Russia

For my presentation, I am going to inform you about one technology that is emerging as a good alternative technology for the cleanup of radioactive waste. Both the EPA and the DOE have made statements that plasma technology is possibly the best alternative technology for vitrification, which means melting soil or melting material so that we can immobilize the radioactive material.

I am going to start out with showing you some sort of a cursory review of the Plasma facilities that are around the world right now. I must say that Japan is a beneficiary of this NASA technology as are other countries of the world. Yet here in the States, we are not really as advanced as we should be. The only thing to which the technology is being applied in the United States is in the metallurgical field. So I'll tell you about some industrial applications. I'll tell you who the suppliers of Plasma Heating Systems are, and it includes the Paton Institute in the Ukraine. I will describe to you, very, very quickly how the plasma torch works, and then I will go into different applications.

The plasma torch is a stainless steel tube. On one side, water for cooling, gas, and electricity are introduced. The electricity is then converted into heat energy. The plasma flame comes out on the opposite end of the system. This concept is quite an improvement from the NASA space program. We have combined electric power input and water cooling with power output and a little bit of gas. A very tiny amount of gas is utilized to generate the plasma. The torch has a plasma flame and a very tiny plasma column that is about 12,000°C. That 12,000°C is surrounded by gas, and that gas is heated by that tiny plasma flame to approximately 4,000–7,000°C. So it has a lot of capability for, lets say, fusing or melting oxides or metals or what-have-you, with very little heat involvement. It is very, very efficient. The electricity to heat conversion is about 92% and the processes are quite efficient as well. The main advantage of the plasma torch is not its temperature, it is really more the enthalpy. In other words, heat energy is delivered to the process with very, very little mass, and therefore we can dispense with any addition of, lets say, borosilicate glass, or something like that, when we are trying to immobilize radioactive soil. With this very high enthalpy, for example, we don't need any additives. And when you compare this, for example, with what DOE is doing right now with their borosilicate facilities, they are adding 60–70% by weight borosilicate to the radioactive waste. Here we can do the radioactive waste all by itself, with no additives. These torches are now made up to about 2 MW and some are testing 2–3 MW. We have a partnership agreement with the Lawrence Livermore Laboratory to test a 6- to 12-MW torch. The small torches are in use for making powder in metallurgy. The 1.5-MW torch is used in industry.

I am just going to give you some information about applications, so that you will have a good feeling that this technology is not just being used in the laboratory, but rather is in use out there in the field. U.S. Steel and Chaparral Steel use the torches to heat many tons of molten steel. At Chaparral Steel, we are casting steel, I-beams, pipes, and so forth. One of the real advantages of the torch is that it revolutionized the way we cast material. We can cast what we need at the moment, according to the order that is coming in. In another metallurgical application, titanium scrap is being recovered by three plasma torches.

The largest plasma facility in the United States can melt 50 tons of low-density steel waste and recover the steel. The advantage of this technology is the fact that you can do the melting in a controlled way, and yet you don't change the chemistry of the steel. Therefore, if you are melting scrap from one type of material, you can actually mold the material directly.

We have billions of tons of low-grade, low-density scrap that we have been throwing away because we had nothing to process it. Today, plasma technology is going to make a great significance. In Norway, the technology is being used to convert chromium oxides into chrome and therachrome.

We have two plants now, one in Canada and one in West Virginia, that process about 10,000,000 pounds of aluminum waste every month and convert it, recovering metallic aluminum. Out of 10,000,000 pounds of scrap, we recover 6,000,000–7,000,000 pounds of aluminum metal.

The largest plasma facility in the world is located in Germany. There, about 150 MW of energy are used every day to convert natural gas into acetylene.

At Union Carbide in California is a torch that was built for NASA. It is now being licensed by another supplier called Retech, a licensee of the Linde Division of Union Carbide. In France, the Aerospatiale torch is being used with space vehicles for testing heat shield materials, just like I did at NASA, when I was back there in the 1960s.

The Westinghouse torch plasma column has an enlarged diameter to hold the magnetic field rotation in order to increase the life of the electrodes. The electrodes in these torches are lasting between 700 and 3000 hours. So the technology is really ready for the industrial sector.

Returning to the torch's plasma arc column, it is about 1 mm in diameter and it is really at a temperature of 12,000°C or more. Gases are introduced to stabilize this arc in the center, thus creating the flame. We can also strike the arc in the inside and have an electrical connection outside. This is called the transferred arc torch.

In 1973, when I left NASA, I developed what we call the reverse polarity torch. With this torch we are able to eliminate a box that is involved with the other torches. Now we can make the torch very, very long, as long as 70 ft, 100 ft, 200 ft. This is helping in remediation in the environment. The idea here is if you have a radioactive contaminated soil, or a contaminated area, rather than handling it, you put down a pipe through that system. You then lower the torch and when you run it, you get a large area of melting, maybe 3 m in diameter. As it cools, all the material vitrifies, immobilizing the radioactive hazards.

As a result of operation, there are three zones: a molten zone, a fused zone, and a reduced plasticity zone. We can then collect the gas and not harm the environment. We can capture the gases, capture any particulates out of there and then throw it right back on the next hole.

From my point of view, and I am not a radioactive expert, I have studied the organic and inorganic contents of low-level radioactive waste and find it to be very similar to municipal solid waste. So I want to describe to you the results of torching municipal solid waste from an actual test at two tons per hour, run for 22 hours. For this test the EPA planted all kinds of equipment to find out what we are discharging. Everything looked right.

For the test, we loaded material into our system. It didn't matter what the organic content or inorganic content was, but the water content has to be below 50%. Other than that, any mix of material can be processed. The plasma flame is used, which involves very little gas. A very small cavity is created in the bottom. In this cavity, simultaneously, we have the vitrification or the melting of the inorganics and the pyrolysis, or the gasification, of all of the organics.

A byproduct of the system that is produced every time, no matter what you load in here, is a fuel gas, which by the way has twice the energy in electricity for what we consume in the torch. In other words, if we are averaging about 500 kW of energy per hour to take care of one ton of municipal waste, we are getting gas with 1000 kW per hour of energy potential coming out of the system from the waste. The other byproduct of the system is the vitrified product.

We checked the contaminants in our output and compared the results with the best incinerator plants in North America, located on Prince Edward Island and in Quebec, with respect to dioxin, furan, and PCBs. With the incineration, you can get up to 300 parts per million (ppm) of dioxin, which is below the dioxin limit. Before we burn our gas, it has 12–27 ppm. After we burn the gas we can't even detect the dioxin. So it is a very clever process here. Similar results are found for the furan, as well as for hydrogen chloride gas.

In another test, I told my staff, "Let's get out all the garbage in this reactor and let's load it just with tires and see how quickly we can gasify the contents." Four minutes after we started, we were already getting about 53% of the output gases as hydrogen, and about 30% of it as CO. There is a lot of interest now in this technology because with this type of gas we can then go directly to making liquid methanol. Liquid methanol is being produced right now by using natural gas, reforming the gas into 60 hydrogen and 30 CO, and here we are already close to that point. We can also burn this gas, combust this gas, and generate electricity.

The other byproduct, we have talked about the gas byproduct, is the vitrified product. We can also use the vitrified product. It passes all EPA leachability requirements, it even passes the French leachability requirements. In France you have to take three readings and add the sums of these three readings, and it has to be less than the allowed. We are now building a 3500 ton a year plant to demonstrate this technology in Bordeau, France, the wine country, to save the ground.

We are also working with asbestos. We have a contract with the Defense Logistics Agency to get rid of about 12 million pounds of asbestos. After vitrification, the vitrified materials are really quite large compared to the original asbestos fibers.

I would like to describe a technique to you that we developed for the Seventh International Ash Conference that I think is very appropriate for any fine radioactive materials. By this I mean dust, or ashes, or what have you. The idea here is to have a vessel with nothing to get rid of in the end. In other words, this has no insulation material. There is no refractory in this. To load then the radioactive material in this case, or ash in our case, and to begin. By the way, there is a hole in the bottom. Then the vitrification or the treatment of the material inside begins. We detect about 2000°C in this melt. Two feet higher up, the gases that are coming out are only 80°C. So all the vapors are captured, really, by the material itself. They remain in the melt as either a metal, metal chrome, or an oxide. The vessel is about 3 ft long and maybe 2 ft in diameter. The idea here is that we feed the material and we are tapping into sand or water.

I am just going to close my statement here by telling you that I am trying to work with the Kurchatov Institute to try to get this technology over there because they have a very serious requirement as well. We have a mobile plasma system. It can do about 2 tons an hour of radioactive waste, or what have you. The system resides in three trailers, one with the power supply, one with the control panel, and the third with the water cooling system and the compressor.

By the way, for my Russian friends, I think Captain Danilyan here was asking for information. I have some copies of radioactive material reports and if you contact me by mail I would be glad to send you DOE reports and also my colleagues from Japan are using this technology or have used this technology for radioactive waste disposal. Thank you very much.

# Techniques Previously Utilized During Location, Assessment, Recovery, Disposal, and Remediation of Ocean-Floor Hazardous Waste Sites

*Daphne Frilot*
Neptune Sciences, Inc., Slidell, Louisiana

*Andrew M. Watt*
SubSea International, Inc., New Orleans, Louisiana

We are going to talk today about some of the projects that SubSea and Neptune Sciences have conducted to recover hazardous wastes in the oceans in different parts of the world. The first project that I wanted to talk about is a project where a deck cargo of arsenic barrels had come off of a vessel in a storm and were on the sea bottom in about 200 ft of water. The method that we came up with to recover these barrels was to deploy a remotely operated vehicle (ROV) from the surface and grab hold of the barrels and place them into specially made racks that had overpacked drums in them. Then the drums themselves were filled with cement pumped into them while they were in the rack and then sealed. Once the whole rack was filled it was brought to the surface. So no contaminants were open on the surface. In this case there was no danger to divers with this very safe method used here.

