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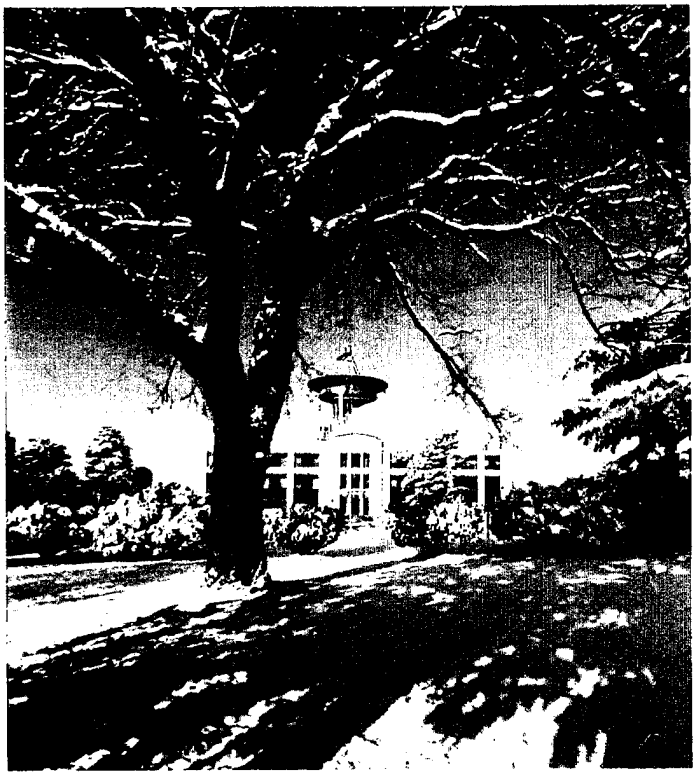
Proceedings of the Workshop on Monitoring of Nuclear Contamination in Arctic Seas

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STEVEN E. KING
EDITOR AND WORKSHOP CHAIRMAN

Radiation Effects Branch
Condensed Matter and Radiation Science Division

May 2, 1995



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13. ABSTRACT (*Maximum 200 words*)

A two day workshop was held as part of the ONR Arctic Nuclear Waste Assessment Program (ANWAP) on 18-19 January 1995 at the Naval Research Laboratory in Washington, DC. Over one hundred scientists and engineers participated in this workshop from across the U.S., Korea, Canada, Norway and the IAEA in Monaco. The goal of the workshop was to foster communication and discussion concerning concepts and requirements for long term monitoring of nuclear contamination in the marine environment. The focus of the workshop was on the sensor technologies and strategies required to monitor the Russian dump sites, the Russian riverine input into the Arctic, potential future accidents and possible additional dumping in the Arctic Seas. Of particular concern is the monitoring of regional transport toward the Alaskan coasts and the Norwegian fishing grounds. Also included in the scope of this workshop are the platform requirements, communications, data collection methods and physical oceanographic data requirements to determine the transport and disposition of the radionuclides.

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I. FORWARD

A two day workshop was held as part of the ONR Arctic Nuclear Waste Assessment Program (ANWAP) on 18-19 January 1995 at the Naval Research Laboratory in Washington, DC. Over one hundred scientists and engineers participated in this workshop from across the U.S., Korea, Canada, Norway and the IAEA in Monaco. The goal of the workshop was to foster communication and discussion concerning concepts and requirements for long term monitoring of nuclear contamination in the marine environment. The focus of the workshop was on the sensor technologies and strategies required to monitor the Russian dump sites, the Russian riverine input into the Arctic, potential future accidents and possible additional dumping in the Arctic Seas. Of particular concern is the monitoring of regional transport toward the Alaskan coasts and the Norwegian fishing grounds. Also included in the scope of this workshop were discussions of platform requirements, communications, data collection methods and physical oceanographic data requirements needed to determine the transport and disposition of the radionuclides.

The workshop was begun by an introduction to the lab by Dr. Tim Coffey, Director of NRL. Twenty one oral presentations were given in three sessions and fourteen poster papers were presented in the poster session. The first session was an overview of the workshop and risk assessment requirements for monitoring. The second session was on sensor technologies for monitoring. The third session dealt with communications, platforms, and radionuclide transport concerns. The poster session included a variety of related papers including results of recent expeditions, measurement techniques and transport mechanisms that may impact monitoring goals. The workshop ended with a very active panel-led discussion of monitoring requirements, implementation goals, and methods.

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Manuscript approved April 4, 1995

II. WORKSHOP AGENDA

Wednesday, 18 January 1995

Time	
8:15 am	Registration
9:00 am	**Welcoming Remarks** Steve King - Workshop Chairman Tim Coffey - Director of the Naval Research Laboratory
	Workshop Overview - Steve King, Session Chair
9:20 am	Workshop Introduction - Gary Phillips, NRL
9:30 am	Robert Edson, ONR, "ONR Program Status"
9:50 am	Kathy Crane, NRL, "GIS - Data Base Status"
10:10 am	Break
10:30 am	David Layton, LLNL, "An Overview of Risk-Based Monitoring Requirements"
10:50 am	William Templeton, PNL, "Data Requirements for Risk Assessment"
11:10 am	Stephanie Pfirman, LDEO, "Coastal Environments of the Southern Kara and Eastern Barents Seas"
11:30 am	Lunch - Bolling Air Force Base Officers Club
	Sensor Technology - Gary Phillips, Session Chair
2:00 pm	Pavel Povinec, IAEA, "Recent Developments in Sea-Bed γ-Spectrometry with HPGe and NaI(Tl) Detectors"
2:20 pm	Gordon Riel, NSWC, "In Situ Extraction and Gamma-Ray Spectrometry"
2:40 pm	Willard Winn, SRL, "Underwater Nuclear Detection Technologies at the Savannah River Site"
3:00 pm	Hugh Copeland, NCCOSC, "Abyssal Radiation Monitoring"
3:20 pm	Break
3:40 pm	Raymond Finucane, LLNL, "Potential Utilization of Existing DoE R&D Assets to Collect and Analyze Arctic Data"
4:00 pm	Greg Klunder, LLNL, "On-Line Detection of Radioactive Ions Separated by Capillary Electrophoresis"
4:20 pm	Charles Hollister, WHOI, "The 'Hummingbird' Sampling System for the Fluff Layer"

Thursday 19 January 1995

8:15 am	Registration
	Sensors Technology (continued) - Robert August, Session Chair
8:30 am	Steve King, NRL, "New Detectors for Monitoring"
8:50 am	James Koster, LANL, "Detection of Alpha Contamination via Ionization"
9:10 am	Nicholas Fisher and David Hutchins, SUNY, "Bioaccumulation of Radionuclides in Mollusks and Echinoderms; Implications for Monitoring and Modeling"
9:30 am	Brad Patt, Xsirius, "Toward High Resolution Compact Scintillation Instruments"
9:50 am	Sensor Technology Discussion
10:20 am	Break

	Related Technologies - Øivind Grenness, Session Chair
10:40 am	Joe Goldstein and Tim Krout, NRL, "Satellite Relay for Remote Monitoring"
11:00 am	Marshall Orr, NRL, "Monitoring Suspended Sediment with In-situ Acoustic Backscattering Systems"
11:20 am	Ron Miles, Neptune Sciences, "Data Links Through Water and Ice"
11:40 am	John Smith, Bedford Institute, "Radionuclide Transport Through the Arctic Ocean"
12:00 am	Lunch - Bolling Air Force Base Officers Club
1:20 pm	**Poster Session - Arctic Measurements and Related Topics**
2:30 pm	Break
3:00 pm	General Discussion on Monitoring Requirements and Strategies

Poster Presentations

M. Baskaran, Texas A&M University, "Concentrations of ^{137}Cs, $^{239,240}Pu$ and excess ^{210}Pb in Sediment and Biological Samples from the Yenisey River and Kara Sea"

Donna Beals, SRL, "Measurement of Long-Lived Radionuclides in Marine Environs"

James Brooks, Texas A&M University - GERG, "Overview of the 1993 and 1994 Arctic Expeditions"

John Brozena, NRL, "AIRDALE - An Airborne Data Acquisition Processing System for Fleet P-3 Aircraft"

Michael Champ and Leonard Johnson, GERG, "Nuclear Contamination in Selected Western Arctic Rivers"

Lee Cooper, ORNL, "What Does Near-Alaska Radionuclide Data Indicate about Future Monitoring Strategies?"

Robert Dyer, EPA and Mark Fuhrmann, BNL, "Geochemical Interactions of Radioactive Contaminants with Sediment from the Kara Sea"

M.Jawed Hameedi, NOAA and Deward Efurd, LANL,"Radionuclides in the US Arctic Environment and Biota: Isotopic Fingerprinting to Determine Source Terms"

Charles D. Hollister, WHOI, "Recent Results form the Komsomolets"

Larry Jendro, USCG, "Arctic Ocean Section 1994"

Deb Meese, CRREL, "Cesium-137 Contamination in Sea Ice"

Mark Mount, LLNL, "Development of Source Term and Release Rate Models for the Former Soviet Union Naval Reactors Dumped in the Kara Sea"

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William Smethie, Jr, LDEO, " The Barents Sea Branch of the Atlantic Layer, A Direct Pathway to the Deep Arctic for FSU Nuclear Waste"

III. Workshop Overview Session

Monitoring Workshop Introduction

Gary W. Phillips
Naval Research Laboratory, Washington, DC 20375

In early 1993 the Russian Federation released a white paper[1] (which has since become known as the Yablokov Report after its principle author) that detailed past dumping activities by the Former Soviet Union (FSU) of solid radioactive waste in the Arctic seas. These revelations led to the appropriation of funds by the US Congress to investigate the extent of the problem and assess the current and potential risk to the Arctic ecology in general and in particular to the Alaskan population and commerce. The Office of Naval Research has put together a broad based program to address this problem of which this workshop is a part.

The workshop focused on three main questions which were covered in the papers that follow and in the discussion period that followed.

1. What are the requirements for monitoring and what needs to be monitored from the point of view of modeling the long term movement of radionuclides in the Arctic and of assessing the risk to human populations and to the environment.

2. What sensor technologies are available, either existing or on the horizon, for long term monitoring of radionuclide levels in the arctic: both nuclear sensors and associated technologies such as oceanographic instruments and communication techniques.

3. What technologies and platforms are available for tracking the transport of radionuclides in the marine environment by factors such as water currents, ice movement, biological concentration, etc.

In addition, there were a number of papers presenting results of radionuclide analysis from the 1993 and 1994 ONR sponsored cruises and which are applicable to the questions of where and at what levels is monitoring necessary. The goals of the workshop were to bring people together from diverse backgrounds in order to get a wide range of views on monitoring, to stimulate discussions and new thinking on the subject, and to begin to formulate a long term monitoring plan.

In the following paragraphs, I will review the source term in order to set forth the areas of concern and the extent of the problem. I will then put forth some of the issues which I presented at the beginning of the workshop and which were the basis of the discussion periods at the end.

Figure 1 is an illustration of the primary region of concern and of the broad extent of the problem. It shows radwaste sites in the Arctic seas north of the Russian mainland and in adjacent territory. (This map is from the NRL Graphical Information System (GIS) data base which is discussed further in the paper by Kathleen Crane.) The light colored stars show sites of nuclear accidents, most notably in the upper left of the figure at the site of the Komsomolets nuclear submarine that sank in the Norwegian sea in 1989. The cross hatched areas indicate low-level liquid radioactive waste dumping by the FSU in the Barents sea over a period of 30 years. The

light squares indicate solid radioactive waste dumping in the Kara sea and adjacent fjords on the east coast of the islands of Novaya Zemlya. Land waste sites on the Russian mainland are shown by dark diamonds. Of most concern are those on the Kola peninsula near and even within the city of Murmansk (including Murmansk harbor). The dark stars indicate the sites of some of the over 100 so-called "peaceful" nuclear explosions conducted by the former Soviet Union. Just off the map to the lower right are the radwaste storage sites in central Siberia at the nuclear reprocessing facilities of Mayak, Tomsk, and Krasnoyarsk. These facilities lie in the watersheds of the Ob and Yenisey rivers which drain into the Kara sea.

Table 1 gives the estimated activities of radioactive waste in the Arctic and adjacent land areas. The relative magnitude of the various sites is illustrated in the chart shown in Figure 2 (note the log scale.) The first two sites are negligible compared to the others. The liquid waste dumping in the Barents and Kara sea amounts to a total of only 24 kCi over a period of 30 years. The reactor on the Komsomolets was shut down after the accident but it contains an estimated[2] 150 kCi of fission products, mostly ^{137}Cs and ^{90}Sr. (The plutonium in the warheads is only about 450 Ci.) By contrast, the solid waste dumped in the Kara sea and adjoining fjords amounts to over 2.4 MCi according to the Yablokov report[1] (and there may be much more that has not been reported.) Of perhaps even greater concern are the land based sources of radionuclide waste. In the Murmansk region, fuel from decommissioned nuclear submarines waiting to be sent to Mayak for processing may contain[3] as much as 20 MCi. By far the largest potential hazard[3] is the waste from nuclear fuel reprocessing at Mayak, Tomsk, and Krasnoyarsk which is stored in underground reservoirs or in above ground holding ponds (which are accidents waiting to happen.) These sites are in the watersheds of the Ob and Yenisey rivers which drain into the Kara sea.

Table 1. Radioactive Waste Storage in Russia

Site	*type*	*Activity (Ci)*
Barents & Kara Seas	liquid waste	24,000
Komsomolets	reactor	150,000
Kara Sea	solid waste	2,400,000
Murmansk Region	nuclear subs	20,000,000
Mayak, Tomsk, Krasnoyarsk	fuel reprocessing waste	3,000,000,000

The nuclear waste dumping in the Kara sea exceeds that in all the rest of the worlds oceans combined, as given in Table 2 and illustrated in the chart shown in figure 3 (data from the Yablokov report[1].) The next largest dumpsite is the NE Atlantic, primarily due to emissions into the Irish Sea from Selafield in the UK. By comparison, total US dumping off its coasts in the NW Atlantic and NE Pacific is an order of magnitude smaller.

Table 2. Ocean Radwaste Dumping

Site	*Activity (Ci)*
Kara Sea	2,400,000
NE Atlantic	1,100,000
NW Pacific	80,000
NE Pacific	15,000

There are a number of issues which I presented at the beginning of the workshop for consideration by the participants during the presentations and discussion period:

1. Is monitoring necessary - what are the needs for risk assessment and for modeling the movement of radionuclides in the arctic, and what are the political requirements such as assuring the public of the safety of the arctic fishing industry.

2. What areas need to be monitored - e.g. dump sites, fjords, straits, rivers, waste storage and reprocessing facilities, accident sites such as the Komsomolets nuclear submarine, fish spawning sites, etc.

3. Sensitivity requirements - what radionuclides do we need to monitor and at what levels, e.g. ambient environmental levels or radiologically hazardous levels, and how do we define these levels.

4. Time requirements - should monitoring be continuous or periodic, and should reporting be continuous, periodic, on interrogation or at time of retrieval of the instrument.

5. What are the requirements for tracking the transport of radionuclides by ocean currents, biological transport, ice transport, etc.

6. What type of platforms are required, e.g. fixed platforms, drifters or AUVs (autonomous underwater vehicles.) What are the ruggedization requirements for the arctic or undersea environments, and what are the power requirements.

7. What are the communication requirements for monitoring, and what are the available technologies.

Most of these issues will be touched upon in the papers to follow. Not all will be fully answered but at least this workshop should serve as a beginning to address these issues.

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[1] "Facts and Problems Related to Radioactive Waste Disposal in Seas Adjacent to the Territory of the Russian Federation," Office of the Russian Federation, 1993.

[2] "The Sunken Nuclear Submarine in the Norwegian Sea - A Potential Environmental Problem?," J. Blindheim et al., Fisken og Havet, Nr. 7, 1994, Havforskningsinstituttet, Bergen, Norway.

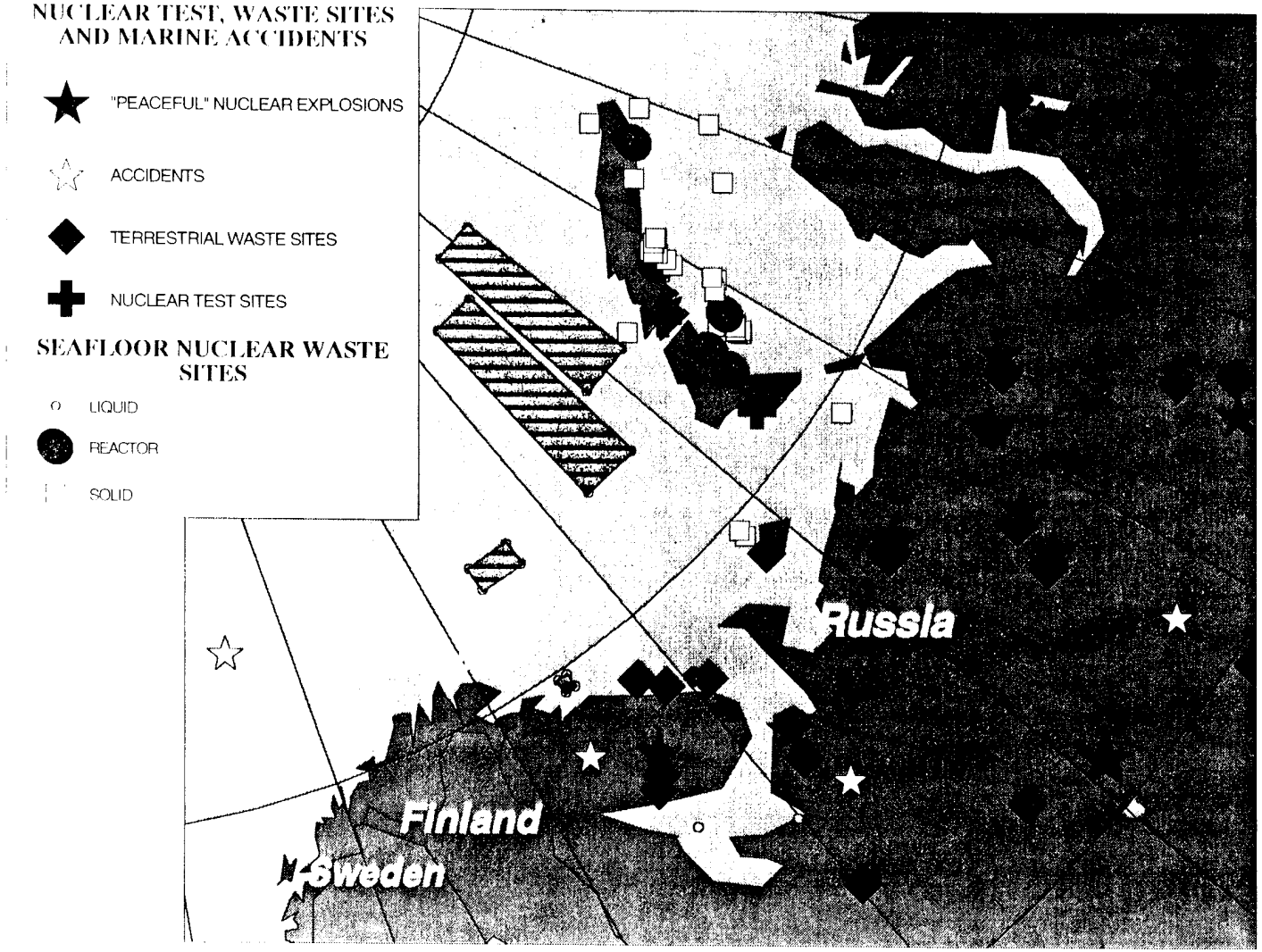
[3] Estimated from various sources, see e.g. "Sources to Radioactive Contamination in Murmansk and Arkhangel'sk Counties," T. Nilsen and N. Boehmer, Bellona Report Vol. 1, 1994, Bellona Foundation, Oslo, Norway.

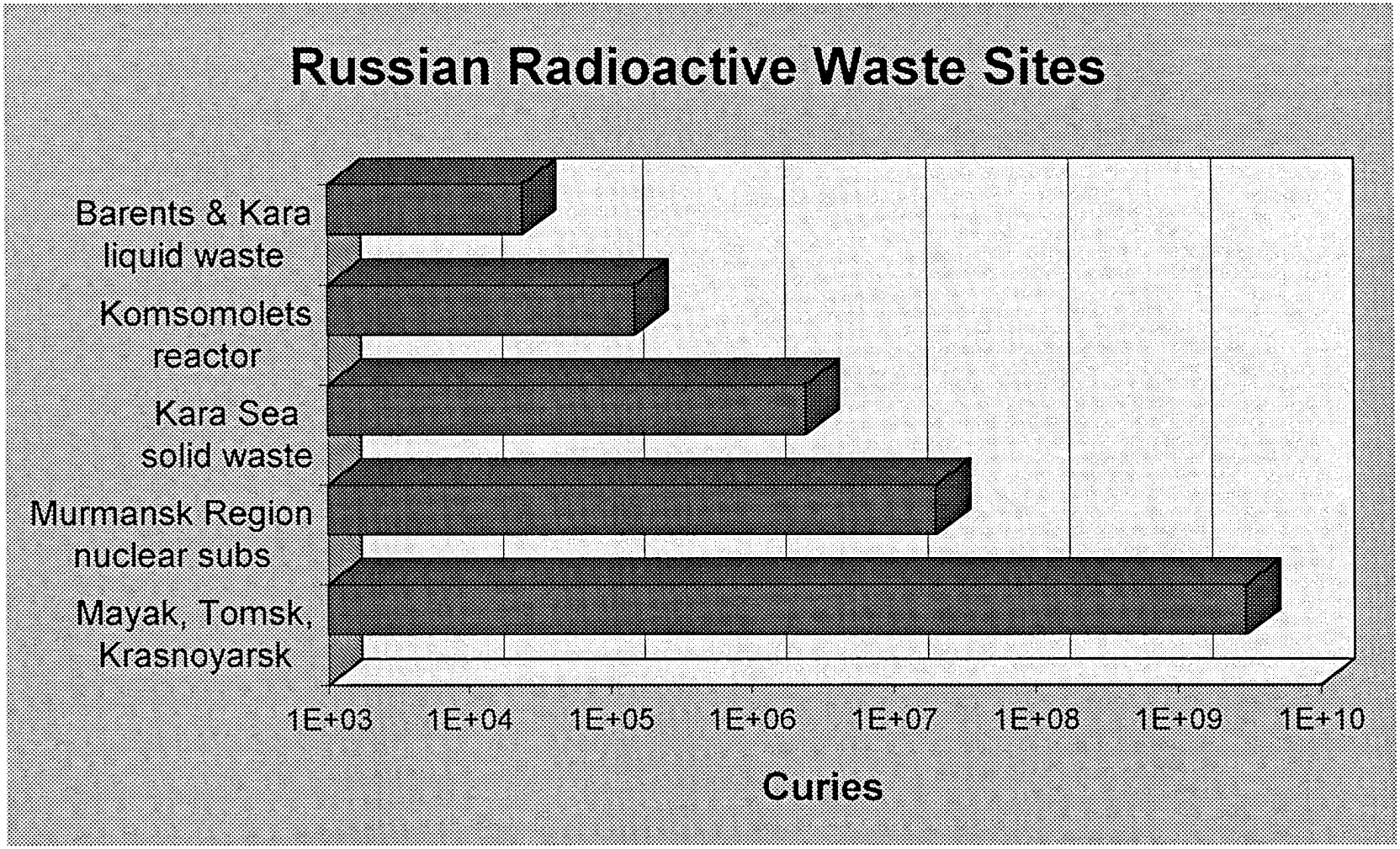
Figure Captions

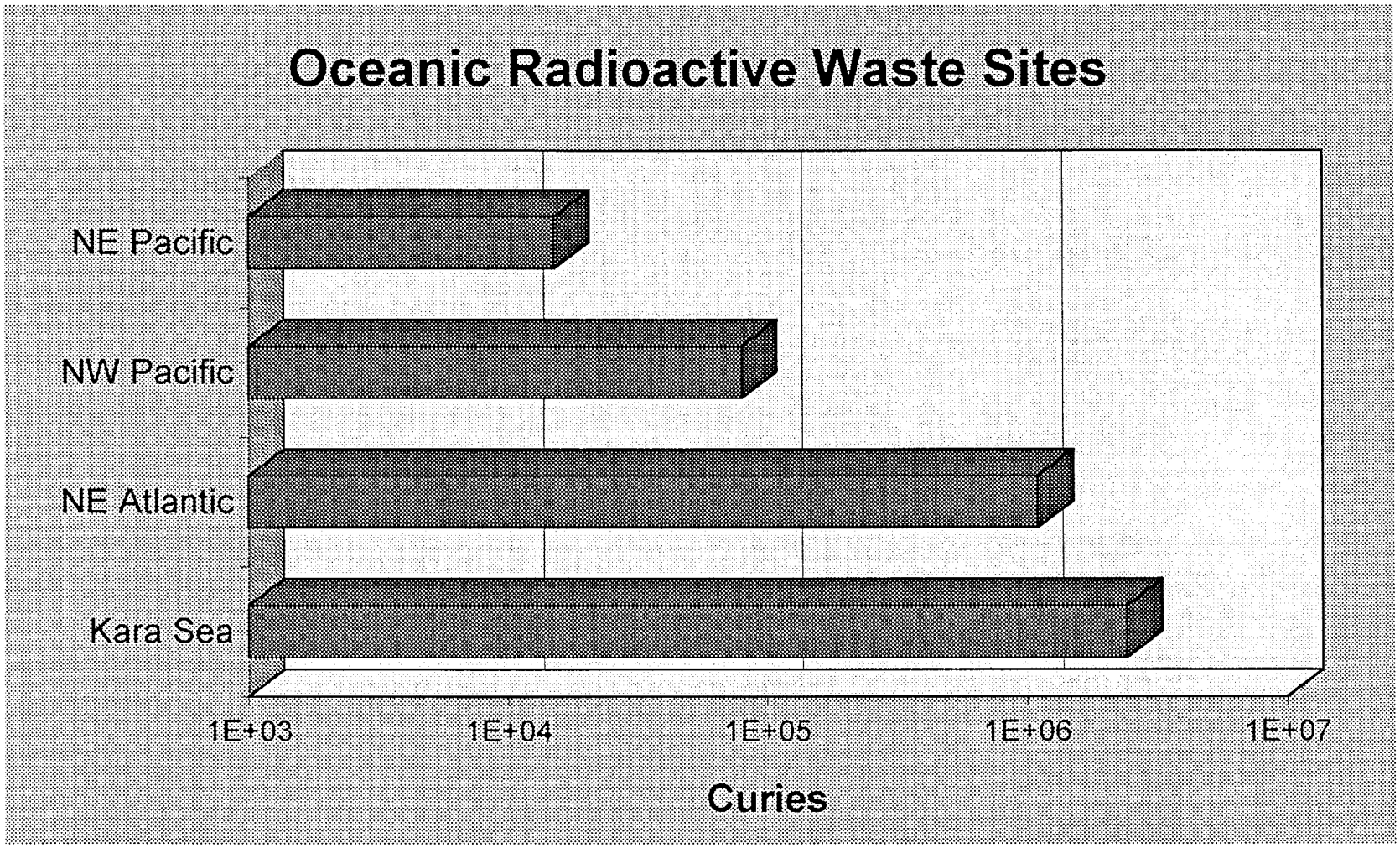
Figure 1. Location of radioactive contamination sites in the region of the Barents and Kara Seas.

Figure 2. Comparison of radioactive waste quantities in Curies at Russian waste sites.

Figure 3. Comparison of radioactive waste quantities at dumpsites in the Earths oceans.


NUCLEAR TEST, WASTE SITES AND MARINE ACCIDENTS
"PEACEFUL" NUCLEAR EXPLOSIONS
ACCIDENTS
TERRESTRIAL WASTE SITES
NUCLEAR TEST SITES
SEAFLOOR NUCLEAR WASTE SITES
LIQUID
REACTOR
SOLID
Russia
Finland
Sweden


Russian Radioactive Waste Sites
Barents & Kara liquid waste
Komsomolets reactor
Kara Sea solid waste
Murmansk Region nuclear subs
Mayak, Tomsk, Krasnoyarsk
1E+03
1E+04
1E+05
1E+06
1E+07
1E+08
1E+09
1E+10
Curies


Oceanic Radioactive Waste Sites
NE Pacific
NW Pacific
NE Atlantic
Kara Sea
1E+03
1E+04
1E+05
1E+06
1E+07
Curies

NORTHERN-OCEAN INVENTORIES OF RADIONUCLIDE CONTAMINATION: GIS EFFORTS TO DETERMINE THE PAST AND PRESENT STATE OF THE ENVIRONMENT IN AND ADJACENT TO THE ARCTIC

Kathleen Crane
Marine Physics
Code 7420
Naval Research Laboratory
Washington DC 20375

Until recently, the Arctic has been thought of as remote and pristine, far from the environmental problems associated with industrial and agricultural development of lower latitudes. The Cold War cloaked many activities in the region under a curtain of secrecy and for most of the world, the Arctic remained largely out of sight and out of mind. First indications that the Arctic was not as remote from our activities as previously thought came with the discovery, more than 20 years ago, that a thick layer of winter air pollution had developed over the Arctic (Barrie and Bottenheim 1991; Shaw 1991; Sturges 1991). This "Arctic Haze", which covers a region the size of Africa, is now attributed to industrial pollution emanating primarily from Eurasia.

With the ending of the Cold War, we have also learned that more than 50% of the rivers in the former Soviet Union are polluted with PCB's, DDT, heavy metals, radioactive waste and viral contaminants (Feshbach and Friendly 1992). These pollutants contaminate the coastal regions influenced by rivers, and some may also be transported across the Arctic by ocean currents and sea ice. The recently released information on deliberate dumping of nuclear materials (including 16 nuclear reactors, six of them with fuel rods intact and over 10,000 containers of lower-level radioactive waste) in shallow Siberian Seas (Yablokov et al 1993) raised even more disquiet about pollution of the Arctic marine environment. It also was revealed that the Ob and Yenisey Rivers might be draining large quantities of terrestrial radioactivity into the Kara Sea from the former Soviet Union nuclear fuel reprocessing plants and from weapons development activities.

The dumping of significant numbers of waste radiation containers and, especially, nuclear reactors with fuel, elicited a strong response among the countries ringing the Arctic. In the U.S. statements of concern were issued by the Arctic Research Commission and the Interagency Arctic Research Policy Committee (IARPC). In addition, the International Atomic Energy Agency (IAEA) focused attention on this discharged and dumped radioactivity. The U.S. Congressional response to the national and international concern had two components. Firstly the Senate Select Committee on Intelligence held hearings in Alaska in August 1992. Secondly, action was taken in Senate Report 102-408 and by a requirement in Public Law 102-396, Section 9110 (b) which stated that of the funds provided to assist Russia and other successor states of the former Soviet Union to dispose of nuclear weapons stockpiles, $10,000,000 would be made available for the study, assessment and identification of nuclear waste disposal by the former Soviet Union in the Arctic region. The funds were obligated through the Department of Defense in conjunction with the Department of Energy, National Laboratories, the Environmental Protection Agency, and the National Oceanic and Atmospheric Administration. The Assistant to the Secretary of the Defense for Atomic Energy further delegated the Office of Naval Research to manage the program of research on nuclear contamination of the Arctic Seas.

Because of the need for rapid response to a problem which was very poorly understood, it became imperative to compile all known data about the state of radionuclide contamination in the Arctic Ocean, its peripheral seas and oceans, in the sediment below and in the

riverine systems that drained into the Arctic. The Naval Research Laboratory was tasked with role of developing a Geographic Information System to address the changing levels of contamination through space and time. A preliminary analysis of published data revealed that almost no comprehensive maps had been constructed of contamination per Se in the worlds oceans and that the magnitude of the transboundary pollution and its effects on the ecosystems of the North could be understood only by constructing maps of the radionuclide contaminants and their concentrations in the water, ice, sediment, flora and fauna of the Arctic and its surrounding regions. Existing time series data needed to be retrieved from Former Soviet Union and Russian monitoring programs and integrated into western data sets. It was also important to gather data from the neighboring seas to provide a means by which one could measure the degree of radionuclide pollution in the Arctic relative to the rest of the worlds oceans and peripheral population centers, with the ultimate goal of estimating the degree of risk these radionuclides pose to the Arctic environment and its inhabitants and to those who depend upon the Arctic marine life for sustenance.

Approach

Our approach has been multifaceted, incorporating a compilation of preexisting radionuclide data, the digitization of preexisting bathymetric, sediment and physical and chemical oceanographic data, the development of connections with Russian colleagues to further the compilation of preexisting data and the development of collection efforts for new radionuclide, sediment and bathymetric data. In addition, some of our efforts have been directed towards developing interfaces with the ARC/INFO system to enable individuals to query the data bases and to gather statistical information related to the distribution of and correlation's between the parameters entered. Efforts have also been placed in developing a more inexpensive and user friendly GIS operating system with pertinent subsets of the data bases upon which individuals may perform their own analyses of the information provided.

Data Types and Caveats in Interpretation

Water contamination data have been compiled for the years of 1950 to 1993 from all of the oceans of the northern hemisphere. Sediment contamination data have been compiled for the years of 1960-1993. Ensuring the quality and comparability of data between laboratories and methodology from country to country is difficult. The data presented in the NRL GIS are the best available and are taken only from published scientific journals and books, but there are many caveats in the interpretation of these data. Because, in many geographic localities, there was at best only sparse coverage and little or no seasonal or yearly sampling, we have included all the data for one radionuclide sampled over 5 to 10 years on individual maps to illustrate the changes in concentrations through time. At present, data bases have been constructed for:

1) the location of stations and ship tracks of 1993 and 1994 expeditions in the Arctic Seas,

2) the distribution and concentration of radionuclides in marine, lacustrine and riverine sediments in the Arctic and in its neighboring regions(data are still being added). These isotopes include, ^{137}Cs, ^{60}Co, ^{90}Sr, ^{228}Th, ^{232}Th, ^{234}Th, ^{238}U, ^{55}Fe, ^{226}Ra, ^{210}Pb, ^{212}Pb, ^{214}Pb, ^{40}K, ^{238}Pu, $^{239/240}Pu$, ^{241}Am, ^{144}Ce, ^{95}Nb, ^{106}Ru, ^{95}Zn, ^{99}Tc, ^{129}I, and ^{7}Be. Other parameters entered into the sediment-radionuclide data base include: ID#, Cruise, Station, Year, Day/Month, Bottom Depth, (m), depth in core (cm), sediment type, %sand, %silt,

%clay, %carbonate, %H2O, grain size, Porosity, Sedimentation rate, macrofauna /m2, biomass (mg/m2), year of deposition, comments and references.

3) the distribution and concentration of radionuclides in the water column in the Arctic Ocean and its neighboring seas from the surface to the seafloor and from 1950 to the present. These include, ^{137}Cs, ^{90}Sr, ^{226}Ra, ^{238}Pu, $^{239/240}Pu$, ^{241}Am, ^{99}Tc and ^{129}I.

4) the distribution and concentration of radionuclides in rivers and lakes.

5) the distribution of nuclear events (e.g. bomb tests, reactor accidents, etc.) which have occurred around the Arctic,

6) the location of radionuclide dump sites in the Arctic, Atlantic and Pacific Oceans. Parameters entered include: ID#, country, site, Start Year of Dumping, End Year of Dumping, Package?, Nature of Waste, # of Reactors with/without fuel, # of containers, Container Type, Container Matrix, Total Weight, (Tons), Total Volume (Liters), Total GBq, Total Alpha GBq, Total Beta-gamma GBq, Total H-3 GBq, Total Ra-226 GBq, Comments, References

7) the distribution of nuclear power plants, weapons factories, and labs, sites of plutonium and uranium production and enrichment, nuclear test sites and military sites around and in the Arctic.

8) digitized Arctic bathymetry from 500 m to ocean depths

9) digitized Arctic Rivers, and

10) digitized distribution of important fish stocks, marine mammals, birds (used as food sources in the Arctic) A complete set of maps and data are contained in two books which have been distributed to ONR entitled "Radionuclides in Water, Historical Compilation: 1950-1993" and "Radionuclides in Sediments, Historical Compilation: 1960-1993".

In addition, efforts are being taken to gather up-to-date bathymetry shallower than 500 m along the Russian shelves with the assistance of Russian oceanographers and the Byrd Polar Research Center.

Sources of Radionuclide Contamination in the Northern Oceans and Sediments

Natural radioactivity in the oceans occurs in the form of potassium-40, through decay products of uranium and thorium, and through a continuous input of tritium via cosmic rays. Heavy radionuclides, which have a low solubility in water, tend to be adsorbed onto particulate matter such as fine grained sediments and organic matter.

Inputs of radioactivity to the sea from human activities started at the end of World War II with the explosion of the first nuclear weapons. Since that time nuclear testing continued from the United States, the USSR, the UK, China and France. These nuclear weapons introduced enriched uranium and plutonium as well as more than 200 different fission products and isotopes into the seas. When exploded into the air, the radionuclides were carried in fine dust into the stratosphere, thereby circling the globe settling back to earth as fall-out primarily between the latitudes of 45°N and 45°S. The most important of these

radionuclides were Strontium-90 and Cesium-137 with a half-life of about 30 years and plutonium-239 with a half-life of 24,400 years.

In addition to nuclear weapons testing, radionuclides have been introduced into the worlds oceans by cooling water and other liquid wastes from both land-based nuclear reactors and fuel-reprocessing plants. A much lessor amount has been introduced through shipboard and submarine release as well as through direct dumping of primarily low level liquid and solid waste. Sea dumping of radioactive solid wastes has been practised since 1946, but in 1972, the London dumping convention regulated all dumping at sea prohibiting the dumping of high-level radioactive wastes (which were considered to be more than 37,000 TBq Tritium, 37 TBq ß and emitters, and 3.7 TBq of Strontium-90 and Cesium-137 (Clark, 1989). In 1994 all dumping at sea was prohibited by the London Dumping convention. However over the period of 48 years, thirteen countries in the northern Hemisphere dumped radionuclude waste into the sea (Figure 1). The waste consisted of contaminated piping, concrete and building material, glassware, protective clothing, etc and was derived from nuclear power stations and reactors operated by industry and nuclear research centers. Disposal most often took place in concrete-lined steel drums, embedded in resin or bitumen. However, ultimately containers corrode and leach their contents out into the surrounding environment but the delay results in a loss of radioactivity and the slow release of the contents ensures great dilution.

Exposure of marine organisms in and around the dump sites (where reported) are thought to be at or below the natural background levels of radiation and well below the dose rates needed to create "harmful effects" to individuals or populations of marine organisms. However, as no measurable radioactivity has yet been released at the official dump sites, the predictions of contamination levels are still based upon theoretical models.

By 1987, more than 400 nuclear reactor power plants were in operation in 30 countries. All of these reactors were cooled by either light or heavy water, carbon dioxide or molten sodium. Spent fuel rods from the reactors may be removed for permanent "safe" storage on land or more commonly are taken to a reprocessing plant where the uranium is recovered for reuse and the plutonium and fission products extracted. Major reprocessing plants that have had a significant impact on the northern oceans exist at Sellafield on the west coast of England, La Hague near Cherbourg on the French Channel and at Karlsruhe in Germany.

Radionuclide contamination of the seas can also occur as a result of run-off from land-based sources. These include rivers which transport the contaminants from nuclear reactors and weapons installations, or seepage from groundwater contaminated by underground nuclear tests, or unprotected nuclear waste sites. Of concern in the Arctic, are the unprecedented numbers of "Peaceful Nuclear Explosions" (Yemelyankov and Popov, 1992) (Figure 2) which were carried out in the Former Soviet Union primarily for oil, gas and mineral exploration in Siberia

Until the admission by the Russian government that six nuclear reactors had been illegally dumped in the Kara Sea, (Figure 3), it was assumed that the most notable anthropogenic radionuclide introduction into the oceans had occurred from U.S. nuclear testing in the Pacific, the testing by the USSR on the Arctic island of Novaya Zemlya, the release of discharges from the Sellafield reprocessing plant into the North Atlantic Ocean, and the Chernobyl power plant accident.

The following maps illustrate a few of the GIS products: ranging from a catalogue of navigation in the Kara Sea by ships engaged in the search and location of dumped Soviet

nuclear waste to the distribution of present day radionuclides in the marine and riverine environments surrounding and within the Arctic.

The Location of dumped Nuclear Waste

One of the goals of the NRL GIS is to provide up to date information on the efforts, success and failures to locate the dumped objects reported in the 1993 Yablokov report.

During the summer of 1993, three ships attempted to locate the nuclear reactor reported to have been dumped in the Novaya Zemyla Trough. Figure 4 illustrates the individual ship tracks along which side-looking sonar and multi-beam swath mapping were carried out. Although all three vessels converged on the reported dump site location, none of the ships were able to locate the nuclear reactor leaving some speculation about the true location of this important source term. Clearly future work must be carried out in this region to locate the dumped reactor.

Figure 5 illustrates the successful location of presumed anthropogenic objects on the bottom of the Kara Sea. These investigations included side-looking sonar operations from the R/V Keldysh and the R/V Fersman. Of greatest interest was the discovery of a vessel (marked as a barge on Figure 5). To date no visual investigation of the site has taken place.

Levels of Radionuclide Contamination in Water (1990-1993)

Figure 6 illustrates the distribution of points in the oceans, rivers and lakes where radionuclides have been measured from the 1950's to 1993 and which are presently in the NRL GIS. Noticeable is the data coverage in the Irish, North, Baltic, Norwegian-Greenland, the Barents and the Kara Seas stimulated by the release of radionuclides from Sellafield into the Irish Sea and the deposition of radionuclides from the Chernobyl fallout. A glance at the concentration levels of Cesium-137, Strontium-90 and Plutonium 239-240 in this region from 1990-1993 reveals the following:

Cesium -137 concentrations in the upper 50 m's of the ocean (and in the river systems) are highest in the Baltic Sea (Nies et al., 1993) and in the Techa River near Chelyabinsk (from 50-650 Bq/m^3) (Trapeznikov et al., 1993) (Figure 7). The high concentrations in the Baltic Sea are a result of fallout from the 1986 Chernobyl accident. In general, concentrations in the Kara Sea are low (from 0 to 20 Bq/m^3) (Strand et al., 1993) with the highest values close to the Ob River estuary and near the Pechora Straits Values in the Yenisey River are by and large low (from 0-10 Bq/m^3) with the exception of measurements reaching 35 Bq/m^3 near 56.68°N (Kuznetsov et al., 1994).

Cs-137 concentrations in the central Arctic Ocean are generally higher than in the entrance to the Barents Sea from the Norwegian-Greenland Sea (10-20 Bq/m^3 compared to 0-10 Bq/m^3) (Roos and Holm, 1993). These higher values may be connected to a previously unknown expulsion of higher concentration Cs-137 from Ob River water into the Kara Sea/Arctic Ocean environment. Another possibility is that the higher concentrations may be attributed to the past Sellafield releases however as the values are equal to or greater than Cs-137 concentration in the North Sea and southern Norwegian-Greenland Sea, this is unlikely.

During the period of 1990-1993, Plutonium 239-240 concentrations in surface sea water range from 100 mBq/m^3 on the western side of the North Sea (Bundesamt fur

Seeschiffahrt und Hydrographie, 1993) to 0-5 mBq/m^3 in the Baltic and Kara Seas (Bundesamt fur Seeschiffahrt und Hydrographie, 1993 and Strand et al., 1993) (Figure 8). Data for river water are scarce, however, measurements made in the Techa River reach 520 mBq/m^3 (Trapenznikov et al., 1993). As for Cesium 137, the highest concentrations of Plutonium 239-240 in the Kara Sea are near the Ob River estuary and in the Pechora Straits (5-10 mBq/m^3) (Strand et al., 1993).

The concentrations of Sr-90 in surface sea water during the years of 1990-1993 range from 50-100 Bq/m^3 in the Black Sea (Yablokov et al., 1993) , 5 - 50 Bq/m^3 in the North Sea and the English Channel (Nies et al., 1993), 15 - 20 Bq/m^3 in the Baltic (Nies et al., 1993) and 0-15 Bq/m^3 in the Kara Sea (Strand et al., 1993) (Figure 9). The highest values in the Kara Sea are located at its northern boundary near the Ob River Estuary suggesting that the source of these higher values may be river run-off rather that a residual signal from Sellafield. Measurements in the Ob River range from 20 - 50 Bq/m^3 near Sakkhelard (Kuznetsov et al., 1994) and up to 20,000 Bq/m^3 in the Techa River near Chelyabinsk (Trapenznikov et al., 1993). In contrast values of Strontium 90 are lower in the Yenisey River ranging from 6 Bq/m^3 at its northern reaches near the outlet into the Kara Sea and up to 20 Bq/m^3 at its southern tributaries (Kuznetsov et al., 1994).

Radionuclide Contamination in Marine, Lacustrine and Riverine Sediments

Figure 10 illustrates the sediment contamination data presently stored in the NRL GIS. Notice the large numbers of samples taken in the Russian Arctic seas and in the Russian rivers. A glance at Figure 11 shows that surface sediments in the Barents and White Seas have very low levels of Cs-137 contamination. The one exception is in Chornaya Bay where concentrations were reported by Smith et al., 1993, Ivanov and Polyak, 1994 and Matishov and Szcypa, 1993 to be as high as 1,444 Bq/m^3.

The highest values in the Kara Sea are aligned along and just to the east of the Novaya Zemlya Trough where values rise to 20 Bq/m^3 from the coastal values of 0-5 Bq/m^3 (Strand et al., 1993, Kuznetsov et al., 1994, Ivanov et al., 1993. However at the mouth of the Yenisey River sediment concentrations rise to > 69 Bq/m^3 (GERG, Cruise Report, 1994) increasing to 370 Bq/m^3 at 57.25°N (Kuznetzov et al., 1994). In contrast (and the reverse of the water concentration patterns), sediment concentrations in the Ob River range from 0-15 Bq/m^3 at its mouth with the Kara Sea to 825,000 Bq/m^3 in the Techa River (Trapenznikov et al., 1993).

Figure 12 illustrates the Plutonium 239-240 concentrations in the surface sediments of the Barents, Kara and coastal Svalbard Seas. Of these three seas, the contamination is the lowest in the Kara where values generally are 0-1 Bq/m^3 (Strand et al., 1993, Ivanov and Polyak, 1993, Kuznetzov et al., 1994), rising to 1-5 Bq/m^3 in the northern most and southern most regions. In contrast values in the Yenisey River mouth reach 5-10 Bq/m^3 (Kuznetzov et al., 1994) and in the Chornaya Bay up to 4,810 Bq/m^3 (Smith et al., 1994, Ivanov and Polyak, 1994). By contrast, values in the Techa River reach 800 Bq/m^3 (Trapenznikov et al., 1993).

Very few measurements are at present available for Strontium-90 in surface sediments. Figure 13 illustrates the distribution and concentration of these values. Notice the very low values in the mouth of the Yenisey River (0.2-3.6 Bq/m^3) (Kuznetzov et al., 1994) while in

the Ob River measurements range from 6-17 Bq/m^3 near Sakkhelard and rise to 1,300 Bq/m^3 in the Techa River (Trapeznikov et al., 1993).

It is anticipated that addition data will become available when published and thus there is the likelihood that the present distribution and concentration patterns will be substantially altered. Updates of the GIS are constantly in progress as new information become available, thus making it an essential tool relevant to any monitoring activities proposed in the region.

REFERENCES

Barrie L. A., and J. W. Bottenheim 1991, Sulphur and Nitrogen Pollution in the Arctic Atmosphere, In Pollution of the Arctic Atmosphere editied by W.T. Sturges, Elsevier Science Publishers, New York, USA

Bundesamt fur Seeschiffahrt und Hydrographie, 1993, Uberwachung des Meeres, Bericht fur das Jahr 1990 Teil II: Daten, Hamburg, 1993 ISSN 0724-0449 Zu Nr. 2500

Chumichev, V.B., and Z.A. Demyanchenko, 1993, Contamination with Sr-90 and discharge of the Radionuclide for the Techa, Karabolka (1974-1990) and Ob' (1961-1990) rivers

Clark, R.B., 1989, Marine Pollution, 2nd edition Clarendon Press, Oxford

Dubasov, Yu.V., A.s. Krivokhatskii, P.B. Malakhov, V.G. Safronov, 1993, Radioecological monitoring on Novaya Zemlya nuclear test site in 1990-1992, Radiation in the Arctic and Antarctic, Kirkenes, Norway Int. mtg.

Feshbach, M., and A. Friendly, 1992, Ecocide in the USSR, Basic Books, Division of Harrper Collins Publishers, Inc.

GERG, 1993 and 1994 Data, Russian Arctic, 1994

Ivanov, G. I., V.L. Ivanov, Yr. K. Bordukov, M.A. Sadikov, L. V. Polyak, 1993, Proceedings, Radioactivity and Environmental Security in the Oceans: New Research and Policy Priorities in the Arctic and North Atlantic, June 7-9, 1993 Woods Hole, Mass.

Kuznetsov, Yu., Rakov, N., Legin W., and Tishkov, V.Y., 1994 An assessment of the contribution by different contamination sources into the total radioactive contamination of the Kara Sea, doc. presented at IAEA mtg. Vienna, Austria May, 1994

Matishov, D.G., D.G. Matishov, V.V. Podovedov, J. Szcypa, J. Solecki and W. Januss, 1992, Radionuclides on the Kola Peninsula, Novaya Zemlya, Franz Josef Land and in the Barents Sea

Matishov D., and E. Szcypa, 1993, Gamma emitters in the Barents Sea Area, Proceedings XX Polar Sumposiium Lublin, Poland, pp. 211-229

Nies, H., 1994, CRESP Task group meeting 28 November-2 December, Amelia Island Plantation, Florida, USA

Nies, H., J. Herrmann, and I. Goroncy, 1993, Temporal Evolution of Artificial Radioactivity in the North and Baltic Sea after the Reduction of the Sellafield Discharges and the Chernobyl Accident

Proceedings, Radioactivity and Environmental Security in the Oceans: New Research and Policy Priorities in the ARctic and North Atlantic, June 7-9, 1993, Woods Hole, Mass., USA

Pozolotina, V., I. Molchanova, E. Karayaeva, P. Yushkov, N., Kulikov, and A. Trapeznikov, 1993, Radioactive Contamination of topsoil in the Lower reaches of the Techa River in the Urals, Kirkenes, Norway 1993

Roos, P., and E. Holm, 1993, Distribution of Radiocesium and Plutonium in Arctic Waters and Sediments, Results from the Swedish Oden-Expedition, 1991, In: Environmental Radioactivity in the Arctic and Anarctic, Kirkenes, Norway, August 23-27, 1993

Shaw, G.E., 1991, "Physical Properties and Physical Chemistry of Arctic Aerosols" in Pollution of the Arctic Atmosphere, edited by W.T. Sturges, Elsevier Science Publishers, New York

Smith, J., K. Ellis, G. Matishov, D. Matishov, G. Ivanov, L. Polyak, S. Daehle and K. Naes, 1993, Radioactivity levels in Barents Sea Sediments off Novaya Zemlya, Proceedings of the International Conference on Environmental Radioactivity Kirkenes, August, 1993

Strand, P., A.L. Rudjord, G.C. Christensen, B. Salbu, A.I. Nikitin, I.I. Kryshev, V.B. Chumichev, V. Roumiantsev, 1993, A Survey of Artificial Radionuclides in the Kara Sea: Kirkenes Norway, 1993, Norway

Sturges, W.T., 1991, Pollution of the Arctic Atmosphere, Elsevier Science Publishers, New York, USA 334 pp.

Trapeznikov, A., A. Aarkrog, N. Kulikov, S.P. Nielsen, V. Pozolotina, G. Polikarpov, V. Trapenznikova, M. Chebotina, V. Chukanov, and P. Yushkov, 1993, Kirkenes, Norway, Conference on Radioactivity in the Arctic and the Antarctic, August, 1993

Yablokov, A., V.K. Karasev, V. M. Rumyantsev, M. Ye. Koleyev, O. I Petrov, V. N. Lystsov, A.F. Yemelyanenkov, and P. M. Rubtsov, 1993, Fakti i problemi svyannie s zachoronenim radioaktivnich otchodov v moryach, omvaishich territoria rossiskoi federatzia. Administrchiya prezidenta Rossiiskoi Federatzii.

Yemelyanenkov, A., and V. Popov, 1992, Atom bez Grifa "Sekretno" Tochki Zreniya. International Physicians for the Prevention of Nuclear War, Moscow, Berlin

OCEAN NUCLEAR WASTE SITES
BELGIUM
FRANCE
ITALY
JAPAN
NETHERLANDS
REP. KOREA
SWEDEN
SWITZERLAND
UNITED KINGDOM
USA
USSR
WEST GERMANY

Figure 1

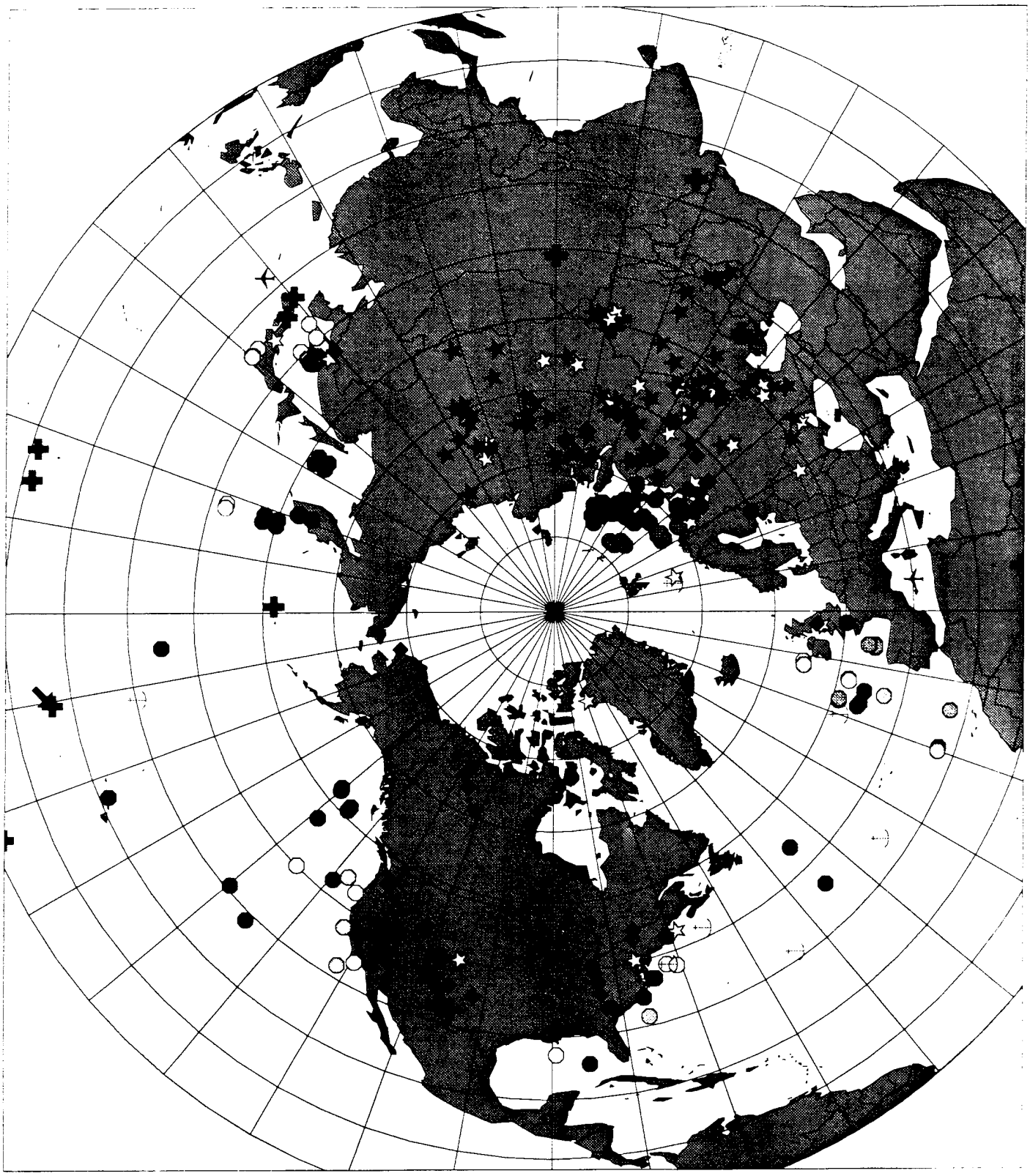


Figure 2

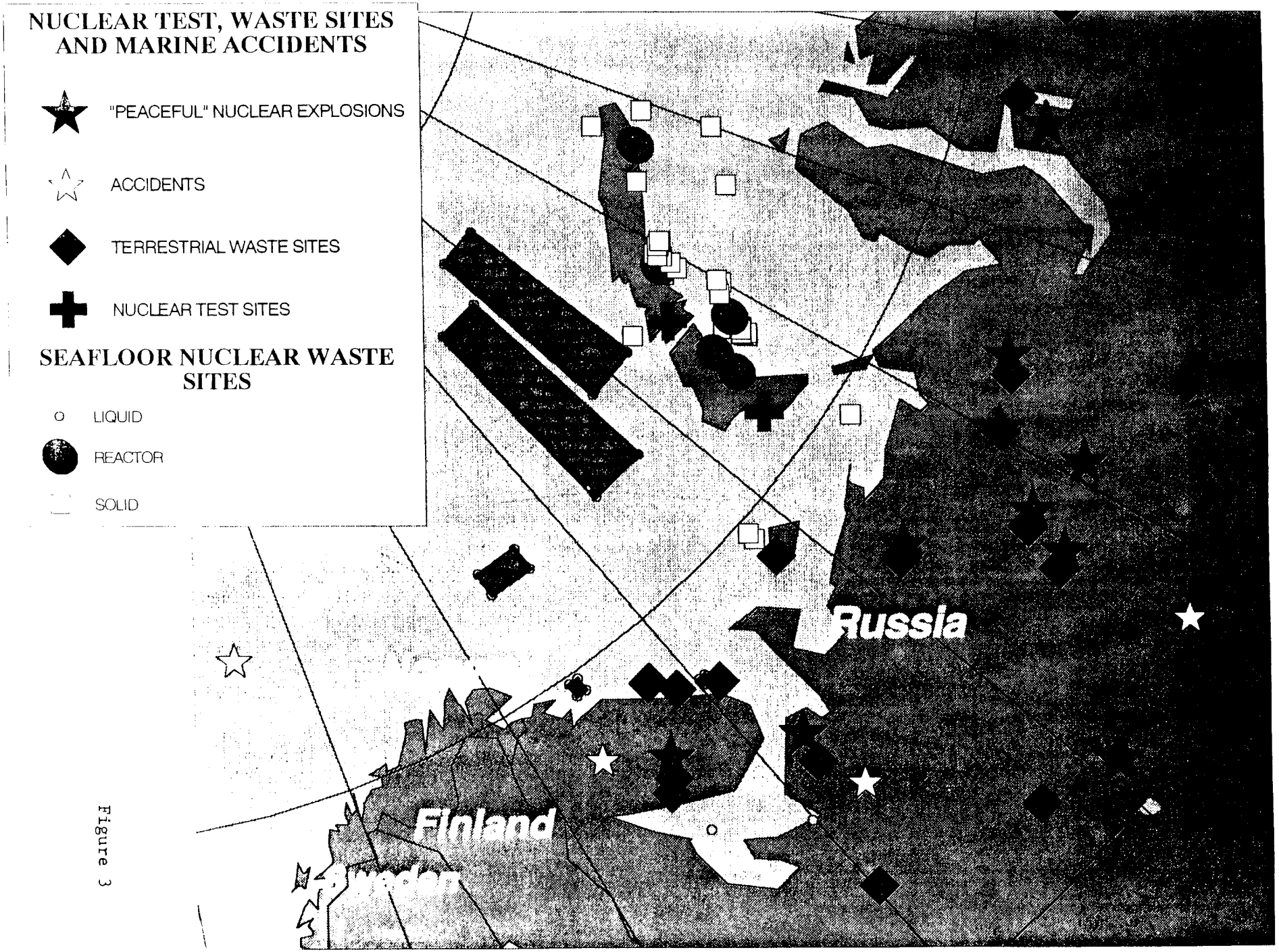

NUCLEAR TEST, WASTE SITES AND MARINE ACCIDENTS
"PEACEFUL" NUCLEAR EXPLOSIONS
ACCIDENTS
TERRESTRIAL WASTE SITES
NUCLEAR TEST SITES
SEAFLOOR NUCLEAR WASTE SITES
LIQUID
REACTOR
SOLID
Russia
Finland

Figure 3

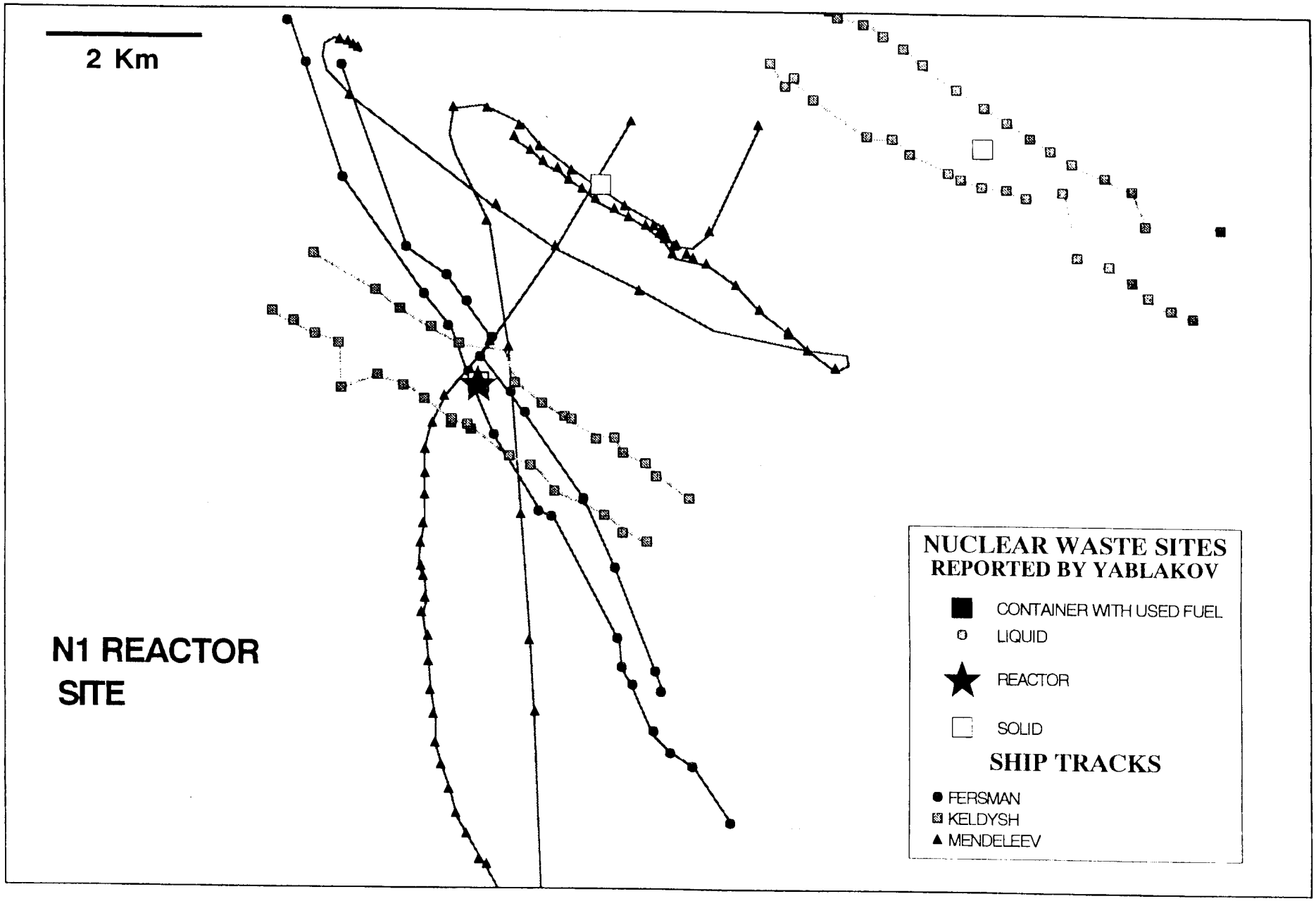

2 Km
N1 REACTOR SITE
NUCLEAR WASTE SITES
REPORTED BY YABLAKOV
CONTAINER WITH USED FUEL
LIQUID
REACTOR
SOLID
SHIP TRACKS
FERSMAN
KELDYSH
MENDELEEV

Figure 4

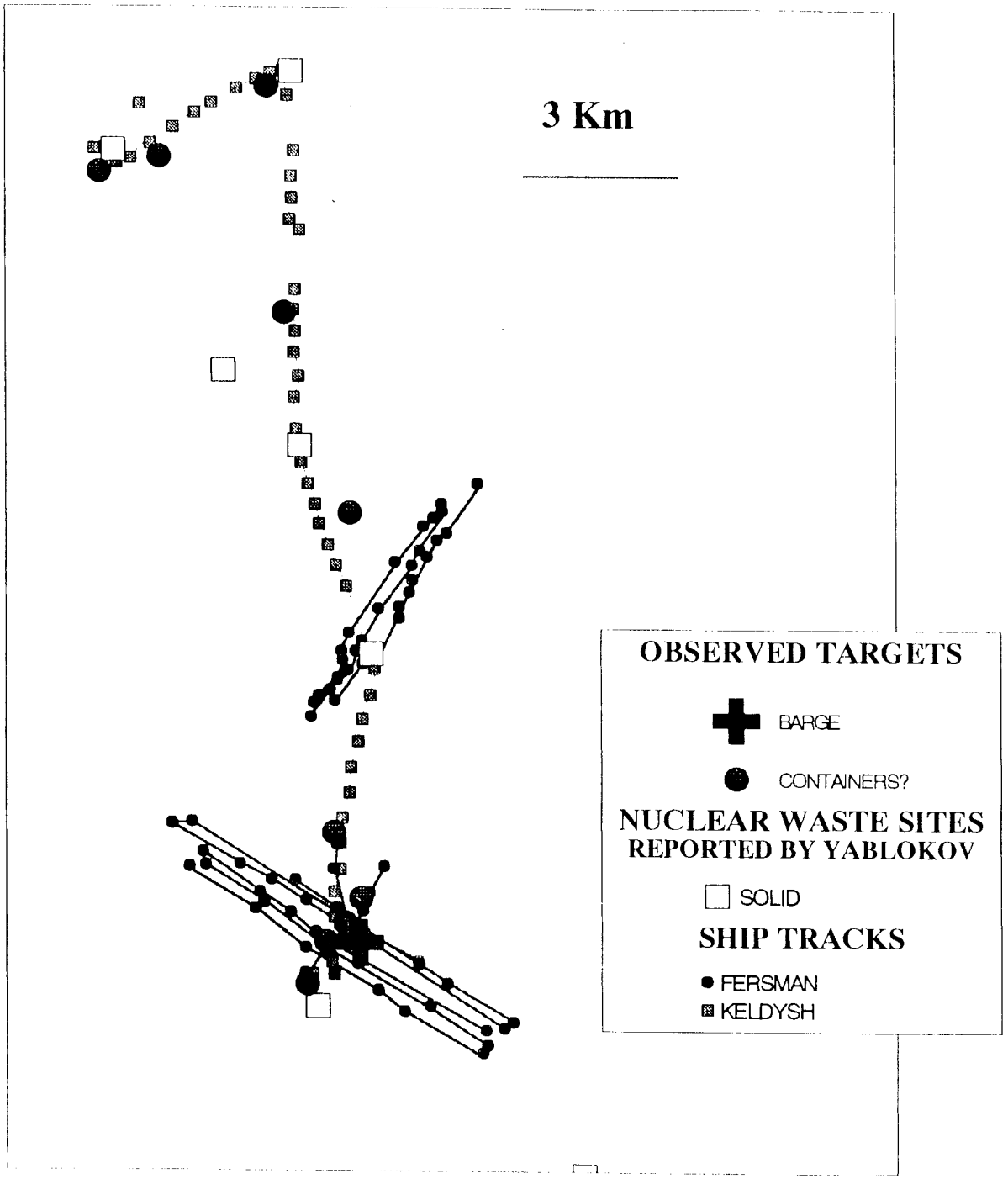

3 Km
OBSERVED TARGETS
BARGE
CONTAINERS?
NUCLEAR WASTE SITES
REPORTED BY YABLOKOV
SOLID
SHIP TRACKS
FERSMAN
KELDYSH

Figure 5

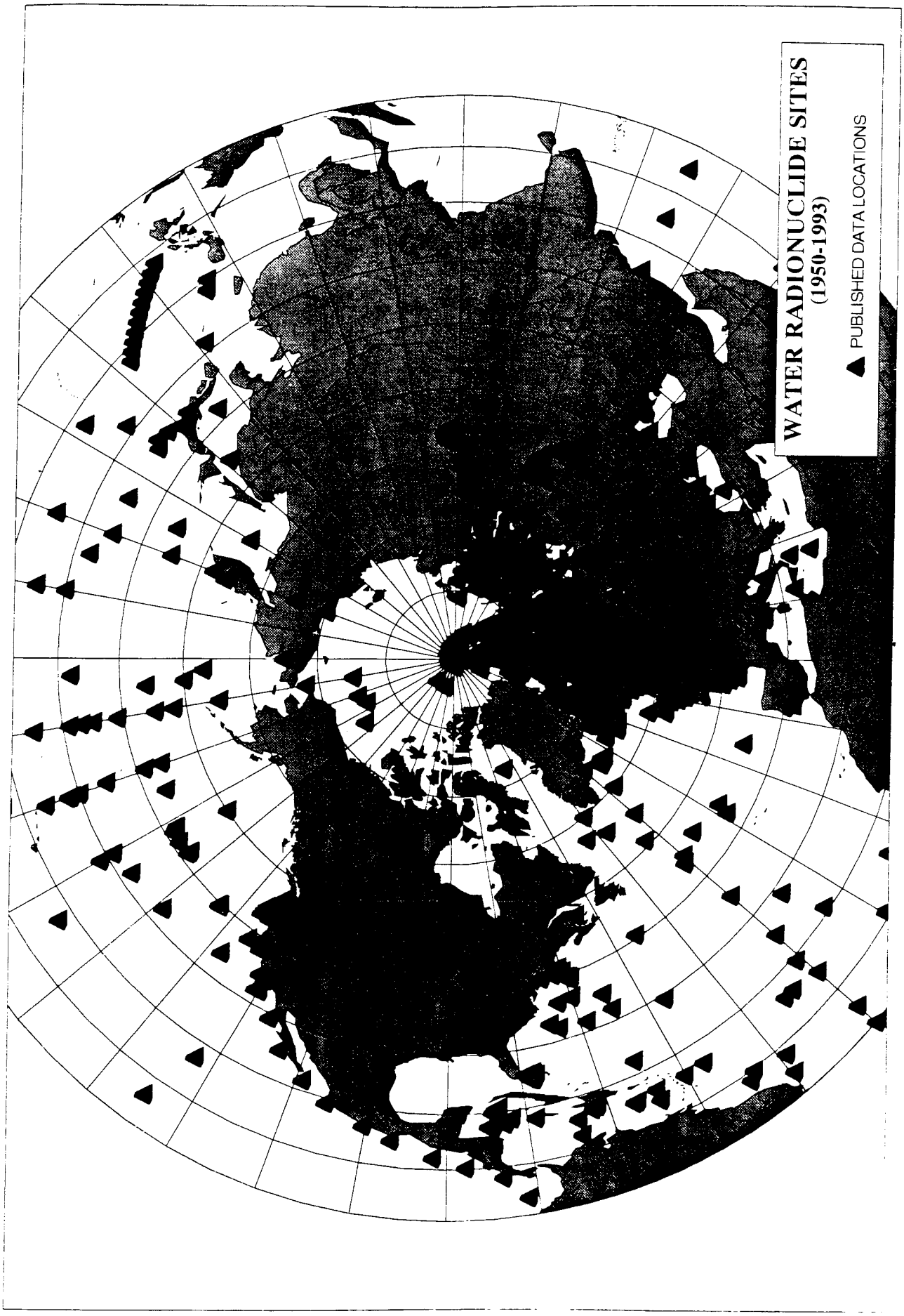
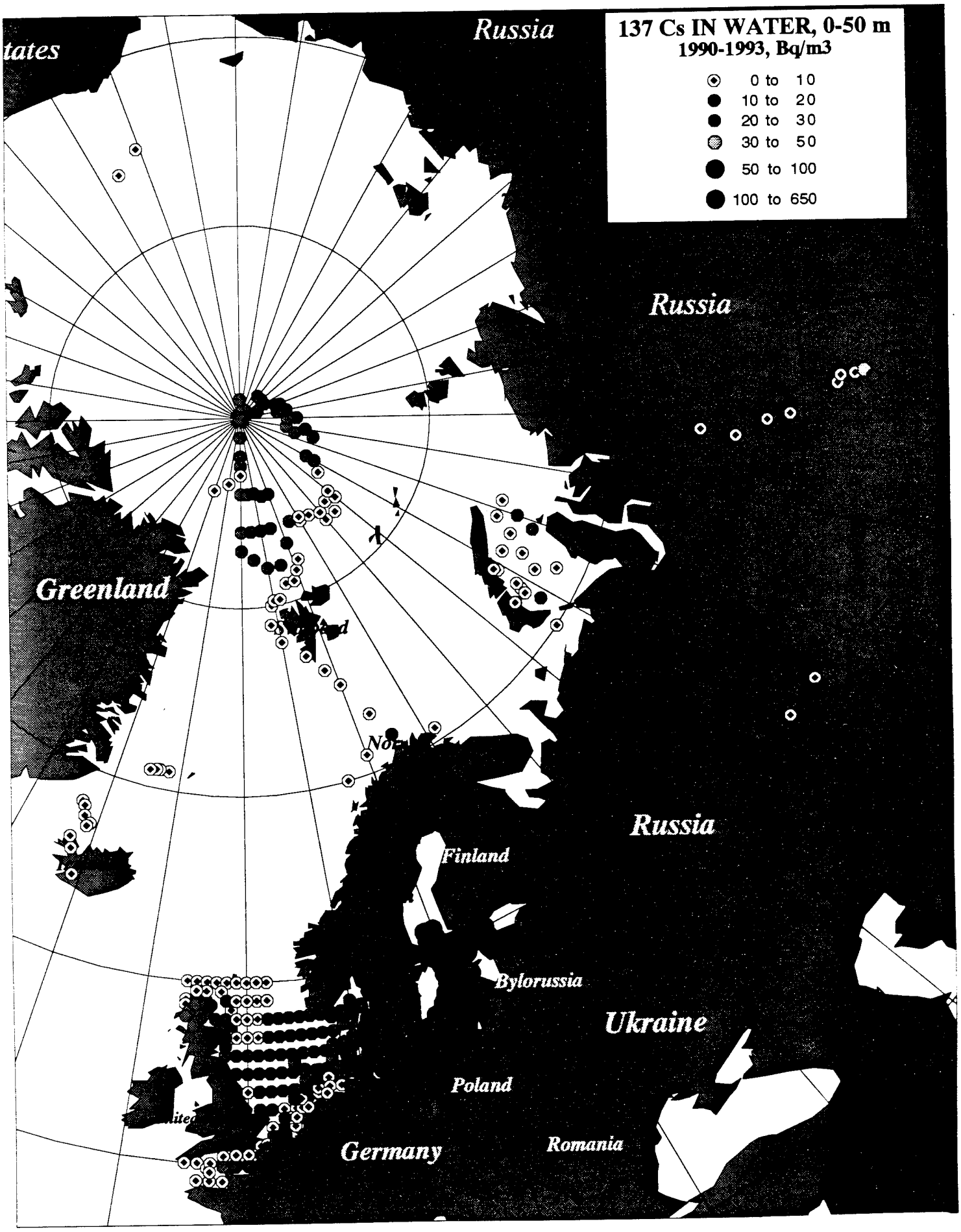

WATER RADIONUCLIDE SITES
(1950-1993)
PUBLISHED DATA LOCATIONS

Figure 6


137 Cs IN WATER, 0-50 m
1990-1993, Bq/m3
0 to 10
10 to 20
20 to 30
30 to 50
50 to 100
100 to 650
Russia
Russia
Russia
Greenland
Finland
Bylorussia
Ukraine
Poland
Germany
Romania

Figure

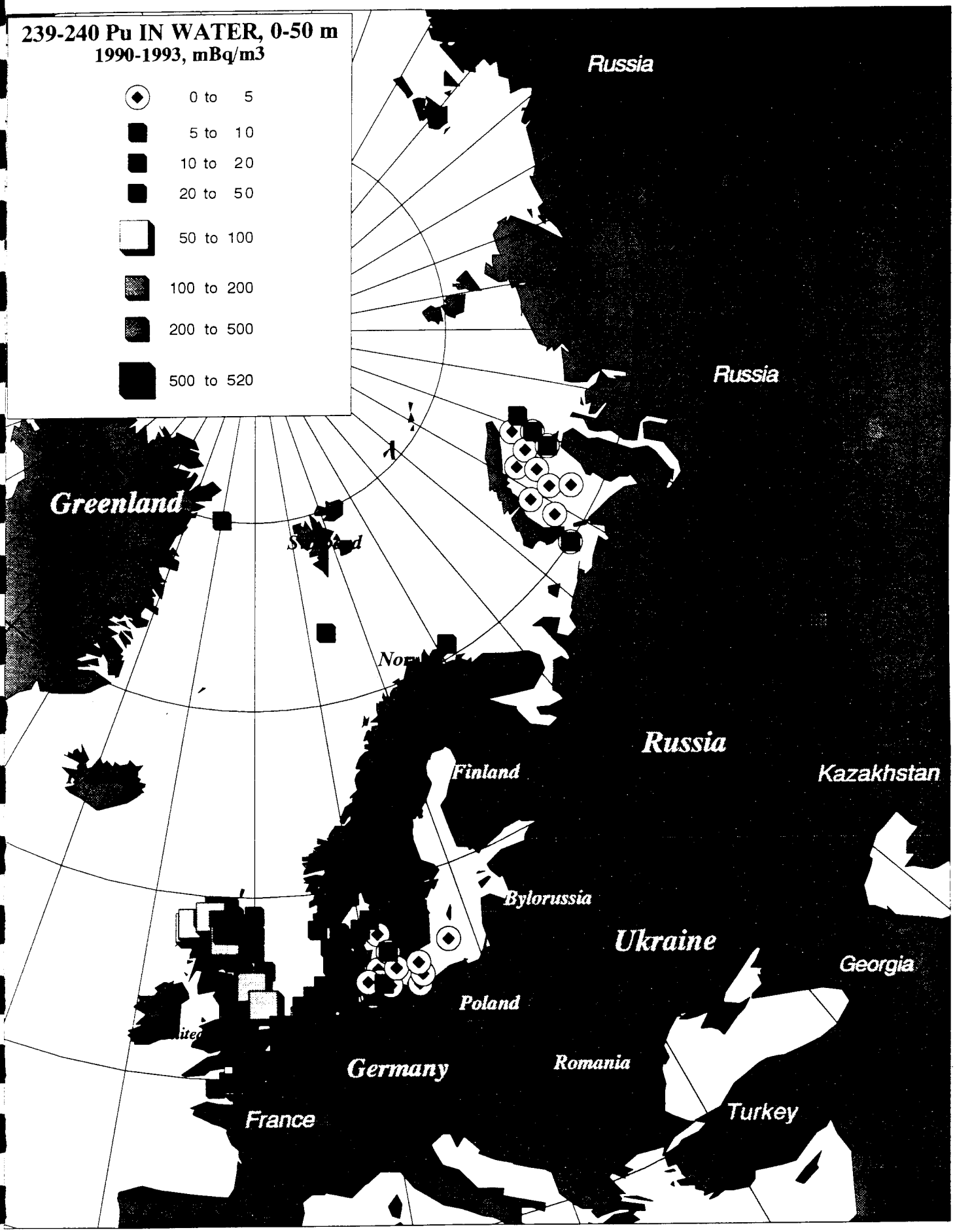

239-240 Pu IN WATER, 0-50 m
1990-1993, mBq/m3
0 to 5
5 to 10
10 to 20
20 to 50
50 to 100
100 to 200
200 to 500
500 to 520
Russia
Russia
Greenland
Russia
Kazakhstan
Finland
Bylorussia
Ukraine
Georgia
Poland
Germany
Romania
Turkey
France

Figure 8

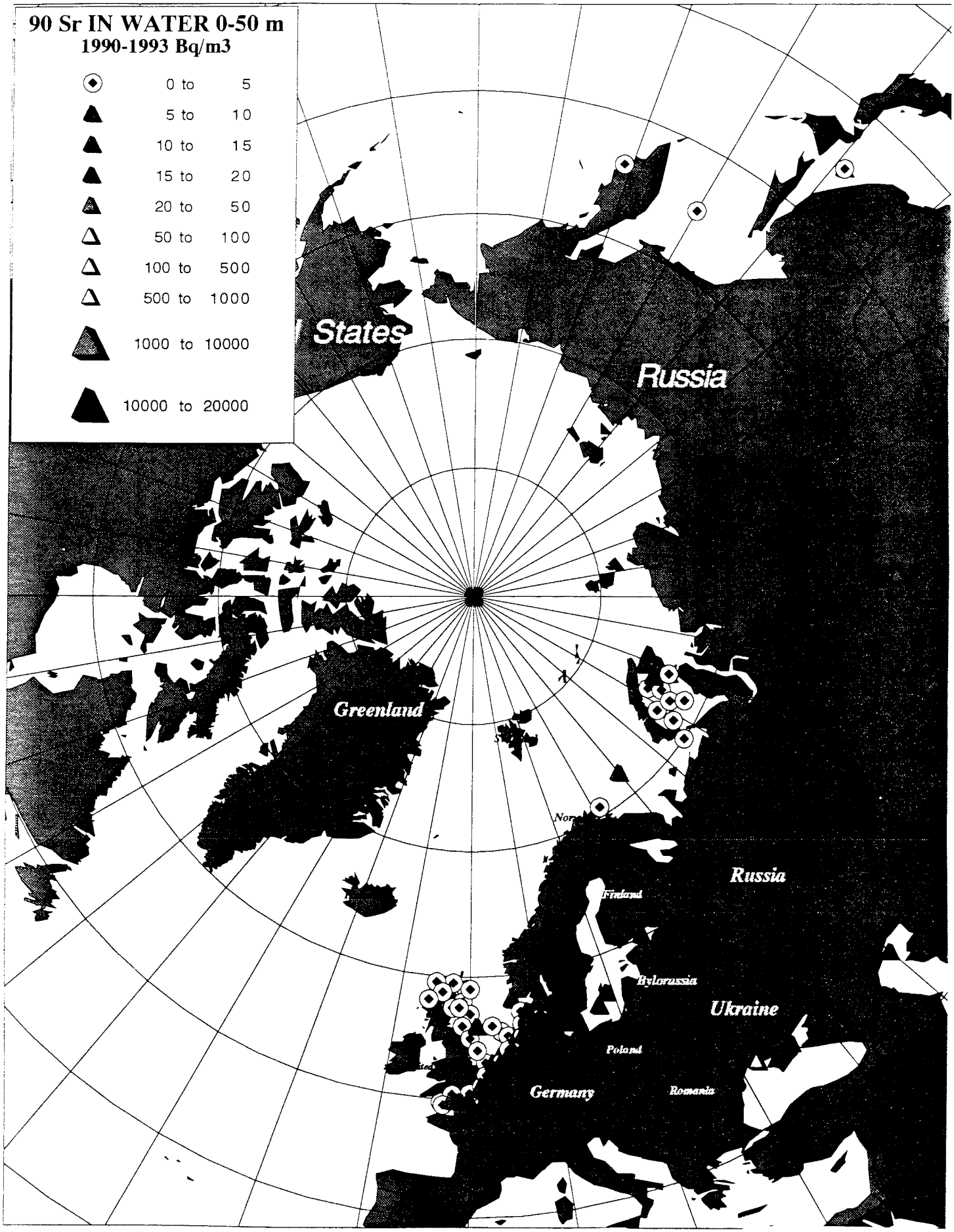

90 Sr IN WATER 0-50 m
1990-1993 Bq/m3
0 to 5
5 to 10
10 to 15
15 to 20
20 to 50
50 to 100
100 to 500
500 to 1000
1000 to 10000
10000 to 20000
States
Russia
Greenland
Russia
Finland
Belarussia
Ukraine
Poland
Germany
Romania