The ROV launch occurred from a barge, so it was a very stable platform for an operation such as this. What the ROV did was pick up each barrel, turn it right side up and then go place it into the rack with the overpack containers. Some of them were pretty beat up by the time they hit the bottom. Unfortunately for these purposes it is not a very quick process. The rack can hold twenty of the containers with the barrel. We developed this system with the rack specifically for this project and that happens a lot in this sort of work that you have to come up with specific technology for the task at hand since all of the situations are fairly different. I think you get an idea of what we came up with to handle that problem.

The next project that I want to talk about is a project where we recovered mercury containers from the cargo of a vessel that had sunk 50 years ago, back in 1944, off the coast of Maine. There was concern by the EPA that this mercury was onboard, so as a consequence it was declared a Superfund site and we were asked to go ahead and try to recover the mercury and the containers, the flasks, that the mercury was in. They were in pretty bad shape after 50 years. They were supposed to be steel containers but obviously they weren't. It was an iron mixture that was used for the containers in this case. So they were all busted up.

Yesterday, Josh Handler spoke a little bit about the panic that happens with the public in some of these toxic contamination situations. We wanted to show what happened when this project started. It is referred to as "a time bomb" at first in the media before anything was even known of the situation and as time went by things changed a little bit and the real news started coming out about the situation as it really existed. "Ticking time bomb off the coast to report tonight. Coast Guard officials have confirmed that a ship that sank some 14 miles out nearly 50 years ago may carry 8 tons of mercury onboard." [Video] So that is a view of what the media comes up with in their first report of a situation. It is a "crisis" and a "ticking time bomb" before we even know anything about it.

The initial part of the project entailed taking background sediments and biota samples around the wreck to see exactly what the mercury levels were in the sediment and in the marine life there. So in this instance, we took grab samples of surface sediment, and used the ROVs as well to take some of the grab samples in certain spots. We have collected lobsters and we had to send off samples to the lab for analysis of mercury. In a pretty timely fashion we were getting results back of what the mercury content was. We had to remove tissue samples and then some of the organs and what not from the animals. There was discussion about quality control of the samples. Throughout the whole project, when we take these sediment and water samples and what not, when we are testing for radionuclides, we had quality control people on board taking notes and making sure that everything was in order.

Now Andy is going to make a presentation about some of the devices and the techniques used in projects that we have worked together on. SubSea International is one of the few companies in the world which designs and builds remotely operated vehicles and works offshore with them. We started off buying vehicles but we could never get the manufacturers to give us what we really required. So we got into this by default. Now we build and operate the vehicle.

We operate about sixty vehicles around the world and we have twenty seven or twenty eight of a vehicle called the Pioneer in service, including one which was purchased by a company in Japan. The ROV to us is what a tractor is to a farmer, nothing more. We have electrical power, electronics, and hydraulic power on these vehicles. In very deep water we can take the ROV and put it on top of a grab and fly the grab to the object we wish to pick up.

As I mentioned, we are nothing but farmers, we even use digging devices. We had to dig some material out of the seabed, 600 ft of water, and we took a standard underwater digger and converted it for marine use. Then someone asked us to come up with a device to drill holes as we ran along the seabed. So we came up with the underwater robotic drilling device.

Then as you may recall, we had major problems in Kuwait. We took the same vehicle and flame-proofed it. It could go into temperatures of 2000°C. This is a remotely controlled vehicle which is controlled through an umbilical cable. So someone then made us aware of munitions problems, chemical weapon problems, and problems in the nuclear industry. In response, we then developed tooling packages for handling hazardous devices.

Moving away from the vehicles themselves for a moment, we own and operate several vessels. We lay pipelines. But to be able to do that you must use many sensors and sonar systems, and side-scan sonar systems. Neptune Science had developed another system which gives information on under-the-seabed, sub-bottom information. Technology is always developing. We should have been testing a new side-scan system, but it is a month behind on the program. We are very hopeful this new system will have some of the latest sonar technology and chip technology. The swath or the beam width off to the side can be 800 m per side.

I would like to show you another system called sonar graphics. Basically with the modern computers being able to handle more data, we can process a lot of data faster and product lots of different displays. Different colors represent different distances below the blue level.

We used this system less than a month ago in Ecuador. It was a national emergency in a dam in Ecuador, a hydroelectric power plant. You have to continually dredge to keep the sediment from building up in the dam. The dredge had gotten stuck. The dam operators tried to recover the dredge but only succeeded in making a crater trying to dredge themselves out. Neptune Sciences and SubSea Systems were contracted to try to find out what was holding the dredge to the dam floor. An image we collected showed that an object had rolled down and trapped the module.

A new system that Neptune Sciences is just bringing on line is the acoustic sub-bottom inspection system. It has an acoustic beam which penetrates the seabed and produces images. Of course we don't manufacture all the items of equipment we use. Some equipment that we use was developed by the British Geological Survey group, including a gamma spectrometer that we used in the North Sea on a project where we were looking at the normally occurring radiation levels.

Another system which we operate has a a laser imaging system. In many of the seas in which we operate, we seem to operate where the visibility is very bad. Where an ROV could visually see only 2 m, with the laser system we could survey at the speed of 4–6 knots, some 8 m above the seafloor. The resulting imaging is incredible. We make a video from the ROV using silicon-intensified target low-light cameras. With digital signal processing and computing power you can zoom in and get very accurate information.

An article describing another of our projects appeared in *Jane's Defense Weekly* in November 1993. We have been working closely with the Atomic Energy Authority in the United Kingdom and have been looking at chemical weapons. That is a very big problem. It is a bit like nuclear waste. So we see a lot of activity with our robotics and we have teamed with AEA. We are the commercial arm for their Silver II system. The article also talks about the quantities of chemical munitions, 31,000 tons in storage in the U.S.A. There are huge problems. It is not just with nuclear waste.

What are we doing about it? We recently purchased a vessel that was built by the Royal Navy. It was called *HMS Challenger*. The article talks about it. We want to convert it into a vessel that will carry vehicles and will carry systems for processing, perhaps nuclear waste.

There are many systems and I could talk a long time about all the different systems that will be fitted to such a vessel. As I say, we do own this vessel and we have plans to convert it, but we want to see a real market with some real dollars and perhaps some real money to help convert the vessel.

There was another article, again, a follow-up on chemical weapons. The article clearly states that the system, the electrical chemical oxidation system, that is the Silver II, is being marketed in the States by SubSea in Louisiana. What is Silver II? Silver II is a system that was developed by the Atomic Energy Authority. It was developed for processing low-level nuclear waste. The heart of the system is the electrical chemical oxidation cell. The material to be processed comes in as a liquid waste, goes through the system, and comes out as wastewater, gases and salts. For nuclear waste this will help to eliminate the bulk of the low-level storage problem.

The advantages we see of this system are its low temperature, low pressure, and it can be portable. We have been conducting some recent trials with the Chemical/Biological Defense establishment in the United Kingdom where we are processing Tabun, Sarin, VX, and Distilled Mustard. I will describe for you some results from the system. This experiment was carried out at both 50°C and 90°C. The agents were destructed 99.873%, 99.882%, at the two temperatures; probably better, but there were no instruments to actually measure if it was any better. For pure agents, destruction was 99.995% for Tabun. Sarin was 99.990%. VX was 99%. These are very, very high destruction capabilities.

There are some other technology that are around. One of the largest remotely operated vehicles in the world was built in Germany. SubSea now owns it. It is called Supra. It was originally built for repairing pipelines but it can be used for picking up radioactive material and putting it into containers. This vehicle can be operated in the manned mode, but we would use it purely in the unmanned mode. We have a design that allows us to pick up 500 tons by putting an additional buoyancy tank on there, but the concept could be used to pick up larger payloads if necessary.

## Keynote Address

*Congressman Curt Weldon (R-PA)*
United States House of Representatives, Washington, D.C.

Good afternoon ladies and gentlemen. Let me first apologize for not being able to stay for the whole conference. As you can imagine things are very exciting in Washington, and I did want to get down for this session but have to get back because of legislation we expect to have on the house floor dealing with national security before the end of January.

I want to commend the past efforts of many in this room and the leadership of this group for the work that they have done in establishing a process, actually a model that worked, allowing us to work together with the Russian government and the Norwegian government to begin to deal with the problem of dumped nuclear waste in the Arctic area. Many of us in Congress believe that long-term relationships between our country, Russia and Japan can be achieved when we have trust, not just between our scientists, our academic leadership and our business leadership, but especially long-term working relationships and institutions within our legislative bodies. Something that perhaps we've not done well in past years.

Our President and your Prime Ministers can work together as they've done, but they cannot do it alone. We've got to have an ongoing dialog and institutional processes in place where legislators can begin to trust one another and begin to work to solve very complex problems. We've done that in Congress, we've done it with the former Soviet Union in several instances. Two and a half years ago Congressman Greg Laughlin, a Democrat from Texas, and I recognized the need to work with the former Soviet states in the area of energy exploration and development.

We formed a Russian American Energy Caucus with Democrats and Republicans, forty-five members of Congress, and worked together to establish ties directly with parliamentarians from Russia. We were specifically working to get approval for what has become the single largest project in Russia, the Sakhalin project, by establishing ties to the legislative body at a time when our President was developing ties at the executive level. In 1992 we had meetings with key members of the Russian parliament, some of whom are no longer in place in that country. Mr. Kalastratov, Mr. Lpravnikov who was Mr. Hashbulatov's top aide, and Mr. Miliakov, all of whom were leaders in Russia on energy issues and all of whom are occupying as we do in democracies, a temporary position, but one of importance for building lasting friendships and working relationships and trust.

Here we are in 1995, and while several of those leaders are no longer in power, the institution continues and we are now working aggressively with Mr. Shifranek, the Russian Energy Minister, and the team of legislators who lead energy issues in the Russian parliament. It can work. We've done it with GLOBE, where we established a network of legislators, not just in Russia and the U.S., but in the European Community and Japan. A network that meets at least twice a year rotating from country to country, and works on a common agenda of environmental concerns that each of us feels are important to our respective countries and more importantly to the world. We met in Moscow in September 1994. We have a meeting in America in Washington this coming year, and last year we also met in Tokyo. In December I was in Lisbon at the invitation of Carlos Pimento, a leading environmentalist and the chairman of GLOBE Europe, to work on priorities that we all share. That institution continues, and regardless of which one of us may in fact not win our election, as we know can happen as we saw in this country this past November, the process of working relationships at the parliamentary level is growing stronger. We think that this foundation that is being laid will help us far beyond concerns such as the ones you're dealing with relative to nuclear waste. In our opinion in Congress, those of us who believe in these ideas, we feel that nothing is impossible.

After all, who would of thought that in May 1994 we would see the first congressional delegation travel to Russia to focus totally on environmental issues. Not issues of national security nor issues of arms, but on environmental issues, and we had some exciting times. In Moscow, meeting with the key leaders of Minatom, including Nicolai Yegorov and meeting with the President of the Academy of Sciences, Nicolai Laverov, who hosted a luncheon in our honor. Meeting with the director of International Science and Technology in the Ministry of Foreign Affairs Sergei Kisliak, and the Ministry of Defense's key person on nuclear issues, General Sergei Gregorov. In each case we had a chance to sit down face to face as legislators and share ideas and concerns, but more importantly begin to build trust honestly and openly.

In Murmansk we were the first Congressional delegation to take our news media with us, hosted by the general in charge of the Northern Fleet, to visit the Atomflot facility to talk about the problem of waste in that area, to talk to their Navy leadership in terms of how we can cooperate, recognizing that the Northern Fleet has been one of the shining stars of a navy that is extremely proud because of its power around the world, yet one that is willing to cooperate and has cooperated with us as we saw in that trip. Also at those meetings we had members of our industry, one of your attendees was there hosting our effort—from Babcock and Wilcox—and we had members of the Norwegian parliament, again trying to establish relationships that transcend geographical boundaries and that transcend differences that we may have in other areas.

Who would have thought that in October 1994, we would complete what has in fact become the largest business venture in Russia. In terms of the deal involving Sakhalin, and that we would also announce in October of last year the beginning of a process to begin the conversion of the Baltic shipyard in St. Petersburg, working with Pavel Grachev, the Russian Defense Minister, and working with the McKinenstrol group from America. Our trade development administration awarded the first $300,000 to begin to assist the Russians in taking the 8,000 workers at the Baltic shipyard, proud workers who built the Kirov class of warships, some of the best warships the world has ever seen, and to begin to retrain those workers into the area of environmental remediation. To allow them to take some of those same warships that are being stored in Murmansk, and in Kaliningrad, and to begin to deal with the problems of asbestos, and PCBs, and ozone-depleting gases, and carcinogenic paints, so that once they are environmentally stabilized they can be dismantled either in Russia or in the U.S., and the steel used to create new jobs for both the Russian people and the American people using money generated through the Nunn–Luger program, which was the original intent of that funding. That's underway now. Who would have thought that could have reached this level with the full cooperation of the Russians, the joint-stock company that owns the Baltic shipyard and one of the major housing facilities in St. Petersburg.

Who would have thought that in May of this year we would be able to bring together legislators from those four regions I have talked about in the GLOBE organization for a major conference on the oceans where we will discuss, with Senator Kerry and myself as the co-chairs, three key issues that affect the oceans of the world. Declining fish stocks, the problem, the status and what we can do collectively to work together to solve the problem of declining fish stocks, which hurts all of our countries. The challenge of sharing ocean research and information, we all know we have vast amounts of data, much of it's been classified and not made available, but there are many areas that we can be sharing data and information and technologies and we will be looking at that this coming May to see where new opportunities exist between countries and working with the private sector.

Thirdly again, taking up legislatively the issue of dumping in our oceans. Following on the work that you are doing today and tomorrow, we will look at what we should be doing legislatively to implement recommendations that will come from this session. Anything is possible and we have certainly seen a new era in world cooperation. But I want to issue a word of caution, and perhaps I'll offend some of my American friends and some of my key friends in the military, but let me say at the outset I'm an ardent supporter of our national security and have been a member of our Armed Services Committee since I have been in Congress, but if we're going to have the kind of open and long-term relationship that we all want, the kind of model that you have helped create in this room, we have to be frank and honest, because if we're going to build trust among our people we have to be candid with each other.

That hasn't always happened and I want to give you one example that I have experienced which bothered me and my colleagues that sit on the Armed Services and Merchant Marine Committees. Following the publication of the Yablokov report, and by the way I have the highest respect for Mr. Yablokov and had the occasion to meet with him at length when I was there this year and hope to welcome him for our oceans conference in May, there was much criticism in the U.S. Some were saying that in fact Russia had not been forthcoming and had not been cooperative in allowing scientists to understand the problem of nuclear dumping, and perhaps Russia had not been willing to announce some of the accidents that had occurred. But let me say that in looking back at some of the situations that were occurring, I think to some extent that we were the hypocrites in America and let me tell you why.

At my request our subcommittee on oceanography convened a hearing on September 30th in the Capital to discuss the Yablokov report and the issue of dumping nuclear waste and nuclear accidents around the world. We heard complaints from some who testified about a lack of cooperation, about the lack of the Russian government supporting the principles of the London Convention as regarding prohibition of dumping nuclear waste. We heard some concerns about the status of the *Komsomolets* and whether or not there was radiation leaking from that vessel. And then for the second part of that hearing we had the American witnesses testify and what did we find? We found that the U.S., while wanting the Russians to agree to the changes at the London Convention, had not been supportive of that convention ourselves, and yet we were applying one standard to the Russians that we were not willing to accept in our own government. Then, we asked our U.S. Navy representative about some nuclear accidents that we have had and the response was "we cannot comment on those in public." So while we were ready to criticize the Russians for perhaps not being candid in regard to the *Komsomolets*, we were not ready to discuss the *Thresher* nor the *Scorpion*.

We wonder why cooperation is sometimes difficult and wonder why trust is not always there when we need it. Partly because of the criticism that we levied at that hearing and as a follow-up to that hearing two weeks later, the U.S. Navy released for the first time film footage of both the *Scorpion* and the *Thresher,* which appeared for the first time ever to the American public on national TV on Ted Koppel's *Nightline* show. We need to understand that for us to have long-term cooperation we have to establish trust at all levels and that means being candid and honest. As a result of the release of that information, we went to work on what we could do to begin to strengthen our response in terms of the nuclear dumping issue.

Following the hearing I led the effort to develop a letter that was signed by all the members of GLOBE in the Congress that was sent to President Clinton in November of last year asking him to change the U.S. position to one favoring the London Convention to permanently ban the dumping of low-level radioactive waste at sea, and our President responded and in fact did what many of us felt was the right thing to do. On February 20, 1994, the London Convention as you all know went into place with our President and leadership leading the way. So not only were we willing to say that this should be something we should all agree to, but we were willing to kind of lead the way.

On March 8 of last year I introduced legislation on the ocean radioactive dumping ban, which eventually passed the House and got to the point where the Senate was about to pass it, but because the press of business and some parochial concerns on other issues, was not able to get it through but will pass so that this year President Clinton can sign that bill into law. We also wanted to explore the possibility of assisting the Russian government in complying with the London Convention, so we organized a co-deal that I mentioned to travel to Murmansk in June 1994. It was a very rewarding experience as I mentioned. In visiting the Atomflot facility, we saw that the capacity was not there to treat all of the liquid radioactive waste generated by both the Russian northern fleet and by the Murmansk fleet of nuclear-powered icebreakers, all of which we were allowed to visit and to board.

Following that visit every member of that group, including the current chairman of the House Committee on National Security, Floyd Spence, signed a letter to Vice-President Al Gore asking and encouraging him through the summer meetings with Mr. Chernomyrdin to join with the Norwegians to help improve the Adamflot facility in Murmansk. As you know, and will be talking about during this conference, that is exactly what happened; that agreement was reached and we have agreed to jointly fund those improvements.

I think the bottom line is that what we are doing in terms of the Baltic area and the Arctic area can be used as a model for us in the eastern part of Russia and with Japan taking an aggressive role and a leadership role, which they have done on so many other issues in wanting to have the same kind of process put into place. We are in a win–win situation, and what I would tell you is that members of Congress from both parties are sitting back with great anticipation to the time when we have solved and dealt with the problem of understanding and dealing with any potential contamination that could cause harm to our environment from nuclear waste that has been deposited in our oceans. But beyond that I think the importance of what you are all involved in is laying the foundation for this bigger area of cooperation.

We all know there are going to be key differences in the policies of our three countries, but we all also know there are far more things we have in common, far more challenges where we can cooperate, whether it is the environment, energy or finding ways where we share concerns and can bring our scientific community and academic community together and cooperate. But I would say to you to keep in mind that for this to be a long-term success we have to continually have the involvement and the genuine support of the legislators.

While scientists have cooperated for years, even when perhaps countries have not been cooperative, we have a new era, a new time period, where we can bring in the legislators and have them understand the importance to make sure this is not just a fleeting circumstance, that we can keep that cooperation for decades to come. That will bring us long-term peace and security throughout the world. And once again trust is critical. We in America, those of our friends in Japan, and those of our friends in Russia should understand that we have to be candid and open. None of us have perfect records in terms of environmental situations. None of us have unblemished records on foreign policy issues. If were honest and open and have an honest dialog I think that we will see that our difficult problems down the road in terms of nuclear disarmament, in terms of local and regional conflicts will be much easier to solve, because first of all we will have built trust and that trust will have been built on honesty and openness. In closing let me say that I grew up in a blue-collar family, the youngest of nine children; that is why some call me an eternal optimist. When you are the youngest of nine kids you have to be eternally optimistic.

My father worked in a factory for 38 years and what he told me as a youngster growing up is very simple but profound advice. He said your only limitations in life are those that you self-impose. You can go through life complaining about everything that is wrong or you can realize that you take the assets that you have been given and use them to their fullest. That same advice applies to us in this room. There is nothing that we cannot solve together, there is no problem that is insurmountable, there is no challenge we cannot face, our only limitations as nations will be those that we impose. If we are not open, cooperative and honest, then in fact we will not succeed. If we build upon the successes that we have had, there is nothing that we cannot solve. There is no reason why ten, twenty years from now we cannot be working together openly and honestly on every major issue that confronts us relative to the oceans of the world, but beyond that relative to our peaceful coexistence as people. I look forward to working on that challenge with you. Thank you.