Figure 9

Figure 10

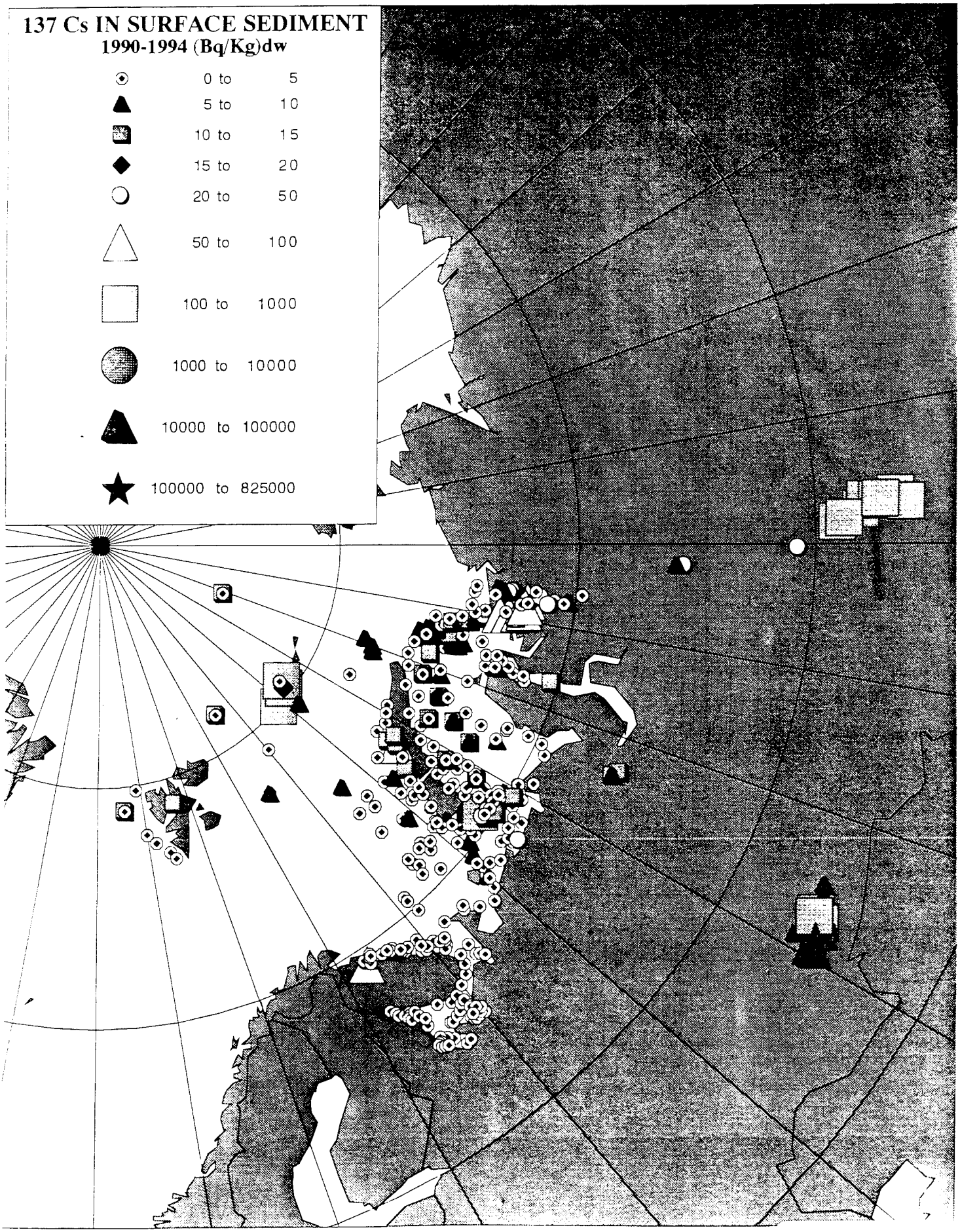

137 Cs IN SURFACE SEDIMENT
1990-1994 (Bq/Kg)dw
0 to 5
5 to 10
10 to 15
15 to 20
20 to 50
50 to 100
100 to 1000
1000 to 10000
10000 to 100000
100000 to 825000

Figure 11

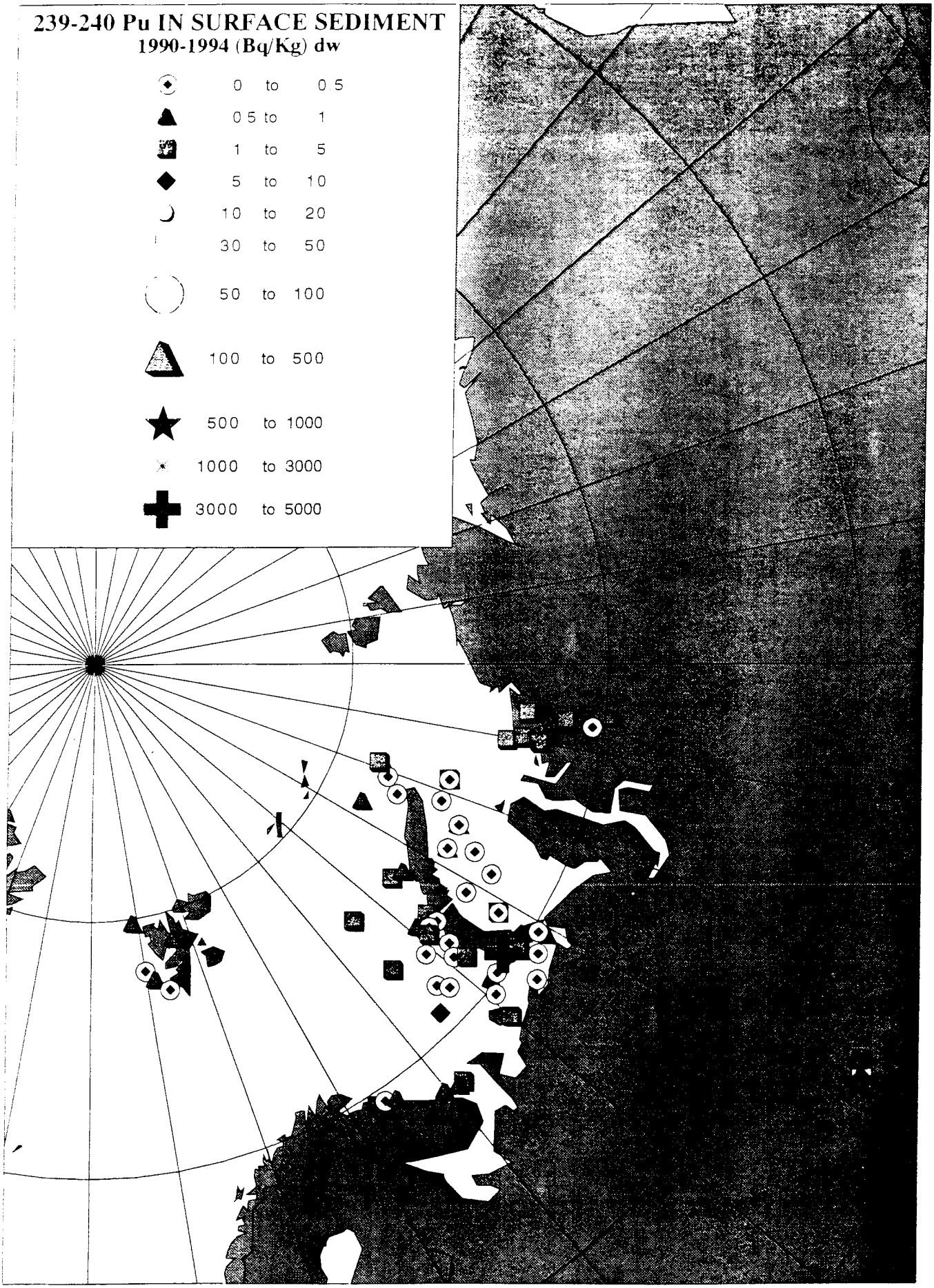

239-240 Pu IN SURFACE SEDIMENT
1990-1994 (Bq/Kg) dw
0 to 0.5
0.5 to 1
1 to 5
5 to 10
10 to 20
30 to 50
50 to 100
100 to 500
500 to 1000
1000 to 3000
3000 to 5000

Figure 1.2

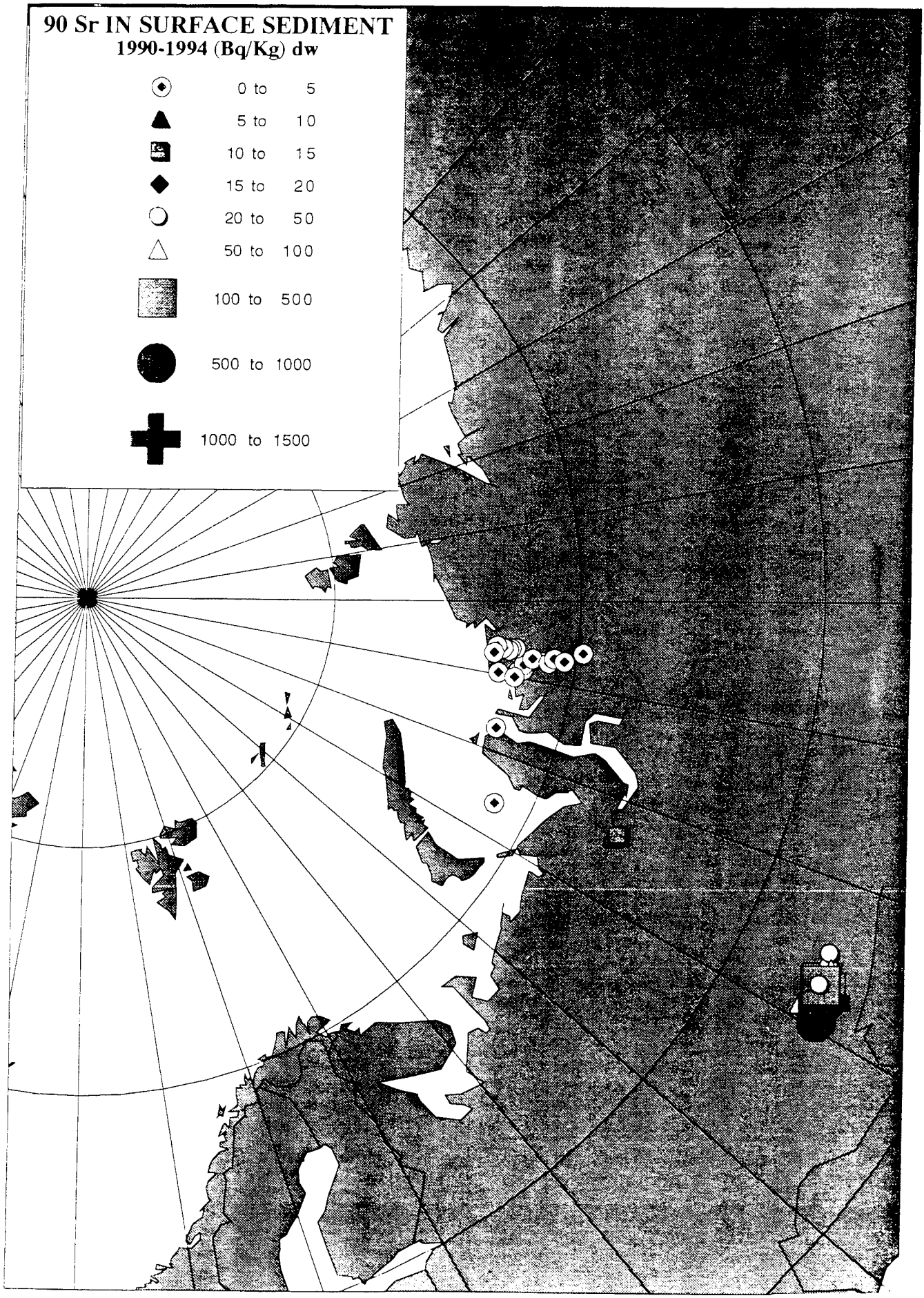

90 Sr IN SURFACE SEDIMENT
1990-1994 (Bq/Kg) dw
0 to 5
5 to 10
10 to 15
15 to 20
20 to 50
50 to 100
100 to 500
500 to 1000
1000 to 1500

Figure 13

An Overview of Risk–Based Monitoring Requirements for Assessing Radionuclides in the Arctic Environment

David W. Layton

Health and Ecological Assessment Division
Lawrence Livermore National Laboratory
7000 East Ave. (L-453)
Livermore, CA 94550

Concern over the contamination of the Arctic environment with radioactive materials has prompted efforts to devise and implement monitoring programs to identify and characterize their occurrence in environmental media. A key challenge facing such programs is the development of survey designs and measurement technologies that will provide the kinds of data needed to assess the health risks posed by nuclear wastes in the Arctic Seas. From a dose- or risk-assessment standpoint, the monitoring parameters of greatest importance are determined mainly by the radionuclides that contribute the most to predicted doses/risks. Related parameters of interest are the physicochemical factors that influence the magnitude of the doses associated with the principal nuclides. A useful way of studying the most influential dose parameters is to conduct sensitivity/uncertainty analyses of how predicted doses change in response to variations in parameters dealing with radionuclide source terms, transport, and food-chain transfers. A preliminary dose assessment of nuclear disposal sites in the Kara Sea indicated that ^{137}Cs and ^{241}Am are important radionuclides, with the principal exposure mechanisms being the ingestion of fish and mollusks, respectively. Traditional diets of indigenous peoples, in contrast, consist mainly of seal, caribou, narwhal, and fish. Consequently, dose assessments and supporting sensitivity/uncertainty analyses are needed to determine which radionuclides constitute the greatest hazard for dietary exposures via Arctic food chains.

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D.W. Layton

Health and Ecological Assessment Division
Lawrence Livermore National Laboratory
P.O. Box 808
Livermore, CA 94550

Workshop on Monitoring Nuclear Contamination in Arctic Seas

Naval Research Laboratory
Washington, D.C.

January 18-19, 1995

INTRODUCTION

- Concern over the contamination of the Arctic environment with radioactive materials has prompted efforts to devise and implement monitoring programs to identify and characterize the occurrence of these contaminants in environmental media.

- A key challenge facing such programs is the development of survey designs and measurement technologies that will provide, in a cost–effective manner, the kinds of data needed to assess the health and ecological risks of the various radionuclides.

RISK ASSESSMENT COMPONENTS

The basic components of a risk assessment involving a given radionuclide in the Arctic Seas include the estimation and/or measurement of

- **its release rate to the marine environment,**
- **its subsequent transport and transformation in water and suspended sediments (and by other transport mechanisms, as appropriate),**
- **its transfer to humans via alternative exposure pathways,**
- **the resulting doses to relevant populations and critical subgroups, and**
- **the associated cancer risks, both population risk and individual risk.**

RISK ASSESSMENT OPTIONS

To put the consequences of nuclear contamination in the Arctic environment into perspective, the risks from three alternative radionuclide sources can be addressed:

- Historic sources of radionuclides

  Nuclear weapons testing
  Releases from nuclear facilities (e.g., Sellafield discharges)
  Chernobyl accident

- On-going releases

  Existing waste sites/riverine discharges

- Future releases

  Accidental ocean or riverine discharges

ASSESSMENT PARAMETERS

The parameters required to conduct dose assessments of radionuclides in the Arctic Seas can be grouped into three broad categories dealing with

- **human exposure factors (e.g., dietary intakes)**
- **physicochemical properties of radionuclides (e.g., half-lives, K_d values, etc.)**
- **the physical, chemical, and biological characteristics of the Arctic Seas (e.g., suspended sediment loads, food-chain relationships, ice cover/movement, etc.)**

ESTABLISHING MONITORING PRIORITIES

From a dose- or risk-assessment standpoint, the parameters of greatest importance are determined mainly by:

(1) the radionuclides that contribute the most to predicted doses/risks, and

(2) the various parameters that influence the dose/risks posed by the key radionuclides.

One way of identifying important parameters for monitoring is to conduct sensitivity/uncertainty analyses of how predicted doses change in response to variations in the different input parameters.

DOSES FOR ^{239}Pu DISPOSED AT A NUCLEAR DUMP SITE IN THE NORTHEAST ATLANTIC AND SELECTED SENSITIVITY ANALYSES (NEA, 1985)

Parameters	Dose, nSv/y
Source terms	
Past dumping, reference case	8.5
Past dumping, longlife packages	5.3
Past dumping, instantaneous release	10
Concentration factors (m^3/t)	
Reference 3×10^3	8.5
Minimum 5×10^2	1.4
Maximum 5×10^3	14
K_d values (m^3/t)	
Reference 1×10^5	8.5
Minimum 1×10^4	19
Maximum 1×10^6	0.64

OTHER POTENTIALLY IMPORTANT PARAMETERS FOR ARCTIC DOSE ASSESSMENTS

- Sediment loading/settling
- Particle resuspension
- Ocean mixing/stratification
- Particle transport by ice
- Airborne transport of sea- and ice-derived particles

RADIONUCLIDE TRANSFERS ALONG THE FOOD CHAIN(S) SUPPORTING NATIVE POPULATIONS

Monitoring data will be needed to quantify the biotransfer of radionuclides along Arctic marine food chains.

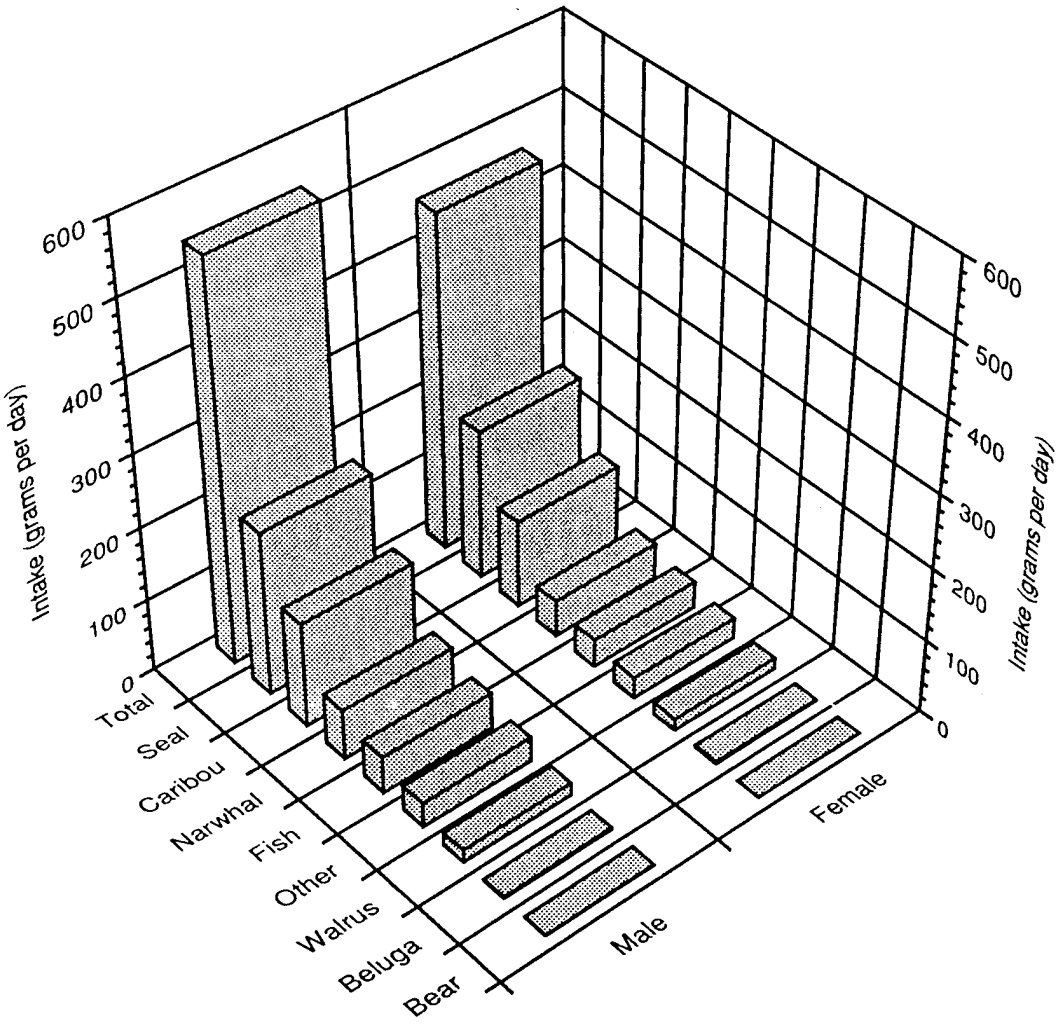
Trophic levels (after Becker, 1994)

1. **Phytoplankton, ice algae, detritus**
2. **Infauna (e.g., oligochaetes) Epifauna (copepods, amphipods)**
3. **Fish, including marine (Arctic cods) and anadromous (Salmon, Arctic char) species**

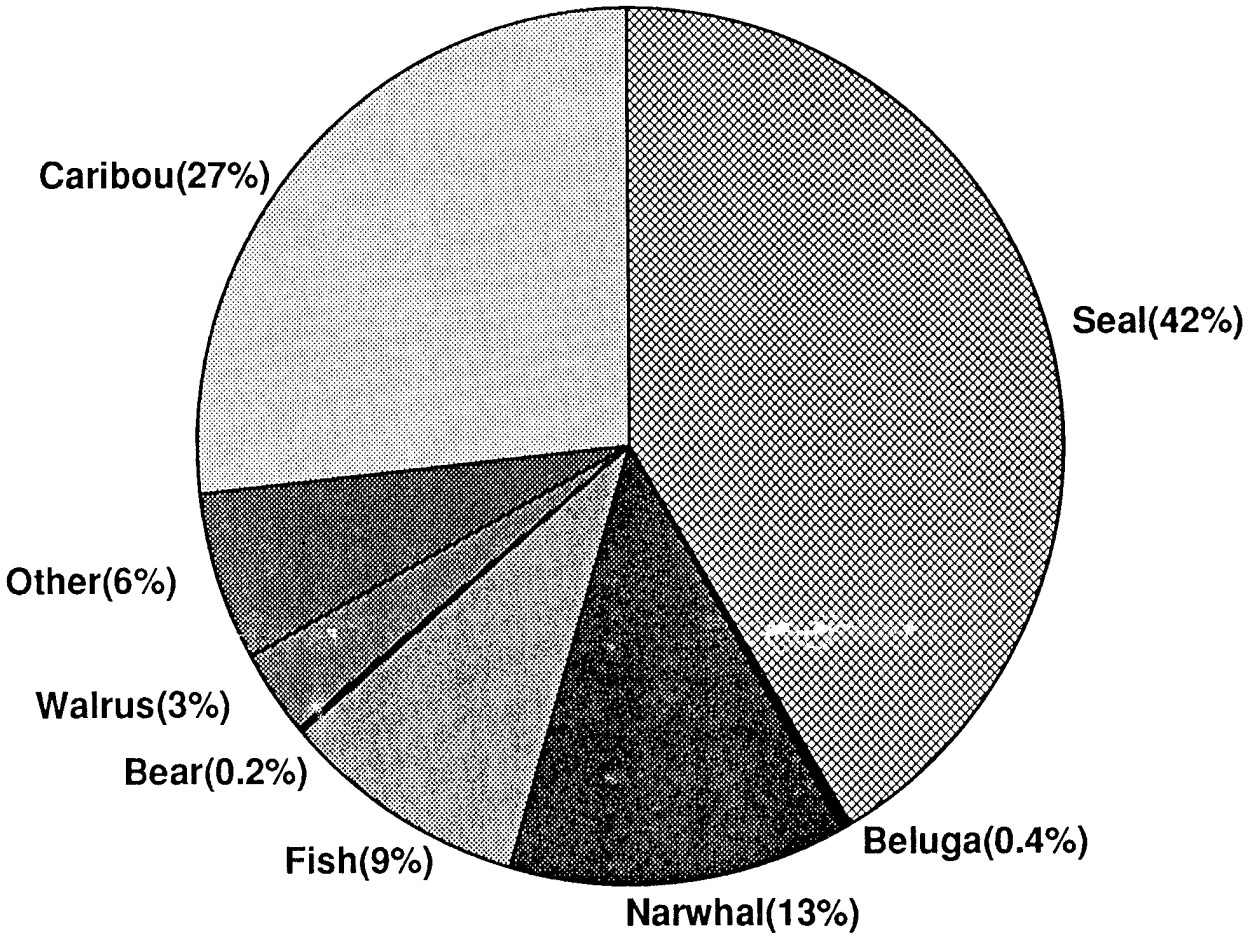
   Walrus
4. **Ringed Seal, Beluga Whale, Narwhal**
5. **Polar Bear**

INTAKES OF TRADITIONAL INUIT FOODS

(from Kinloch et al., 1992)



BREAKDOWN OF FOODS IN THE TRADITIONAL INUIT DIET



SUMMARY

- In order to quantify the potential doses associated with the consumption of traditional foods, analyses are required to determine the key radionuclides of concern and related parameters that affect their transfer from the Arctic environment to critical populations.

- An integrated assessment approach that relies on both modeling and monitoring to predict doses/risks for various nuclear source terms will help ensure that resources are devoted to those parameters that provide the most useful risk-assessment information.

Data Requirements for Risk Assessment

Bruce A. Napier
William L. Templeton

Battelle
Pacific Northwest Laboratories
Richland, Washington

Radiological risk assessment is the process of predicting the transport, environmental accumulation, and uptake by man of radionuclides released to the environment. The general approach to estimating radiation doses to individuals and populations may be described hierarchically. The primary inputs to such a calculation are the concentrations of radionuclides in air, water, soil, and foods, and the level of exposure of the individuals or groups to each. If such local concentrations are not known, they may be estimated from information about radionuclide concentrations in the ocean at the locations of interest and the uptake of radionuclides by biota and sediments. If the radionuclide concentration in the ocean at the location and time of interest, in turn, is not known, it too may be estimated by either extrapolation of monitoring data elsewhere or from knowledge of the quantities released at the source (the "source term") and environmental transport modeling. Because uncertainties are added with each step away from the primary input to the dose calculation, it is always best to use data from as close to the problem as possible, and to incorporate the uncertainties in information from other sources.

Dose to humans depends on radionuclide concentration in various environmental media and the type and duration of the human exposure to each medium. Each exposed population group will have different levels of environmental contamination as well as different types of exposure. Types of exposure may include direct exposure to water, shoreline deposits, and windblown particulate, as well as to material contaminated with water or sediments during fishing activities. Fishing may vary between traditional subsistence techniques, commercial fishing, and recreational fishing. Food supplies may vary with individual and location, including locally-caught fish, meat from aquatic mammals (e.g., seals) or bears, of imported uncontaminated supplies. Commercially caught fish may be exported and pose a low-level contamination hazard to large numbers of people outside of the arctic regions.

Radionuclides of dosimetric concern are those that are environmentally mobile (transportable), bioavailable (accumulate in fish and animals), and sufficiently long-lived to arrive at locations of interest. Different sources of radionuclides to arctic waters have different types of radionuclides associated with them. High-level wastes, either directly dumped (e.g., reactor cores) or leaching from inland sources, may contribute Sr-90, Tc-99, Cs-137 and I-129. Activation products such as nickel-59 are released from irradiated components. Lost weapons components may contribute Pu-239 and Am-241. The need for these sources is the release rates and solubilities of radionuclides of concern. Operational effluents from once-through reactors include moderate-lived, biologically available Zn-65 and P-32.

Risk assessments are the bottom line of this field of research. The risks to humans and ecosystems drive need for any remedial actions. Data collected should, directly or indirectly, support this type of assessments.

Data Requirements for Risk Assessment

Bruce A. Napier
William L. Templeton

Battelle
Pacific Northwest Laboratories
Richland, Washington

Radiological Assessments

Predicting the transport, environmental accumulation, and uptake by man of radionuclides released to the environment

Multiple pathways of exposure:

- External
- Inhalation
- Ingestion
  - Fish
  - Mammals
  - Other foods

Scenarios of Exposure

Define the combinations of pathways, duration and magnitude of exposures, and number of people involved, e.g.,

Subsistence fishing - individual exposures

Coastal hunting - individual exposures

Commercial fishing - population exposures

Dose / Risk Calculations

Concentrations in local environmental media

- Water
- Sediment
- Fish
- Marine mammals

Human exposure parameters

- Amounts consumed
- Length of time exposed to various media
- Obtained through demographic studies

Concentrations in Environmental Media

Concentration in ocean water and sediments

- Obtained from monitoring
- Obtained from modeling

Concentrations in foodstuffs

- Obtained from monitoring
- Obtained from modeling (transfer factors)- Generally only available for temperate climates or from stable element data

Concentrations in Ocean Water

Transport

- Transit time (decay)
- Concentration

Chemical form

- Solubility
- Bioavailability

Source

- What radionuclides?

Transport Considerations

For each location of potential interest:

What gets there?

When does it get there?

How does it get there?

- Solute transport in water
- Particulate transport in water
- Mass transport by ice

Source Term Considerations

High-level wastes (Strontium-90, Cesium-137)

- Directly dumped
- Leakage to rivers

Activation products

- Irradiated components (Nickel 59)
- Release rates?

Actinides

- Weapons components (Plutonium-239)
- Release rates, solubilities?

Operational effluents from once-through reactors

- Moderate-lived, biologically available (Zinc-65, Phosphorus-32)

Radionuclides of Interest

Environmentally mobile (transportable)

Bioavailable (accumulates in fish and animals)

"Long-lived" (sufficient to arrive at locations of interest)

Demographics

Number of people

- Sex
- Age
- Location

Lifestyle

- Food sources
- Consumption rates
- Exposure patterns

Summary

Risk assessments are the bottom line of this field of research

Risks to humans and ecosystems drive need for any remedial actions

Data collected should, directly or indirectly, support this type of assessments

Coastal Environments of the Southern Kara and Eastern Barents Seas

Stephanie Pfirman
Barnard College, Columbia University
Lamont-Doherty Earth Observatory

Nuclear activity on land and dumping of waste in the Siberian shelf seas, mean that the Kara Sea is most likely to experience inputs of radioactivity. Contaminant fate here will be influenced by processes associated with ice formation and ocean currents as well as the distribution of river discharge. Monitoring efforts should encompass both import and export of water, sea ice, and sediments which may contain entrained contaminants. For example, satellite images of temperature and turbidity distributions suggest that both ice and water are exchanged with the Barents Sea through Karskiye Vorota, south of Novaya Zemlya. Coupled with analysis of clay mineralogy carried out by other investigators, there is growing evidence pointing to this region as a potential pollutant transport pathway. Understanding of the timing, spatial structure, variability and governing forces involved in exchange through the straits and passages along the boundaries of the Kara Sea are required for assessment of contaminant export to the Norwegian fishing grounds and Alaskan coasts.

Research and monitoring programs examine ice and water as potential conveyors of pollutants should investigate:

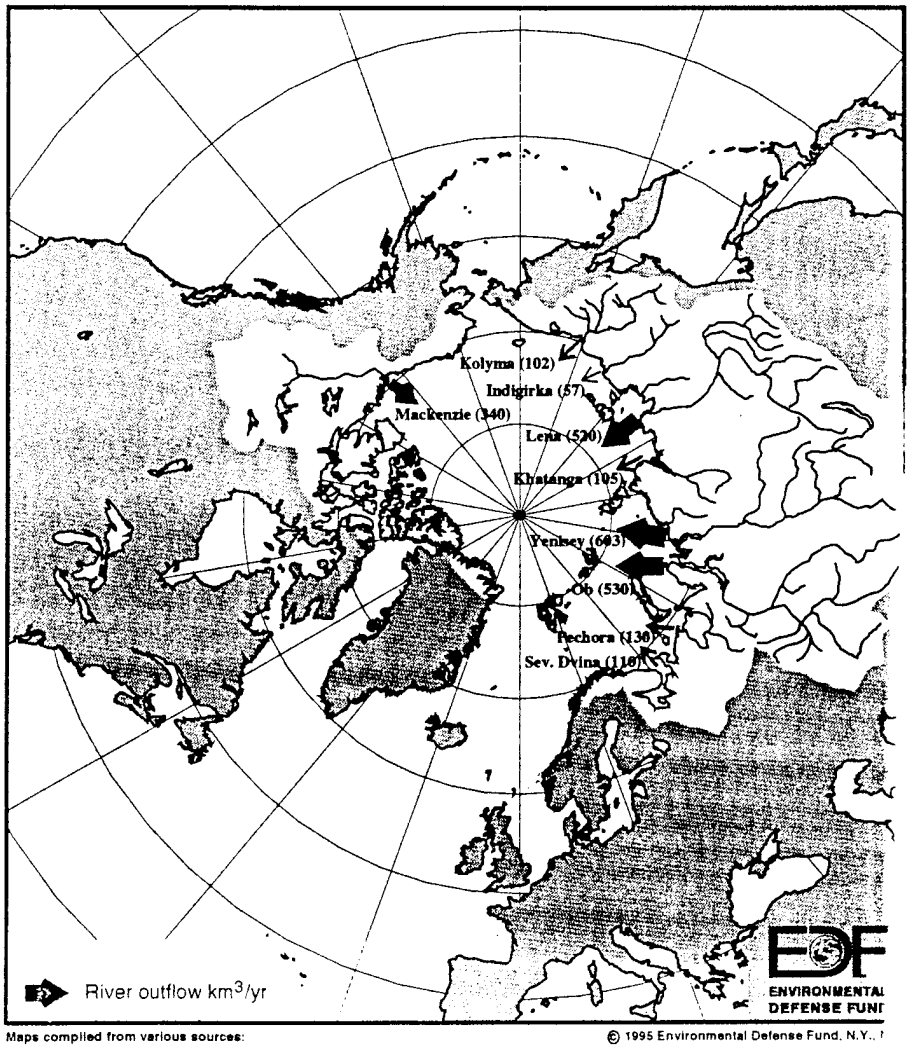
1) processes involved in resuspension of radionuclides and particulates,
2) entrainment of radionuclides and particulates in sea ice and ocean currents,
3) advection of ice and water out of the Kara Sea through straits to the Arctic Ocean and adjacent seas,
4) interaction between the Transpolar Drift Stream and the Beaufort Gyre,
5) evolution of particle and radionuclide distribution during aging of multiyear ice floes,
6) release of particles and radionuclides from ice, and deposition from ocean currents, including identification of likely depocenters.

Methods required to achieve these objectives include:

1) field studies,
2) experiments to understand entrainment and release of radionuclides and particles from sea ice,
3) remote sensing to document the distribution of ice, and temperature and turbidity of surface waters, throughout the annual cycle,
4) time series measurements in strategic locations to understand fluxes of radionuclides and particles out of the Kara Sea. Locations with high priority include: Kara Gate (Karskiye Vorota), St. Anna Trough, Vilkitsky Strait, and the region of river runoff export just west of Severnaya Zemlya. Also of priority are the strait between Novaya Zemlya and Frans Josef Land, and Voronin Trough.

Finally, we should obtain information not only on the prevailing currents of the Kara Sea, which are responsible for long term changes in pollutant concentrations, but also on the structure of the highly variable polynya dynamics, river discharge, and iceberg activity as well as wind-induced circulation and tidal phenomena. Although average conditions are important in the transport of pollutants, events such as storms and ice gouging may be critical in deciding the ultimate fate of dumped and released contaminants.

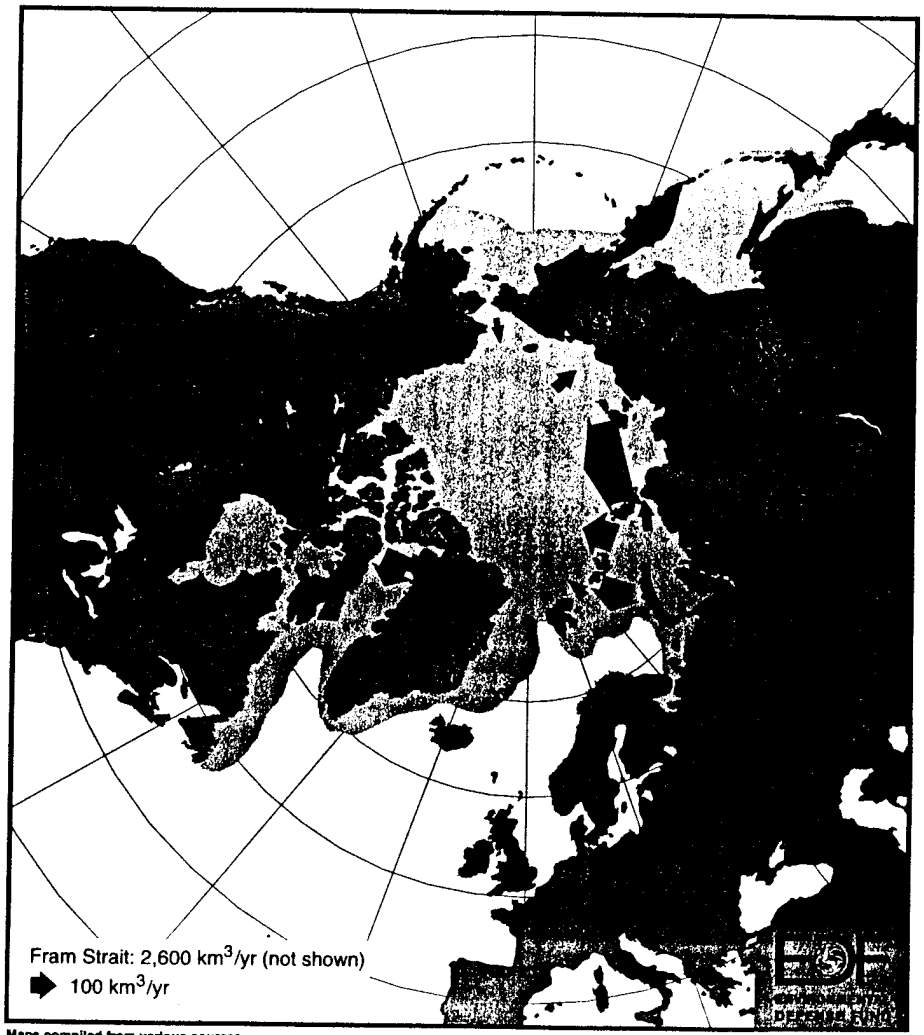
Arctic Ocean Watershed



Maps compiled from various sources:
see tables for citations.

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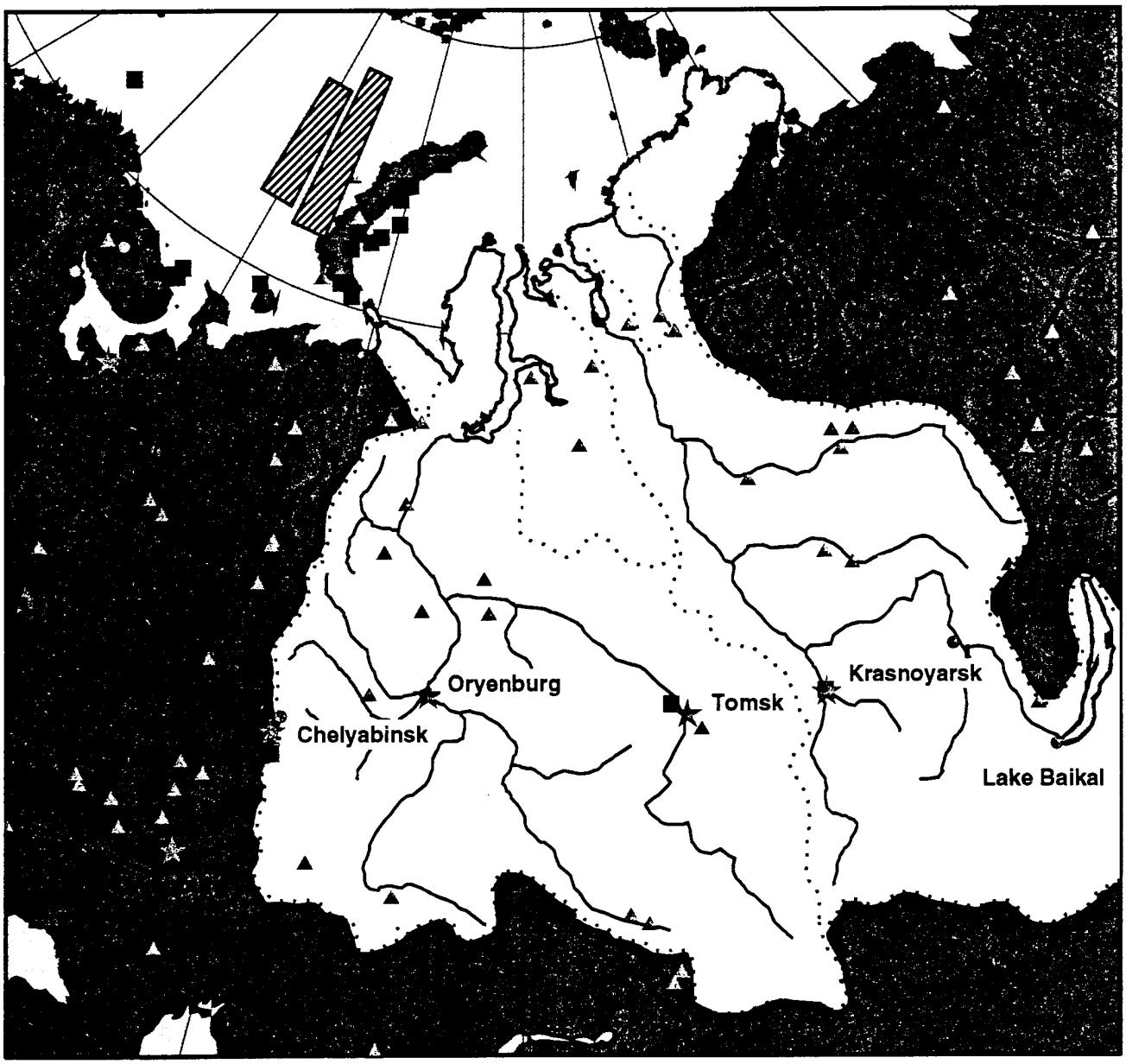
Sea Ice Flux



Maps compiled from various sources:
see tables for citations.