# Korean Observer's Remarks

*Gi Hoon Hong*
Korean Ocean Research and Development Institute
Seoul, Republic of Korea

I commend the excellent organization of this workshop and the important papers and issues delivered in order to promote cooperative efforts for building an international study group on dumped nuclear waste in the Russian Far Eastern Seas and the North Pacific Ocean.

Personally I have been involved in numerous meetings, both as a technical advisor to the Korean government, and as a research scientist investigating the consequences of the radioactive waste disposed in the East Sea (Sea of Japan) by the former Soviet Union and Russian Federation. This research has been performed in domestically organized expeditions and the Korea–Japan–Russian trilateral joint expedition in 1994. A second joint expedition is being planned in the Sea of Okhotsk and the North Pacific Ocean as well as the Japanese and Korean low-level radioactive waste dumping areas in late 1995. Marine-science-oriented programs of academic research will complement the official governmental level of preliminary investigations.

Therefore, I am very pleased to see the concrete development of international cooperation to tackle the important environmental and political issues of nuclear waste sea dumping in the Russian Far Eastern seas. As presentations by Dr. Tkalin of Russia and Drs. Cooper and Kantha of the U.S. have indicated, there are a few ongoing regional oceanographic programs in the East Sea where the most radioactive waste was dumped, such as Circulation Research of the East Asian Marginal Seas (CREAMS) among Korean, Japanese and Russian scientists, as well as other bilateral programs among the countries sharing the East Sea. Those programs are closely tied or provide essential information for assessment of the environmental consequences of dumped radioactive waste in the seas, including contaminant dispersal modeling, comparative baseline radioactivity data, radiological assessments and radionuclide cycling pathways.

Since March 1993 when the Russian White Book became available, the Republic of Korea has been deeply involved in, and has keen interests in, the potential damage from Russian nuclear waste dumped in the seas adjacent to Korea, as well as fisheries-rich areas of the Sea of Okhotsk and near the Kamchatka Peninsula. Therefore, Korea should not be left out in these important issues. Korea is also concerned about the establishment of storage and treatment facilities in Vladivostok.

Personally I think the trilateral study group should be expanded to include the Republic of Korea under the spirit of cooperation among all concerned parties. I would like to ask the organizers of the Japan–Russia–United States Study Group to provide officially the results of this workshop to the Korean government for appropriate action. The appropriate official is Mr. Hae-Wook Chung, Director, Science and Environmental Division, International Economic Affairs Bureau, Ministry of Foreign Affairs, Seoul 10-760, Korea. I think that the Korean government is ready to assist positively with the work of the study group.

Thank you for your attention.

# Workshop Conveners' Closing Remarks

**James Auer**

Yesterday, Steve Walton, a journalist for the *Clarion Ledger,* a local newspaper, who is covering this meeting, asked me why a professor from Tennessee is in Mississippi helping to put together a conference on Japan, Russia and the United States? Unfortunately for him, it took me about 1 hour and 20 minutes to answer his question. Fortunately for you, I will answer in about five minutes.

Basically I have two points and two reasons I am here. First of all, as many people have noted over these last two days, I am one of those great admirers of Janos Radvanyi. I have had the honor of knowing Dr. Radvanyi for a little over ten years. We worked together in the mid-1980s on a couple of conferences that he organized to discuss the common interest of the United States, Japan and China in dealing with the Soviet Union. Secondly, at the hands of Edwin Reishower, the late ambassador and professor, I learned that the United States and Japan, for all their differences in language, culture, history, tradition, etc., have a very special interest and that special interest lies in the fact that both of these countries sit in the Pacific Ocean. I think that comment of Mr. Reishower is so much more pertinent today than 25 years ago when he said it. It was true then, but it is even more true today.

As you know, the Pacific has become the center of the world economy. The United States and Japan, which are the two largest economies in the world, have this special interest and this special responsibility in providing stability in the post-Cold-War world in this Pacific economy. Particularly in retrospect, I think we can see that one of the advantages of the Cold War was that it was a relatively stable situation. There was certainly a threat of nuclear exchange between the United States and the Soviet Union, but if that didn't take place the world was quite stable. On the other hand, after the end of the Cold War, one of the down sides is the world is a less stable place and this leads to that special interest of the United States and Japan. If the Pacific remains stable, these two rich nations will continue to prosper.

If they take advantage now of the special opportunity that neither Japan nor the United States could have dreamed about five years ago to push market economics into the former Soviet Union, China, Korea and Eastern Europe, the entire economic pie will grow and everybody will prosper. The United States and Japan will become even richer in that scenario. This special responsibility I believe comes from the fact that the United States and Japan have only seven percent of the world population, but that seven percent of the world population is controlling forty percent of the world's gross national product.

I believe the United States and Japan have a very special responsibility to keep the treaty between them. The treaty of mutual cooperation and security that helps provide that stability but also a responsibility to expand relations via confidence-building measures with Korea, with China and with far east Russia. I think this nuclear dumping issue that we have talked about is a confidence-building measure.

As I mentioned yesterday, I thought the purpose of this conference was to learn the scope of the dumping problem in the areas we have had under discussions. I think, thanks to a very forthcoming presentation from the Russian side, a very good view of that has been achieved. I have gained the impression from presentations made at this conference that Russian experts don't know about similar information concerning United States waste disposal methods. It is also my impression that Japanese experts are not completely comfortable about the consistency of information they may have received in the past from the Russian side. A third perception is that, at least to some extent, the United States and Japan are both perceived by their Russian colleagues as possibly favoring stricter restrictions on Russia than on themselves.

I am now an academic but really my main career was as a seagoing naval officer, an operating officer. Many of the ships I served on were based in Japan rather than in the United States. The U.S. and the Japanese Navy, the Maritime Self Defense Force, worked extremely closely together. We had many bilateral exercises but we jokingly said these were trilateral exercises because the Soviet navy was usually there watching us. I think that today it is very thinkable that we have trilateral exercises among the U.S., Japanese and Russian navies, and I think that further progress in the nuclear dumping area is an additional good step that should be taken. If confidence increases, then perhaps this kind of naval cooperation would be possible towards the end to create a very secure environment. If we do create that secure environment, then I think we can even go a step beyond that towards the task of integrating the Russian Far East economy into the Asian Pacific economy, which would certainly be good for Russia, good for the United States, good for Japan and good for the Pacific. So I think in conclusion we owe another vote of thanks to Dr. Radvanyi for starting this process. He is not only a hero of Hungary, but he is a hero of the United States, of Japan and of Russia. Thank you.

**Bruce Molnia**

Jim, your summary leaves me with very little to say. It also is a very difficult act to follow. When we set up the organizing committee, my primary responsibility was to worry about the scientific content of this conference and Dr. Radvanyi and Dr. Auer's involvement was focused on the policy and international relations side.

I walked into this meeting not sure what I would learn scientifically. When I came here I had several questions in mind. The first being "What do we presently know?" From my personal point of view it wasn't very much. I had read the Yablokov report, I had seen the results of some of the CREAM expedition, but there were many scientific questions in my mind that still needed to be answered. My second question was "What do we need to know?" What must we have in hand in order to be able to address my third question, which is, "Is there a risk?" When we say "risk" there are many different kinds of risk to consider. There are risks to the local environment, risks to the larger-scale ocean ecosystem. There are terrestrial risks and there are global environmental risks. Then, from a very chauvinistic point of view, and in the United States that's generally what determines whether Congress funds U.S. involvement, is there a risk to the United States? Is there a risk to the U.S. fishery? We are talking about the fishery in the northern Pacific and the fishery in the Bering Sea.

I was very pleased by Captain Danilyan's presentation. It answered many questions that I had that were not clearly spelled out in the Yablokov report. It also made me feel much more comfortable with the accuracy of the information presented in the Yablokov report.

I was also very pleased to learn about the CREAMS expedition in more detail than I had previously heard. What that told me is that even though we now have international cooperation, there are still many geographic areas where we have not been able to collect any scientific data. Although none of the places where we have gone show any evidence of substantial amounts of radioactivity or of even more than background amounts in most cases, it still does not completely put the question to rest. Is there any leaking? Are there areas where we haven't been able to go where there might be some evidence of discharge? And I still feel that this needs to be addressed further.

I am becoming more comfortable with the fact that there have been successful international cooperative activities on the part of Russia, Japan and Korea. I hope to also see the U.S. become involved in looking at the sites. Mr. Kokeev has pointed out very eloquently that it is not just a Russian dumping question. It's an international waste disposal question. We need to work cooperatively to assess whether there are any other areas where potential environmental impacts might exist.

I want to thank all of you—our international participants; our U.S. participants; the workshop staff; our Mississippi State University sponsors and hosts, Dr. Ward and Dr. Ray; and the Office of Naval Research, and the Japan America Friendship Committee for financial support. I especially want to thank Congressman Weldon. He left us with a challenge. He said to me before he left, "I want to see the results and recommendations of this workshop. And I want to be able to take them back to Congress and to use them to all of our advantage." He left us with a mission. That is for the organizing committee to summarize what has transpired here over the last two days and to come up with a series of recommendations. These will be sent to all of you for your comments and for your feedback. We need to do this quickly. In fact, I would think in order to take advantage of the present situation, we would need to have a letter off to the Congressman within no more than six weeks. So we will try to formulate a short summary and some recommendations and give them to you very quickly for your comments.

On a much more important scale for the global perspective, we heard from a number of people that there is not only a scientific issue but there are perception, social and political issues. As it was pointed out several times, we in the scientific community have been failing, and failing very badly, in conveying to the general public the results of our scientific observations. We heard the concerns about the perception of dangerous environmental conditions and their impact on the price of fish in Japan. We could have said the exact same thing five years ago about the price of fish from the Norwegian Sea.

Unless we do a good job of collecting scientific information, systematically analyzing it and doing our best to bring the facts to the general public, we may hear the same concerns about the price of fish from the Pacific Ocean. So we have a responsibility as scientists and as policy people to convey our findings, our information, the "accurate information," as Captain Danilyan said, to the general public.

We need to work with the media. We need to work with Congress and the people of the United States. We need to work with GLOBE. But we also need to work beyond our own sphere of influence.