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NUCLEAR ACTIVITY



★ Nuclear Accidents

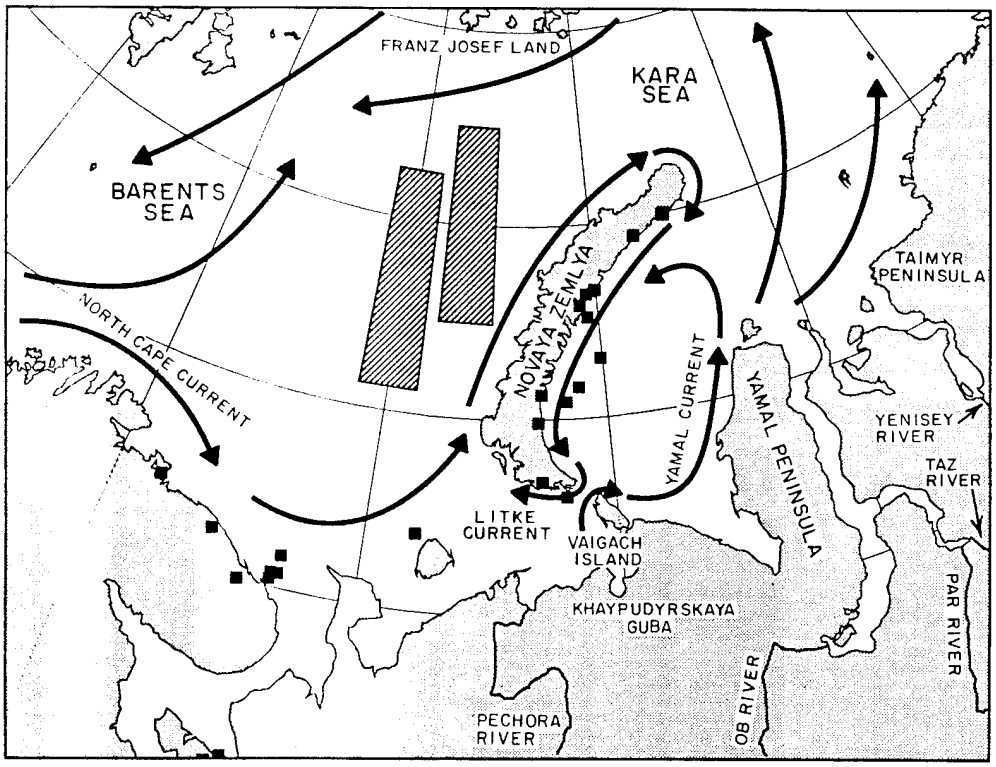
▲ Peaceful Nuclear Explosions

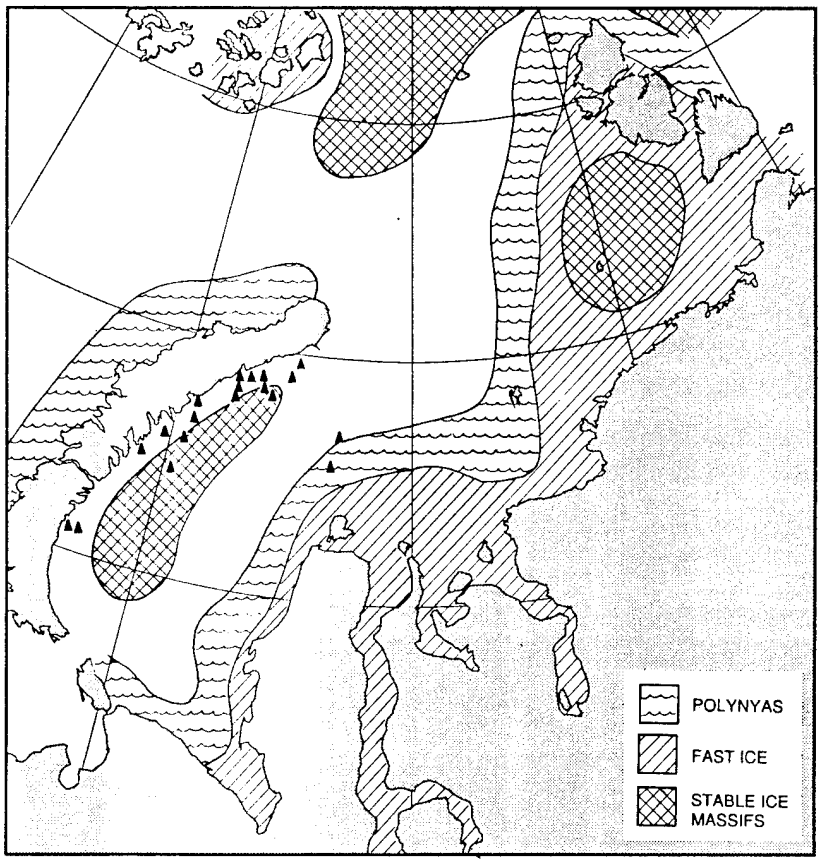
\+ Nuclear Power Plants

● Nuclear Deposits and Processing

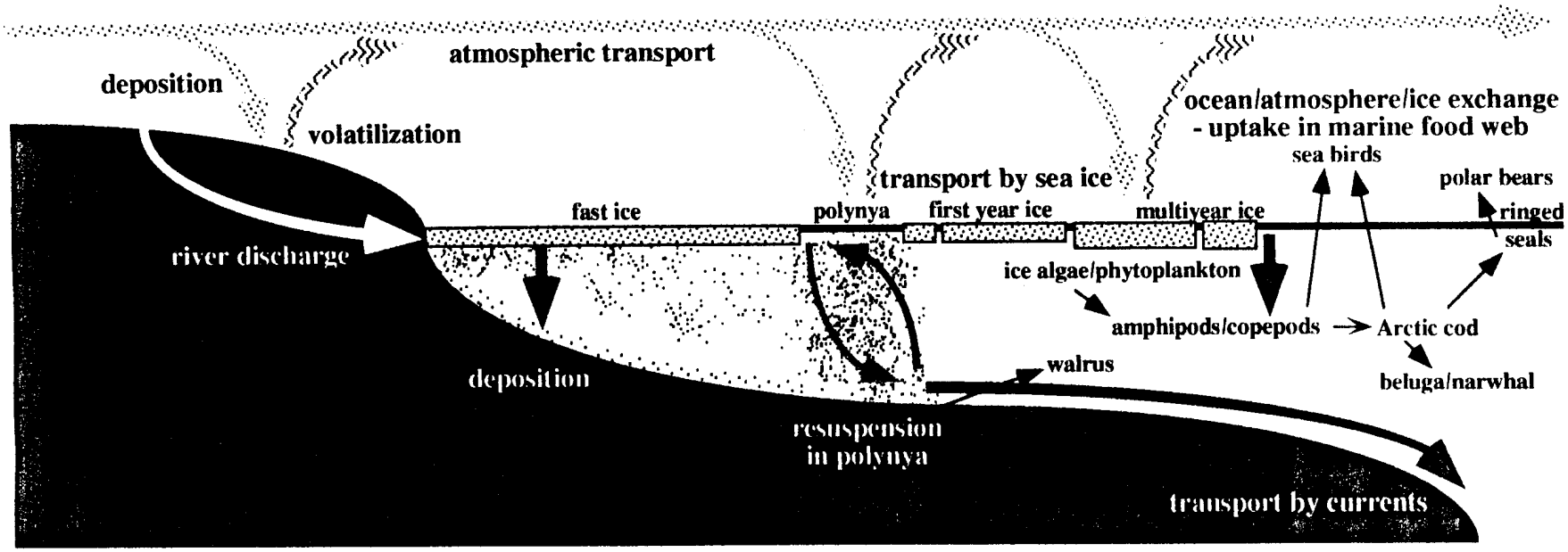
■ Nuclear Waste Sites

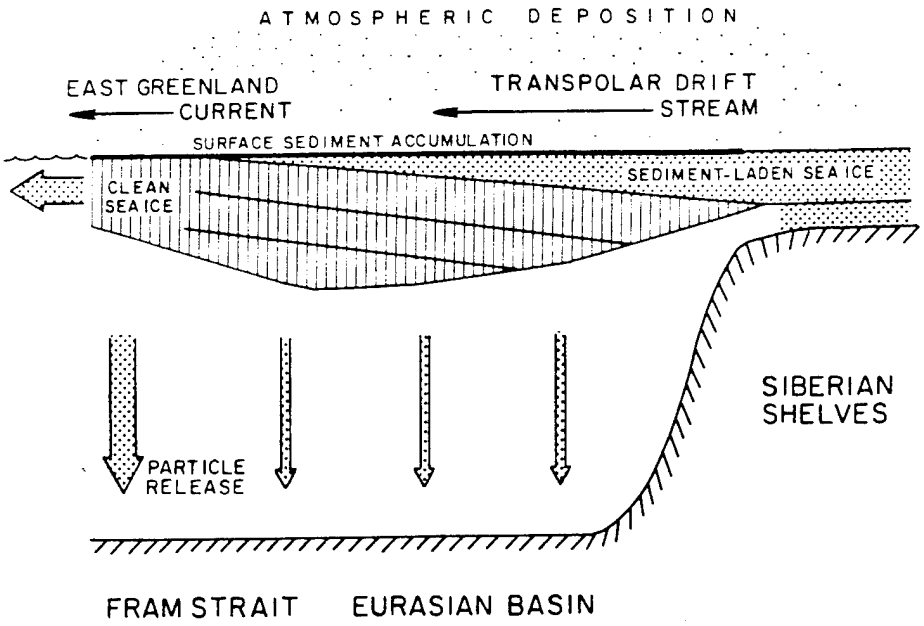
▨ Liquid Waste Sites

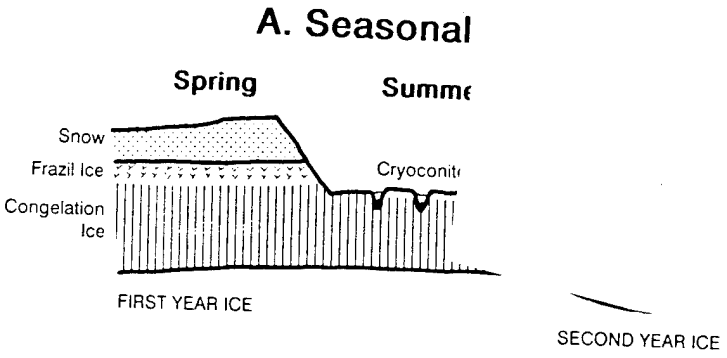

FRANZ JOSEF LAND
KARA SEA
BARENTS SEA
NOVAYA ZEMLYA
TAIMYR PENINSULA
NORTH CAPE CURRENT
YAMAL CURRENT
YAMAL PENINSULA
YENISEY RIVER
TAZ RIVER
LITKE CURRENT
VAIGACH ISLAND
KHAYPUDYRSKAYA GUBA
PAR RIVER
OB RIVER
PECHORA RIVER

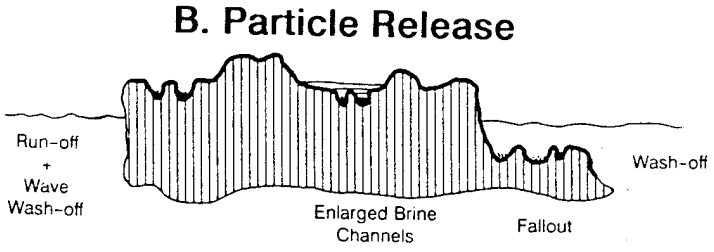

POLYNYAS
FAST ICE
STABLE ICE MASSIFS

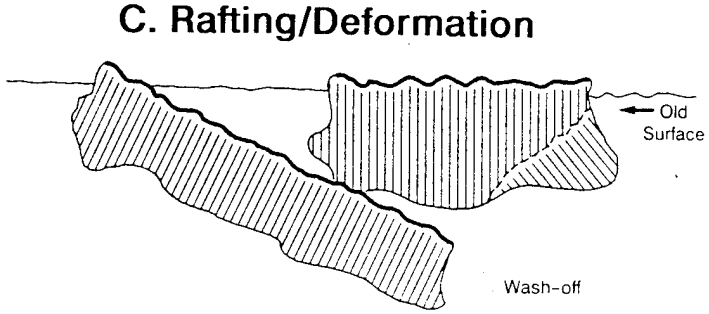
SEDIMENT/CONTAMINANT CYCLING




ATMOSPHERIC DEPOSITION
EAST GREENLAND CURRENT
TRANSPOLAR DRIFT STREAM
SURFACE SEDIMENT ACCUMULATION
CLEAN SEA ICE
SEDIMENT-LADEN SEA ICE
SIBERIAN SHELVES
PARTICLE RELEASE
FRAM STRAIT
EURASIAN BASIN


A. Seasonal
Spring
Summe
Snow
Frazil Ice
Congelation Ice
Cryoconite
FIRST YEAR ICE
SECOND YEAR ICE


B. Particle Release
Run-off + Wave Wash-off
Wash-off
Enlarged Brine Channels
Fallout


C. Rafting/Deformation
Old Surface
Wash-off

IV. Sensor Technology Session

In-situ monitoring of gamma-radioactivity in the Kara Sea

P. P. Povinec, I. Osvath, M. S. Baxter, I. H. Harms

International Atomic Energy Agency, Marine Environment Laboratory
MC 98012 MONACO

Abstract

Recent developments in cryogenic physics and associated portable micro-electronics have enabled the operation of HPGe detectors without liquid nitrogen cooling in deep underwater conditions. This has been recognised as a great advantage to *in-situ* NaI(Tl) γ-spectrometry, which in turn has many advantages relative to traditional sampling and laboratory analysis, such as the ability to carry out large area and long-term monitoring and mapping in the vicinity of disposals of radioactivity and to optimise and focus traditional sampling and monitoring on either representative or "hot spot" areas.

An *in-situ* γ-spectrometer designed for underwater operations is described. The spectrometer consists of separately housed HPGe and NaI(Tl) detectors with electronics, data acquisition and processing electronics (two MCA cards with a micro PC) located with the detectors, communicating with a shipboard PC through a modem link, and a supporting system consisting of a hydraulic winch with 1200 m conducting cable. Characteristics of the system and results obtained during operational tests in the Irish Sea are discussed. Data obtained during the deployment of the spectrometer in the Kara Sea are also presented. The spectra measured with the HPGe detector represent the first set of high resolution sea-bed γ-spectra ever recorded *in-situ*. The HPGe spectrometer sensitivity is $5 \cdot 10^{-4}$cps/Bq kg^{-1} for ^{137}Cs in superficial bottom sediments.

A possible utilisation of underwater γ-spectrometry for *in-situ* monitoring of leakages of radionuclides from dumped or sunken nuclear objects/wastes is discussed. It is shown that remote stationary γ-spectrometers based on scintillation detectors (e. g. NaI(Tl), BGO, CsI) operating on the sea-bed with dumped radioactive wastes (e.g. in Abrosimov Bay, Tsivolki Bay, Novaya Zemlya Trough) and/or in the open sea (e.g. Kara Gate, Central Kara Sea) with satellite data transmission would be a very efficient way of long-term monitoring of possible leakages from dumped radioactive wastes in the Kara Sea. Such systems could also be equipped with other sensors, like current, temperature and salinity meters, and thus provide comprehensive oceanographic information for the region.

This radiometric subproject complements other aspects of IAEA-MEL's contributions to the IAEA's International Arctic Seas Assessment Project (IASAP) and to the Norwegian-Russian expeditions to the Kara Sea. The latter activities, including radionuclide analyses, analytical intercalibration exercises, database compilation, computer modelling of potential dispersion and radiological assessment, are briefly summarised.

1. Introduction

The IAEA's Marine Environment Laboratory's Arctic programme, organized in the framework of the IAEA's International Arctic Seas Assessment Project (IASAP) (Sjoeblom & Linsley, 1993), includes the following activities (Baxter *et al.*, 1993a):

i) participation in the 1992, 1993 and 1994 official expeditions to the Kara Sea;

ii) assistance with *in-situ* and laboratory-based radiometric measurements of current radionuclide concentrations in the Kara Sea;

iii) organisation of analytical quality assurance intercalibration exercises amongst the participating laboratories;

iv) provision of a central database facility for the IASAP project, including collation of all past and present radioactivity concentrations in the Arctic Seas;

v) contribution to the international programme of local, regional and global scale computer modelling of the potential dispersal of radionuclides released from the dumped waste and of assessment of the associated radiological consequences.

In this paper, we present characteristics of, and the first results obtained, by the deployment of an underwater γ-spectrometer in the Irish and Kara Seas. The possible utilisation of the spectrometer for *in situ* monitoring of leakages of radionuclides from dumped or sunken nuclear objects/wastes is discussed.

2. Underwater γ-spectrometry

In-situ γ-spectrometry has many advantages relative to traditional sampling and laboratory analysis for several aspects of marine radioactivity monitoring:

i) investigation of radionuclide levels around dumped or sunken nuclear objects/wastes when a much larger area can be investigated in comparison with single sample (water or sediment) collection and analysis;

ii) long-term monitoring of possible leakages of radionuclides from dumped or sunken nuclear objects/wastes;

iii) mapping of large sea-bed areas for assessing the distribution and levels of investigated radionuclides (natural as well as anthropogenic);

iv) traditional marine radioactivity research when long-term time-series of investigated radionuclides can replace sporadic sampling;

v) optimisation and geographical focusing of conventional sample collection on areas which can be expected to be either representative or most contaminated.

Recent developments in cryogenic physics and associated portable micro-electronics have enabled the operation of HPGe detectors without liquid nitrogen cooling in deep underwater conditions. This has been recognized as a considerable and complementary advance on the *in-situ* NaI(Tl) γ-spectrometry which has previously been applied to sea-bed mapping of radionuclides emitting γ-radiation (Miller *et al.*, 1982).

2.1. Description of the underwater γ-spectrometer

An underwater γ-spectrometer consisting of separately housed HPGe and NaI(Tl) detectors with electronics, data acquisition and processing electronics (two MCA cards with a micro PC) located with the detectors, communicating with a shipboard PC through a modem link, and a supporting system consisting of a hydraulic winch with a 1200 m conducting cable has been developed in collaboration with Challenger Oceanic Sensors (UK).

2.1.1. Detectors, electronics and data acquisition

The detection part of the spectrometer consisting of HPGe and NaI(Tl) detectors with electronics is shown in Fig. 1. The HPGe detector has at present 20 % efficiency relative to a 75x75 mm NaI(Tl) crystal. An external helium cooling system is used to cool the propane in the cryogenic unit of the detector down to 20 K. The HPGe detector then operates between 20 and 120 K without external cooling. The deployment time is about 24 hours. Further deployment of the detector requires repeated external cooling with the helium cooler (for about 6 hours).

The second γ-detector is made of a ruggedised NaI(Tl) scintillator of 100 mm diameter and 150 mm length. The photomultiplier has a flexible connection to the scintillator to reduce vibration. The electronics have integral temperature stabilisation to prevent spectral drift.

The electronics for data acquisition and processing consist of a submerged micro-PC (486) with 2 multichannel analyser boards (2k and 8k channels for NaI(Tl) and HPGe detectors, respectively), communicating with a shipboard PC through a modem link (Fig. 1). The submerged electronics are housed together with the NaI(Tl) detector in a pressure tube (Fig. 2). The shipboard PC controls data acquisition functions of the submerged assembly and performs real-time data processing. The software driving the system includes data acquisition, remote communication and various utilities allowing management of the multichannel analysers and of the two linked computers. γ-spectrum processing is achieved with commercial software (TMCA, INTERGAMMA).

Several computer codes have been developed and implemented, such as a special software which allows graphic treatment of spectral data, and a batch file performing integration of spectra over pre-defined regions of interest, generating an output usable for mapping.

The detectors are housed in individual pressure-resistant containments and are assembled together in a polypropylene "sledge", which can be suspended in the water column or dragged on the sea-bed. The sledge prevents the detectors from being damaged during towing operations.

Deployment of the system is controlled by a winch with 1200 m of conducting cable (which feeds power to the system and returns the signal), hydraulically driven by an electric motor. For sea-bed surveys, a 15 m long weighted tail with a heavy chain core is fitted in front of the sledge.

2.1.2. Spectrometer characteristics

In order to test the domain of autonomy of the HPGe system, which is operational at temperatures up to 120 K, the temperature level of the crystal was monitored during several cooling/warm-up cycles in different ambient conditions. If a vacuum of $3 \cdot 10^{-4}$ bar between the propane reservoir and the system casing and a low temperature (20 K) of the propane cooler are achieved initially, the autonomy can be maintained for 24 hours.

The stability of the spectrometric systems during immersion in water was evaluated. Data recorded during deployment in the Kara Sea were analyzed and yielded an energy shift of <3% for the NaI(Tl) detector operating for up to 12 hours at ambient temperatures ranging from 273 to 295 K. Over the same period of deployment, an energy shift of <0.07% was observed for the HPGe detector.

The detection efficiency for point sources was evaluated for the NaI(Tl) detector.

IAEA-MEL UNDERWATER SPECTROMETER

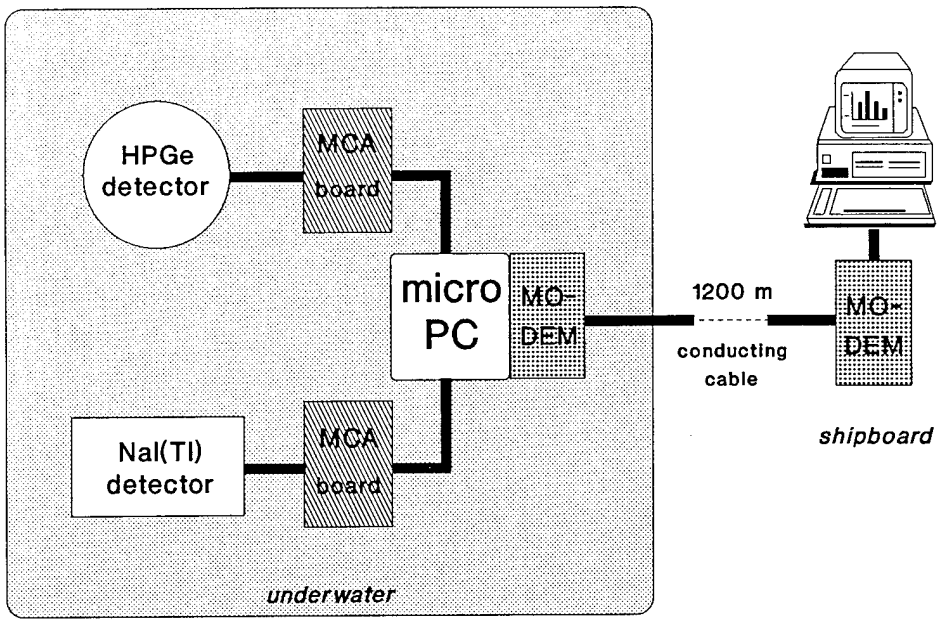


Fig.1: Schematic of data acquisition, transfer and processing.

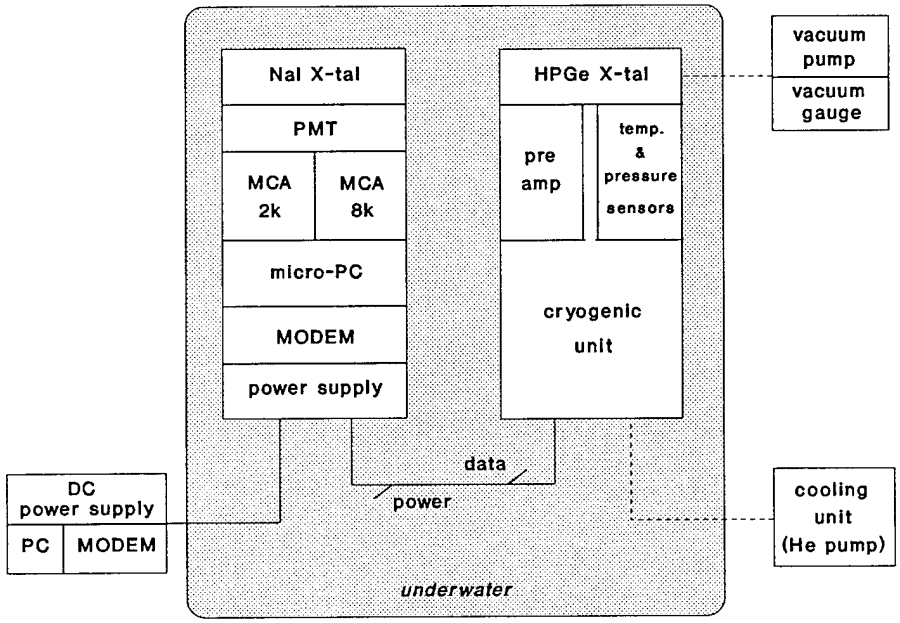


Fig. 2: Block scheme of spectrometric system.

The sources were placed tangentially to the detector casing, at midheight (75 mm) along the longitudinal axis of the crystal. Values of 7.8% and 2.9% for the 661.6 keV (^{137}Cs) and 1332.5 keV (^{60}Co) lines respectively were obtained.

2.2. Sea-bed γ-spectra

Fig. 3 shows typical γ-spectra recorded by the HPGe and the NaI(Tl) detectors during tests in the Irish Sea. Relatively high concentrations of ^{137}Cs have been measured in comparison with natural radionuclides in the U and Th decay series. The superior performance of the HPGe spectrometer is clearly visible. The spectra obtained with the HPGe detector represent the first set of high resolution sea-bed γ-spectra ever recorded *in-situ*.

Fig. 4 shows HPGe and NaI(Tl) spectra recorded in one of the stations in Stepovovo Bay (Kara Sea). The much superior resolution of the HPGe detector has enabled observation of a low ^{137}Cs concentration which was not visible in the NaI(Tl) spectrum.

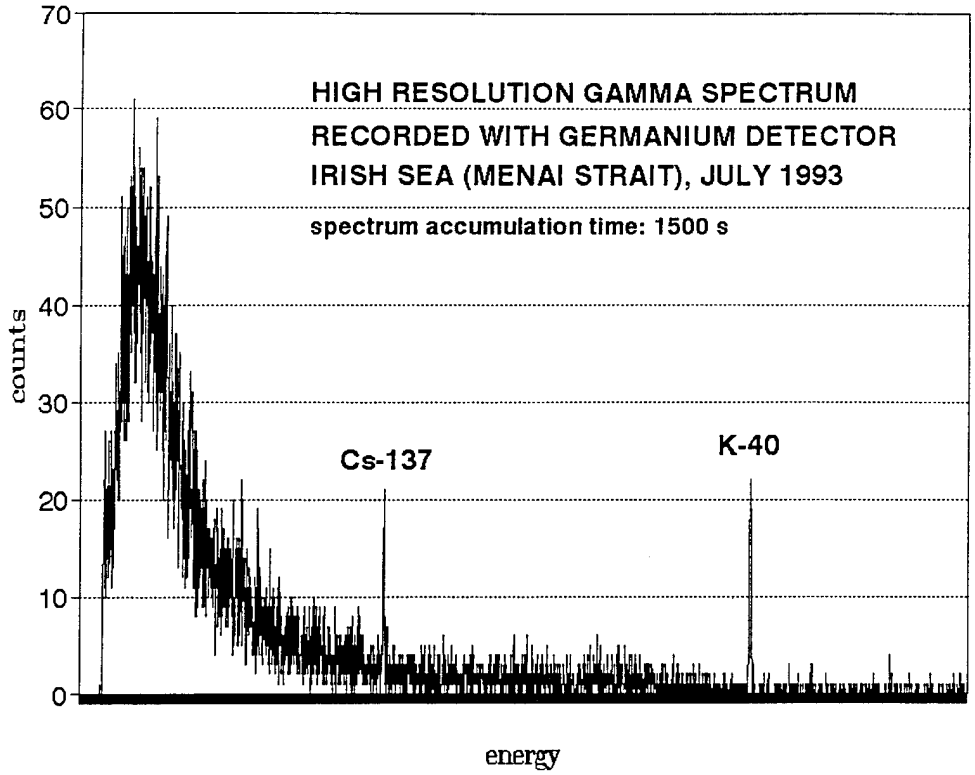
Preliminary evaluation of the detection efficiency of the HPGe detector when deployed on the sediment surface, based on spectra recorded in the Irish and Kara Seas in areas of known radionuclide concentrations (without taking into account vertical profiles and concentrations in water), give about $5 \cdot 10^{-4}$ cps/Bq kg^{-1} for ^{137}Cs in surficial bottom sediments.

Future improvements to the system are being focussed on enhancing performance (longer autonomy and higher efficiency of the Ge based spectrometer, extension of the maximum operating depth), on redesigning components to increase both the ease and safety of deployment and positioning of the submerged device and on developing of new software for data evaluation and mapping.

3. Development of stationary γ-monitoring systems for the Kara Sea

The present approach for investigation of the dumping sites in the Kara Sea via yearly expeditions during the short season of ice-melting is not effective for a long-term monitoring programme. It has, of course been essential in order to obtain the initial information on the location of the dumped objects, their forms and conditions, and on present radionuclide levels around the dumped objects. Apart from the dumping site in the Novaya Zemlya Depression, all important dumping sites have been investigated. It is thus possible now to plan the introduction of a more effective system for long-term monitoring of the dump sites.

Preliminary modelling results (Baxter *et al.*, 1993a) suggest that any releases from the dump sites in the Kara Sea should not have significant global radiological impact. However, calculations performed on regional and local scales using circulation and dispersion models show that, for a continuous release of 1 TBq y^{-1} of ^{137}Cs in Abrosimov Bay, the average ^{137}Cs concentrations in the entrance of Abrosimov Bay could reach 2 kBq m^{-3}. Activity concentrations in sediments and suspended particles would be considerably higher, according to nuclide K_d factors, with implications for local exposures, by resuspension, wind-flow and inhalation, by external γ-radiation on shorelines and of course by transfer to marine organisms and subsequently through the food-web. It is therefore important, in order to protect local populations, fauna and flora, that an efficient and continuous monitoring system should be in place.


HIGH RESOLUTION GAMMA SPECTRUM
RECORDED WITH GERMANIUM DETECTOR
IRISH SEA (MENAI STRAIT), JULY 1993
spectrum accumulation time: 1500 s
Cs-137
K-40
counts
energy
70
60
50
40
30
20
10
0

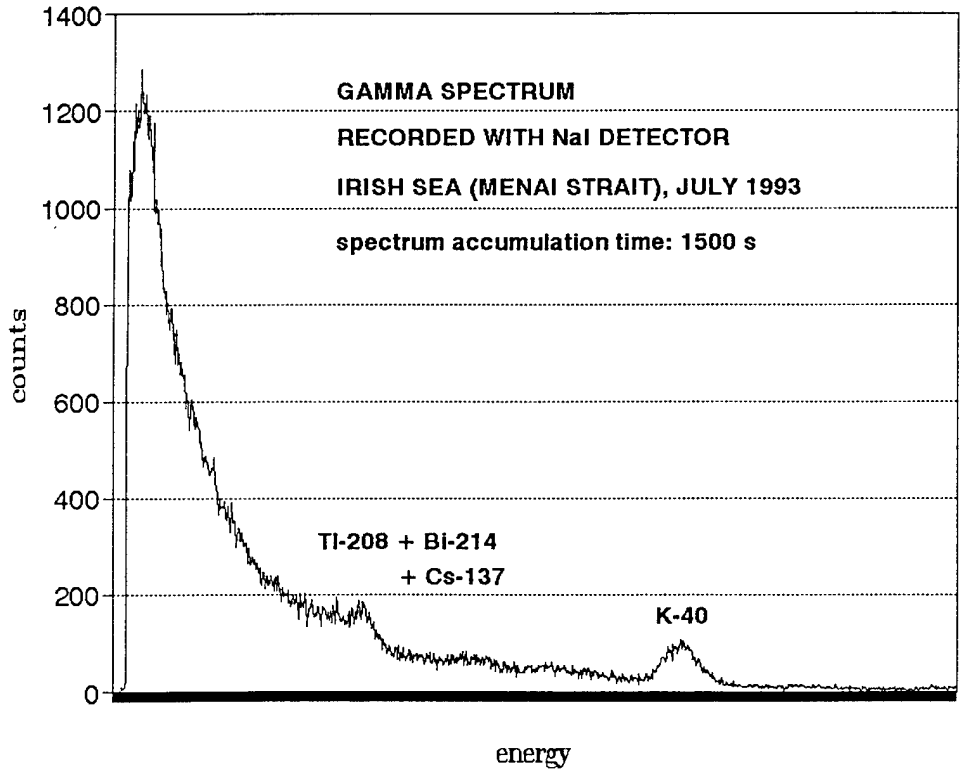
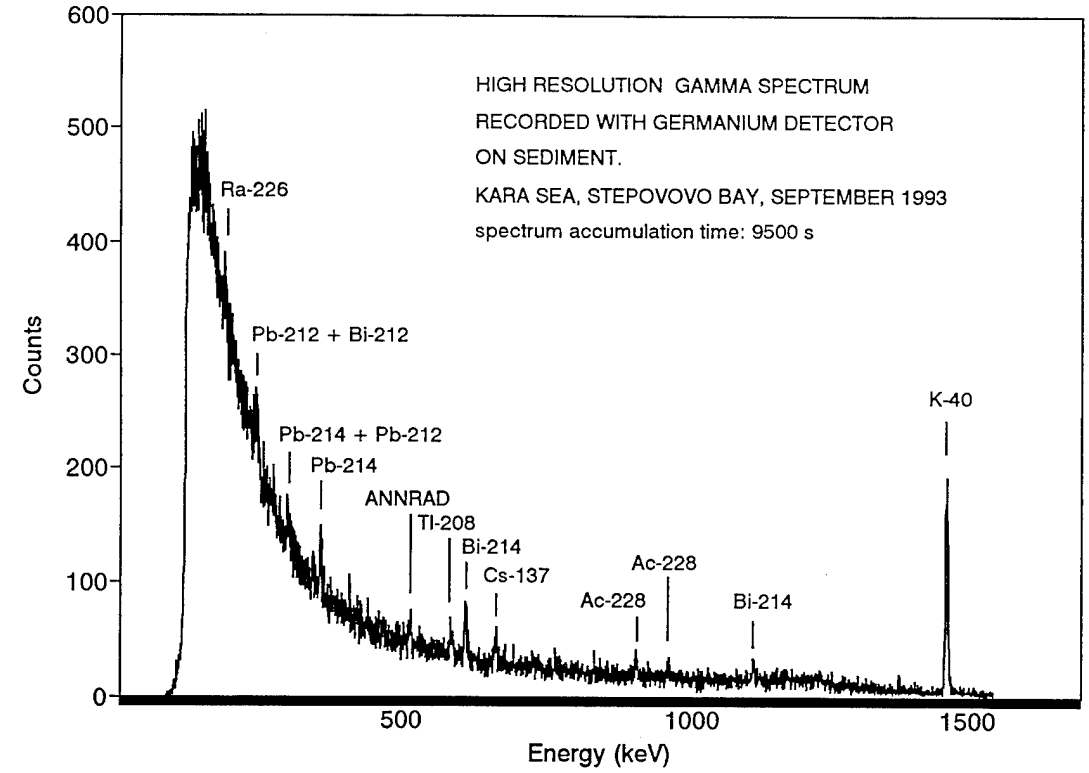

GAMMA SPECTRUM
RECORDED WITH NaI DETECTOR
IRISH SEA (MENAI STRAIT), JULY 1993
spectrum accumulation time: 1500 s
Tl-208 + Bi-214
+ Cs-137
K-40
counts
energy
1400
1200
1000
800
600
400
200
0

Fig. 3


HIGH RESOLUTION GAMMA SPECTRUM
RECORDED WITH GERMANIUM DETECTOR
ON SEDIMENT.
KARA SEA, STEPOVOVO BAY, SEPTEMBER 1993
spectrum accumulation time: 9500 s
Ra-226
Pb-212 + Bi-212
Pb-214 + Pb-212
Pb-214
ANNRAD
Tl-208
Bi-214
Cs-137
Ac-228
Ac-228
Bi-214
K-40
Counts
Energy (keV)

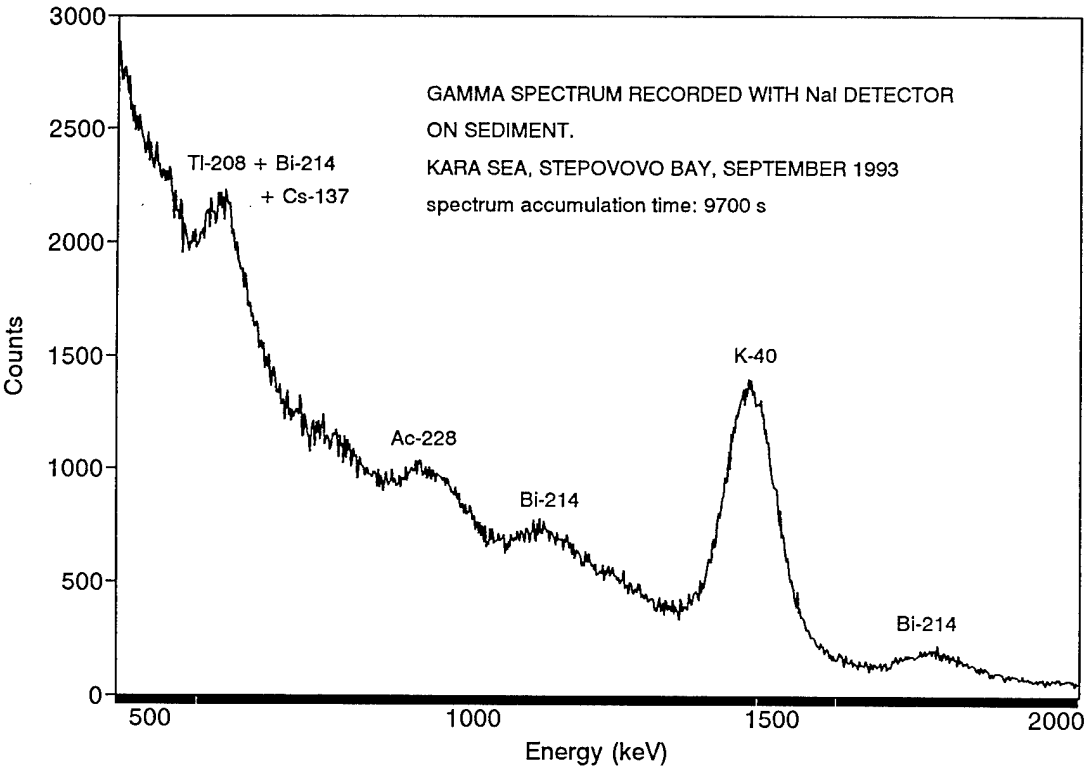

GAMMA SPECTRUM RECORDED WITH NaI DETECTOR
ON SEDIMENT.
KARA SEA, STEPOVOVO BAY, SEPTEMBER 1993
spectrum accumulation time: 9700 s
Tl-208 + Bi-214
+ Cs-137
Ac-228
Bi-214
K-40
Bi-214
Counts
Energy (keV)

Fig. 4

3.1. Radionuclide inventories in dumped wastes

The estimated present inventories of radionuclides in the radioactive wastes dumped in the Kara Sea are given in Table 1. It can be seen that the most important dumping site is Abrosimov Bay, where about 50% of the fission and activation products have been dumped. This also is one of the oldest dumping sites, disposals beginning there in 1966 (White Book 3, 1993). Therefore we have suggested development of a stationary γ-monitoring system at this bay (Povinec, 1994). The other two most important dumping sites are the Novaya Zemlya Depression and Tsivolki Bay, where similar systems could operate. Stepovovo Bay, although having a lower inventory of fission and activation products (Yefimov *et al.*, 1994), is also of interest because of observed leakage from containers filled with radioactive wastes (Osvath *et al.*, 1995). Techeniye Bay, having only activation products in reactor components, lies at the lower end of the region of interest as the dissolution of ^{60}Co from steel and other structural components is unlikely to be quantitative within the short mean lifetime of this nuclide.

3.2. Topography of bays and dispersion modelling

The topography of Abrasimov Bay, the locations of the major dumped objects and a possible location for a monitoring system are shown in Fig. 5.

Table 1. Estimated (1993) radionuclide inventories of dumped nuclear reactors in the Kara Sea.

	Activity range [PBq]				Reference
Dump site	Actinides	Fission products	Activation products	Total	
Abrosimov Bay	0.009-0.261	7.21-7.88	1.39	8.61-9.53	M
Stepovovo Bay	0.0004	0.39	0.003	0.4	Y
Tsivolki Bay	0.086	1.88	0.23	2.2	S
Novaya Zemlya Depression	0.004-0.128	2.97-3.21	0.20	3.17-3.54	M
Techeniye Bay	- -	- -	2.14	2.14	M
Total	0.099-0.475	12.45-13.36	3.56	16.52-17.81	

References: M: Mount *et al.*, 1993
S: Sivintsev, 1993
Y:Yefimov *et al.*, 1994

A narrow trench with a maximum depth of 20 m leads to the inner parts of the bay where the dumped objects are located at average depths of 10 - 15 m. Towards the open sea the depth increases rather rapidly down to more than 40 m. Near the northern coast of the entrance, a small island is situated and the slope seems to be less than near the southern coast. Advantage of this topography can be taken in siting the

detection/transmission system, e.g. the monitor can operate at the bay entrance which is only 2 km wide.

The dispersion modelling suggests flushing times of the bay in the order of a few months depending on wind speeds and wind directions. Southerly winds, as the most dominant wind directions in the southern Kara Sea (Pavlov *et al.*, 1993), can flush the bay within 4 months, providing very calm conditions with an average wind speed of 5 m/s. Higher wind speeds of storm scale (>15 m/s) can shorten the flushing times considerably. Near the mountainous coasts of Novaya Zemlya, maximum wind speeds of up to 40 m/s are possible. However, the probability of such storms is rather low, particularly in summer. During the winter season, the flushing time can be longer. A closed and landfast ice cover isolates the water surface from the transfer of momentum and can inhibit flushing during the whole freezing period, which might be several months.

Water circulation within the bay strongly depends on the wind direction and wind speed. Fig. 6 shows a stationary state dispersion of ^{137}Cs in Abrasimov Bay due to southeast and southwest winds with a simulated release rate of 1TBq/y in the inner part of the bay at 20 m depth. Simulated time-depth diagrams for the entrance of the bay showing the time dependent vertical distribution of ^{137}Cs concentrations due to southeast and southwest winds are presented in Fig. 7. Both figures suggest that for southeast winds the outflow of contaminated waters is predominantly in the bottom layers and for southwest winds in the surface layers.

These results were achieved assuming constant wind speeds and directions over several weeks. A more realistic, transient wind forcing with short-period variances in speed and direction will probably result in a mixture of the two circulation types. Vertically mixed conditions thus seem most likely and monitoring the bottom waters could therefore represent a reasonable compromise for this shallow bay.

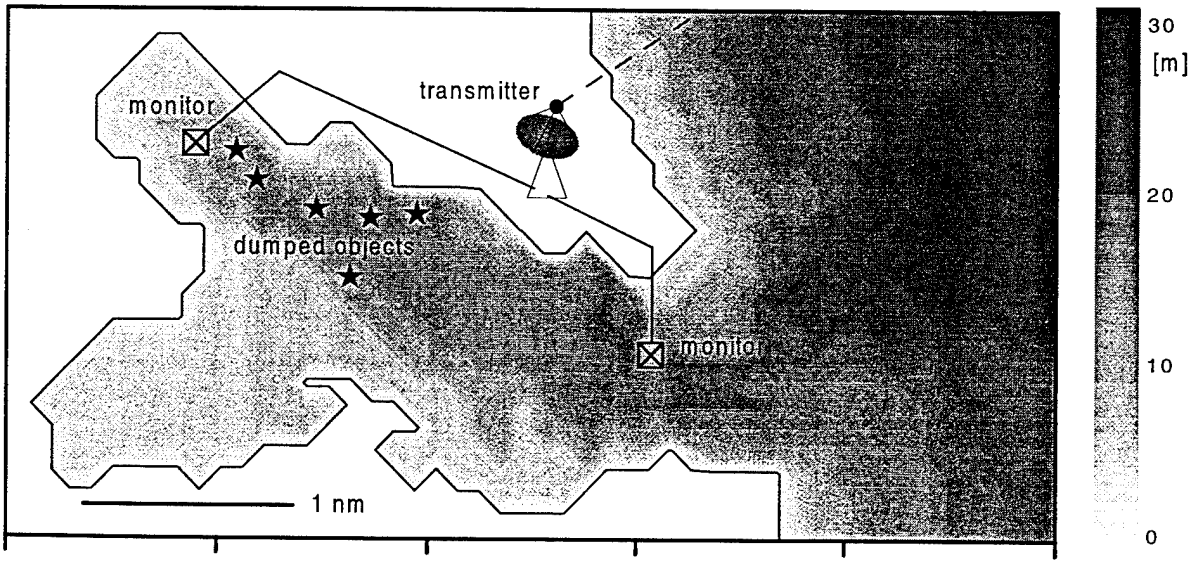


Fig. 5: Topography of Abrasimov Bay.

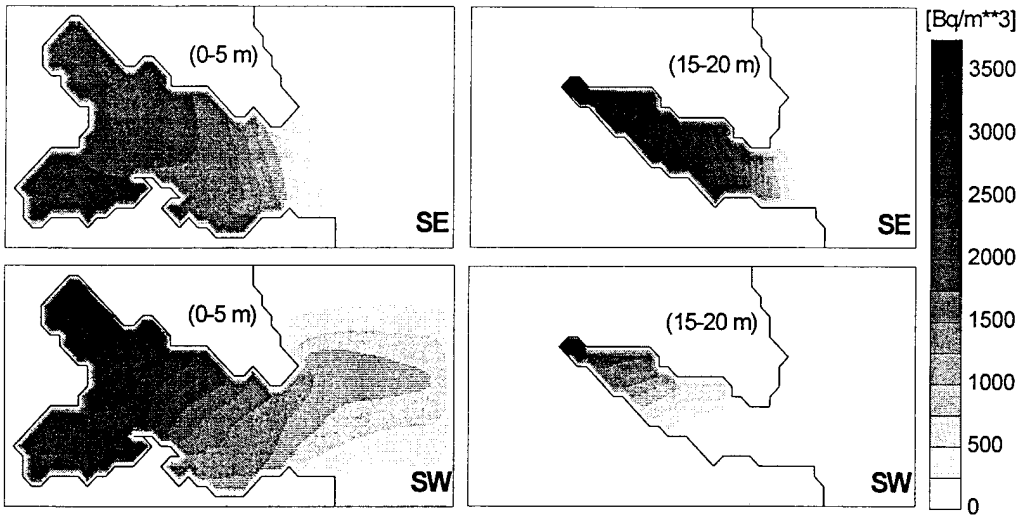


Fig. 6: Stationary state of dispersion of Cs-137 from Abrasimov Bay, due to southeasterly winds (upper panel) and southwesterly winds (lower panel). Simulated release rate is 1 Tbq/y in the inner parts of the bay, in 20 m depth.

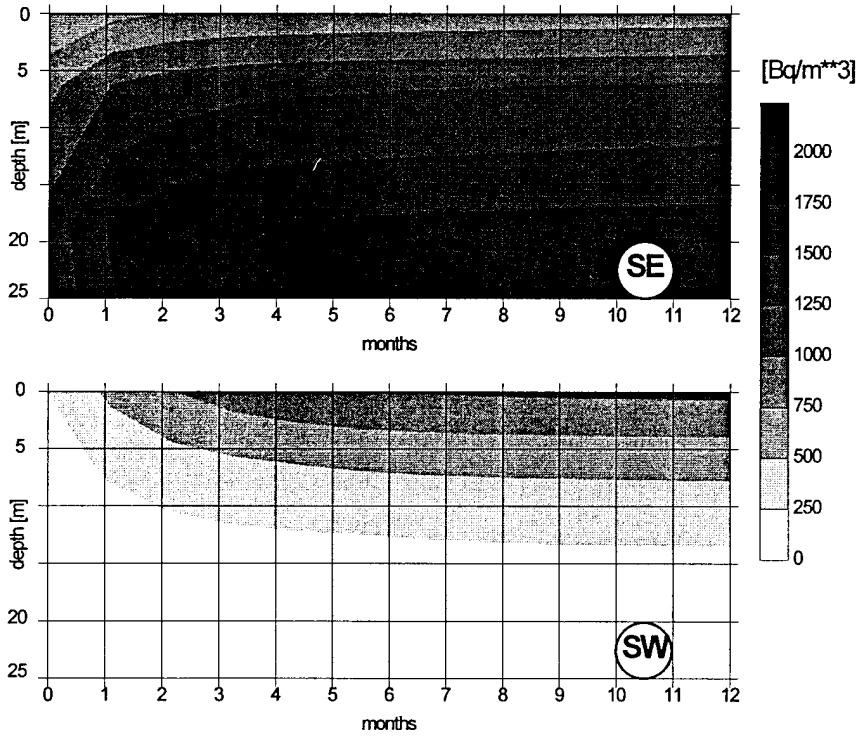


Fig. 7: Simulated time-space diagram from the entrance of Abrasimov Bay, showing the time dependent, vertical distribution of Cs-137 concentrations due to southeasterly winds (upper panel) and southwesterly winds (lower panel). Release rate 1TBq/y.

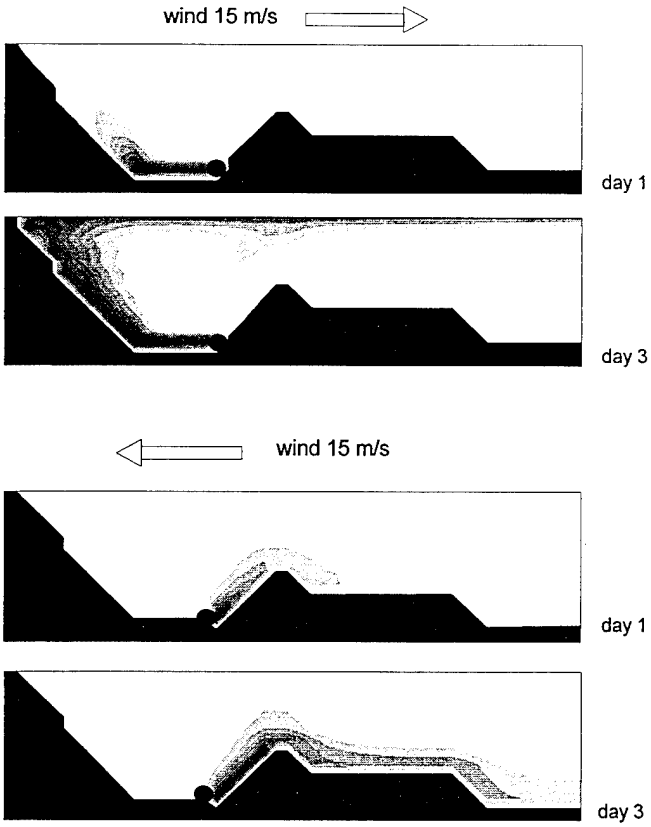


Fig. 8: Principle dispersion patterns on a vertical section in Stepovovo Bay due to offshore and onshore winds.

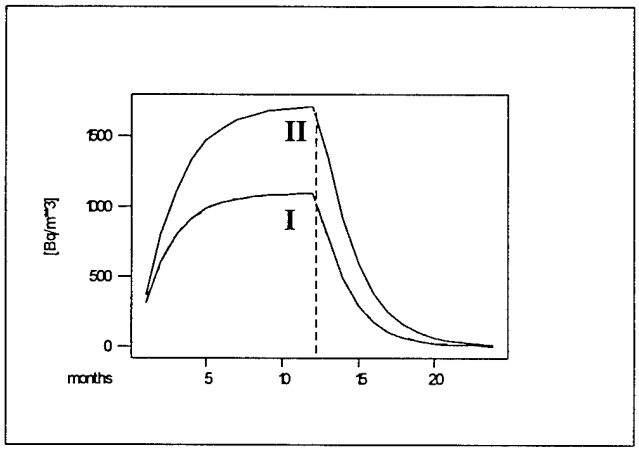


Fig. 9: Increase and decrease of average Cs-137 concentrations due to on- (I) and offshore (II) winds and a 1 TBq/y release in the inner parts of Stepovovo Bay. The dashed line denotes the stopping of the release.

Very similar conditions apply to Stepovovo Bay. Due to the channel type shape of this bay, with a shallow sill in the middle, the two major dispersion patterns are even more pronounced than in Abrasimov Bay (Fig. 8). The applied wind directions include on- and offshore winds, blowing along the channel, in order to simulate the orographic effect of the surrounding mountains. Like in Abrasimov Bay, the flushing times are in the range of 3 to 4 months, as seen from the time series data in Fig. 9.

3.3. A proposal for an *in-situ* γ-monitoring system for the Kara Sea

To optimise a practical approach to *in-situ* monitoring of possible leakages from radioactive wastes dumped in the Kara Sea, it is necessary to answer several questions;

i) which radionuclides should be monitored ?

ii) what detectors should be used for monitoring ?

iii) where should the monitors be installed ?

iv) how will the data be transmitted ?

i) As fission and activation products dominate the dumped wastes (reactors and containers), we suggest that monitoring need be carried out only for γ-emitters like ^{137}Cs and ^{60}Co. These two radionuclides have already been observed at elevated concentrations around the dumped wastes (Osvath *et al.*, 1995). It is highly unlikely that actinides and/or β-emitters leaking from the wastes would not be accompanied by γ-emitters. Therefore a γ-monitoring system would provide an excellent solution for the long-term monitoring of dumped radioactive wastes in the Kara Sea.

ii) A large volume scintillation detector of high efficiency and reasonable resolution, capable of withstanding temperatures down to 273 K would be the best choice for long-term γ-monitoring of sea water. For example the NaI(Tl) γ-spectrometer described above would fulfil these requirements. The sensitivity is good enough to perform even 24 hour measurements. BGO detectors, because of their better resolution, would be technically preferable, but they are more expensive. From the points of view of energy resolution and power consumption, inorganic scintillators coupled to photodiodes (replacing conventional photomultipliers) would perhaps provide the ideal solution. However, their operational characteristics (for high sensitivity and long-term remote operation) are at present still inferior to those of NaI(Tl) detectors. Semiconductor detectors operating without external cooling (e.g. CdTe, CdZnTe, HgI_2, GaAs) have a better energy resolution but are still available in insufficient volumes to compete with scintillation detectors in terms of efficiency.

The γ-spectrometric detectors could of course simultaneously be equipped with other oceanographic sensors, e.g. current, temperature and salinity meters, the data from which could also be transmitted through the satellite network, thus providing comprehensive information on the oceanographic regime in the region.

A cheaper solution would be to use integrating monitors (dosimeters), especially if they could be operated from a Novaya Zemlya base. However, such a monitoring system would not provide information on the composition of the released radionuclides and it would require regular cruises to the dump sites.

Sorbents exposed for long periods (one year) and subsequently analyzed in a laboratory would also give a comprehensive picture on yearly release rates and on the nuclide mix. However, this would again require regular cruises to the dump sites.

iii) The modelling results suggest that the best place for operation of monitoring systems would be close to the dump sites. As Figs. 5-7 shows for Abrosimov Bay, a detector placed close to the sea-bed will monitor any releases of radionuclides from the bay on a long timescale. A similar situation applies to the other Novaya Zemlya bays and to the Novaya Zemlya Depression. A close, high frequency monitoring system would provide fast information on the situation in the bays and, if necessary, remedial actions can be implemented on short timescales. This approach would, however, require installation of several monitors.

For the monitoring of the dump sites in the open Kara Sea, monitors could be installed in surface waters, e. g. in the Kara Gate to monitor an important backward current from the Kara Sea to the Barents Sea and/or in the central Kara Sea.

iv) A scintillation γ-spectrometer mounted on the sea-bed or deployed in the water column, connected with a land-based satellite transmission system through a cable, or using a buoy for data transmission, would allow long-term remote monitoring of γ-radioactivity in the Kara Sea. Serious problems with operation of the system in the open sea arise from the ice cover (for about 8 months the Kara Sea is covered with ice) and its drift. As the transmission of data through the ice cover to a satellite is at present not readily achievable, the transmission system should ideally have a buoy on the water surface and during the winter on the ice. It is very probable, however, that such a transmission system would be damaged by drifting ice. To prevent the system from damage, another solution could involve a floating transmission system below the ice layer with transfer of pressurized data only during summer months. An even cheaper version could employ only a local recording system operated from a Novaya Zemlya base.

4. Further IAEA-MEL contributions to the IASAP project

The radiometric subproject on the development of underwater γ-spectrometry described in this paper complements other aspects of IAEA-MEL's contributions to the IAEA's IASAP project. These activities included radionuclide analyses, radioanalytical intercalibration exercises, database compilation, computer modelling of potential dispersion and radiological assessment.

The results of radionuclide analyses of samples collected during the 1992, 1993 and 1994 expeditions to the Kara Sea show unambiguously that, as yet, there has been no major leakage from the disposed radioactive wastes. The present anthropogenic radioactivity of Kara Sea water and sediments is predominantly due to direct deposition and catchment run-off of global fallout from nuclear weapons tests, discharges from the reprocessing plants in West Europe and the former Soviet Union, Chernobyl fallout and local fallout from nuclear tests performed at Novaya Zemlya. However, at major dumping sites in Abrosimov, Stepovovo and Tsivolki Bays, elevated concentrations of ^{137}Cs and ^{60}Co have been found. These results indicate that a local leakage from dumped wastes has occurred which is, however, not detectable outside the immediate vicinity of the dumping sites (Baxter *et al.*, 1993a; Strand *et al.*, 1993; Hamilton *et al.*, 1994; Strand *et al.*, 1994; Osvath *et al.*, 1995).

Intercomparison exercises have been organized by IAEA-MEL for those institutions participating in the analyses of Kara Sea samples. A bulk sample of sediment from the 1992 cruise, a water sample taken during the 1993 cruise and a seaweed sample

collected during the 1994 cruise to the Kara Sea have been prepared for intercomparison. Reasonable agreement has been observed between participating laboratories.

A further contribution by IAEA-MEL within the Agency's IASAP programme is via its Global Marine Radioactivity Database (GLOMARD) programme. MEL is acting as a central facility for the collection and synthesis of all data on marine radioactivity, i.e. in sea water, sediments and biota. The database provides a scientific resource designed to serve several important functions, such as the provision of immediate and up-to-date information on radioactivity levels, the generation of snap-shots of activities at given times and locations, the investigation of temporal changes, the identification of gaps in available information, etc.

For modelling of dispersal of radioactive pollutants on a global scale, we have developed and implemented a number of compartmental models. The work summarized here is based on the 16 box ARCTIC-2 model, with enhanced structure in the Arctic region (Baxter *et al.*, 1993b). The model provides a satisfactorily accurate prediction of Sellafield ^{137}Cs dispersion through the northern seas. For a gradual release of ^{137}Cs over 20 years following dumping from the naval reactors containing spent nuclear fuel disposed of in the Kara Sea, the model predicts the maximum average concentration of about 30 Bq m^{-3}, attained in Kara Sea bottom waters (Fowler *et al.*, 1993). A simple evaluation was made, on the basis of information available at present, of the radiological effects for a worst case scenario. Dose calculations based on estimated maximum inventories in reactors dumped in the Kara Sea (Mount *et al.*, 1993) indicate a committed collective effective dose of around 30 man Sv, if instantaneous release would occur at the time of dumping. More than 70 % of this dose is delivered by ^{137}Cs, and less than 30 % comes from activation products. These computations are based on the assumption that the fish catch in the Kara Sea is about 20 kton/y (Matishov, 1993).

The preliminary modelling results on a local scale have already been discussed. A detailed description of circulation and dispersion models and evaluation of results will be published in a separate paper.

5. Conclusions

Recent developments at IAEA-MEL in monitoring marine γ-radioactivity *in-situ* have been outlined. The spectrometer consists of separately housed HPGe and NaI(Tl) detectors with electronics, data acquisition and processing electronics (two MCA cards with a micro PC) located with the detectors communicating with a shipboard PC through a modem link, and a supporting system consisting of a hydraulic winch with 1200 m conducting cable. The system has been successfully deployed in the Irish and Kara Seas. The spectra obtained with the HPGe detector represent the first set of high resolution sea-bed γ-spectra ever recorded *in-situ*. The HPGe spectrometer sensitivity is $5 \cdot 10^{-4}$ cps/Bq kg^{-1} for ^{137}Cs in surficial bottom sediments.

A possible utilisation of underwater γ-spectrometers for *in-situ* monitoring of leakages of radionuclides from dumped or sunken nuclear objects/wastes has been discussed. Remote stationary monitoring systems based on NaI(Tl) γ-spectrometers operating either on the sea-bed of dump sites (e.g. in Abrosimov Bay, Novaya Zemlya Depression) or in the open sea (e.g. Kara Gate, central Kara Sea) with satellite data transmission has been suggested for long-term monitoring of possible leakages from

dumped radioactive wastes and/or radioactive contamination from the Ob and Yenisey rivers .

Our study, along with the recent work of Russian and Norwegian colleagues, shows that the present levels of radioactivity in the Kara Sea are relatively low and within the range expected from global fallout and from other sources mentioned above. Preliminary modelling contributions by IAEA-MEL to the international consequence assessment programme for the Arctic Seas suggest that only radiological effects on regional and local scales may be of importance. Additional data on sediment accumulation and mixing rates, sediment geochemistry, fishing statistics and improved understanding of the influence of inputs from the Ob and Yenisey rivers on the Kara Sea will improve our present assessment.

All aspects of radioactive dumping in the Arctic Seas are being comprehensively studied in the IAEA's International Arctic Seas Assessment Project (IASAP). The final results will be reported to the London Convention in 1996.

Acknowledgements

The authors are indebted to the Norwegian and Russian Governments for their invitation to IAEA-MEL to participate in the investigatory cruises to the Kara Sea. The collaboration with the Challenger Oceanic Sensors (UK) during the development of the underwater γ-spectrometer is highly acknowledged The IAEA-MEL operates under an agreement between the International Atomic Energy Agency and the Government of the Principality of Monaco.

References

Baxter, M. S., Hamilton, T. F., Harms, I. H., Osvath, I., Povinec, P. P. & Scott, E. M. (1993a). IAEA programmes related to the radioactive waste dumped in the Arctic Seas. Part 2. Arctic Seas Assessment Project at the IAEA Marine Environment Laboratory. In *Proc. Environmental Radioactivity in the Arctic and Antarctic.* NRPA, Osteras, pp. 93-96.

Baxter, M. S., Osvath, I., Povinec, P. P., Scott, E. M., Miquel, J.-C., & Hamilton, T. F. (1993b). Non-local radiological consequences of nuclear waste dumping in the Arctic Seas: a preliminary assessment. In *Proc. Conference on Radioactivity and Environmental Security in the Oceans: New Research and Policy Priorities in the Arctic and North Atlantic.* WHOI, Woods Hole, pp. 329-341.

Fowler, S. W., Baxter, M. S., Hamilton, T. F., Miquel, J.-C., Osvath, J., Povinec, P. P., & Scott, E. M. (1993). International radiological assessments programmes related to radioactive waste dumping in the Arctic Seas: IAEA-MEL' role. *Workshop on Arctic Contamination.* 3-7 May 1993, Anchorage, (in print).

Hamilton, T. F., Ballestra, S., Baxter, M. S., Gastaud, J., Osvath, I., Parsi, P., Povinec, P. P. & Scott, E. M. (1994). Radiometric investigations of Kara Sea sediments and preliminary radiological assessment related to dumping of radioactive wastes in the Arctic Seas. *J. Environ. Radioactivity,* **25**, 113-134.

Harms, I. H. & Backhaus, J. O. (1992). Numerical dispersion studies of passive tracers in the Barents and Kara Seas. In *Proc. 2nd Intern. Offshore and Polar Engineering Conf.* ISOPE, San Francisco, Vol. 1. pp. 31-37.

Matishov, G. (1993). Personal communication.

Miller, J. M., Thomas, B., W., Roberts, P. D., & Creamer, S. C. (1982). Measurement of marine radionuclide distribution using a towed sea-bed spectrometer. *Marine Pollution Bulletin*, **13** (9), pp. 315-319.

Mount, M. E., Sheaffer, M. K. & Abbott D. T. (1993). Estimated inventory of radionuclides in former Soviet Union naval reactors dumped in the Kara Sea. In *Proc. Environmental Radioactivity in the Arctic and Antarctic.* NRPA, Osteras, pp. 81-87.

Osvath, I., Ballestra, S., Baxter, M. S., Gastaud, J., Hamilton, T. F., Harms, I. H., Huynh-Ngoc, L., Liong Wee Kwong, L., Oregioni, B., Parsi, P., Pettersson, H. & Povinec, P. P. (1995). IAEA-MEl Report (in preparation).

Pavlov, V. K., Kulakov, M. Yu. & Stanovoy, V. V. (1993). Oceanographical description of the Kara and Barents Seas, Arctic and Antarctic Research Institute Report, St. Petersburg.

Povinec, P. P. (1994). IASAP Advisory Group Meeting. IAEA, Vienna.

Sivintsev, Y. (1993). Study of nuclides composition and characteristics of fuel in dumped submarine reactors and atomic icebreaker "Lenin". Part I. Russian Research Center "Kurchatov Institute" Report, Moscow.

Sjoeblom, K. L. & Linsley, G. (1993). IAEA programmes relevant to the radioactive waste dumped in the Arctic Seas. Part 1. International Arctic Seas Assessment Project (IASAP). In *Proc. Environmental Radioactivity in the Arctic and Antarctic.* NRPA, Osteras, pp. 89-92.

Strand, P., Rudjord, A. L., Salbu, B., Christensen, G. C., Foyn, L., Lind. B., Bjornstad H., Bjerk T., Nikitin, A. I., Kryshev, I. I., Chumichev, V. B., Dahlgaard, H. & Holm, E. (1993). Survey of artificial radionuclides in the Kara Sea. In *Proc. Environmental Radioactivity in the Arctic and Antarctic.* NRPA, Osteras, pp. 53-65.

Strand, P., Nikitin, A., Rudjord, A. L., Salbu, B., Christensen, G., Foyn, L., Kryshev, I. I., Chumichev, V. B., Dahlgaard, H,. & Holm, E. (1994). Survey of artificial radionuclides in the Barents Sea and the Kara Sea. *J. Environ. Radioactivity*, **25**, 99-112.

White Book 3 (1993). *Facts and Problems Related to Radioactive Waste Disposal in Seas Adjacent to the Territory of the Russian Federation.* Office of the President of the Russian Federation, Moscow.

Yefimov, E. I., Gromov, B. F., Pankratov, D. V. (1994). Radionuclides composition of activity in NPP with liquid metal coolant dumped in the Kara Sea and some assessment of radiological consequences of this activity release. Institute of Physics and Power Engineering Report, Obninsk.

In situ Extraction and Gamma-Ray Spectrometry

Gordon Riel, CDNSWC code 682 Silver Spring, MD 20903-5640
Phone 301-394-2474, DSN 290-2474, FAX 394-5135, Voice 394-2267

ABSTRACT: The CDNSWC has simple rugged systems that are capable of measuring contamination in or near the Arctic Ocean. We can determine the concentration in the contaminated waters, and we can measure isotopes at a few percent of natural background to determine their effect on adjacent seas. We have monitored sunken submarines, weapon tests, radioisotope releases, and global fall-out. We measured the distribution of fall-out cesium in three estuaries and discharges from seven nuclear reactor sites. We followed the radioactive water for six weeks after an underwater test of a nuclear warhead. We measured Chromium-51 60 miles down the coast from the Columbia river. We tested the Berring Sea after a weapon test in the Aleutian Islands.

The spectrometers measure isotopes at 3% of the natural potassium-40 background. Nothing in the underwater probe requires service. Therefore, they operate for years without being opened. A high output photomultiplier tube drives two miles of 50 ohm underwater cable without amplification. We learned to protect the NaI(Tl) crystal from thermal and mechanical shock by floating it in foam. It has survived a ten foot drop onto a steel deck.

Our selective extraction system concentrates selected elements from the sea water. Cesium-137 can be measured at 0.03% of the natural potassium-40 background.

Our Underwater RADIAC tells a diver the dose rate and identifies the isotopes responsible. It is self contained, but it can communicate with the surface over an acoustic data link.

In situ Extraction and Gamma-Ray Spectrometry

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INTRODUCTION: While the USA was testing nuclear weapons and releasing radioisotopes into rivers, the Naval Ordnance Laboratory (now the CDNSWC) produced systems to measure radioisotopes in the water. We have monitored sunken submarines, weapon tests, radioisotope releases, and global fall-out. The spectrometers measure isotopes at 3% of background, and extraction lowers this to 0.03%. Our Underwater RADIAC is a self contained isotope identification system. The systems are simple, rugged, and capable of measuring contamination in or near the Arctic Ocean.

SELF CONTAINED SYSTEM: Our Underwater RADIAC tells a diver the dose rate and identifies the isotopes responsible. It is self contained, but it can communicate with the surface over an acoustic data link.

SELECTIVE EXTRACTION: The extraction medium must be highly selective for the element of interest versus sodium. Sea water contains 19,000 parts per million (PPM) of sodium, while we measure 0.01 pCi/liter (0.37 Bq/cubic meter) of cesium-137, which is only 10^{-13} PPM. The sea also contains 400 PPM of naturally radioactive potassium which is more difficult to separate from cesium. We considered 25 versions of ferrocyanides that have the desired selectivity, but vary in their ability to process thousands of liters of water in a reasonable time. Other elements require other media. For example, calcium phosphate selects strontium.

EXTRACTION SYSTEMS: We built a simple portable system for shallow water measurements. This system, shown in figure 1, has a filter, pump, resin bed, and flow meter. We deployed it in the Berring Sea, to test coastal water after a weapon test in the Aleutian Islands. We used it to measured the distribution of fall-out cesium in three estuaries, and we modelled the exchange of water in the Chesapeake Bay from the data, Figure 2. Global fall-out on the Bay's surface and a one year residence time of cesium in the water predicts the observed concentration.

We looked for cesium-137 in the deep ocean by attaching the exchange system to the underwater spectrometer. We counted the resin in the deep water, to eliminate the possibility of contamination if we brought it to the surface. None was found.

UNDERWATER SPECTROMETERS: The underwater probes contain NaI(Tl) crystals. The crystal's height equals its diameter, either two inch (5.1 cm) or five inch (12.7 cm). We will call these 2X2 and 5X5. The detector is the third from left in figure 3. The 5X5 crystal is at the bottom, surrounded by foam. To keep the background low, a foil wrapped lucite light pipe separates the crystal from the photomultiplier tube in the black magnetic shield. The voltage divider, mounted on the phototube, is the only circuit in the probe. These probes operate for years without being opened. Nothing needs service unless water gets in or something breaks.

HOW TO BREAK, OR NOT BREAK, A CRYSTAL: The 5X5 crystal housing has a heavy flange, but if it is mounted by the flange, it breaks when the probe bangs against the side of the ship. Crystals break from thermal shock when the cold probe comes up from the deep ocean and is opened on the hot deck. We learned to protect the crystal from thermal and mechanical shock by floating it in foam. It has survived a ten foot drop onto a steel deck.

RELIABLE CIRCUITS FOR SINGLE CONDUCTOR CABLE: All the circuits in figure 4. avoid the problems of multiconductor cables. Only the last one (IV) is used now. At first, the cable just carried the signal (I). Next, we also put the high voltage on it (II). Then, we eliminated the battery (III), and finally we eliminated the amplifier (IV). A high output photomultiplier tube drives two miles of 50 ohm underwater cable. The signal is only a few millivolts, but low noise preamplifiers can measure it. A short on the underwater cable may destroy the preamplifier, but we have a circuit that usually protects it. Good underwater connections and water blocked cables rarely become shorted.

TEMPERATURE, DEPTH, AND SALINITY: Underwater spectra contain little information in the low energy range, so we build gauges with a low energy emitting isotope and a shield. Cobalt-57 (122 keV) on a thermometer contacting the inside wall of the probe measures the water temperature. Tellurium-121M (212 keV) on a pressure gauge outside the probe measures depth. We can calculate the salinity from the concentration of naturally radioactive potassium-40 (1460 keV).

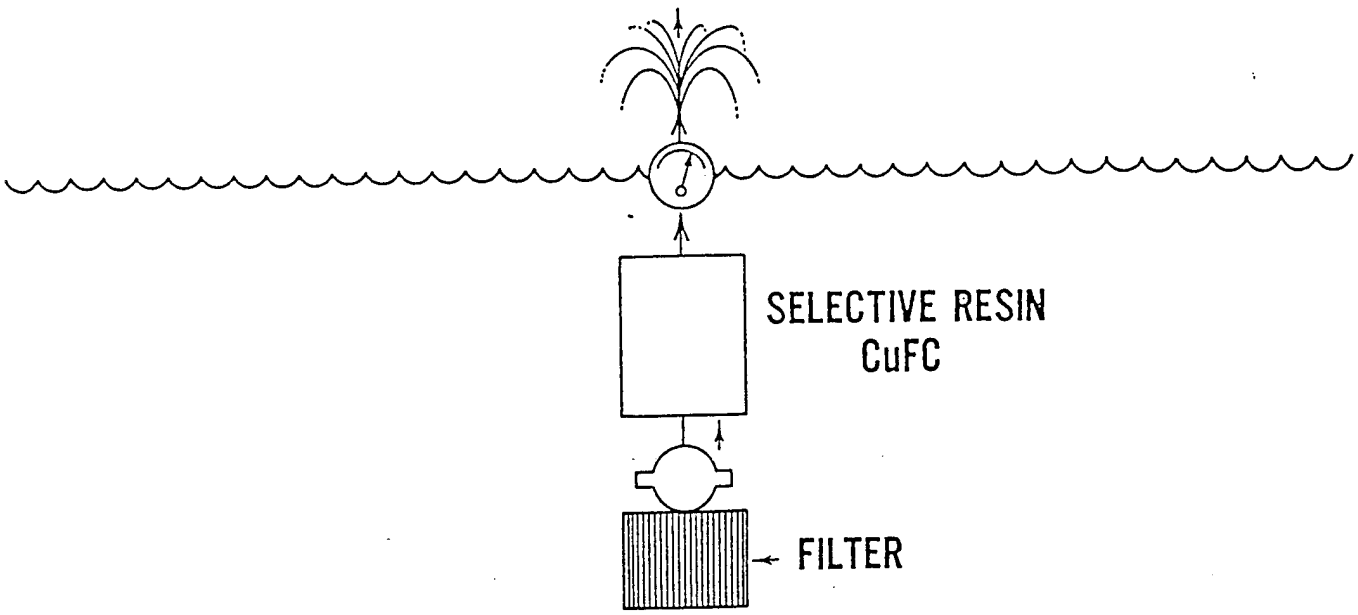
GLOBAL FALL-OUT STUDIES: The spectrometers measured radioactive fall-out from distant weapon tests in the Atlantic and Pacific Oceans and in inland waters of the USA. Most of these were near the East Coast of the United States, as seen in figure 5. Zirconium-95 was found in shallow and deep waters until the moratorium on atmospheric testing began in 1963, figure 6. It persisted for several more months, as radioactivity continued to fall from the atmosphere. It became undetectable within two years, as one would expect given its 65 day half life.

REACTOR EFFLUENT: We measured the discharges from seven nuclear reactor sites. Chromium-51 from Hanford served as a tracer for the mixing of the Columbia River with the Pacific Ocean. The river water was elevated in chromium-51 and lower in potassium-40 than the open ocean, figure 7. We were able to trace it for 60 miles (115 km) down the Oregon Coast, figure 8.

UNDERWATER NUCLEAR WEAPON TEST: The pool of radioactive water remained distinct from the ocean. We followed the pool for six weeks, and gave up while it was still easy to measure. It grew as shown in figure 9. We measured many spectra and analyzed them to determine the concentration of the radioactive isotopes, figure 10.

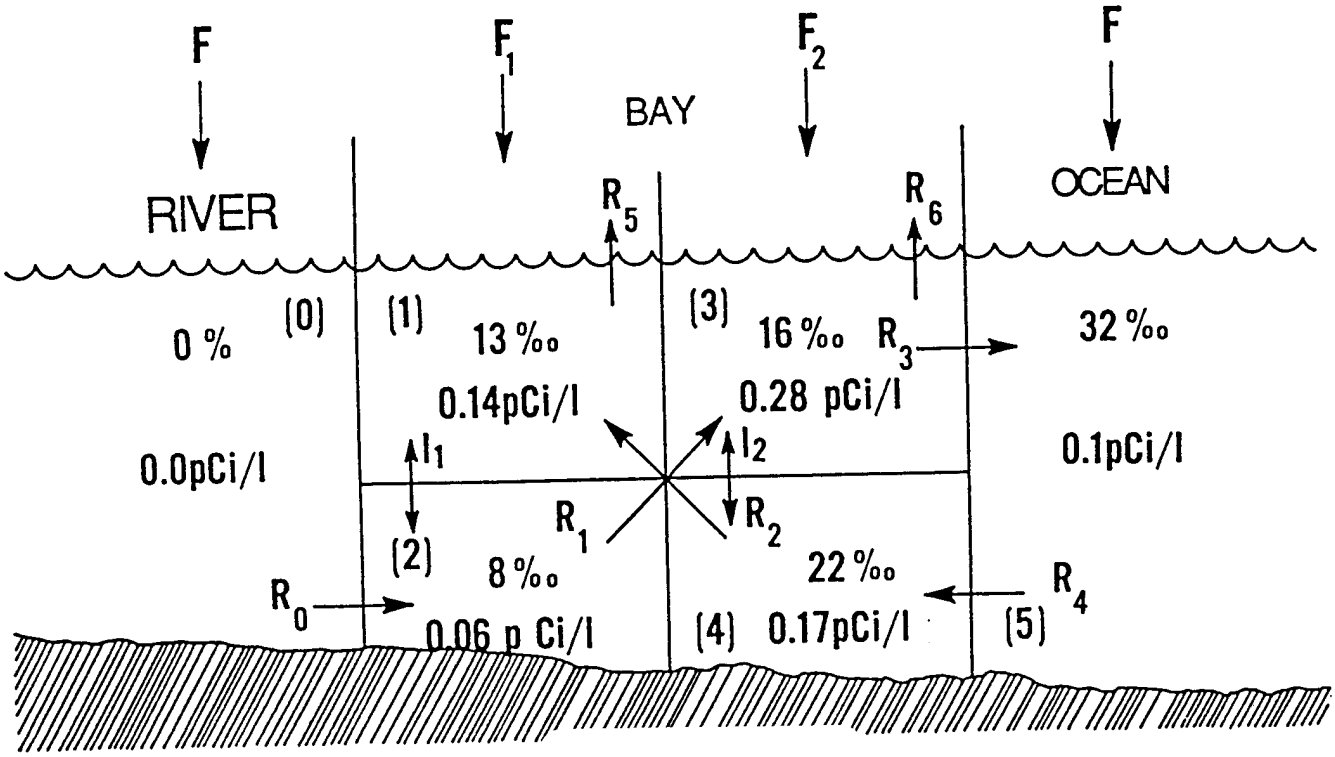
CONCLUSION: The CDNSWC has systems that can perform much of the monitoring needed. We can determine the concentration in the contaminated waters, and we can measure isotopes at a few percent of natural background to determine their effect on adjacent seas.

1. EXTRACTION SYSTEM



$$p\ Ci/l = \frac{p\ Ci}{l\ (Eff.)}$$

2. MODEL OF FALLOUT CESIUM-137 IN THE CHESAPEAKE BAY



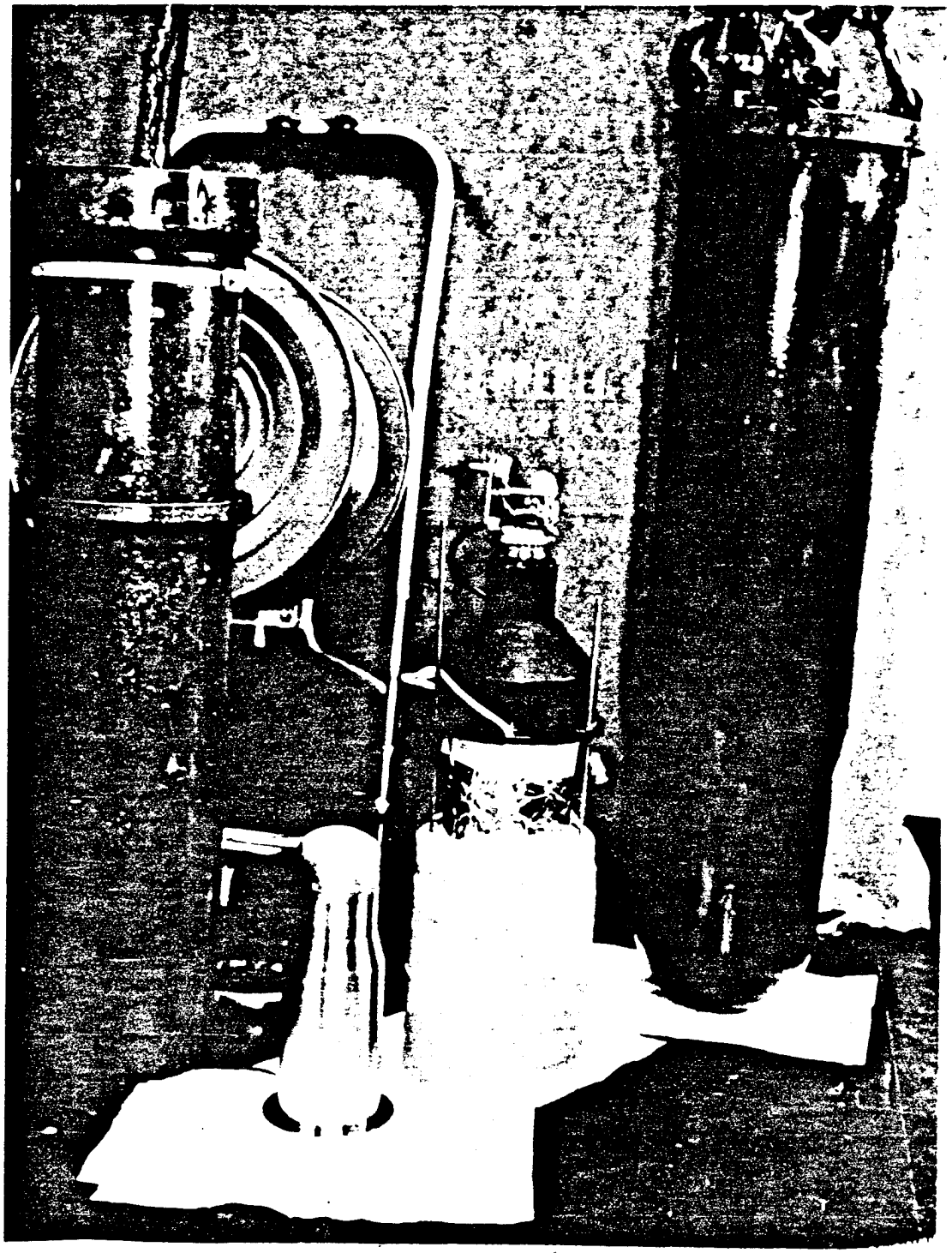
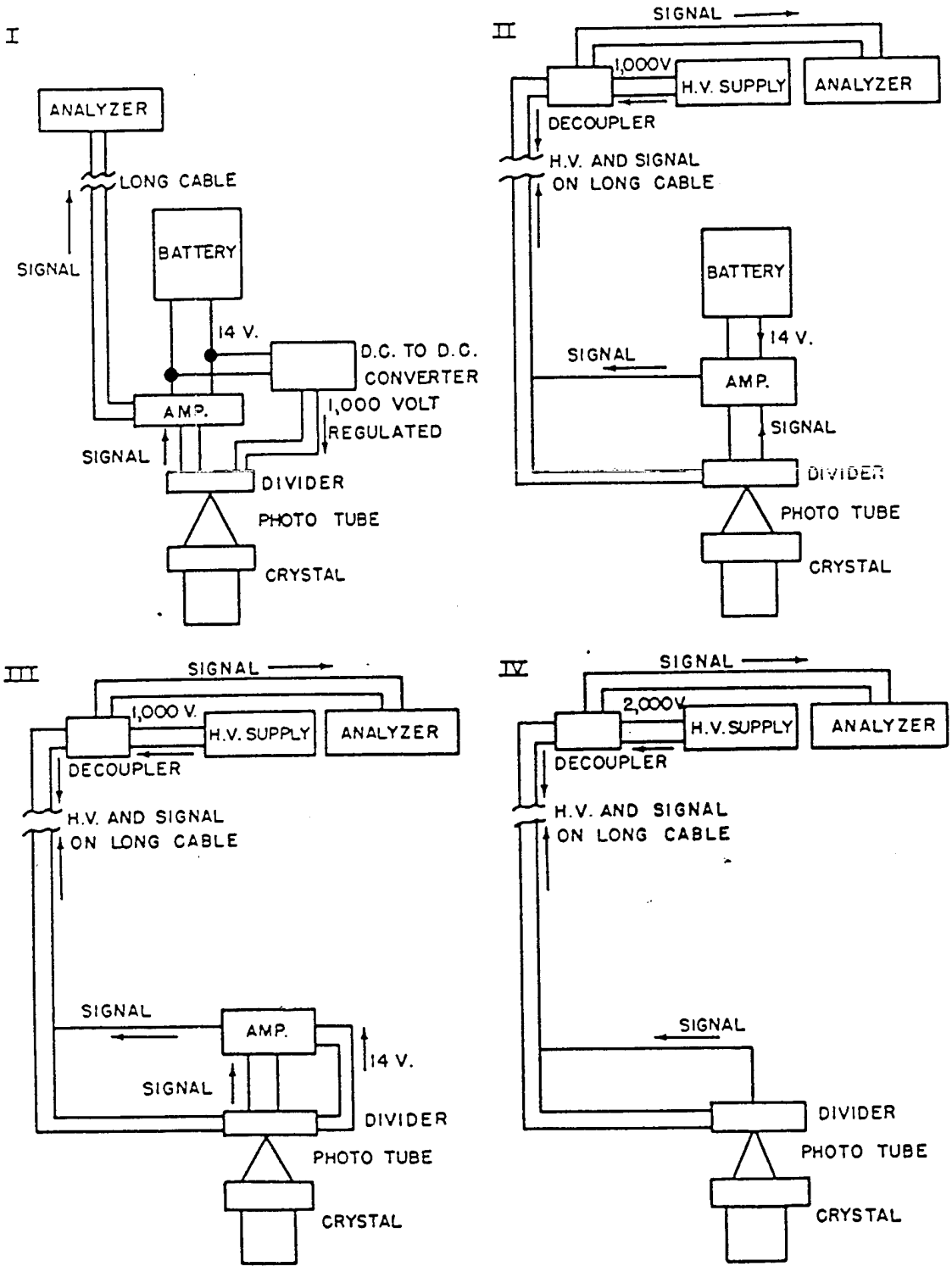
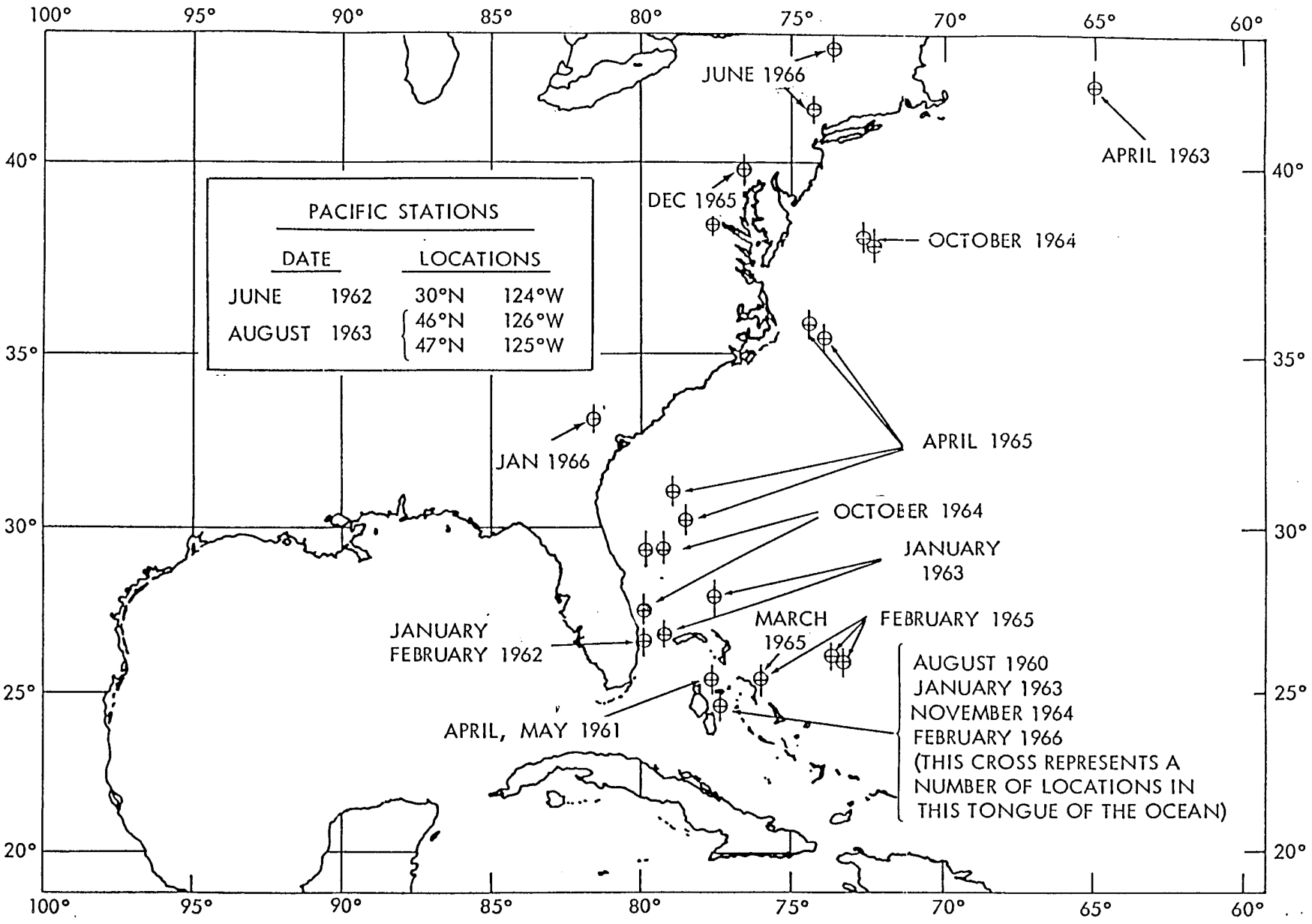