I also want to focus on something that Doug Posson said. You remember Doug said that normally he's at the end of the program because no one pays much attention to data management. Here we gave him an opportunity to speak up front and he did very well at the beginning of the program. I want to urge this group to consider using a well-established and effective means of providing information exchange within the scientific community, the concept of a metadata directory, such as the Arctic Data Directory. We can broaden its scope to include our Japanese colleagues and their data from the Sea of Japan, the Sea of Okhotsk and the north Pacific region. We also need to use this data management mechanism to go beyond our own scientific community. We need to use other available mechanisms—the Internet, bulletin boards and other ways of distributing our results and recommendations to a much larger audience.

So I'd now like to turn over the proceedings to Dr. Radvanyi, who will tell us where we go from here in terms of follow-on workshops, international cooperation and what we can do based on the success that we've had yesterday and today. Thank you.

**Janos Radvanyi**

For the last four years, I have been working together with my Japanese friends, with Counselor Hideaki Domichi, with Ambassador Nobuo Matsunaga, with many others to put together a program and to assist East Central Europe, mainly in the environment field. As I already told you, we were successful and there is a concrete result. The Japanese government is going to give, and is already dispersing, about one billion dollars to the cleanup of East Central Europe. The United States will also participate and contribute a substantial amount. For us, that success was a model to try to apply elsewhere. We started to think about what to do next. It is a great personal satisfaction for me and a great honor for me that today I can be here together with, in addition to my old Japanese friends and of course together with my American compatriots, our new Russian friends.

Through this cooperation, I can work to make the life of the Japanese children, the American children and the Russian children, as well as all the other children in the area, safer. And for me a dream comes true. This workshop gave me great encouragement. It helped me to understand the problems related to waste disposal. It helped me to understand that we have to work together on this issue much more because there is still a great deal of uncertainty.

People do not trust each other. Nations do not trust each other. But I think that I begin to understand that the world has changed. We are not in a peaceful coexistence anymore. We are in a peaceful cooperation and that is a big difference. To be more practical, I think, and I hope you will agree, that this conference was a good start and the first step. Our aim should be to expand on this success, based on the experience of this first workshop.

At the next meeting, we have to see closer U.S., Japan and Russian science cooperation. I think we should, and I think Mr. Yamazaki will help us to establish more financial cooperation with the International Monetary Fund; the Overseas Economic Cooperation Fund, a great Japanese financial institute that has helped Eastern Europe with the one billion dollar program, and the EBRD. I think what we need to do is to expand the involvement of the private sector and at the same time we need the assistance of government agencies.

Then last, and that is the real music which I learned here, we have American congressional support. Congressman Weldon's presence here, in these very turbulent hours and days in Washington, shows that we have real support. But that is not enough; we need to have the same support from the Japanese. We need to have support from the Russian Duma. With that note I would like to thank everybody for their cooperation, their encouragement and the work they put in. Everybody tried to give their best. Perhaps the best thing was that here in Biloxi, we created a neutral forum and everybody was able to say whatever he or she wanted, even if we didn't agree. It helped because at least we know what each other person had in mind. So again, once more thank you so much for letting my dream come true.

On behalf of the Center for International Security and Strategic Studies, I would like to take this opportunity to reiterate our indebtedness to all our contributors for their generous assistance and stimulating thoughts. I owe a special thanks to Naotoshi Sugiuchi, and Michail E. Kokeev, who chaired the Japanese and Russian panels, as well as William A. Nitze and Congressman Curt Weldon, who graciously co-chaired the American panel. Preparatory Committee member Dr. Bruce L. Molnia provided invaluable advice, information and insight on scientific topics. Preparatory Committee member Dr. James E. Auer worked tirelessly as the project's primary Japanese advisor. And, for their generous financial support, I would like to express my appreciation to the Office of Naval Research, and the Japan–United States Friendship Commission. I am also grateful for the corporate co-sponsorship of Mitsubishi International Corporation, Plasma Technology Corporation, and Neptune Sciences, Inc. Finally, I would like to express many thanks to David Cate of the *Arctic Research of the United States* for his help in seeing these proceedings through publication.

Thank you.

# Closing Remarks

*Melvin C. Ray*
Office of the Vice President
Mississippi State University, Mississippi State, Mississippi

On behalf of the entire family of Mississippi State University, we would like to thank you for your participation in this conference. As a criminologist I thought upon coming here I would be coming to see gang warfare fighting over turf. I'm very much pleased to find the level of cooperation that has been exhibited here, this trilateral cooperative agreement to address a very serious problem.

We appreciate the opportunity to work with you and to support this effort. I've been given the task to try and recognize all of the people or most of the people who gave a hand in presenting this program. I'll try to do so. Now if I should leave out someone, please blame it on my mind and not on my heart. I have a pretty good heart but my mind tends to flee sometimes. First of all I would like to say a word of thanks to Dr. Roy Crochet of the Stennis Space Center and the Mississippi Science and Technology Center who helped in putting together the preliminary details of this conference for his contribution. He helped to bring off a wonderful conference. We also are especially thankful to agencies and corporations who worked with the coordinating committee. To name a couple here, the Office of Naval Research, U.S. Japan Friendship Commission, and also the corporations who sponsored some of the workshops: Mitsubishi, Plasma Technology, Neptune Sciences Inc, and SubSea International. We also need to say a word of thanks to Mr. Sidney Rushing of the Hancock Bank. We are also happy to have in attendance Dr. Ronald Aqua of the United States Japan Foundation, and Mr. Jeffrey Magee of the Center for Global Partnership. I'm supposed to now talk or acknowledge our organizing committee but I would like to save them for last and talk about the other people who worked with them, their staff. Without them, as we all know, these conferences never go as they should. So I think first of all let us give some thanks and a word of acknowledgement to Miss Tan Tsai for a wonderful job as well as the others who are part of the preparatory committee: Miss Brett Brinegar, Miss Olga Murova and Mr. David Sites of the CISS; Mr. Robby Smith of MSU transportation; Ms. Terry Linton of the U.S. Geological Survey, Miss Barbara Vaneck from the MSU Science and Technology Research Center; Mrs. Evelyn Watts from the Mississippi Center for Air and Sea Technology; and Ms. Natalia Lauren Erval, our translator.

Now I would also like to thank the organizing committee. A few months ago when I got a call from Dr. Radvanyi, he said, "We need to go down to the Stennis Center to make arrangements for a conference." I had the pleasure of coming down with three fine gentlemen who have led this charge and I think we all owe our gratitude to these three individuals, Dr. Bruce Molnia, Dr. James Auer and Dr. Janos Radvanyi, for their hard work that brought this conference together and made it a successful adventure. I think we all need to share in a round of applause for them.

I would just like to end with a brief story that I heard last night. Several years ago, there were three whales that were caught in the ice near Barrow, Alaska. I heard about the efforts that brought about the saving of those three whales and the story went something like this. The whales were caught in the ice and the Natives were there chopping holes in the ice so the whales could breathe. The Natives needed equipment to come in to help with that mission. What they did was they called on the Japanese for one of their ice-cutting machines that came in and helped chop the ice. But that wasn't enough; the whales were still not safe.

The U.S. was working and was sending in its technology. U.S. scientists were working with the Japanese trying to get these whales out. Those two groups could not do it alone. The last resort was to call in the Russians, because the last little piece of ice that was left was thick and hard and prevented the whales from getting out. It could only be broken by some technology that the Russians had. With that help, with that trilateral cooperation, the three whales were saved.

Then I thought, could we transform those three whales into the three seas we've been talking about here today and put forth that same cooperation, that same effort, belief, and trust to do the world some good? With that I close. Thank you very much.

# Scientific Summary and Conclusions

*Janos Radvanyi, Brett Brinegar and Charles Sparrow*

## Introduction

Information gathered at the Biloxi workshop produced substantial timely useful material. Russian scientists and representatives of the Russian Navy offered comprehensive and detailed pictures of the past activities of Soviet Naval dumping of nuclear wastes, and described the Russian Navy's practices of nuclear waste disposal. During the course of the workshop, Russian participants were quite forthcoming about the amount and character of radioactive waste disposed in the Sea of Japan, and went beyond the well-known Yablokov report by disclosing at least one additional dumping—the 1993 disposal of 0.38 curies of low-level liquid waste.

The Biloxi workshop produced twenty scientific papers, as well as a number of scientifically based presentations and panel discussions. New material presented added to the already existing knowledge base being used for comprehensive evaluation of the physical environments of all three dump areas.

## Dumped Materials

Presentations made by the Russian Navy indicated that the amount of dumped liquid and solid low-level waste in the Sea of Japan is not significantly greater than the approximately 250,000 curies described by the Yablokov Commission report. However, extensive details concerning the disposal of low-level waste in the Sea of Japan were presented by chemical experts of the Russian Navy. New data revealed in Captain 1st Rank V.M. Danilyan's report, "Nuclear Waste Disposal Practices in Russia's Pacific Ocean Region," are of significance. Contamination created by an accidental release of $^{137}Co$ in 1985 has been monitored in order to provide data concerning the transport of radionuclides in the Sea of Japan. Some indication of the magnitude of radioactive waste disposal problems confronting the Russians was presented candidly at the conference. Not only did the Russian attendees identify the history of radioactive waste disposal activities carried out by the Navy of the Former Soviet Union (FSU), but from several sources there was a reasonably consistent identification of the storage and disposal requirements that result from the normal operation and from the decommissioning of nuclear submarines and surface ships. Annually, 20,000 m$^3$ of liquid radioactive waste and 6,000 tons of solid radioactive waste are generated from naval operations. While the actual volume produced depends upon treatment technology used, nevertheless, it is obvious that considerable quantities of waste, liquid and solid, must be handled.

However, it is important to note that data presented at the Biloxi workshop indicate that transportation pathways for materials released at dump sites are still unknown. Preliminary results suggest that the Sea of Japan upper-level water mass circulation would probably transport suspended or dissolved materials in a south to southeasterly direction toward the northern Japanese islands.