Fig. 3 UNDERWATER GAMMA-RAY SPECTROMETERS, From left to right:

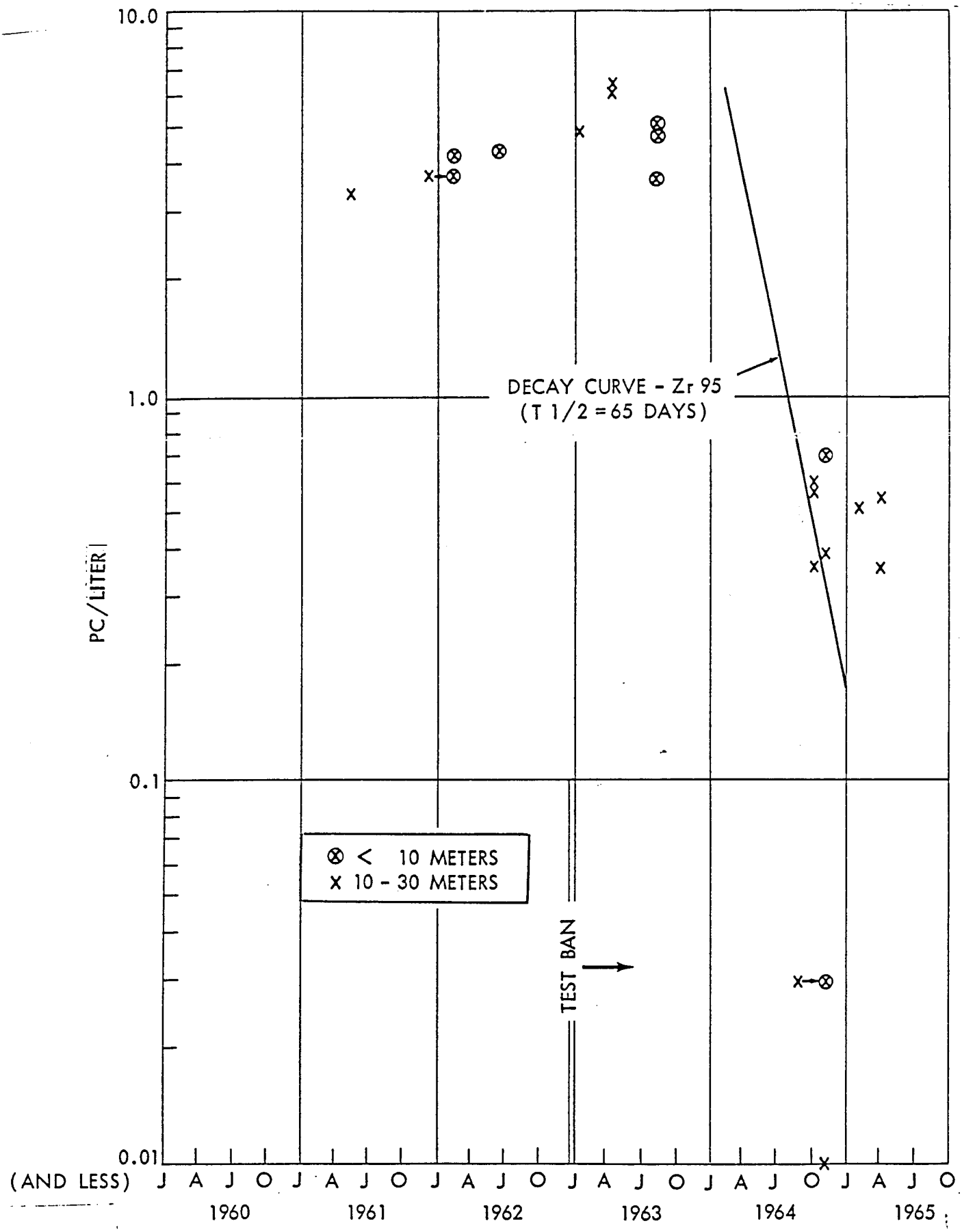
CRYSTAL SIZE	WEIGHT	MAXIMUM DEPTH	INTERNAL BACKGROUND
5X5 inches	45 pounds	10 meters	5 cpm K-40
2X2 inches	16 pounds	5000 meters	20 cpm K-40
5X5 inches	35 pounds	Detector Only	5 cpm K-40
5X5 inches	250 pounds	3000 meters	5 cpm K-40



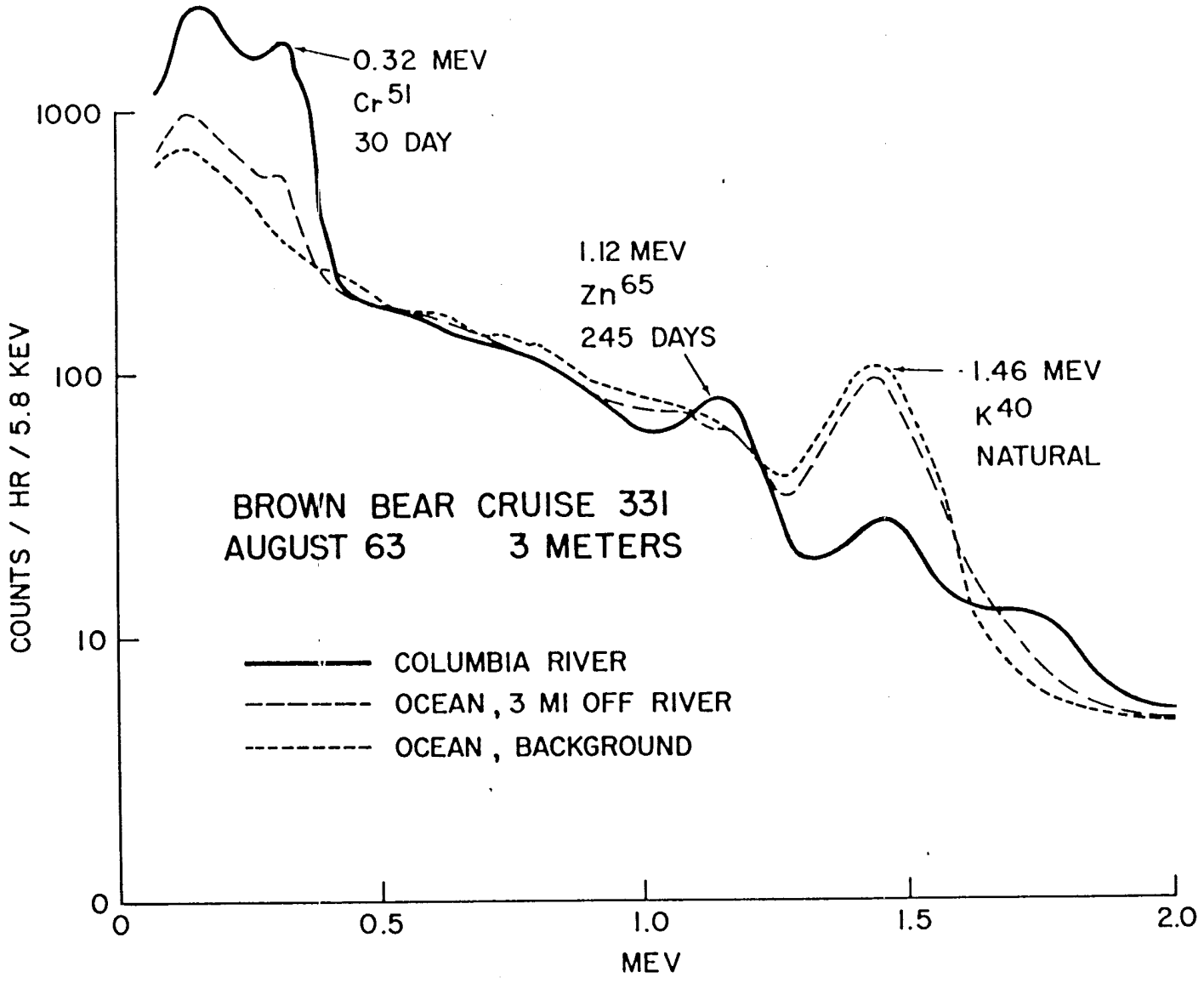
4. BLOCK DIAGRAMS OF UNDERWATER
γ RADIATION SPECTROMETERS



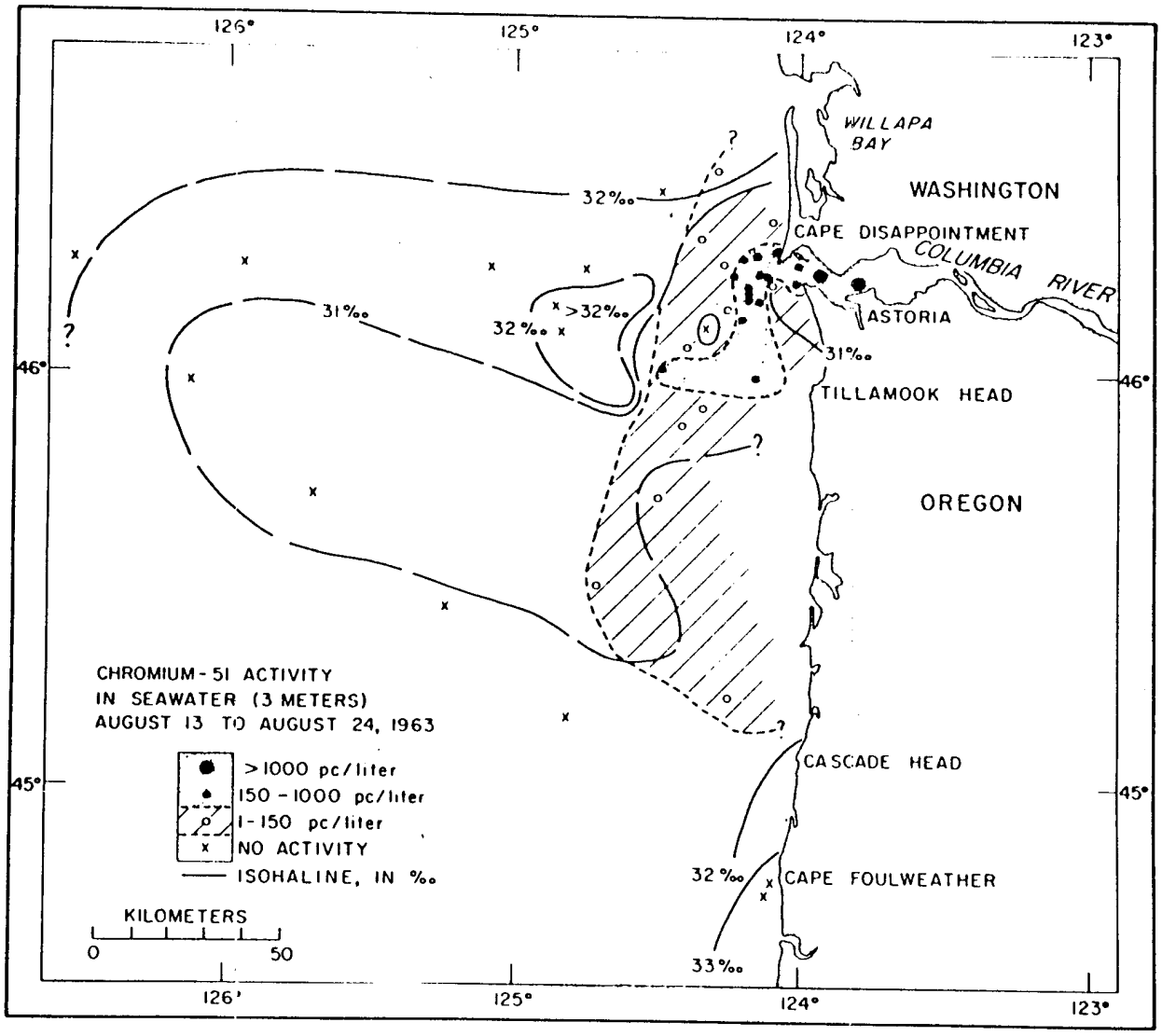
5. RADIOISOTOPIC DATA STATIONS - 1960 - 1966



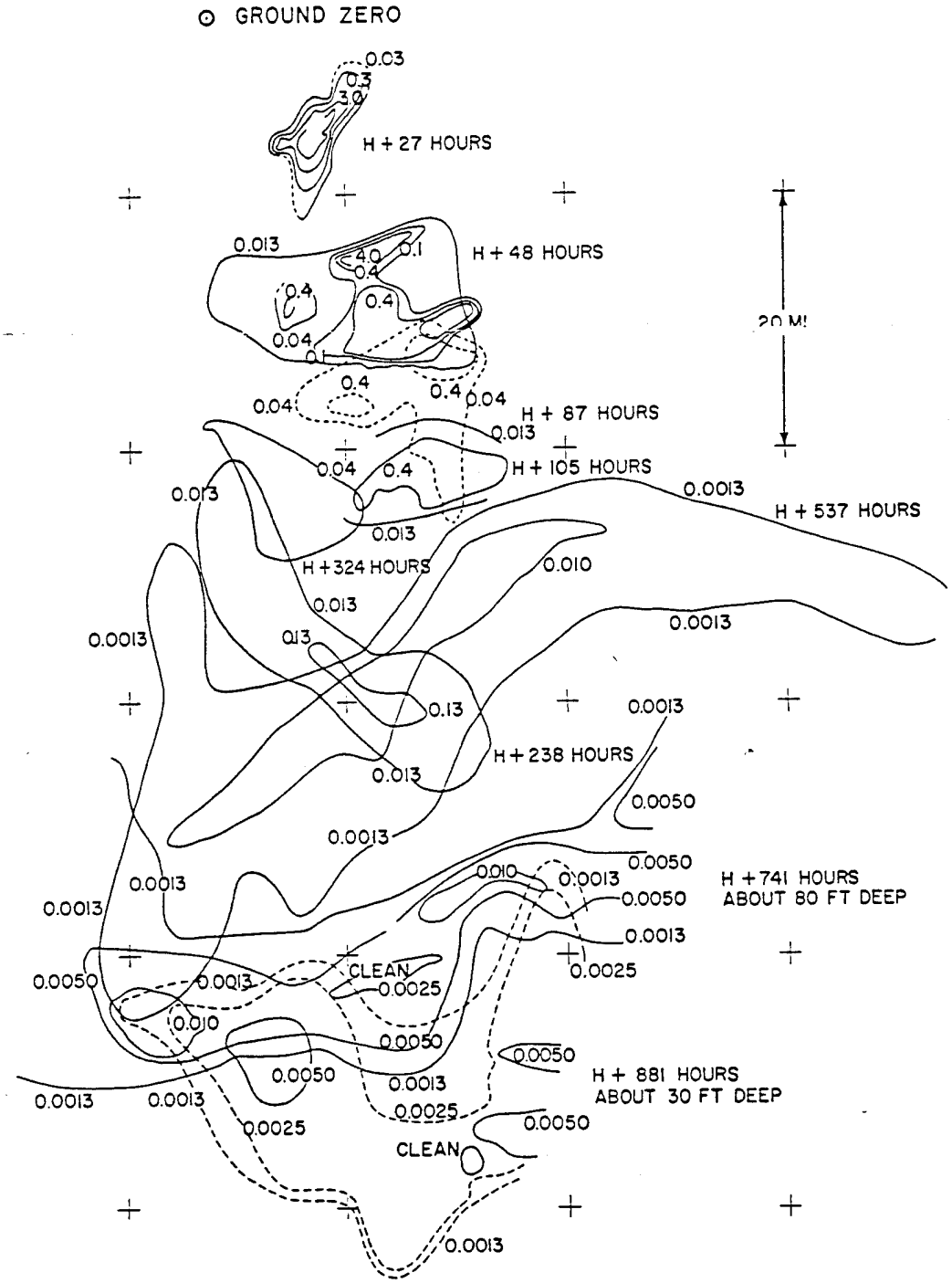
6. Zr 95 - WESTERN NORTH ATLANTIC, TONGUE OF THE OCEAN, AND EASTERN PACIFIC DATA.



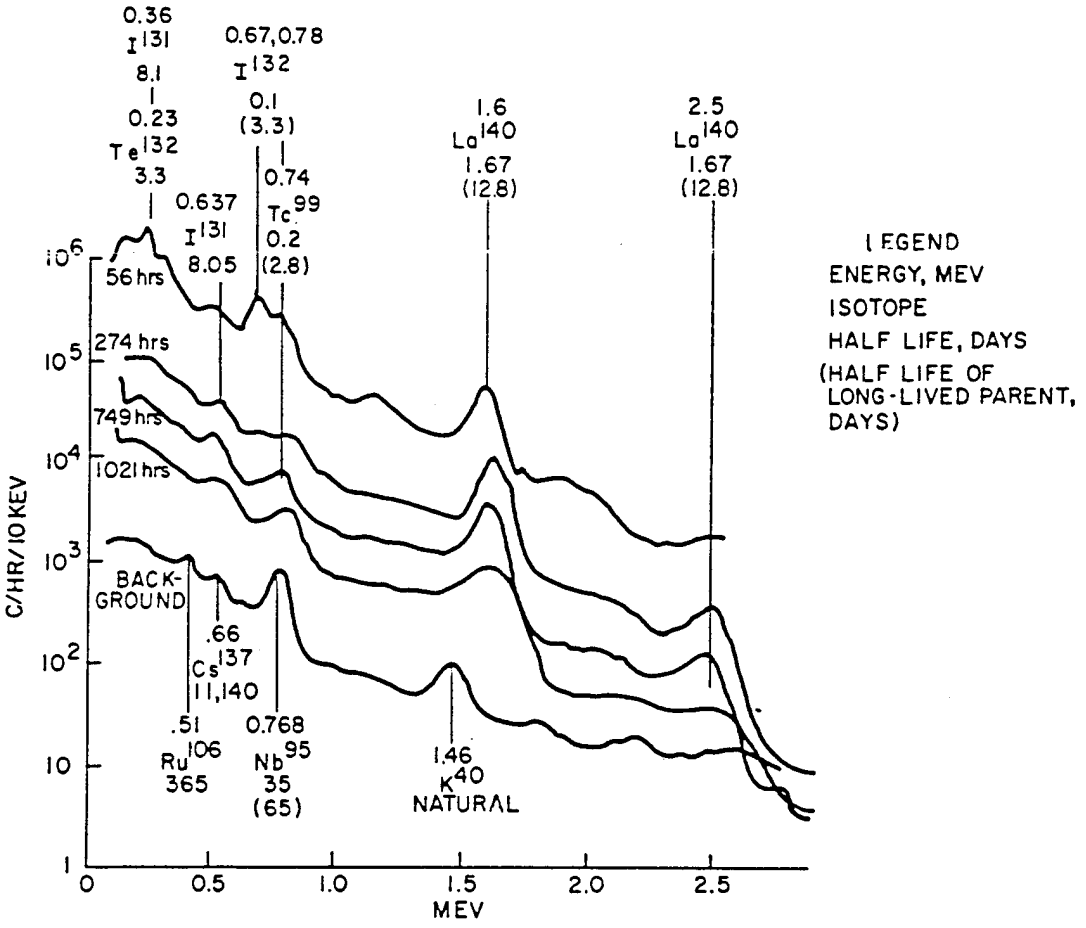
7. UNDERWATER GAMMA-RAY SPECTRA



8. DISTRIBUTION OF CR^{51} OFF THE COAST OF OREGON



9. MR/HR AT TIME INDICATED FOR START OF SURVEY, SELECTED SURVEYS TO SHOW DRIFT AND SHAPE OF RADIOACTIVE POOL



10. GAMMA RADIATION SPECTRA IN WATER VS TIME AFTER SHOT

Underwater Nuclear Detection Technologies at the Savannah River Site

W.G. Winn

Environmental Technology Section
Savannah River Technology Center
Aiken, SC 29808

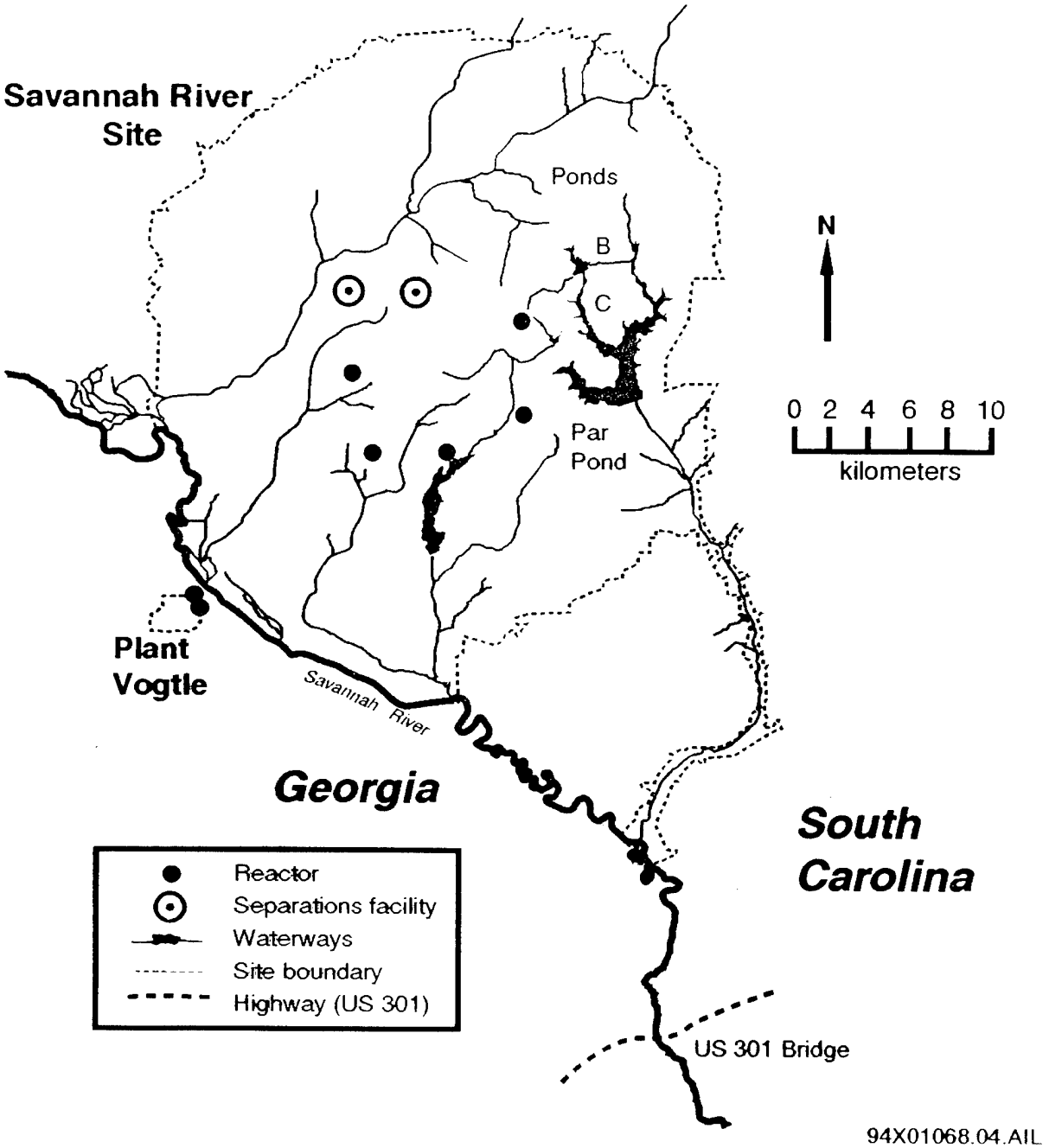
Underwater Nuclear Detection Technologies at the Savannah River Site

Willard G. Winn
Savannah River Technology Center
Building 735-A, D-Wing
Aiken, SC 29808

Underwater nuclear detection technologies have been under development and deployed in applications at the Savannah River Site since its inception in the early 1950's. These technologies have included both in situ detector measurements and sampling/laboratory analysis schemes. Current strategies often implement in situ measurements followed by laboratory analyses of field samples when further refinements are required. As such, the "treasure hunt" capabilities of in situ monitoring assures that the samples collected are of potential interest for laboratory analysis, reducing the prospect of bogus sample analyses.

Recently SRS has been employing both NaI and HPGe underwater detectors for in situ measurements. Since 1987, the NaI underwater detector has monitored gamma-emitting effluents in the Savannah River from both SRS (DOE) and Plant Vogtle (Georgia Power), at levels well below hazard/legal concerns. During 1991-92, the HPGe underwater detector was used to successfully map the activity of gamma-emitting sediments at the bottom of cooling ponds at SRS, to project exposure levels anticipated for planned lowerings of the pond water levels. Enhancements for these type of in situ measurement programs are anticipated per recent SRS investigations in the use of submersible systems outfitted with remote control navigation and video transmission features.

The above in situ techniques have been supplemented with sampling and laboratory analysis of water, sediment, and biota. Water sample collections are generally concentrated using resin collection techniques, and then concentrated further by ashing. The samples are counted in the SRTC Underground Counting Facility, specially designed and constructed to be well-shielded and ultra-clean. This facility includes high efficiency HPGe detectors with low-background active/passive shielding. Based on such gamma-ray analyses as a guide, additional SRTC lab-based nuclear analyses have frequently been implemented as appropriate; these include alpha spectroscopy, liquid scintillation, and mass spectrometry.


Savannah River Site
Ponds
B
C
Par Pond
N
0 2 4 6 8 10
kilometers
Plant Vogtle
Savannah River
Georgia
South Carolina
Reactor
Separations facility
Waterways
Site boundary
Highway (US 301)
US 301 Bridge
94X01068.04.AIL

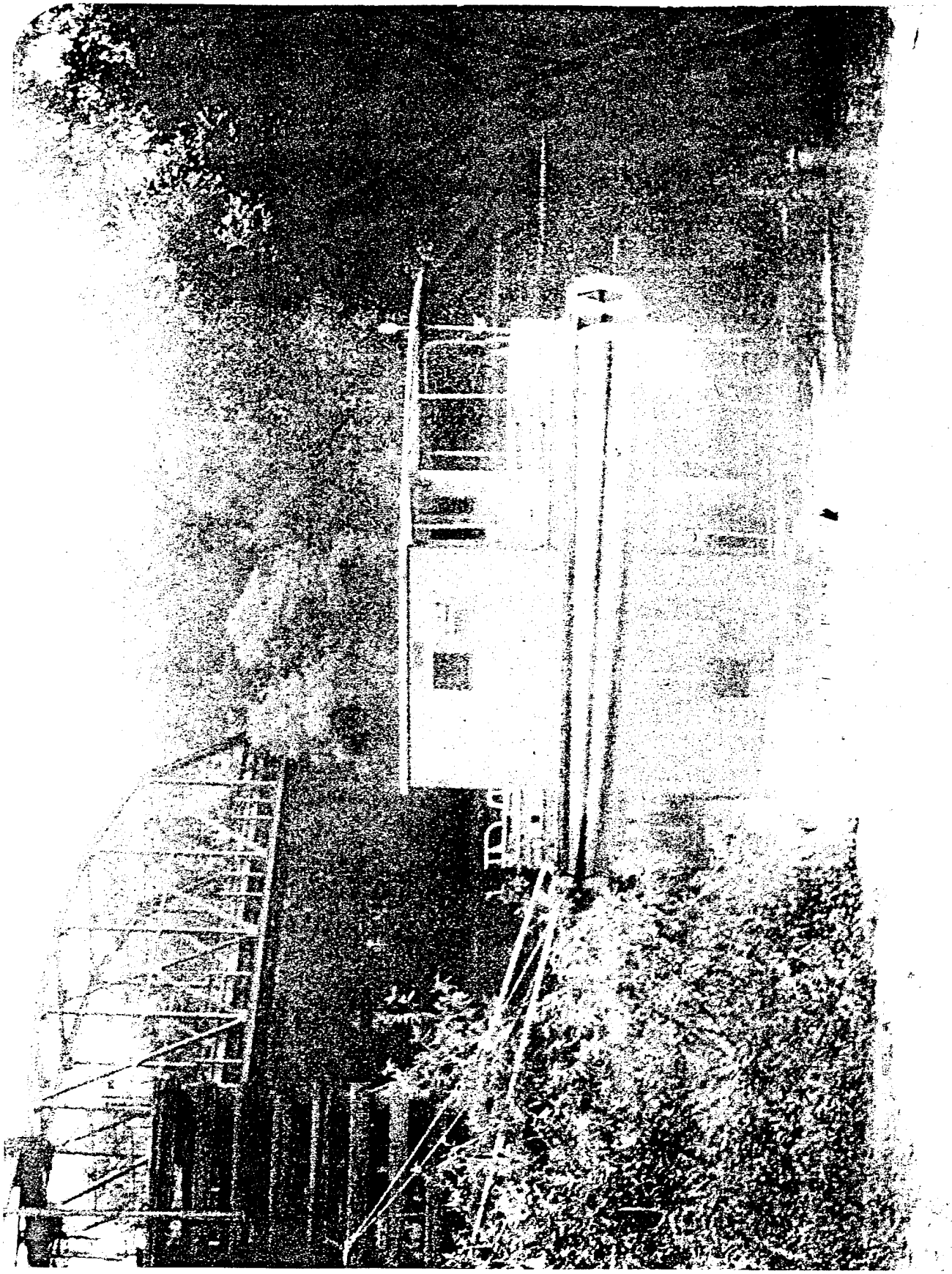
Underwater NaI Detector

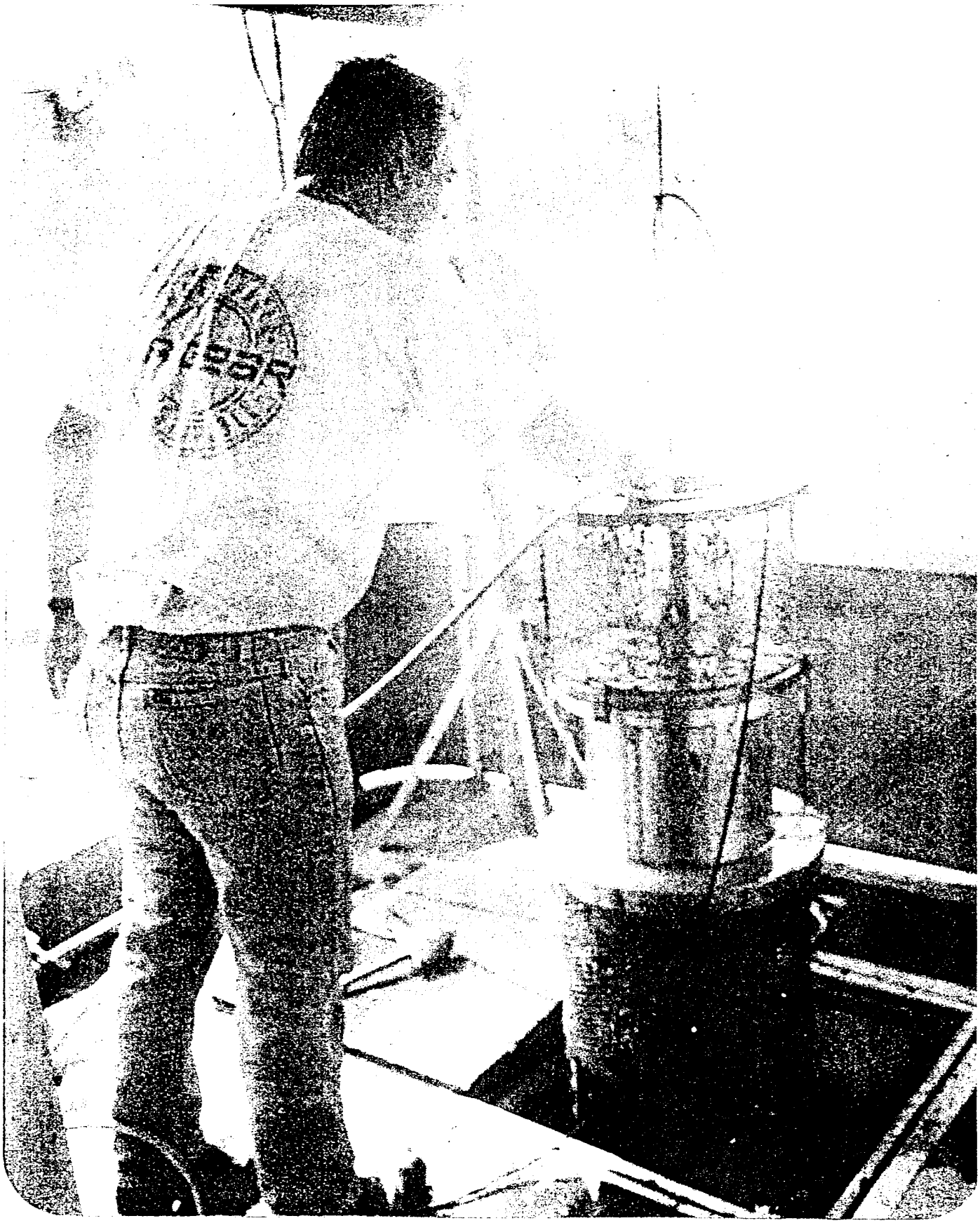
Applications: Continuous monitoring of nuclear plant releases
Sediment appraisals
Identification of effluent paths/contents

Components: Pontoon platform with shore power
Portable Compaq computer with MCA card
Custom high-voltage power unit
Standard NIM bin amplifier
UPS for electronics power
Electrical hoist for detector deployment

Detectors: 9" diam x 4" long NaI detector with features below
- Mounted within thin SS hemisphere
- Single electrical cable (AC signal/DC-power)
- Continuous 1-day counts
- Depths down to 100 ft possible
- Lifted by steel cable

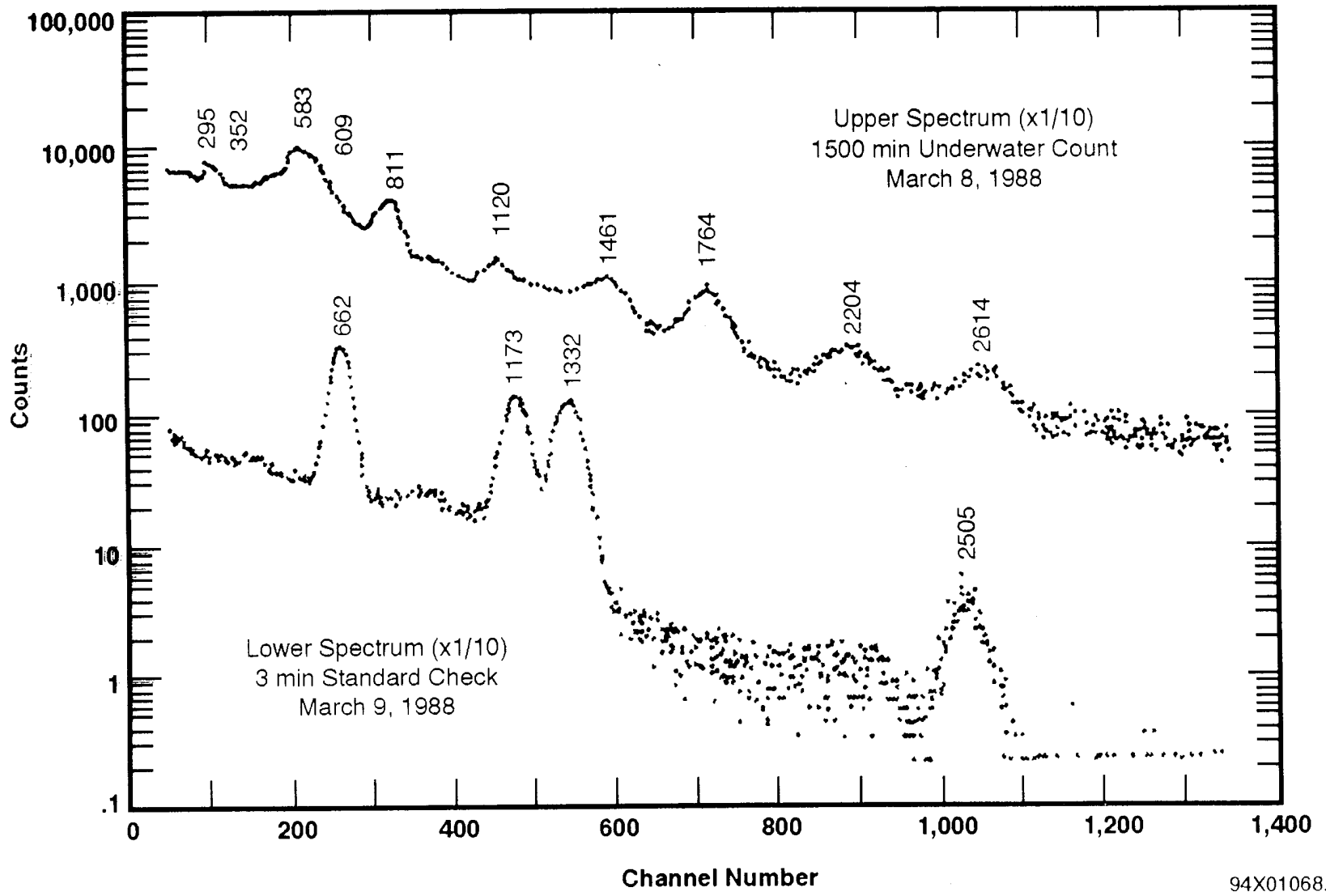
Sensitivity: 0.1 pCi/L Co-58 in water (1-day count)





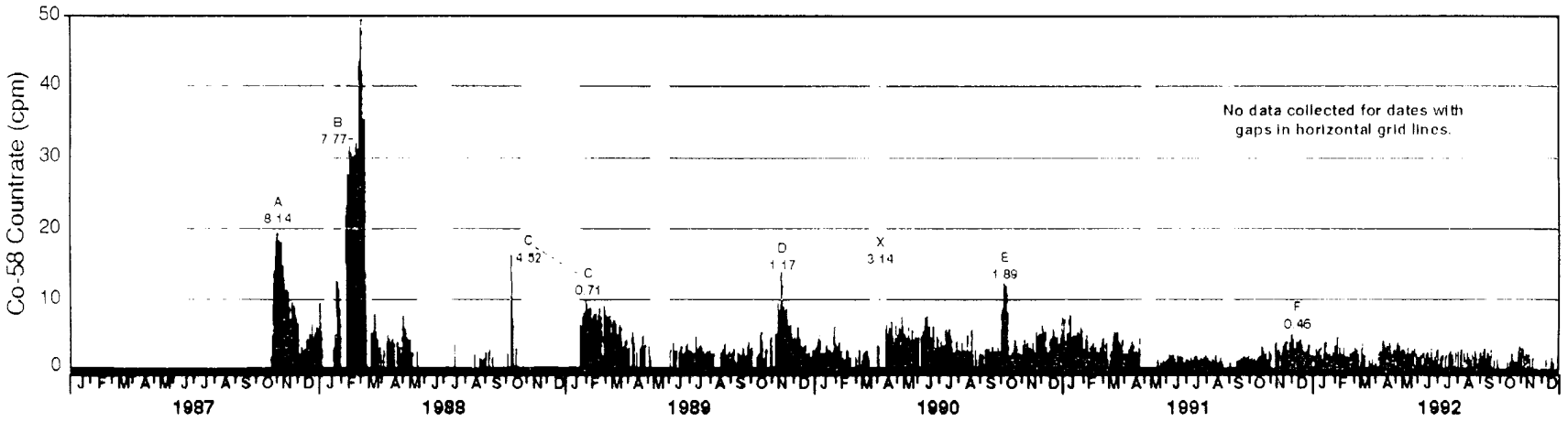


Underwater NaI Spectra



94X01068.03.AIL

NaI Underwater Detector ^{58}Co Countrate - 1987 to 1992



94X01068.07.AIL

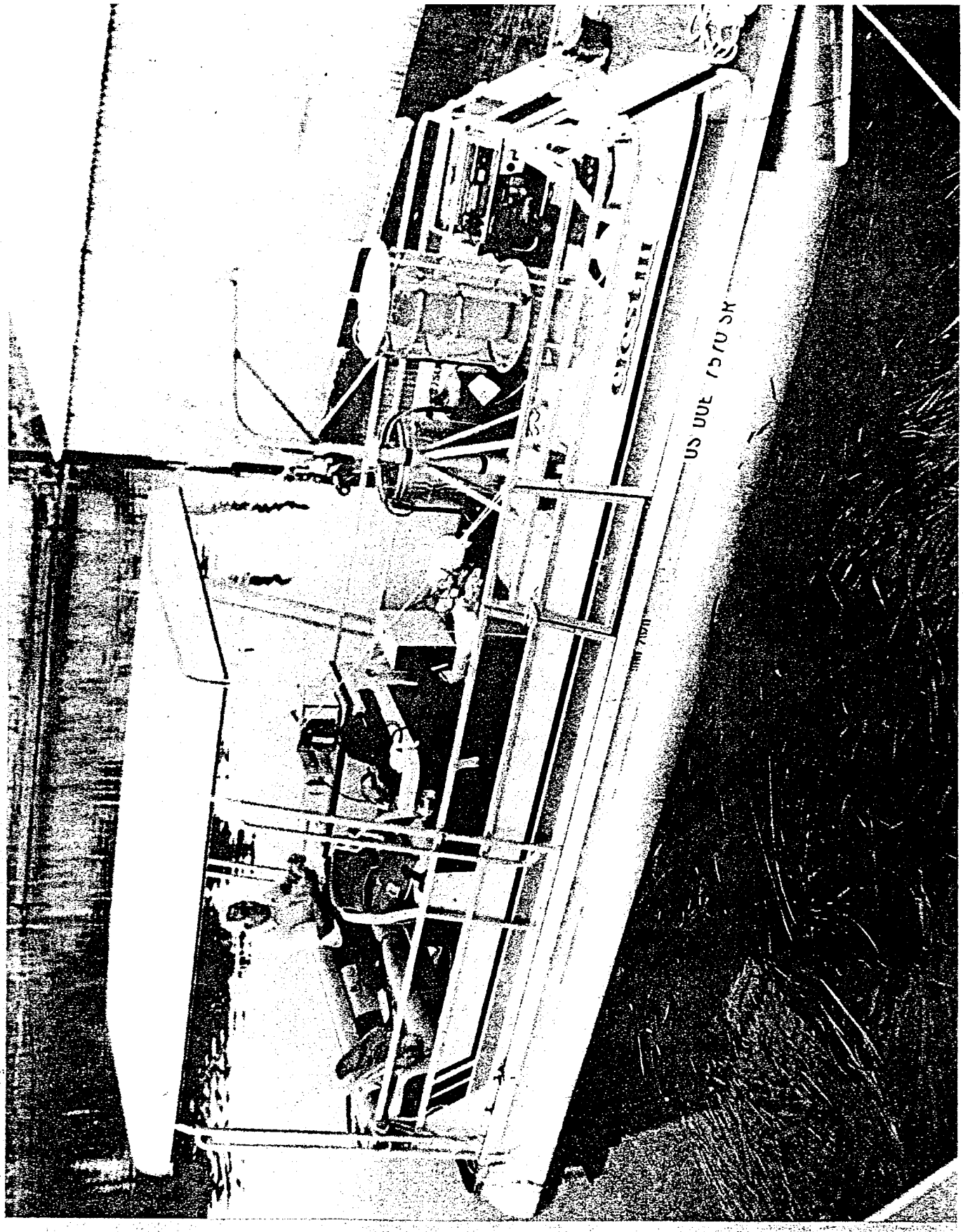
Underwater HPGe Detector

Applications: Quantifying radioisotopes in SRS pond sediments
Identification of effluent paths/contents

Components: Pontoon boat (operations platform)
Laptop portable 386 computer (battery operable)
NOMAD portable electronics unit (battery operable)
MCA per NOMAD/computer coupling
5 KVA gasoline generator and UPS
Electrical hoist for detector deployment

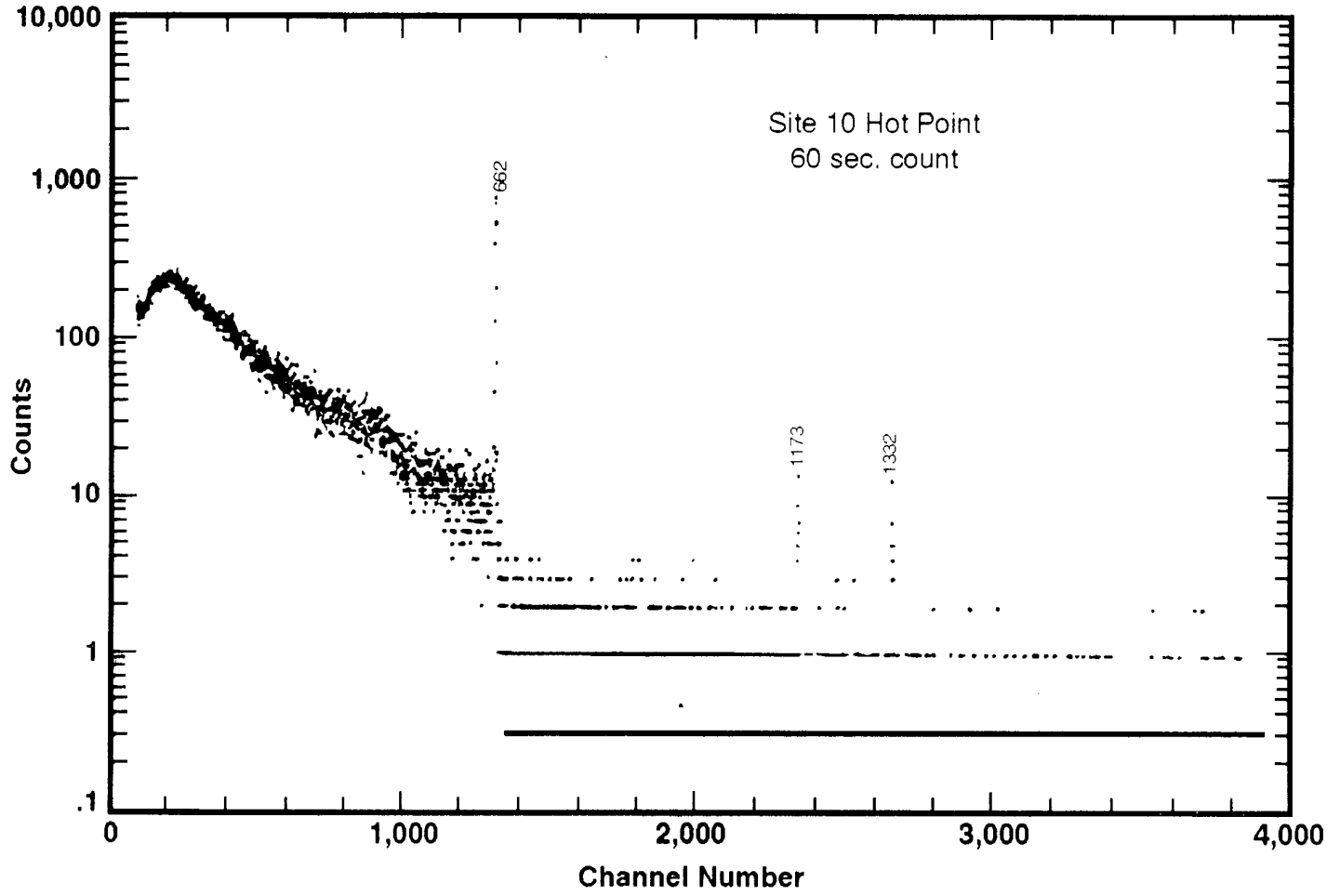
Detector: 30% HPGe detector with features below
- Mounted with dewar in rigid screen can
- Screen can about 1.5' diam x 4.5' tall
- Dewar LN2 hold time 4-5 days
- Depths down to 100 ft possible
- Electrical cables and vent tubes
- Lifted by steel cable

Sensitivity: 0.3 $\mu Ci/m^2$ Cs-137 in pond sediment (1-minute count)

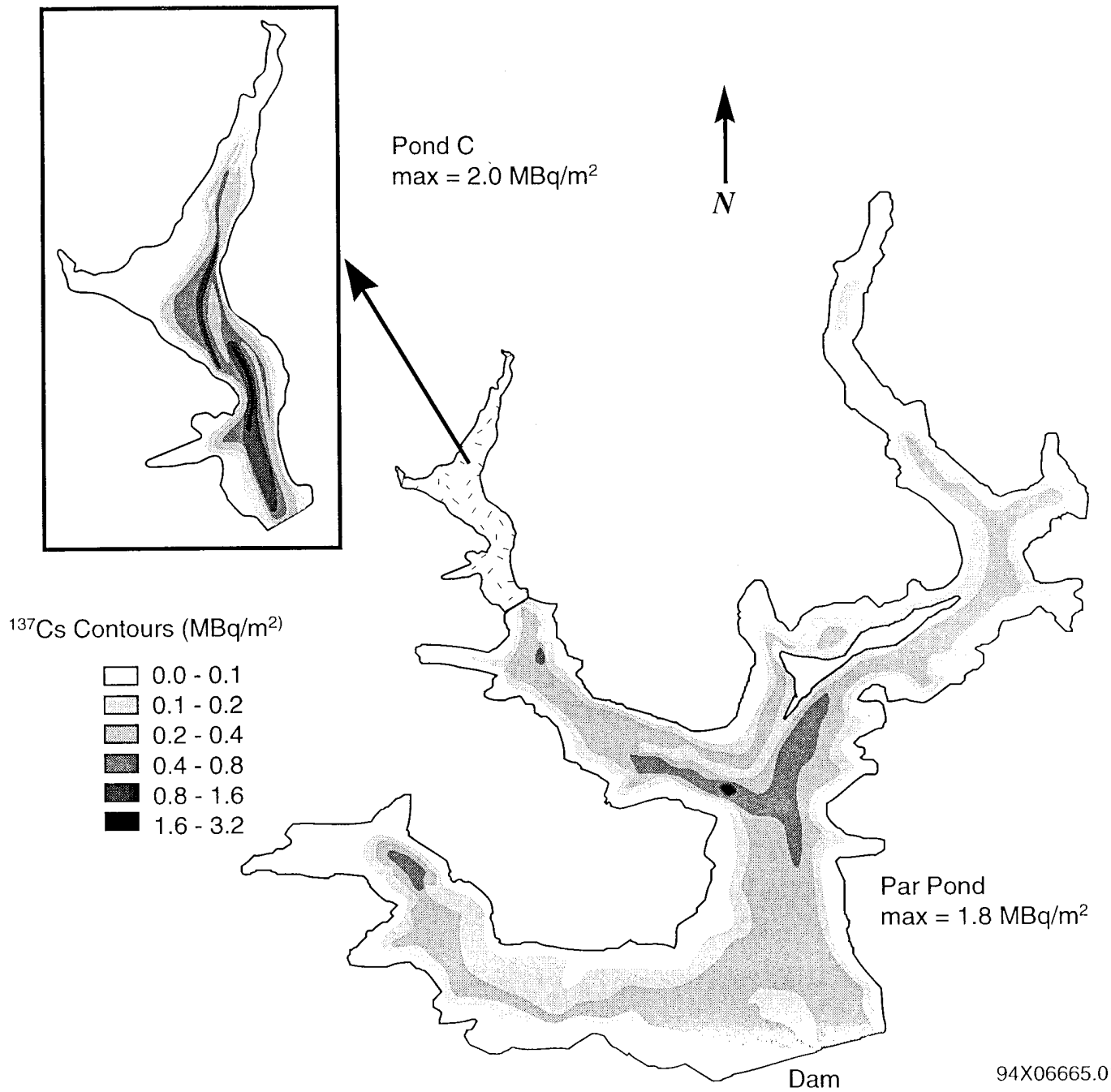


SSING

Underwater HPGe Spectrum



94X01068.05.AIL


Pond C
max = 2.0 MBq/m²
N
137Cs Contours (MBq/m2)
0.0 - 0.1
0.1 - 0.2
0.2 - 0.4
0.4 - 0.8
0.8 - 1.6
1.6 - 3.2
Par Pond
max = 1.8 MBq/m²
Dam
94X06665.01 AIL

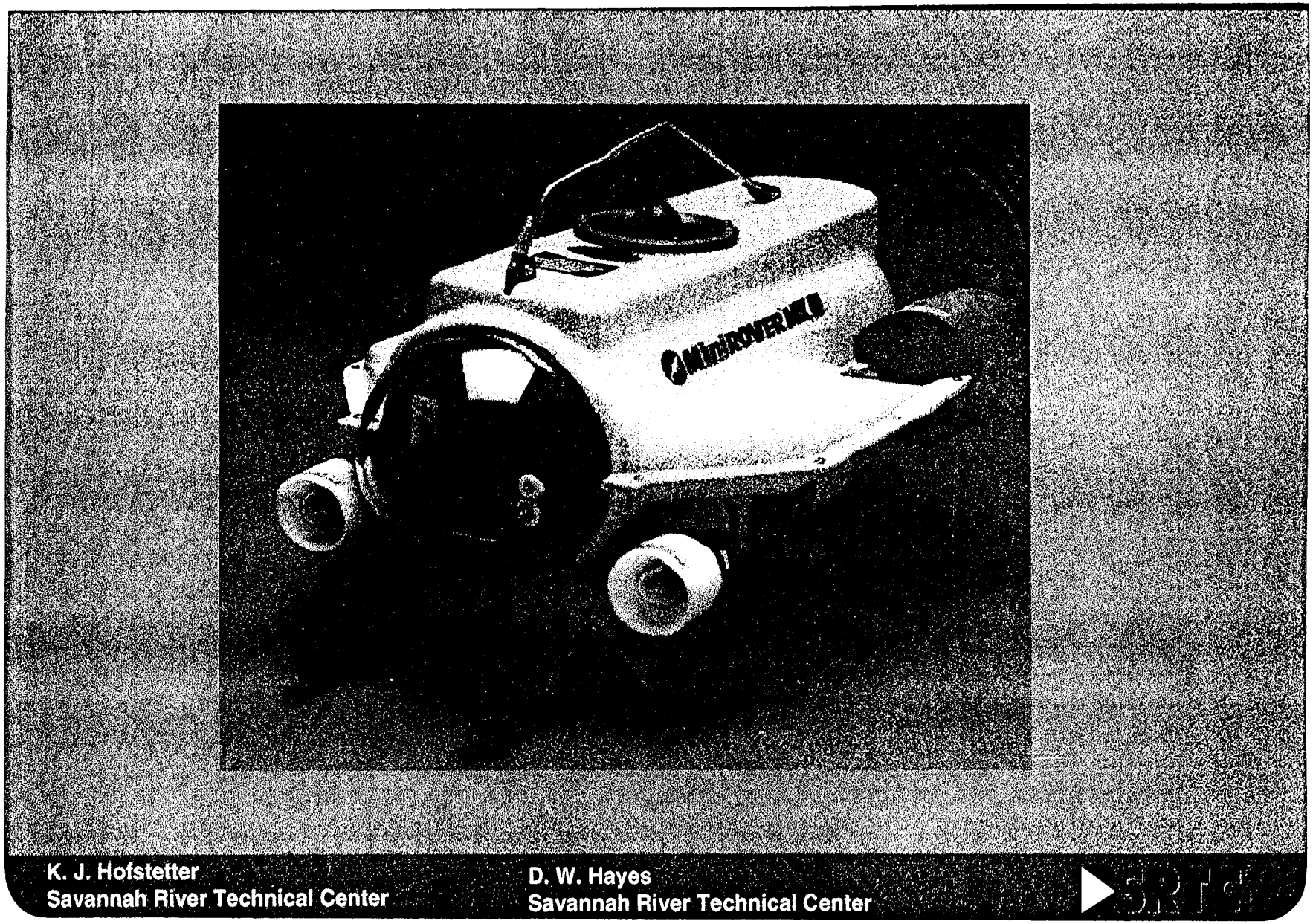
Submersible Data Acquisition System
(being procured)

Applications: Radionuclide migration studies
Lake/river bottom surveys
Radioactive source location identification

Components: Navigation and propulsion system
Pan/tilt color video camera
Digital depth and heading system
Umbilical for data transmission
Control console
Videographs data display

Detectors: NaI(Tl) scintillation detector
CdTe semiconductor detector
CsI-PIN detector

Sensitivity: To be examined by Ken Hofstetter, SRTC/ETS
(principal investigator)



Order No. 016-1130-00

Tektronix

Underground Counting Facility for Analysis of Collected Samples

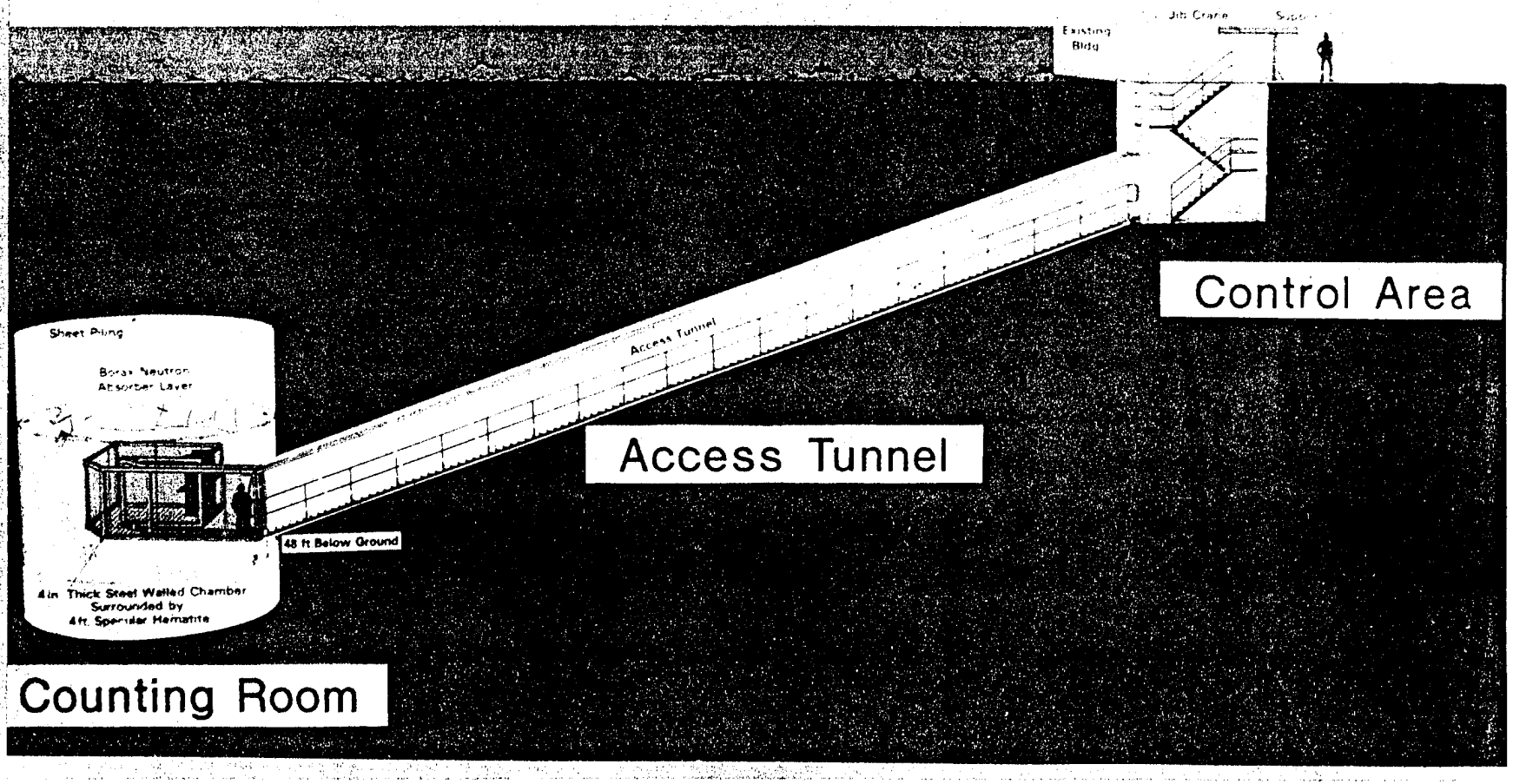
Applications: Water, biota, sediments of SRS waterways
Special studies for DOE, IAEA, NASA, USGS, etc

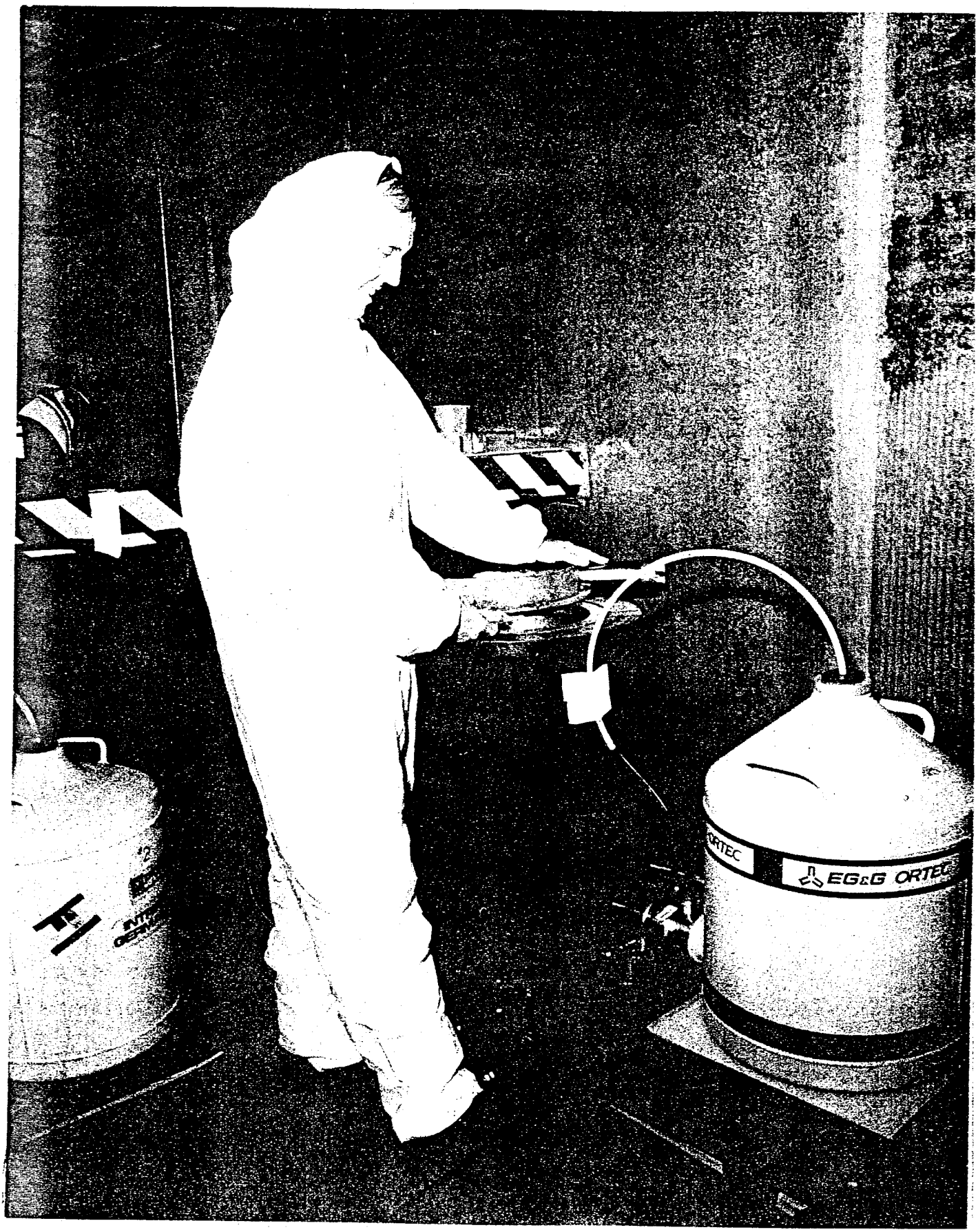
Components: Pre-WWII steel chamber 50 ft below ground
Shielding silo with 4-7 ft specular hematite shield
Access tunnel and maze shielding entrance
Ground-level control room for counting analysis
Air filtering system for Class 10,000 clean room

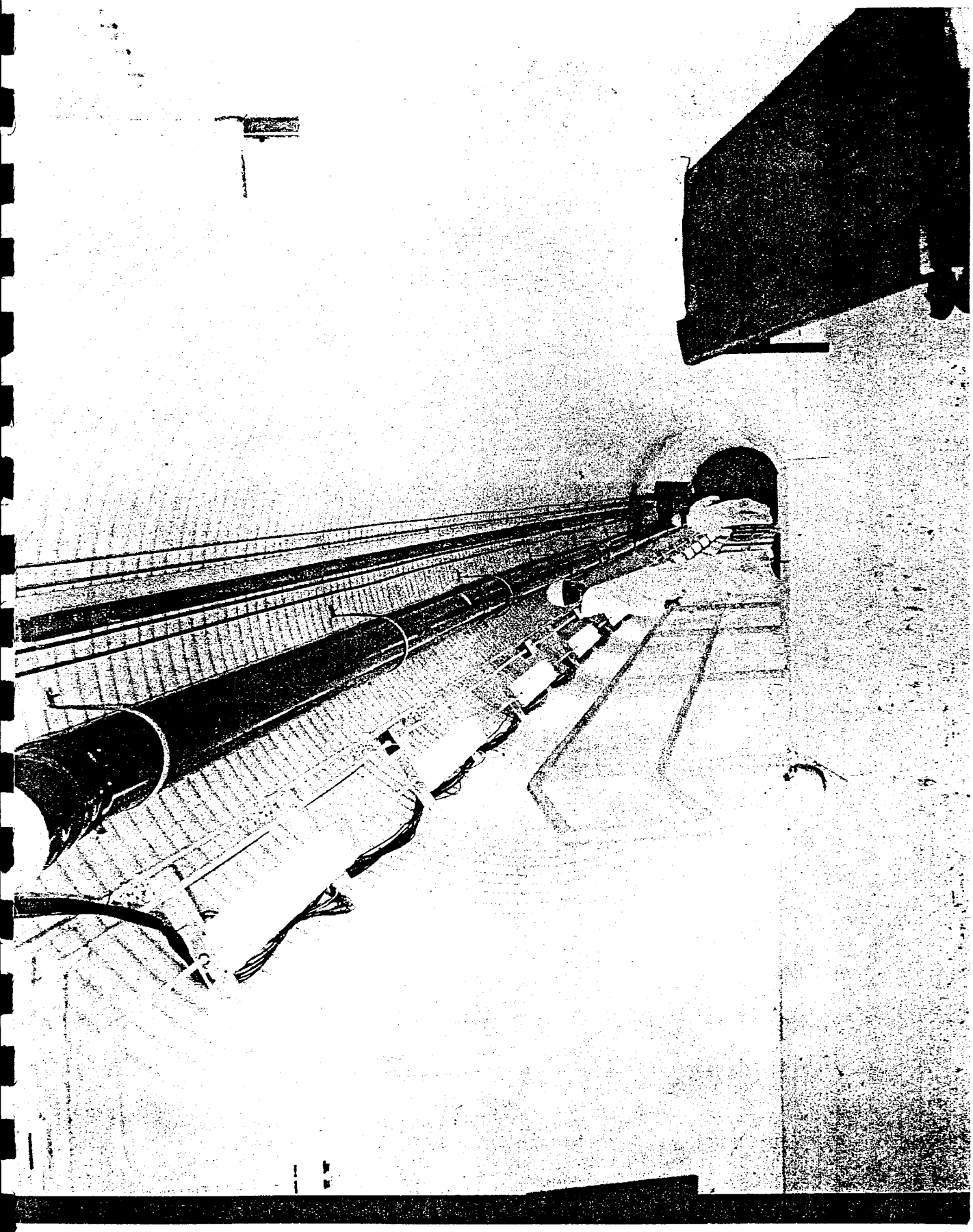
Detectors: 20% HPGe well (low background materials/geometry)
25% HPGe well (low background geometry)
90% HPGe (low bkg mats/geo & active/passive shield)
175% HPGe - expected in February 1995

Sensitivity: Refer to "Sample Analysis" slide

Underground Low Level Counting Facility




EG&G ORTEC



Sample Analysis

Collection: Water sample filters ashed after pumping 320 L
Biota (~30 g) in counting vial <could densify>
Sediment (~150 g) in counting vial

Counting: Count time of 1-5 days but typically overnight
Constant background conditions

Analysis: GRABGAM spectral analysis code with features below
Developed at SRTC to address low-level counts
Peak find using three trapping filters
Integral peak profiles for centroid and FWHM

Sensitivity: Typical limits for overnight count with 90% HPGe

	Water (fCi/L)	Biota (pCi/kg)	Sediment (pCi/kg)
Co-60	0.5	25	7
Cs-137	0.9	45	8
U-235	1.5	280	60

ABYSSAL RADIATION MONITORING

Hugh Copeland
Naval Command, Control and Ocean Surveillance Center
San Diego, CA 92152-6320

This paper discusses differences in the in-situ abyssal gamma spectrometers used on Keldysh cruise 31. It suggests additional technologies and techniques for in-situ abyssal gamma spectroscopy based on lessons learned from this voyage. Cruise 31 for the RV Akademik Mstislav Keldysh, August 1993, was a voyage to the site of the nuclear submarine Komsomolets. An international group of five foreign scientists and specialists were invited to participate in a survey of the oceanographic and radiological aspects of the site. Dr. C. Hollister from Woods Hole Oceanographic Institute and H. Copeland from NRaD participated in this voyage.

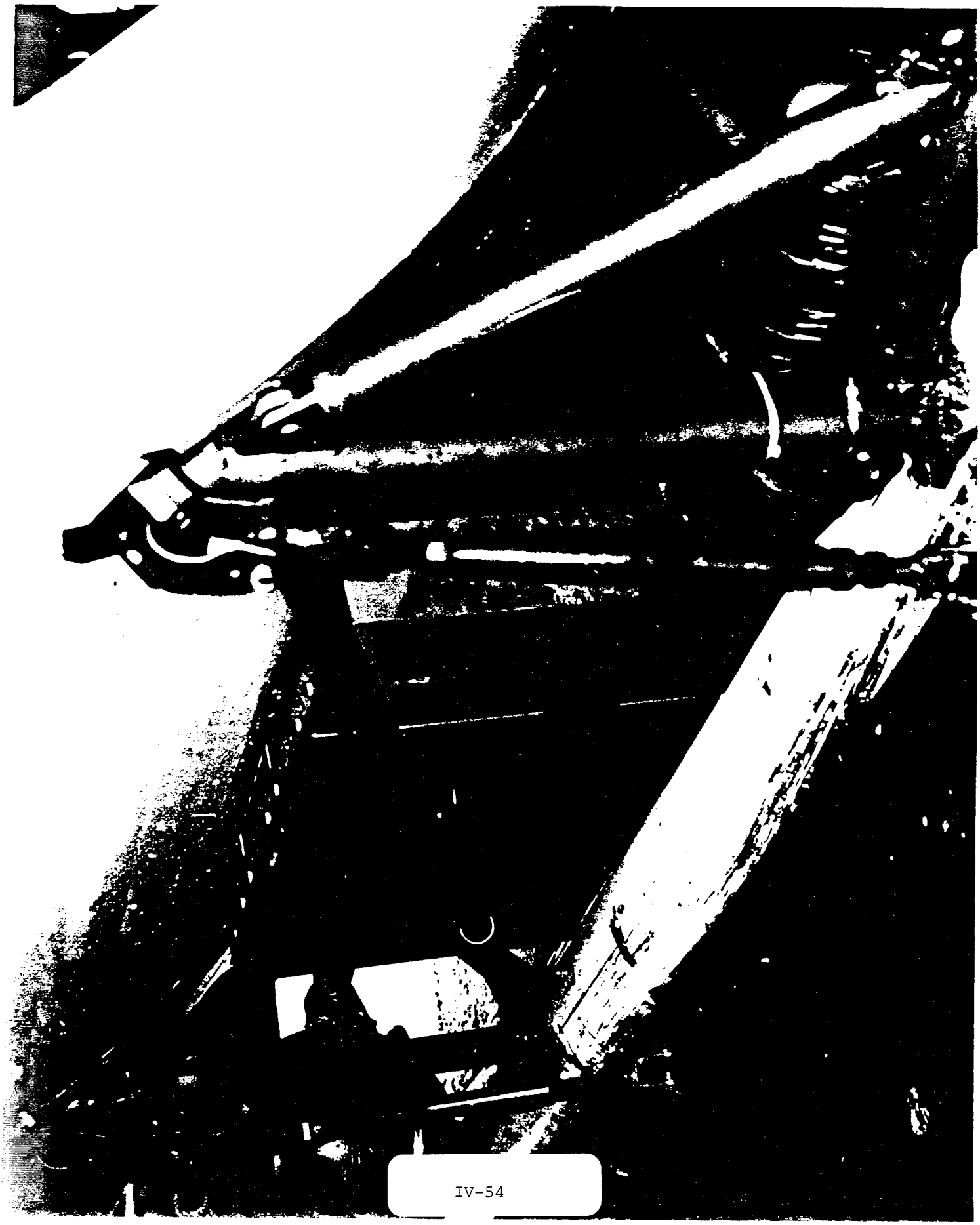
Three sodium iodide (NaI) based gamma spectrometers were used at the site. Krylov Shipbuilding Research Institute supplied a system based on an 80 mm dia. X 400 mm long NaI in a titanium housing (named EKO-5). The Radium Institute provided REM-2, which was based on a 200 mm dia. X 100 mm thick NaI crystal in a spherical aluminum housing. NRaD supplied K-1, consisting of a 76 mm dia. X 200 mm long NaI crystal in an alumina ceramic housing. The resolutions (FWHM) were 9.3%, 10.5%, and 6.7% at 662 Kiloelectron Volts (KeV) respectively.

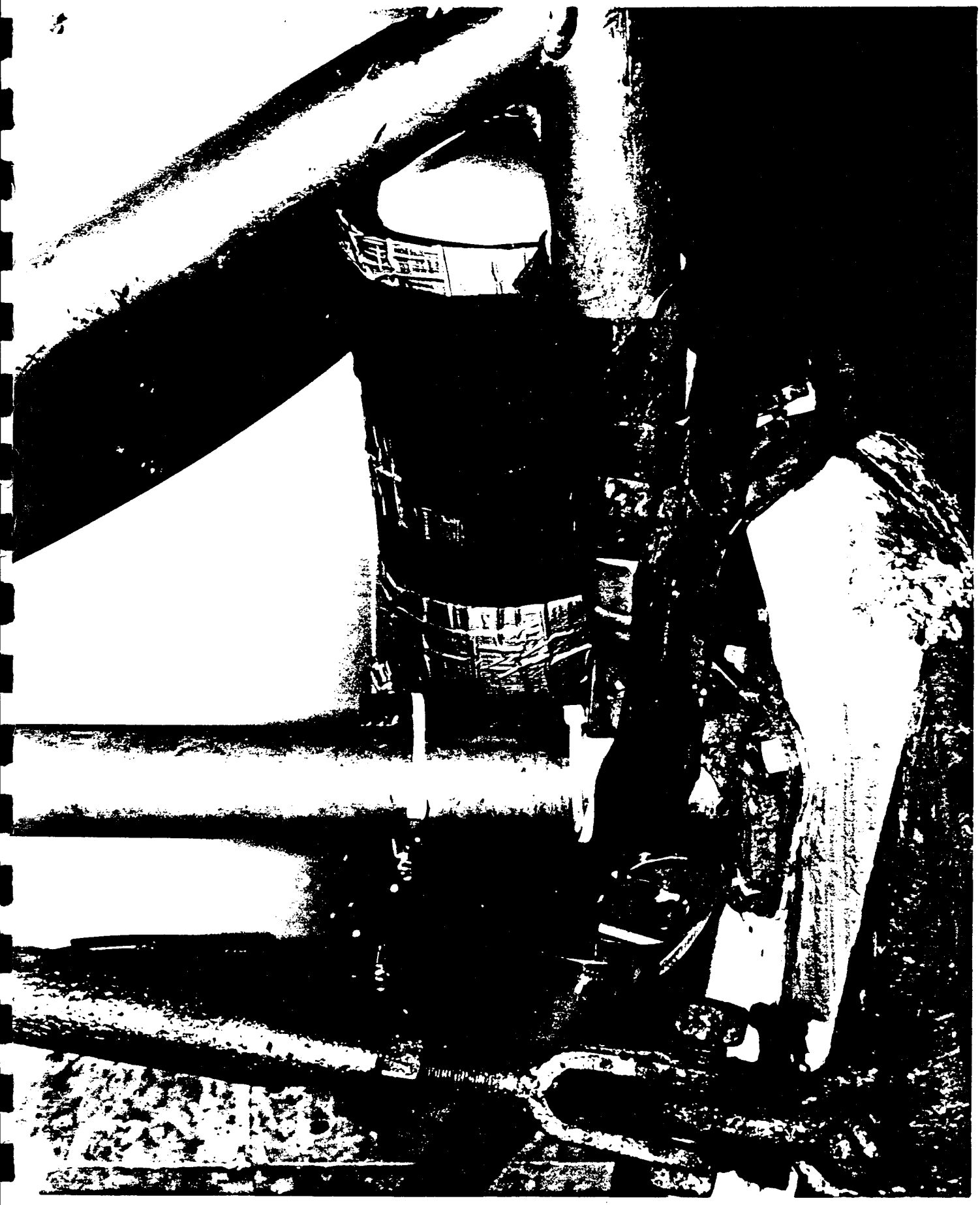
The count rates for ^{40}K tracked with detector volume. The count rate for K-1 under the ^{40}K peak was about half that of EKO-5. For gamma energies above 662 KeV the larger crystal provides a count rate advantage over K-1, which allows shorter data acquisition times. Data acquisition periods specified for the EKO-5 and REM-2 were 5 minutes. This short period avoids problems associated with temperature drift. This drift is a concern in the first 2-3 hours on the bottom if the detector has not been temperature conditioned prior to deployment. Shorter acquisition periods also minimize the use of the submersible for the gamma spectroscopy portion of the dive. K-1, on the other hand, provided a significant resolution improvement. This is essential for resolving energy peaks below 900 KeV in this low count rate environment. The enhanced resolution is due in part to the smaller crystal, and in part to the advanced materials in the pressure housing that reduce scattering and attenuation of gamma photons.

To overcome the acquisition requirements of the relatively high resolution NaI-based abyssal gamma spectrometer, the ideal system would be a completely self-contained. Deployment is performed either by a submersible or by the surface support ship. Recovery is initiated with acoustic signals from the ship for ballast release,. GPS homing signals transmitted from the system provide surface location for pick up.

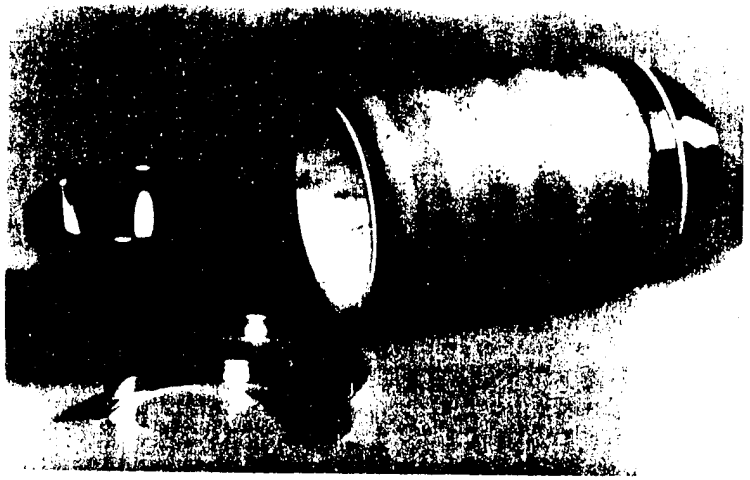
Autonomous spectrometer systems minimize impacts on other mission elements. When integrated with oceanographic systems, they can provide correlation between radiation and oceanographic parameters. Because autonomous systems are deployable for long periods of time, they can accommodate the longer data acquisition cycles associated with smaller, higher resolution crystals. It is possible to envision a gamma spectrometer combined with an oceanographic station deployed at the site of a potential radiation source such as the Komsomolets. A surface deployed vehicle, such as the NRaD-developed "Flying Plug", would perform periodic routine servicing functions such as battery charging and data retrieval.