The report presented by the representative of the government of South Korea notes that current values of $^{137}Cs$ in the Sea of Japan are in the neighborhood of 3 mBq/kg at the surface. Reported data for 1977–1978 show a higher concentration than would be supported by later measurements. With the exception of this point, these data are consistent with a model in which there is little removal of $^{137}Cs$ due to transport by currents. A separate report, compiled by several Russian participants, "Investigations of Marine Environment Radioactivity in the Dumping Areas and Coastal Zone of the Sea of Japan," confirms the values for $^{137}Cs$ noted in the Korean scientific report. Activities of $^{137}Cs$ ranged from 2.6 to 3.4 mBq/kg. These activities do not differ from background levels attributable to fallout from nuclear weapons testing and are consistent with the data presented by Russian Navy representatives. In other words, if the assumption is made that low-level liquid radioactive waste originates from processing of spent nuclear fuel, then the radionuclides disposed at sea are the same as those that originate from atmospheric testing. Hence, it is not possible to determine the levels of radionuclide originating from marine disposal practices, since the inventory of nuclides such as $^{137}Cs$ from waste disposal is significantly less than the inventory from weapons testing. The $^{60}Co$ in Chazhma Bay furnishes the best indicator of dispersion, since $^{60}Co$ is not a fission product and therefore is not produced in explosions of nuclear weapons. Further, the half-life of $^{60}Co$ is 5.27 years, so measurable levels of activity correspond to dumping events within the past two or three decades. Russian reports assert that radioactive waste dumped in the Sea of Japan between 1974 and 1993 was dumped at station 9 (SNW 2,234), for which the depth is approximately 3,300 m. A total of 10,840 curies were dumped in this twenty-year period. Kurchatov Institute scientist Dr. Serguei A. Bogatov claims that 10,600 curies were released in a single year around 1985. The composition of this is not known.

However, additional data from the CREAMS (Circulation Research of East Asian Marginal Seas) research cruise in the summer of 1993 shows no special elevation of $^{137}Cs$ activity in surface waters at this sampling station. Several expeditions—one joint Japanese–Russian–Korean March–April 1994 cruise to the Sea of Japan sites, and the CREAMS 1993 joint Japanese–Russian–Korean expedition—support this finding.

## Land-Based Hazards

There is an immediate need to investigate the scale of the on-land storage problem in the Russian Far East, as well as to try to anticipate the potential for accidents involving mothballed or inoperative submarines and other sources of nuclear materials. Serious concerns were raised by several scientists about the extremely large quantity of nuclear waste remaining in Russian Far East on-land temporary storage sites, and what manner of disposal would be used for this waste. There was some dispute as to whether or not this waste may be a larger, long-term source of environmental problems and concerns than waste previously dumped at sea. Accidents involving decommissioned submarines, either during destruction or transport, were cited as principal concerns. Much of the high-level radioactive submarine waste of the Russian Pacific Submarine Fleet falls into this category, and this concern is one that needs additional, substantial investigation. The absence of carefully investigated, environmentally sound permanent disposal sites further complicates this problem. Given the close proximity of the port of Vladivostok to Japan—less than 600 miles—any accident involving this waste could create a potential threat to human health. Therefore, further study of the radioactive waste problem must concentrate on land-based waste, along with ocean dumping, with regard to safe and scientifically proven disposal methods. Data furnished by workshop participants assisted in identifying the extent of Russian nuclear waste disposal.

## Conclusions

The Biloxi workshop provided a forum for identification and description of Russian Navy nuclear waste disposal at sea since the beginning of the use of nuclear propulsion in the FSU. A complete record of disposal at sea was provided by Russian attendees. Their information was verified as measurements and analyses presented at the workshop by American and Korean scientists were generally consistent with Russian reports of dumping. Problems, such as the hazard and potential risks caused by stored radionuclides, were identified. Scientists, private sector participants and representatives of NGOs worked together to suggest solutions to the radioactive waste disposal and storage crisis in Russia. Private-sector scientific firms, such as Mitsubishi International Corporation, Washington, D.C.; SAIC; Plasma Technology; and Neptune Science, presented information based on their own work with both marine and land-based state-of-the-art radioactive waste disposal methods.

However, this workshop also established that more scientific work is needed, including more accurate identification of marine dumping sites. A clearer picture needs to be formed as to how spent liquid and solid nuclear waste will be disposed of in the future. It is not presently known how close the sampling locations were to the dumping sites. No remote operational vehicle (ROV) studies or photographic examinations were conducted of the disposal sites. In order to supplement existing data, these studies are desirable. In addition, environmental risk assessments would be appropriate to determine the extent of the threat regarding the Sea of Japan, the Sea of Okhotsk and the North Pacific Ocean. Also, research about sublethal effects of radiation upon simpler life forms in the ocean could be a subject of investigation. Last but not least, workshop results indicate that more information gathering on the land-based waste situation is warranted.

# *Interagency Arctic Research Policy Committee*

*Committee Members and Agency Representatives Present: Neal Lane (Chair) and Charles Myers, National Science Foundation; Donald O'Dowd and Garrett Brass, Arctic Research Commission; Bradley Smith, Department of Defense; Ari Patrinos, Peter Lunn and Merrill Heit, Department of Energy; Peter Hartsock, Department of Health and Human Services; James Devine and Bruce Molnia, Department of the Interior; David Colson and Robert Senseney, Department of State; Alan Summy, Department of Transportation; Joseph Alexander, Environmental Protection Agency; Nancy Maynard, National Aeronautics and Space Administration; Thomas Laughlin and Edward Myers, National Oceanic and Atmospheric Administration; Sarah Horrigan, Office of Management and Budget; Ross Simons and William Fitzhugh, Smithsonian Institution.*

## *Thirteenth Meeting: May 31, 1995*

Dr. Neal Lane, Director of the National Science Foundation and Chair of IARPC, convened the meeting at the National Science Foundation, Arlington, Virginia. Following introductions, Dr. Lane noted that this year was the tenth anniversary of the IARPC. He briefly highlighted several accomplishments of the IARPC over the past ten years:

- Development of the United States Arctic Research Plan and its biennial revisions;
- A near doubling in real terms of Federal Arctic research budgets;
- Development of U.S. Arctic Research Policy;
- Creation and continued publication of the journal *Arctic Research of the United States*;
- Development of a Statement of Principles for the Conduct of Research in the Arctic; and
- Greatly improved interagency cooperation in Arctic research.

### *Review of U.S. Arctic Policy*

Dr. Lane called on David Colson, Department of State, to review U.S. Arctic Policy. Mr. Colson noted that since the breakup of the Soviet Union, the international community has begun to look at Arctic issues as regional issues. As an example, he mentioned the International Arctic Environmental Protection Strategy.

Mr. Colson recalled that earlier this year the President met with Canadian officials and indicated U.S. support for an Arctic Council. In the next year an international focus will be on the Arctic Council concept. By addressing Arctic issues in an international forum, the U.S. will need to review policies and laws that have been in place for decades.

Another policy issue discussed was the Gore–Chernomyrdin agreement on U.S.– Russia cooperation. Garrett Brass asked if clearance for research groups was discussed as part of the Gore–Chernomyrdin process. Colson responded that it was.

### *Government-Wide Arctic Research Budgets*

Dr. Lane began by stating that the Administration's budget identifies science and technology as priority areas for investment. Thomas Laughlin, NOAA, was invited to review government-wide Arctic research budgets and NOAA's new initiative on Arctic contamination. He noted that the NOAA initiative builds on existing programs, as well as on IARPC's contamination initiative. Three new elements have been added:

- A Native knowledge component;
- The Cooperative Institute for Arctic Research (CIFAR); and
- Activities under the Arctic Environmental Protection Strategy, including the Arctic Monitoring and Assessment Program (AMAP).

Dr. Lane thanked Mr. Laughlin for his report.

### *Beringian Systems Initiative*

Dr. Lane introduced this agenda item by stating that the Beringian Systems initiative was a program of the National Park Service (NPS), the Smithsonian, NOAA and other agencies. He asked William Fitzhugh to describe the program. Mr. Fitzhugh stated that the program is an integrated science program designed to take advantage of unprecedented opportunities for research in the Russian Arctic.

The Beringian Systems Initiative was formulated to stimulate and assist ongoing U.S. research efforts aimed at understanding the oceans, lands and history of the regions surrounding the Bering Strait. This area has a very productive ecosystem with a wealth of resources. The Bering region offers potential for major advances in two areas:

- The application of interdisciplinary systems science in a unique natural environment; and
- Global change research, particularly in the natural and social sciences.

Dr. Lane commented that within the NSF global change program there has been an increased interest in social sciences and that interagency cooperation has helped focus NSF's Human Dimensions of Global Change studies.

Charles Myers, NSF, added that the NSF Office of Polar Programs has just concluded a meeting with representatives of the Russian Foundation for Basic Research. U.S. and Russian participants agreed to develop cooperative research proposals and jointly review proposals.

### *IARPC Data Management Activities*

Dr. Lane noted that the IARPC Arctic environmental data working group is charged with several tasks, including the establishment of modern systems to distribute Arctic information. Bruce Molnia, U.S. Geological Survey (USGS), provided an overview of the activity.

He reported that the Arctic Environmental Data Directory (AEDD) is available globally through the Internet. Several cooperating institutions such as the United Nations Environmental Program have also established home pages on the Internet. An International Arctic Data Directory, an international version of the AEDD, has been established through cooperation with Russia, Norway, Finland, Canada and Japan. The U.S. AEDD currently has about 400 quality-controlled entries. Peer review is used to determine content of the AEDD. USGS is working with Russia to establish international standards for quality control.

Dr. Lane thanked Mr. Molnia for his presentation and encouraged the agencies to continue to contribute to the project.

*IARPC Biennial Revision to U.S. Arctic Research Plan*

Dr. Lane asked for approval of the revision to the U.S. Arctic Research Plan. The Plan has two major sections: coordinated interagency initiatives and interagency programs. The staff working group completed a first draft in January 1995. Later drafts were reviewed by the Arctic Research Commission, the Polar Research Board, the Inuit Circumpolar Conference and other organizations. The document has been approved by each agency. Dr. Lane recognized the excellent work by the staff in preparing the revision and requested concurrence for transmittal to the White House. All IARPC members concurred.

*Comments from the Arctic Research Commission*

Dr. Lane thanked Donald O'Dowd, Chair, Arctic Research Commission, for his dedicated efforts and leadership of the Commission. Dr. O'Dowd restated concerns he had shared at the July 1, 1993, meeting of the IARPC. The first was his request that an Arctic section be established in the Office of Polar Programs. This section is now in place and will soon have a director.

Other concerns had included:

- That NSF establish and maintain an Arctic logistics and information source to serve Arctic researchers needing assistance in working in the Arctic;
- That NSF establish a separate logistics budget to support Arctic research;
- That IARPC reactivate its working group on logistics;
- That the scientific merit of Arctic research proposals be reviewed separately from their logistics costs;
- That agencies provide support for the use of Navy submarines in Arctic Ocean studies and develop an integrated science plan; and
- That an interagency plan be prepared for the study of Arctic contaminants, including nuclear, industrial, agricultural and any other foreign materials that might be transported to the Arctic.

Dr. O'Dowd stated that all of these concerns had been addressed and acted upon in the past two years.

The Commission has identified additional priorities for Arctic research:

- Funding for the Arctic contamination study;
- Support for an Arctic research vessel;
- Continuation of the Arctic submarine research cycle, scheduled until 1999; and
- Further development of Arctic health and medical research programs.

Dr. O'Dowd stated that the past two years have shown great progress in Arctic research. He thanked the NSF and other agencies for supporting these efforts.

*Public Comments*

Dr. Lane introduced Syun Akasofu, Director of the Geophysical Institute at the University of Alaska. Dr. Akasofu gave a brief presentation on the activities undertaken at the Institute. Since Dr. Akasofu became director in 1986, funding from the various IARPC agencies has helped the university strengthen its research capabilities in the Arctic. Dr. Akasofu presented information on current Geophysical Institute facilities.

He stated that the Geophysical Institute plans to focus on international research opportunities through funds to be provided by the Japanese government. Currently about 30% of the researchers are from the international community. The proposal is for the Japanese government to match U.S. funds. He stated that Japan shares the view that Arctic research is one of its high priorities in science.

# 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.*

## 1995

**International Conference for Arctic Research Planning**
**5–9 December 1995, Hanover, New Hampshire, USA**
Contact: Oran R. Young, Director, Institute of Arctic Studies, 6193 Murdough Center, Dartmouth College, Hanover, New Hampshire 03755, USA
Fax: 1 603 646 1279
E-mail: oran.r.young@dartmouth.edu

**Monitoring of Permafrost and Frozen Soils: Implications for Studies of Periglacial Processes Under a Changing Climate (proposed) American Geophysical Union Fall Meeting**
**11–15 December 1995, San Francisco, California**
Contact: Bernard Hallet, Quaternary Research Center, AK-60, University of Washington, Seattle, Washington 98195, USA
Tel: 1 206 685 2409; Fax: 1 206 543 3836
E-mail: hallet@u.washington.edu

## 1996

**Workshop on Arctic Tourism Guidelines**
**19–22 January 1996, Longyearbyen, Svalbard, Norway** [By invitation only]
Contact: WWF-Arctic Programme
Fax: 47 22 20 06 66
E-mail: wwfap@oslonett.no

**The 11th International Symposium on Okhotsk Sea and Sea Ice: Workshop on International Multidisciplinary Plans in the Sea of Okhotsk**
**25–28 February 1996, Mombetsu, Hokkaido, Japan**
Contact: Mr. Soshi Hamaoka, Secretariat of 11th International Symposium on Okhotsk Sea and Sea Ice, c/o Department of Planning and Coordination, Mombetsu Municipal Office, Saiwai-2, Mombetsu, Hokkaido, 094 Japan
Tel: 81 1582 4 2111; Fax: 81 1582 3 1833
E-mail: kunio@lt.hines.hokudai.ac.jp

**International Workshop on the Okhotsk Sea and Arctic: The Physics and Biogeochemistry Implied to the Global Cycles**
**29 February–1 March 1996, Tokyo, Japan**
Contact: Takatoshi Takizawa, Ocean Research Department, JAMSTEC, 2-15 Natsushima, Yokosuka, Japan 237
Tel: 0468-67-5571; Fax: 0468-65-3202
E-mail: takizawat@jamstec.go.jp

**26th Arctic Workshop**
**14–16 March 1996, Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado, USA**
Contact: Cynthia Ocken-Roberts, INSTAAR, University of Colorado, Boulder, CO 80309-0450, USA
E-mail: ocken_c@cubldr.colorado.edu

**International Union of Circumpolar Health Meeting**
**Third week of May 1996, Anchorage, Alaska, USA**
Contact: Tom Bender, International Union for Circumpolar Health, P.O. Box 212001, Anchorage, Alaska 99521-2001 USA
Fax: 1 907 786 4353

**International Conference for Polar Snow–Ice and Global Change**
**15–20 April 1996, Lanzhou, China**
Contact: Dr. Li Shize & Dr. Li Shongqin, Lanzhou Institute of Glaciology & Geography (LIGG), 730000 Lanzhou, China
Tel: 86 0931 88 25 815; Fax: 86 0931 88 85 241

**The 1996 IASC Annual Meeting**
24–25 April, 1996, Bremerhaven, Germany [By invitation only]
Contact: Odd Rogne, The IASC Secretariat, P.O. Box 5072, Majorstua, 0301 Oslo, Norway
Fax: 47-22 95 96 01
E-mail: iasc@npolar.no

**Climate Change, Water Resources and Energy Production in the Nordic Countries**
**26–28 April 1996, Reykjavik, Iceland**
Contact: Kristinn Einarsson, Orkustofnun, Grensasvegi 9, IS-108 Reykjavik, Iceland
Fax: +354 568 8896
E-mail: ke@os.is

**Seventh ITEX Workshop**
**26–29 April 1996, Copenhagen, Denmark**
For scientific/technical matters contact: Preben Gudmandsen, Technical University of Denmark, Building 348, DK-2800 Lyngby, Denmark
Tel: 45 45 25 37 88; Fax: 45 45 93 16 34
E-mail: pg@emi.dtu.dk
For organizational matters contact: Mrs Iris Madsen, The Danish Polar Center, Strandgade 100 H, Dk-1401, Copenhagen K, Denmark
Tel: 45 32 88 01 00; Fax: 45 32 88 01 01
E-mail: im@pops.dpc.min.dk

> 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.

**The Fourth Circumpolar Symposium on Remote Sensing of Polar Environments**
**26 April–1 May 1996, Copenhagen/Lyngby, Denmark**
For scientific/technical matters contact: Preben Gudmandsen, Technical University of Denmark, Building 348, DK-2800 Lyngby, Denmark
Tel: 45 45 25 37 88; Fax: 45 45 93 16 34
E-mail: pg@emi.dtu.dk
For organizational matters contact: Mrs Iris Madsen, The Danish Polar Center, Strandgade 100 H, DK-1401 Copenhagen K, Denmark
Tel: 45 32 88 01 00; Fax: 45 32 88 01 01
E-mail: im@pops.dpc.min.dk

**Xth International Congress on Circumpolar Health**
**19–24 May 1996, Anchorage, Alaska, USA**
Contact: Michele A Hansen, Xth ICCH Coordinator, c/o American Society for Circumpolar Health, P.O. Box 242822 Anchorage, Alaska 99524-2822 USA
Tel: 1-907-561-4406; Fax: 1-907-562-7802
E-mail: icch@epi.hss.state.ak.us

**ISOPE '96–Offshore and Polar Engineering Conference**
**26–31 May 1996, Los Angeles, California, USA**
Contact: Jin S. Chung, Chairman, ISOPE-96, Box 1107, Golden, Colorado 80402-1107, USA
Tel: 1 303 273 367; Fax: 1 303 420 3760

**Second International Conference on Cryopedology**
**June 1996, Syktyvkar, Russia**
Contact: David Gilichinsky, Institute of Soil Science and Photosynthesis, Pushchino, Moscow Region, Russia
Tel: 7 095 923 1887
E-mail: gilichin@issp.serpukhov.su

**16th Polar Libraries Colloquy**
**16–21 June 1996, University of Alaska, Anchorage, USA**
Contact: Barbara Sokolov, Director, UAA Consortium Library, Univeirsity of Alaska Anchorage, 3211 Providence Drive, Anchorage, AK-99508-8178, USA
Tel: 1-907-786-1825; Fax: 1-907-786-6050
E-mail: anbjs@orion.alaska.edu

**Second International Scientific Conference on the Global Energy and Water Cycle**
17–21 June 1996, Washington, DC, USA
Contact: Meetings Division (Judy Cole), 101 Research Drive, Hampton, Virginia 23666-1340, USA
E-mail: cole@cais.com.

**Changing Glaciers: Revisiting Themes and Field Sites of Classical Glaciology**
**24–26 June 1996, Norwegian Glacier Centre, Fjarland, Sognefjord, Norway**
Contact: Elisabeth Isaksson, Norwegian Polar Institute - Brekontoret, P.O. Box 5072, Majorstua, N-0301 Oslo, Norway
Tel: 47 22 95 95 00; Fax: 47 22 85 95 01
E-mail: elii@npolar.no

**Interpraevent 1996: Protection of Habitat Against Floods, Debris Flows and Avalanches**
**24–28 June 1995, Garmisch-Partenkirchen, Germany**
Contact: Interpraevent 1996, c/o Bayerisches, Landesamt für Wasserwirtschaft, Lazarettstr. 67, D-806365 Munich, Germany

**International Symposium/Workshop on Polar Desert Ecosystems**
**1–4 July 1996, Christchurch, New Zealand**
Contact: The Secretary, National Institute of Water and Atmospheric Research, Ltd., P.O. Box 8602 Riccarton, Christchurch, New Zealand

**The Oceanography Society (TOS) Meeting on Marine Environment and the Global Change Programs**
**8–11 July 1996, Amsterdam, The Netherlands**
Contact: TOS, 4052 Timber Ridge Drive, Virginia Beach, Virginia, USA
Tel: 1-804-464-0131; Fax: 1-804-464-1759
E-mail: jrhodes@ccpo.odu.edu

**VI International Symposium on Cold Hardiness in Animals and Plants**
**14–19 July 1996, Copenhagen, Denmark**
Contact: Hans Ramliv, Chemical Institue, lab.III, H C Irsted Institute, Universitetsparken 5, DK-2100 Copenhagen 1, Denmark
E-mail: hans@kiku.dk
or
Iris Madsen, Danish Polar Center, Strandegade 100 H, DK-1401 Copenhagen K, Denmark
Tel: 45 32 88 01 00; Fax: 45 32 88 01 01
E-mail: im@pops.dpc.min.dk

**High Arctic Field Meeting, Ellesmere, Axel Heiberg, and Cornwallis Islands**
**8–17 July 1996, Ottawa, Ontario Canada**
Contact: Antoni G Lewkowicz, Department of Geography, University of Ottawa, Ottawa, Ontario, Canada K1N 6N5
Tel: 1-613-562-5704; Fax: 1-613-562-5145
E-mail: alewkowi@acadvm1.uottawa.ca

**30th International Geological Congress**
**4–14 August 1996, Beijing, China**
Contact: Professor Zhao Xun, 30th International Geological Congress, P.O. Box 823, Beijing 100037, China
Tel: 86 1 8327772; Fax: 86 1 8328928

**International Symposium on Representation of the Cryosphere in Climate and Hydrological Models**
**12–15 August 1996, Victoria, B.C., Canada**
Contact: Secretary General, International Glaciological Society, Lensfield Road, Cambridge, CB2 1ER, United Kingdom
Tel: 44-1223 355974; Fax: 44-1223 336543
E-mail: 100751.1667@compuserve.com
WWW site: http://www.dow.on.doe.ca/crysis/igs96.html

**8th International Cold Regions Engineering Conference**
**12–17 August 1996, Fairbanks, Alaska, USA**
Contact: Larry Bennett, School of Engineering, University of Alaska, Fairbanks, Alaska 99775, USA
Tel: 1 907 474 6121; Fax: 1 907 474 6087

**Traditional Knowledge and the Contemporary World—The 10th Inuit Studies Conference**
**15–18 August 1996**
Contact: Irene Mazurkewich, Department of Linguistics, Memorial University, St. John's NF A1B 3X9, Canada
Tel: 1-709-737-8299; Fax: 1-709-737-2548
E-mail: imazurk@kean.ucs.mun.ca

**IX International Symposium on the Physics and Chemistry of Ice**
**27–31 August 1996, Hanover, New Hampshire, USA**
Contact: Victor Petrenko, 8000 Cummings Hall, Dartmouth College, Hanover, New Hampshire 03755-8000, USA

**International Conference on Oil, Gas and Ecology of the Earth Cryosphere**
**September 1996, Nizhnevartovsk, Tumen**
Contact: Vladimir Melnikov
Tel: 34 52 24 3649; Fax: 34 52 22 3380
E-mail: root@ikz.tyumen.su

**4th International Symposium on Glacier Caves and Cryokarts in Polar and High Mountain Regions**
**1–7 September 1996, Alpine Centre Rudolfshétte, Uttendorf, Salzburg, Austria**
Contact: Univ. Prof. Dr. Heinz Slupetzky, c/o Institut für Geographie, Universität Salzburg Austria
Tel: +43 (0) 662 8044 525

**Images of the North Through Prism of Science and Tourism**
**10–12 September 1996, Geological Institute, Econord, Khibiny Co., Nordic Study Centre, Royal Academy of Sciences**
Contact: Mikhail Torokhov, Fersman str., 14, Apatity, Murmansk Reg., 184200 Russia
Fax: +47-78914153 from all countries
Fax: +7 512 9514153 only from Norway and Finland
E-mail: mitor@ksc-gi.murmansk.su

**NAFO Symposium "Visioning Sustainable Harvests from the Northwest Atlantic in the Twenty-First Century"**
**10–12 September 1996, St John's, Newfoundland, Canada**
Contact: Hans Lassen, Danish Institute for Fisheries Research, Charlottenlund Slot, DK-2920 Charlottenlund, Denmark
Tel: 4533-96-3300; Fax: 4533-96-3333
E-mail: hl@dfu.min.dk
or
Tissa Amaratunga, NAFO Secretariat, P.O. Box 638, Nova Scotia B2Y 3Y9, Canada
Tel: 902-469-9105; Fax: 902-469-5729

**Polartech '96**
**24–26 September 1996, St Petersburg, Russia**
Contact: Boris Polonsky; Fax: 7 812 127 95 95
E-mail: krylspb@sovam.com

**PICES 5th Annual Meeting**
**14–20 October 1996, Nanaimo B.C., Canada**
Contact: PICES Secretariat, c/o Institute of Ocean Sciences, P.O. Box 6000, Sidney BC, Canada V8L 4B2
Tel: 1-604 363 6366; Fax: 1-604 363 6827
E-mail: pices@ios.bc.ca

## 1997

**8th International Symposium on Ground Freezing and 3rd International Symposium on Frost in Geotechnical Engineering**
**14–17 April 1997, Luleå, Sweden**

**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
Tel: 44 1223-355974; Fax: 44 1223-336543
E-mail: 100751.1667@compuserve.com

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

**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
Tel: 1-612-589-3411
E-mail: bsharratt@mail.mrsars.usda.gov
or
Jerry Radke
Tel: 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

**ISCORD 1997 International Symposium on Cold Regions Development**
**16–19 June 1997, Anchorage, Alaska, USA**
Contact: Ted Vinson, Department of Civil Engineering, Oregon State University, Corvallis, Oregon 97331-2302, USA
Tel: 1 503 753 0725; Fax: 1 503 753 3052
E-mail: vinsont@ccmail.orst.edu

**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
Tel: 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
Tel: 1-514-343-6821; Fax: 1-514 343 5782
E-mail: bouchami@ere.umontreal.ca

**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
Tel: 7-821-22-25213; Fax: 7-821-22-25231
E-mail: gilichin@issp.serpukhov.su

**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
Tel: 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
Tel: 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
Tel: 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**

**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
Tel: 1 613 992 7813; Fax: 1 613 992 2468
E-mail: heginbottom@gsc.emr.ca

***Directory of Arctic Social Scientists***

An international directory of social scientists working in the Arctic is being compiled with a grant from the U.S. National Science Foundation, Office of Polar Programs. "Social science," for purposes of the directory, includes, but is not necessarily limited to, the following fields: archaeology, cultural anthropology, economics, environmental studies, geography, history, human ecology, linguistics, medical anthropology, political science, psychology, social anthropology and sociology. The region encompassed by the term "Arctic" will be left to the individual judgments of people engaged in northern research; it will extend at least as far south as the northern part of regions that are usually considered subarctic (including Iceland). If you wish to be included in the directory, or if you know someone else (especially graduate students) who should be included, please send names and addresses to E.S. Burch, Jr. 3500 Market Street, Suite 106, Camp Hill, PA 17011-4355 USA, or fax to 717-975-3592.

# *Interagency Arctic Research Policy Committee Staff*

The following individuals are the principal staff representatives for the Interagency Arctic Research Policy Committee. Additional staff support is provided by the Federal agencies for specific activities through working groups, as necessary.


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**Back Cover**

*(clockwise from upper left)*
*Drill rig inside the drill dome.*
*Storage room for GISP2 ice cores at the National Ice Core Laboratory in Denver, Colorado.*
*Horizontal thin section of GISP2 ice from 3001 m deep, viewed between crossed polarizers. At his depth the crystals exceed 25 mm in diameter and are irregular in shape.*
*Processing the ice core for chemical analysis in the processing trench under the snow adjacent to the GISP2 drill dome.*

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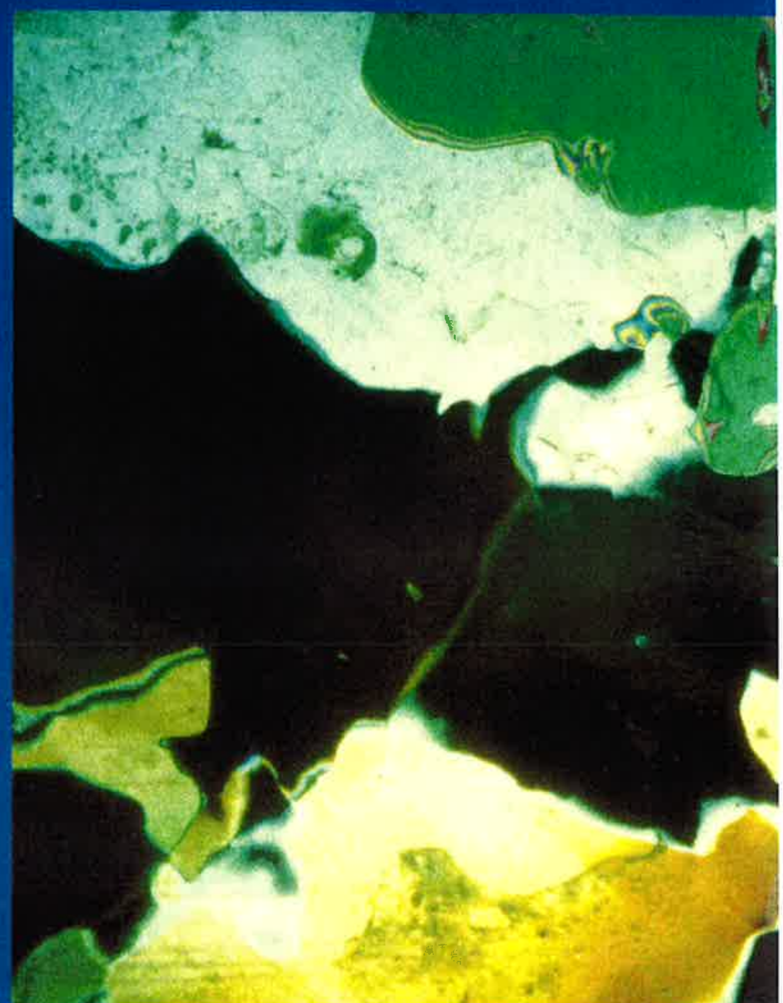

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