Ceramic Housings



Unique Features

- Lightweight material when compared to other deep submergence (to 20,000 ft) external-pressure vessels
- Low-density material
- Commercially available in certain sizes and ceramic types at relatively low cost

Specifications Performance

• Ceramic composition <AD998 ALUMINA>	99.8% Al_2O_3
• Modulus of elasticity	50 x 10^6 psi
• Comprehensive strength	>300,000 psi
• Flexural Strength	>48,000 psi
• Poisson's ration	0.22
• Shear modulus	22 x 10^6
• Bulk modulus	33 x 10^6
• Specific gravity	3.89
• Coeff of thermal expansion at room temperature	3.7 x 10^{-6}/^{0} F

Status

Applied to other projects

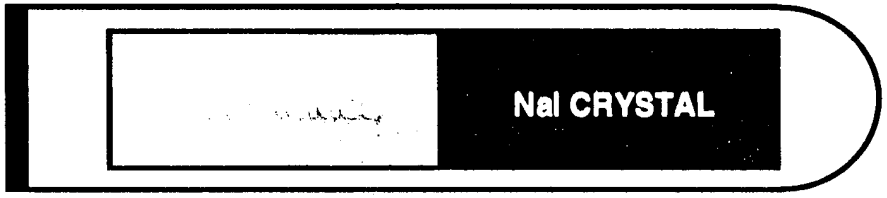
D0466 6 52

Gamma Sensors
Keldysh 31

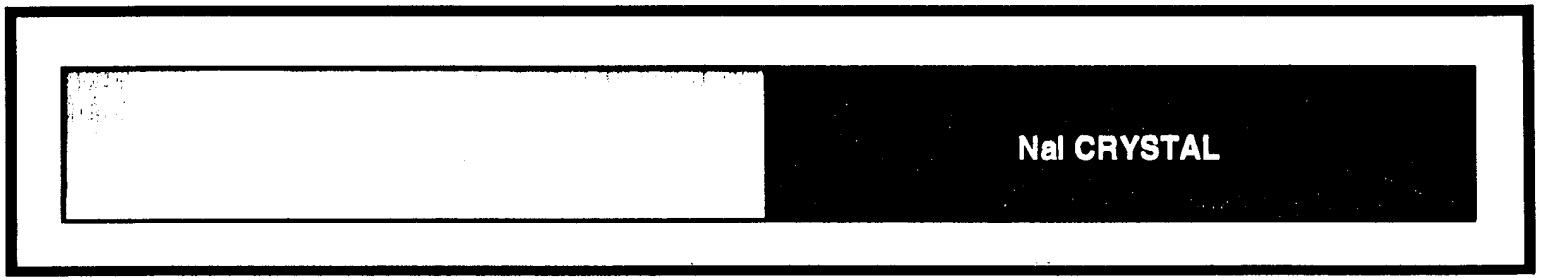
REM-2
200 mm X 100 mm NaI
10.5% FWHM @ 662 KeV
ALUMINUM HOUSING



K-1
76 mm X 200 mm NaI
6.7% FWHM @ 662 KeV
ALUMINA CERAMIC HOUSING



EKO-5
80 mm X 400 mm NaI
9.3% FWHM @ 662 KeV
TITANIUM HOUSING

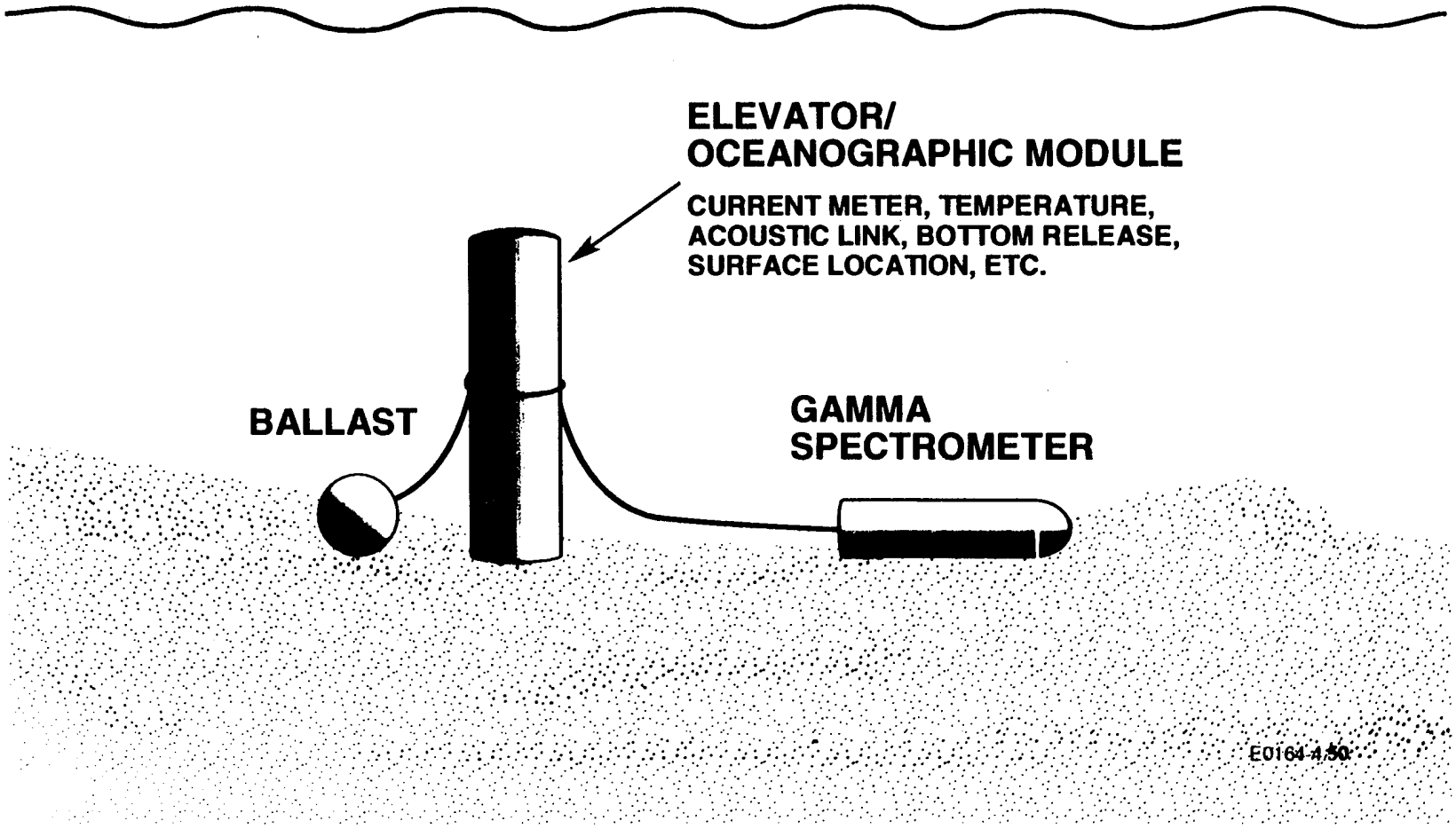


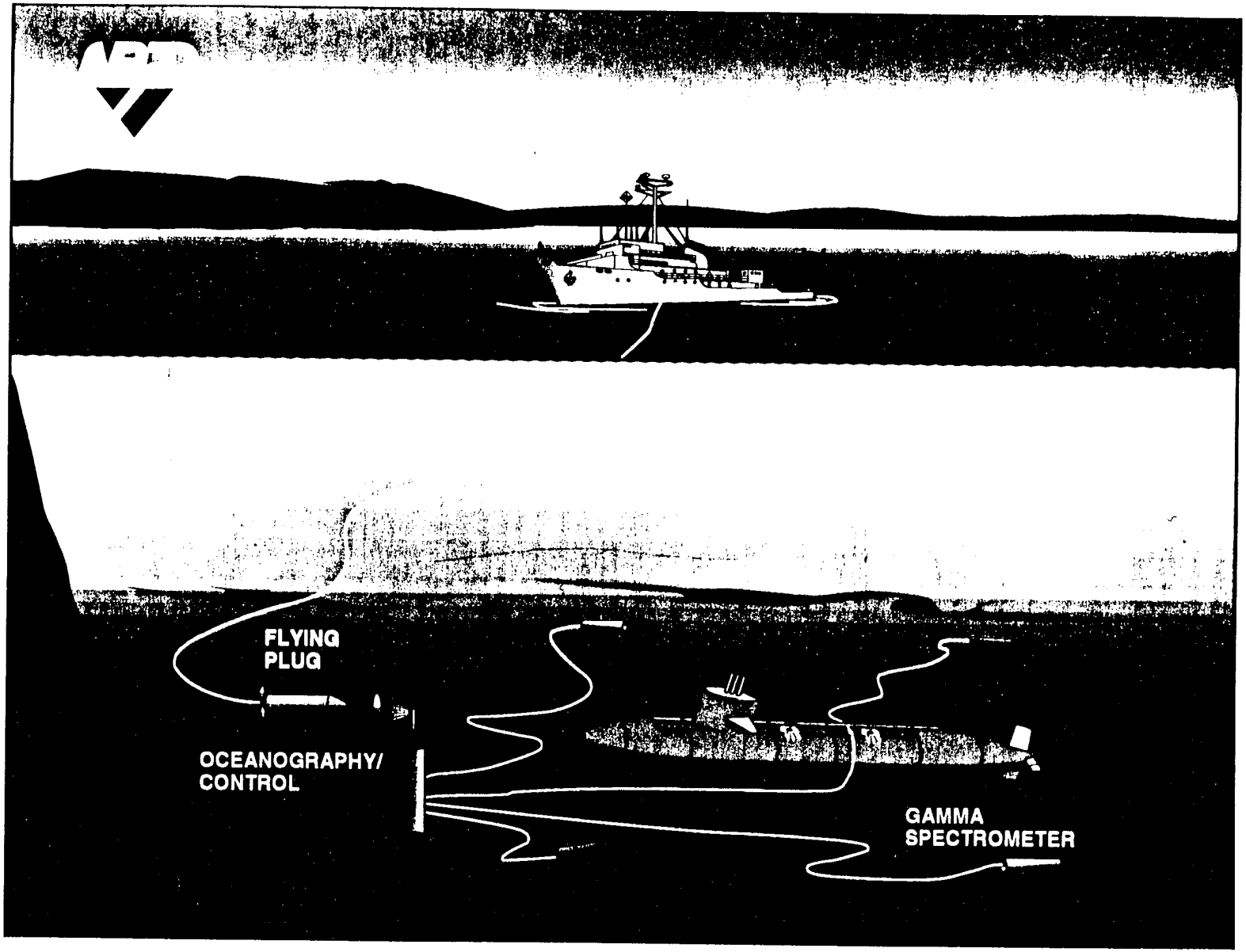
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Why Deployable Sensors

- Low Counting Rates
- Statistical Nature of Spectral Gamma Ray Analysis
  - Larger numbers allow better statistics
  - Low count rates require long counting times
- Long Counting Times = Long Deployment
- Deployability = Vessel Freedom for Other Missions

Recoverable Abyssal Radiation Spectrometer





E0164-5.50

Abstract

Title: AMPS Program Overview

Sponsor: Mike O'Connell and Ralph Hastings, DOE/NN, Washington DC

Authors: Jeff Bradley, SNL, Albuquerque NM
Ray Finucane, LLNL, Livermore CA
Mike McWhirter, EG&G RSL, Las Vegas NV
Wayne Meitzler, PNL, Hanford WA

As an active participant in the research and development of new generation remote sensing technology, the U.S. Department of Energy has established a program for aerial data collection, integration, and analysis. This program, the Airborne Multisensor Pod System (AMPS), was established through the Office of Arms Control and Non-Proliferation (DOE/NN). It is currently being developed through the cooperative efforts of the EG&G Energy Measurements Remote Sensing Laboratory (RSL), the Sandia National Laboratories (SNL), the Pacific Northwest Laboratory (PNL), the Savannah River Technology Center (SRTC), the Lawrence Livermore National Laboratory (LLNL), the U.S. Navy, and the National Oceanic and Atmospheric Administration (NOAA). We have completed five data collection missions (1994).

The primary objective of the AMPS program is to collect multisensor data that can be used for data research, both to reduce interpretation problems associated with data overload and to develop information products more complete than can be obtained from any single sensor. Secondary objectives include sensor development and technology demonstrations. AMPS is not intended to be an operational program, although sensors and techniques developed through the AMPS program could be used in follow-on operational systems and missions.

With a modified Lockheed RP-3A as an aerial platform, the suite of wing-mounted multisensor pods collects co-located imaging and non-imaging data. This method of collecting data with multiple sensors over the same area will markedly advance data integration techniques. Currently, AMPS includes a synthetic aperture radar (SAR) pod and a multisensor pod designed by SNL and RSL, respectively. Each contains sensors and instruments described on the AMPS Home Page (http://www.amps.gov) under "Hardware and Instruments." Plans also include the expansion of test bed capabilities with the imminent addition of an effluent species identification (ESI) pod, a collaboration between PNL, SRTC, and LLNL.

Although pod instrumentation is intended ultimately for autonomous operation, onboard controls allow technical personnel to manipulate pod components as necessary. Imaging media include digital and analog videotapes, photos, and digital data tapes. Digital files are generated by a diverse array of non-imaging sensors.

The DOE/NN intends to make the information products available for distribution to the national laboratories and other agencies. While the AMPS program can accommodate numerous interrelated objectives, its primary mission is to provide a scientific environment for researching multisensor data and developing information products that are superior to those produced by a single sensor. As sensor operation and data collection methods mature, AMPS may be used to demonstrate technology for potential use for arms control treaty verification, non-proliferation surveillance, environmental monitoring, and disaster control. Targets of opportunity (e.g., chemical spills, large fires, and earthquake damage) may also be investigated if schedules and platform availability permit.

AMPS Data Access System Prototype



Program Overview

Program Objectives

Program Background

Acronym

Sample Images

Schedule

Instrument Specification Sheets

AMPS Mission/Data Request Form

Hardware and Instruments

- **Aerial Platform**
- Sony DXC-750 3-CCD Video Camera
- Wild Heerbrugg RC-30 Large Format Camera
- Barr & Stroud IR18 Thermal Imager
- Synthetic Aperture Radar
- COHU 5560 Low Light Camera
- CASI Hyperspectral Imager
- Daedalus Airborne Multispectral Scanner (AMS)
- Echelle Grating Spectrometer
- Air Concentrator-Ion Trap Mass Spectrometer (AC-ITMS)
- Target Tracking System
- Krypton Sampler
- Real-Time Airborne Radionuclide Analyzer and Collector (R-TARAC)
- Multisensor Pod (Image ~ 103 Kb)

AMPS HOME PAGE

http://www.amps.gov

AIRBORNE MULTISENSOR POD SYSTEM (AMPS) PROGRAM PLAN

1.0 AMPS PROGRAM OBJECTIVES

The Department of Energy's Office of Research and Development within theOffice of Intelligence and National Security (DOE/IS) has established a program identified as the Airborne Multisensor Pod System (AMPS) which is integrated into the overall DOE/IS-20 technology development program. The primary purpose of the AMPS program is to collect multisensor data which can be used for data research both to reduce interpretation problems associated with data overload and to develop information products more complete than that of any single sensor. Secondary objectives include sensor development and technology demonstrations. AMPS is not intended to be an operational program, although sensors and techniques developed through the AMPS program could be used in follow-on operational systems.

In order to collect data, the AMPS program will develop three wing-mounted pods which will be flight certified on U.S. Navy RP-3A aircraft. After aircraft certification, the pods will be flown as experimental testbeds against calibration targets, known targets and real field targets.

As sensor operation and data collection methods mature, AMPS may be used to demonstrate technology for potential use for arms control treaty verification, non-proliferation surveillance, environmental monitoring and disaster control. Targets of opportunity (i.e. chemical spills, large fires, earthquake damage) may also be investigated if it does not interfere with the basic research mission of AMPS.

The AMPS program interacts with the other technology programs of DOE/IS-20 by using sensors developed under the on-site inspection, effluent analysis or standoff sensor programs. AMPS adapts these sensors for airborne pod operation and uses them to collect data.

1.1 Multisensor Data Collection Research

One of the main problems with current data collection techniques is data overload. So much information is collected that it is difficult to separate the important data from the uninteresting. It is hoped that by using multiple sensors, it will be possible to generate algorithms for automatically highlighting the data which is likely to be of greatest interest. This can be accomplished by using one sensor to cue another so that superfluous information is never collected. Or it could be used to point out collected information which is a higher priority for analysis. Data to test these techniques will be collected by AMPS.

A related problem is how to combine data from different sensors to provide a more complete information package. For example, a Forward Looking Infrared (FLIR) scanner, a radiometric thermal imager, and an infrared (IR) spectrometer all work in the infrared but, as individual sensors, do not provide a complete picture. AMPS performance could be enhanced by combining the sensor

data. The FLIR would serve as a survey instrument to look for hot spots. Once one is found, the IR spectrometer could analyze the hot effluents while the thermal imager estimated the total heat generated by the target. The resulting information could be combined to determine the size of the hot spot, its temperature and its chemical composition. This information could be used by a software package to readily estimate the nature of the target and estimate if it was of interest. No single sensor could generate as complete of an information package or identify the target with as much certainty as the combined package.

1.2 Sensor Development

Sensor development is a secondary objective of the AMPS program. Both off-the-shelf and developmental sensors have been modified to operate in wing-mounted pods. Candidate sensors, in various stages of development, have been selected based on program objectives, performance potential, instrument development interests, flight suitability, availability, and cost. The sensors selected for pods one and two have been previously used in various aircraft and helicopters and have some proven performance characteristics related to aircraft use. The AMPS program relocates these sensors from internal aircraft mounting locations to external pod mounted locations. This pod feature may ultimately lead to mounting AMPS on a variety of aircraft, depending on mission requirements. Additionally, the transition of sensors into pods is an intermediate method in which sensors may be developed and/or proven for satellite use.

A third pod, the Effluent Species Identification (ESI) Pod is an additional example of the pods adaptability features. In this case, sensors which have been developed under DOE/IS-20 programs, are being transitioned from ground operations and laboratories directly into the wing-mounted pods. The pod is being designed to allow upgrades to the sensors as they are developed by the laboratories.

In the future, other sensors being developed at the national laboratories could be transferred into the AMPS program, either as replacements for sensors on current pods or as instruments on new pods. Sensors of particular interest include advanced mass spectrometers, lidar systems, and other standoff sensors.

The choice to move towards pods indicates a desire for modularity and autonomy. Ideally the sensors should be able to operate with a simple command to turn on or off but it is recognized that developmental systems will require operator support. It is an objective to minimize the number of operators.

1.3 Data Collection

Data collection is another critical step toward data integration. Mission scenarios are being planned and developed to provide data collection opportunities. They will progress from shakedown flights through controlled releases to field tests against real targets. Flights may also be flown against targets of opportunity such as chemical spills, oil spills and forest fires. Flights may also be made in cooperation with events planned by other agencies such as field trials or flights over "remediated" areas.

Sensor targets will initially require the ability to provide a controlled environment so that sensors can be calibrated and data can be qualified and quantified. Data integration methods must start with a baseline of known target data. Data from multiple sensors will be combined with each other in order to verify accuracy and look for synergisms. Algorithm development will be necessary to handle and sort through massive quantities of data. Other algorithms will be written which will enable the data from one sensor to initiate operation of another sensor.

AMPS is not an operational system but a research tool. Its use to demonstrate technology should not be construed as being a platform designed to collect routine data or to respond to emergencies.

2.0 AMPS PROGRAM BACKGROUND

The Airborne Multisensor Platform Selection Study of 28 November 1990 (Refer to Appendix D, IDI bibliography item #1) examined four alternatives of airborne platforms for use in the research of sensor suitability for treaty verification. The study recommended that a non-intrusive, externally mounted pod be designed and built which could be used on multiple aircraft. This recommendation was based on the ease of assembly, flexibility, cost effectiveness, and operational mission adaptability.

The U.S. Navy RP-3A aircraft, operated by the Naval Air Warfare Center (NAWC) at Point Mugu California, was selected to carry the pods. These particular aircraft are dedicated to research, development, test and evaluation missions and can be configured for AMPS relatively easily which ensures that DOE program costs are kept to a minimum. The current arrangement is for the Navy to own and operate the RP-3A aircraft which DOE uses on a cost per use basis.

Three cargo pods were purchased through the U.S. Navy supply system. The pods are constructed in a modular fashion which allows for some changes in instrumentation based on technological and mission developments. Instruments may be modified within the pods for particular missions or to update current sensors. The first pod is designed to support a Synthetic Aperture Radar (SAR), operated by Sandia National Laboratories (SNL). The second pod, operated by EG&G Remote Sensing Laboratory (RSL), carries a suite of six imaging sensors. The third pod, initially a spare, was designated as the ESI Pod in 1993 and will be operated by Lawrence Livermore National Laboratory (LLNL). Additional pods are being considered for future purchase and integration into the AMPS program.

All three pods are being converted from being a cargo carrier to sensor use by RSL. Air worthiness is being certified by Consulting Aerospace Engineers (CAE) and reviewed by the Naval Air Systems Command (NAVAIR). Flight readiness will be performed by the Navy at Point Mugu. It is anticipated that the first two pods will be flight certified by the end of 1993 and the third pod will be flight certified during FY94. It is anticipated that each flight may be run with one or multiple pods operating simultaneously.

The AMPS program is split into separate projects at the national laboratories. Project assignments are summarized in Table 2.1.

TABLE 2.1 - AMPS PROJECTS

ST NO.	LAB	PROJECT
ST506	SNL	Synthetic Aperture Radar (SAR) Pod (Pod #1)
ST507	RSL	Multisensor Imaging (MSI) Pod (Pod #2)
ST513	NAWC	Aircraft Platform and Program Integration
ST442	PNL	AMPS Data Formatting and Storage Requirements
ST408	LLNL	Effluent Species Identification (ESI) Pod (Pod #3)
ST445	PNL	Radionuclide Sampler for the ESI Pod
ST447	PNL	Air Concentrator-Ion Trap Mass Spectrometer for the ESI Pod
ST454	SRTC	Atmospheric Kr-85 Plume Grab Sampler for the ESI Pod
ST740	LLNL	Echelle Grating Spectrometer for the ESI Pod

3.0 POD SYSTEMS

The sensors have been organized by pod. A brief description of the sensors available in each pod is given in the following paragraphs. Table 3.1 provides a general summary of pod information. More detailed information is available upon request.

TABLE 3.1 - OVERVIEW OF AMPS SENSORS

POD 1 SYNTHETIC APERTURE RADAR (SAR) POD			
Sensor	**Waveband**	**Uses / Limitations**	**Data Output**
Synthetic Aperture Radar	Ku-Band	All Weather Day/Night Operation Requires Operators	1-3m Images Digital
POD 2 MULTISENSOR IMAGING (MSI) POD			
Sensor	**Waveband**	**Uses / Limitations**	**Data Output**
RC-20 Camera	Visible	High Quality Images Limited Film Onboard Requires Daylight	Film Images
IR-18 Thermal Imager	Infrared	Works Best at Night Radiometric	Thermal Images Heat Output
CASI Hyperspectral Camera	Visible NIR	Narrow Bands Limited Species ID	Spectral or Imagery
Multispectral Camera	Visible Infrared	Multiple Broad Bands	Images
Video	Visible	Real-Time Survey	Real-Time Images
Low-Light Video	Visible	Night Operation Only Medium Resolution	Real-Time Images
POD 3 EFFLUENT SPECIES IDENTIFICATION (EFI) POD			
Sensor	**Waveband**	**Uses / Limitations**	**Data Output**
Video	Visible	Survey and Aiming Requires Daylight Requires Operator	Real-Time Images
FLIR	3-5 Micron	Survey and Aiming Day/Night Operation Requires Daylight/Hot Source Requires Operator	Real-Time Images
ROMAC EGS	3-5 Micron	Effluent Species ID 1-2 km Standoff Requires Daylight/Hot Source	IR Spectrum
AC-ITMS	---	Effluent Species ID Requires Contact w/ Effluent	Mass Spectrum
R-TARAC	---	Real-Time Radionuclides Capture Organics Requires Contact w/ Effluent	Gamma Detection
Grab Sampler	---	Capture Noble Gases Requires Contact w/ Effluent	Lab Analysis

3.1 Synthetic Aperture Radar Pod (Pod # 1)

Synthetic Aperture Radar (SAR) is an airborne imaging sensor that transmits radio waves, senses the echoes reflected from the ground, and forms two-dimensional images similar in some ways to a photograph. Relative to more conventional radar, SAR systems create improved image resolution in the direction parallel to the flight track (along-track) by gathering and processing echoes from many pulses of the radar signal. These pulses are transmitted at well-defined points along the aircraft flight track; in essence, a very long antenna array is "synthesized" using an antenna of practical size by utilizing the aircraft's motion. Along-track image resolution is essentially constant regardless of how far a point in the image is from the aircraft. Image resolution in the direction perpendicular to the flight track (cross-track) is achieved by both the form of the transmitted pulse and through signal processing.

The Sandia SAR is capable of storing both the digitized, raw radar echoes (phase histories) and the formed imagery (magnitude and phase). SARs can produce images during day or night operation and under adverse weather conditions, such as through cloud cover or precipitation. As a result, radar images can be acquired when optical systems cannot be used. The SAR images are useful for a number of applications including verification, surveillance, and inventory of the earth's resources.

The SAR system being utilized for AMPS is capable of resolutions between one and three meters, which is somewhat better than currently available commercial systems. Sandia has been using a DeHavilland Twin Otter aircraft for development of a SAR system that is being transitioned, with minimal modification, into the pod environment for AMPS. In the pod configuration, the SAR will be side-looking, to the right of the aircraft, at depression angles from 15-70 degrees. Two operator stations and equipment racks have been installed in the RP-3A to support operation of the SAR system. A video camera is mounted next to the antenna to provide ground truth data for the system during clear, daylight conditions.

The Sandia SAR contains many components including a radar system, a signal processor, an inertial navigation system, a gimbal assembly, a data handling system, GPS, operator interface equipment, and a pilot's display. The subsystems are described in the references listed in the bibliography (See Bibliography, Appendix D, Sandia List, references 1 and 2).

The SAR contains an embedded keyed P-code GPS receiver. The SAR has unique requirements for Global Positioning Systems (GPS) capability relative to the other AMPS pods. SNL's GPS requirements are defined in the reference (See Bibliography, Appendix D, Sandia List, reference 3).

After initial calibration against well-defined corner reflector targets, the Sandia SAR is self-calibrating. The calibration can be verified periodically, when convenient, by flying the system against the calibrated corner reflector targets.

The Sandia SAR is comprised of research and development oriented, laboratory (prototype) quality hardware. There are two such systems in existence, each acting as a back-up for the other. The

original system is not owned by DOE; the second is owned, for the most part, by DOE Defense Programs (DP). The second system is targeted for use by AMPS as well as by other DOE and non-DOE projects; AMPS is considered a primary user of the systems. Use of the SAR system by projects other than AMPS will be negotiated with DOE/IS-20 to minimize negative programmatic impacts on AMPS, as well as on other users.

3.2 Multisensor Imaging Pod (Pod # 2)

All instrumentation in the Multisensor Imaging (MSI) Pod look nadir through windows and ports in the bottom of the pod. Each instrument is controlled by a switch panel, operated by a mission specialist. Time and data position is provided by dual Garmin GPS-100 units on-board the RP-3A aircraft. The position information is then linked into the MSI pod and recorded on tape. GPS time is manually set on a Society of Motion Picture and Television Engineers (SMPTE) time code generator. From the generator, time will be set by keyboard into the Daedalus/Compact Airborne Spectrographic Imager (CASI) and by switch into the video systems. The aircraft GPS will be used as a reference during ground setup. The videos will be linked together via a SMPTE Model 22 time code generator to a small video splitter box and into the Barr and Stroud recorder, Color Video Camera (CVC) recorder, and Low Light Level (LLL) recorder. The RC-20 time coding will be manually set from the generator. A RS-232 port from the Garmin GPS-100 aircraft unit will allow GPS/MSI Pod integration. A unit will be built to interface GPS data once per second to each subsystem with latitude, longitude, altitude, and time recording.

The sensors are described in the following paragraphs. Information on warranties, maintenance agreements, and calibration requirements for the MSI Pod are summarized in Appendix B, AMPS Equipment Ownership List .

3.2.1 Wild Heerbrugg RC-20 Large Format Camera

The RC-20 is a large format aerial camera used for mapping and general reconnaissance purposes. It utilizes film widths of 9 1/2 inches with film lengths of 400 feet. A useful image area of 9 X 9 inches per frame results in 420 high resolutions per roll.

Photography can be acquired at three-second intervals during flight which permits overlapping photographic coverage of the ground with aircraft speeds of 250 knots or slower at altitudes of 1,000 feet and above. Coverage of the ground can be as small as a 750-foot square area at a 1,000-foot altitude or a 21-mile square area at 43,000 feet.

Because of size limitations, The RC-20 can only utilize its 88mm focal length lens when it is in the pod. Optical filters may be used on the lens to control the spectral bandwidth reaching the film. Any color or black and white film can be used to fit specific mission requirements.

3.2.2 Barr & Stroud IR-18 Thermal Imager

The Barr & Stroud thermal imager is a passive thermal infrared sensor that is especially useful for nighttime reconnaissance of heat-generating targets. Operating much like a video camera, the imager is sensitive only to thermal infrared energy. It's lens is a dual, afocal germanium telescope offering 2.5X or 9X power options. The system is cooled by a Joule-Thompson gaseous nitrogen unit. Data acquired with the IR-18 is recorded with the TEAC V-80AB-F. This high resolution video recorder utilizes a Hi-8mm format which captures higher frequencies and bandwidths than those from a conventional VHS video recorder. Although this recorder is small and lightweight, its durable, front-loading design operates on unregulated 28 VDC, permitting aircraft or vehicular use.

3.2.3 CASI Hyperspectral Imager

The CASI is a passive, electro-optical imaging spectrometer. It is designed to detect and digitally record reflected visible and near-infrared electromagnetic energy in narrow wave bands. Sometimes referred to as a hyperspectral imager, this instrument can acquire data over spectral bands as narrow as 1.9 nanometers.

This "pushbroom imager" can detect an entire across-track row at one time. Spectral data for each scene element are dispersed across the second dimension of the Charge Coupled Device (CCD) detector. The system produces up to 288 spectral bands with 578 elements across the screen.

This system can be operated in an imaging or spectrometer mode. In the spectrometer mode, 288 spectra can be recorded for a small subset of scene elements. In the imaging mode, complete spatial coverage is obtained for user-selected sets of spectral bands. Adjacent spectral bands can be automatically summed to optimize signal strength.

Hyperspectral image data can prove useful for a wide range of target signatures and environmental monitoring applications. With this system, small spectral anomalies can be detected that might be otherwise masked within the broader bands of multispectral scanner systems.

3.2.4 First Generation Intensified Monochrome CCD Camera

The COHU 5560 is a highly sensitive, high resolution CCD camera designed for low level conditions. Using a first generation image intensifier which is fiber-optically coupled to the CCD image, the 5560 provides clear images in extremely limited light conditions. Employing a solid state CCD image sensor for increased durability, the 5560 is contained in a special environmental housing. It is primarily designed for nighttime use as it can be used to image targets under starlight conditions. Images are recorded with the TEAC V-80AB-F, the same high resolution video recorder used with the Barr & Stroud.

3.2.5 Sony DXC-750 3-CCD Video Camera

The DXC-750 3CCD video camera uses high resolution CCDs, each frame having 380,000 pixel elements. This low power consumption camera also has low lag and a high resistance to image burning with no deflection distortion. Electronic shutter options enable the camera to produce clear images in still or slow-motion playback even when the objects are moving at very high speeds.

Acquired data is recorded with the SONY DVR-2 Portable Digital Cassette Video Tele-Recorder (VTR). Utilizing a digital recorder removes dropouts which may occur with an analog system. This aspect, coupled with the recorder's light weight and durable design, makes the DVR-2 an ideal choice for specialized airborne operations.

3.2.6 Airborne Multispectral Scanner

The Daedalus 3600 Airborne Multispectral Scanner (AMS) system is a dual optical port multispectral scanner which simultaneously records up to six spectral channels directly onto 8mm digital tape. The AMS provides calibrated thermal information for the determination of radiometric temperature relationships for various remote sensing applications. The compact scan head and electronics can be installed in a wide range of aircraft using standard aerial camera ports and seat assemblies.

The standard sensor configuration offers a dual element thermal infrared detector and an 8-channel, visible/near infrared spectrometer so that a total of 10 spectral bands are available. Up to six of these bands may be selected for recording by the operator. An ultraviolet detector/dichroic assembly may be substituted for the spectrometer to expand system capabilities.

The system's built-in-test capabilities deliver a high level of confidence in mission success. An on-board image display provides a real-time check of flight line coverage and data quality. Data from the aircraft's navigation computer can be automatically inserted into housekeeping data via a built-in navigation interface.

The AMS collects data for such diverse applications as geological mapping, forest inventory, fire mapping, oil spill detection/mapping, and water chlorophyll studies.

3.3 Effluent Species Identification Pod (Pod # 3)

The purpose of the third pod is to field sensors that are capable of identifying the chemical species in airborne effluents. The initial sensor complement includes one stand-off optical sensor and three air samplers/analyzers. The pod is being designed with a modular sensor interface to permit sensor upgrade and change-out and to limit the number of invasive modifications to the aircraft. For example, sensor operation will be through a single wire ethernet control network. In addition, position and time data will be provided to the sensors from a GPS receiver in the fuselage for the geographic keying of the recorded data. The third pod represents a unique chance to field state-of-the-art instrumentation for performing high sensitivity chemical species measurements under the adverse field conditions of an airborne deployment platform.

3.3.1 Target Locating and Tracking Platform

A commercially available 14 inch diameter, externally mounted ball turret will be mounted on the front of the pod for use in target location and tracking. The Versatron system is equipped with 4-axis stabilization resulting in an ultra-stable viewing platform. At a minimum, the turret will be equipped with a video camera and autotracking system. Additional payload space is available to permit a FLIR imager, optical telescope, elastic backscatter lidar, or electronically wavelength tuned video camera to be co-boresighted with the video camera. Either a Mitsubishi 3-5 mm FLIR or a Westinghouse 8-12 mm MicroFLIR can be accommodated in the 14 inch turret. These additional sensors provide target characterization information and can be used in identifying high value targets. The integrated system can be used to compare the performance of and evaluate the complementary information provided by FLIR, or an elastic backscatter lidar with visual imagery in locating and characterizing effluent plumes. The turret also provides a basis for developing pointing and tracking capabilities to address the optical design issues associated with the long dwell times and off-nadir viewing requirements of the initial and future stand-off sensors in the pod.

3.3.2 Mid-Infrared High Resolution Spectrometer

The LLNL Echelle Grating Spectrometer (EGS) has been designed to detect trace levels of a broad range of chemicals in exhaust plumes by measuring the absorption of terrestrially reflected sunlight at high resolution in the infrared spectral region. The EGS instrument has no moving parts and was specifically designed for operation in mechanically stressing environments such as AMPS. The instrument incorporates a novel cross-dispersion design using a coarsely-ruled echelle grating combined with an achromatic prism doublet. The dispersed two-dimensional spectrum is focused onto a 320 x 256 element indium antimonide (InSb) infrared detector array. The present instrument is designed to operate from 2.0 to 4.2 microns in the mid-infrared at a spectral resolution of 0.1 cm^{-1}. Sunlight reflected from the ground along the line-of-sight is collected by a six inch diameter Cassegrainian telescope and coupled into the spectrometer through an infrared optical fiber bundle. The instrument is expected to be capable of measuring trace species in exhaust plumes at ppm levels at stand-off ranges of up to 10 km. The on-target measurement time required to achieve this level of performance will range from 10 to 60 seconds.

3.3.3 Air Concentrator/Mass Spectrometer

The Pacific Northwest Laboratories' (PNL) Air-Concentrator Ion Trap Mass Spectrometer (AC-ITMS) is an air-sampling mass spectrometer for use from an airborne platform. The instrument is based on an ion trap design which results in a system which is small, rugged, reliable, efficient, and capable of performing advanced mass spectroscopic techniques such as tandem mass spectrometry (MS/MS). Mass spectra up to 250 amu (extendible to > 650 amu) can be measured at better than unit mass resolution. A glow discharge ionization source is employed due to its long term ruggedness and high tolerance to high levels of oxygen and water vapor. Direct inlet sampling of the air stream permits real time measurement of a broad range of chemical species below ppb levels. Additionally, a sorbent-based concentration system is used to boost detection sensitivity for airborne organic compounds to sub-ppt levels. The discrete sampling throughput of the mass spectrometer system with the air concentrator is reduced to one sample every 30 seconds to 2 minutes, depending on the required concentration factor.

3.3.4 Airborne Radionuclide Detector

The PNL Real-Time Airborne Radionuclide Analyzer and Vapor Collector (R-TARAC) is an air sampling gamma ray spectrometer capable of measuring short-lived radionuclides in the atmosphere. Whole air is sampled at a rate of up to 10 m^3/min though a filter cartridge placed in front of a high sensitivity, large volume intrinsic germanium (IGe) detector to provide near real-time analysis of gamma-emitting radionuclides in the sampled air stream as they are being collected on the filter cartridge. The radionuclides are identified by their characteristic gamma-ray energies. A carousel mechanism is provided to exchange fresh cartridges and store sampled cartridges for subsequent analysis at a ground-based laboratory. Radon daughters, halogen radionuclides (organic and elemental radioiodines and radiobromines), and the daughter decay products of radioactive noble gases (e.g. ^{88}Rb, ^{91}Sr and ^{139}Ba) are examples of the types of radionuclides that the system is designed to detect. Initially, the system will have a capacity of 10 to 20 filter cartridges. The in-stream sampling time between cartridge exchanges can range from as short as 10 seconds to as long as several minutes.

3.3.5 Krypton Sampler

The Savannah River Technical Center (SRTC) Aerial Krypton Grab Sampler is a whole air sampler which selectively concentrates the noble gas fraction from the air stream for subsequent analysis of the ^{85}Kr concentration at a ground-based laboratory. The instrument is an extremely compact, rugged, modular system which samples and processes air at the rate of 10 liters/min. Molecular sieve cartridges are used to first remove water and carbon dioxide from the sampled air stream. The air is then pumped into a Mordenite zeolite sorbent bed cartridge where the noble gas fraction is selectively trapped. Solenoid valves automatically operate to close off and open each sorbent bed cartridge in succession. Approximately 10 minutes are required to process 100 liters of air per sample and the instrument is capable of collecting up to 12 discrete air samples. Post-mission laboratory analysis of the collected ^{85}Kr samples can be performed by radioactive decay counting or through mass spectrometric methods.

ON-LINE DETECTION OF RADIOACTIVE IONS SEPARATED BY CAPILLARY ELECTROPHORESIS

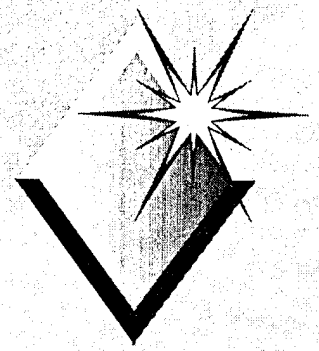
Gregory L. Klunder, John E. Andrews, Jr., Richard E. Russo, Pat Grant and Brian D. Andresen

Lawrence Livermore National Laboratory, P.O. Box 808 L-371, Livermore, CA 94550. (RER) Lawrence Berkeley Laboratory, M/S 90-2024, Berkeley, CA 94720.

Worldwide environmental interests have placed a great demand on developing techniques and instrumentation for characterization of contaminated soil, groundwater, and seawater. This workshop addresses one particular area of interest: the monitoring of nuclear contamination in the Arctic Seas. In our laboratory, we have been investigating the separation and detection of radioactive fission products.

Capillary electrophoresis is a relatively new and rapidly developing separation technique, which offers faster results with better resolution that previous methods such as high performance liquid chromatography (HPLC) and ion chromatography (IC). In CE, a potential (500V/cm) is applied across a fused silica capillary column (50 μm i.d.) which is filled with an electrolyte solution. An analyte sample (1-10 nl volume) is injected onto the column and the ions are separated according to their size and charge as they migrate through the column. The chemical composition of the running electrolytic buffer is very important for separating ions of similar mobilities. We are studying a number of buffer systems for an optimized separation of representative radioactive species, both cationic and anionic. An UV absorption detector which provide detection limits in the low ppm to ppb range is used for the mass detection.

Two on-line radioactivity detectors for CE are currently being investigated. An on-line scintillation detector coupled to a high gain photodiode light sensor has been designed and constructed in house. Several scintillator materials and reflective coatings are being tested. A CdTe semiconductor detector has been designed. Electropherograms showing separation of radioactive species of interest will be presented, along with a discussion of the detector design and performance.



On-Line Detection of Radioactive Ions Separated by Capillary Electrophoresis

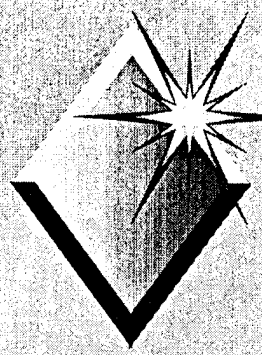
Greg Klunder

Brian Andresen

Pat Grant

Rick Russo

John Andrews



Applications for Radioactivity Detection in CE

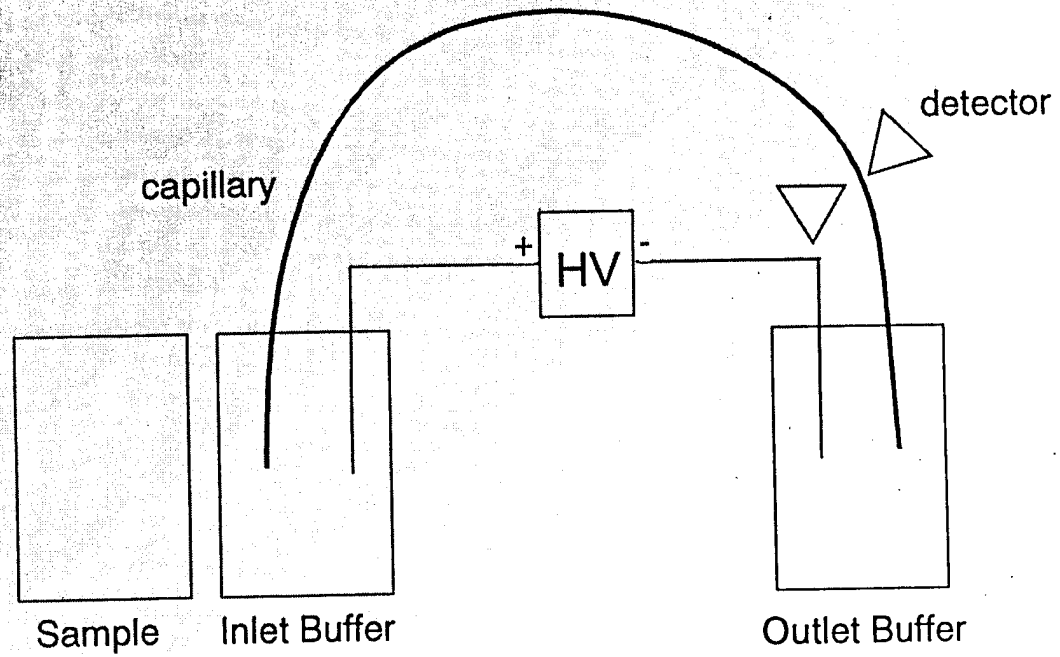
- Environmental monitoring
- Nuclear medicine/Radiopharmaceuticals
- Non-proliferation effluent samples
- Nuclear forensics

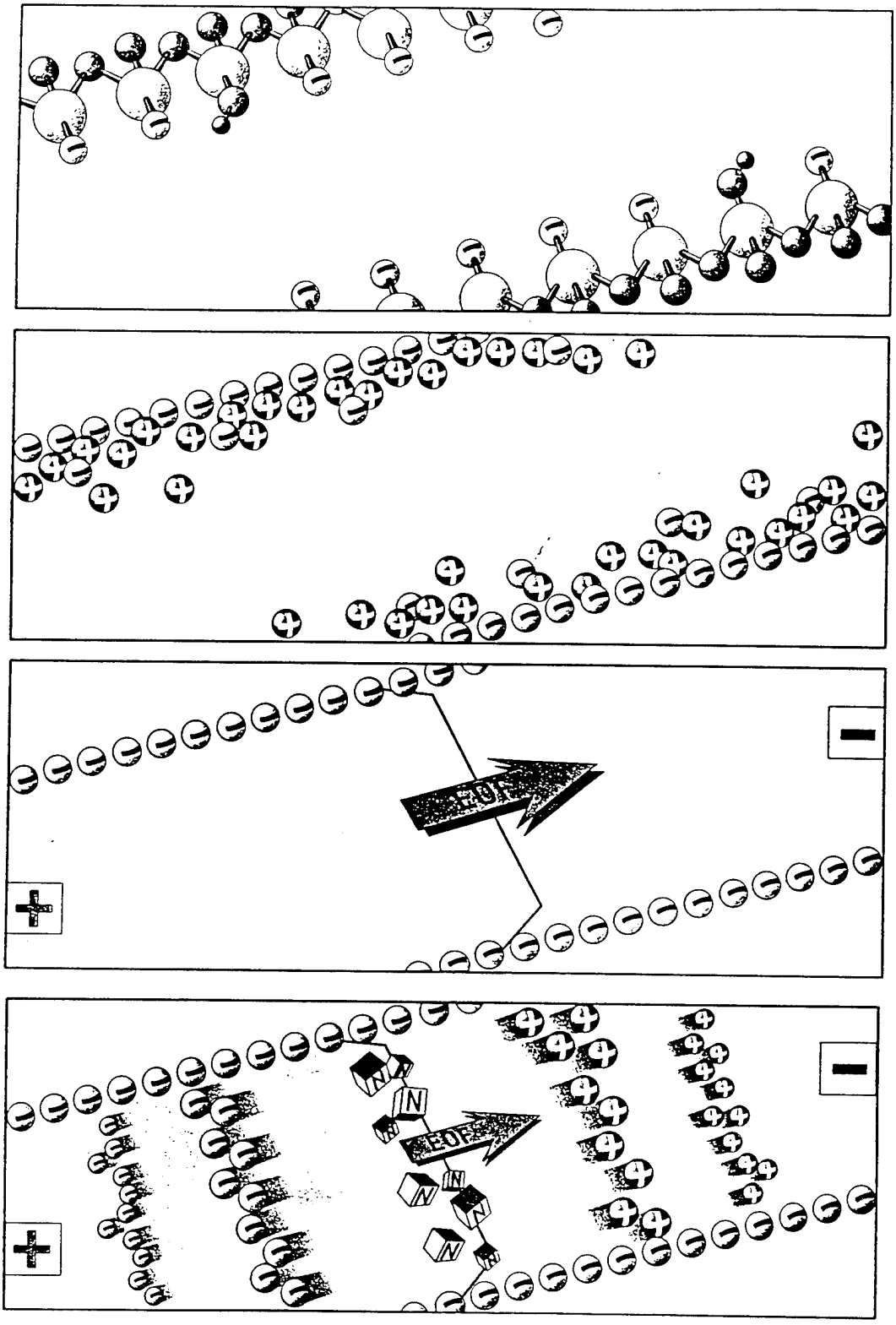


Capillary Electrophoresis

- Simple technique (separation by size and charge)
- Fast separations
- Small sample volumes
- Low detection limits
- Cation and anion analysis
- Fraction collection

Capillary Electrophoresis Schematic




EOF
EOF

Fission Products

Diverse half-lives, speciation, and environmental mobility

	Species	Nuclide	$t_{1/2}$
Cations:	Cs^{+}	134	2.06 y
		136	13.2 d
		137	30.2 y
	Ba^{2+}	140	13.0 d
	Sr^{2+}	89	51.0 d
		90	29.0 y
	Y^{3+}	91	58.0 d
	Sm^{3+}	151	90.0 y
Anions:	I^{-}	131	8.04-d
	RuO_4^{-}	103	39.0 d
	MoO_4^{2-}	99	2.75-d

BUFFER SYSTEMS

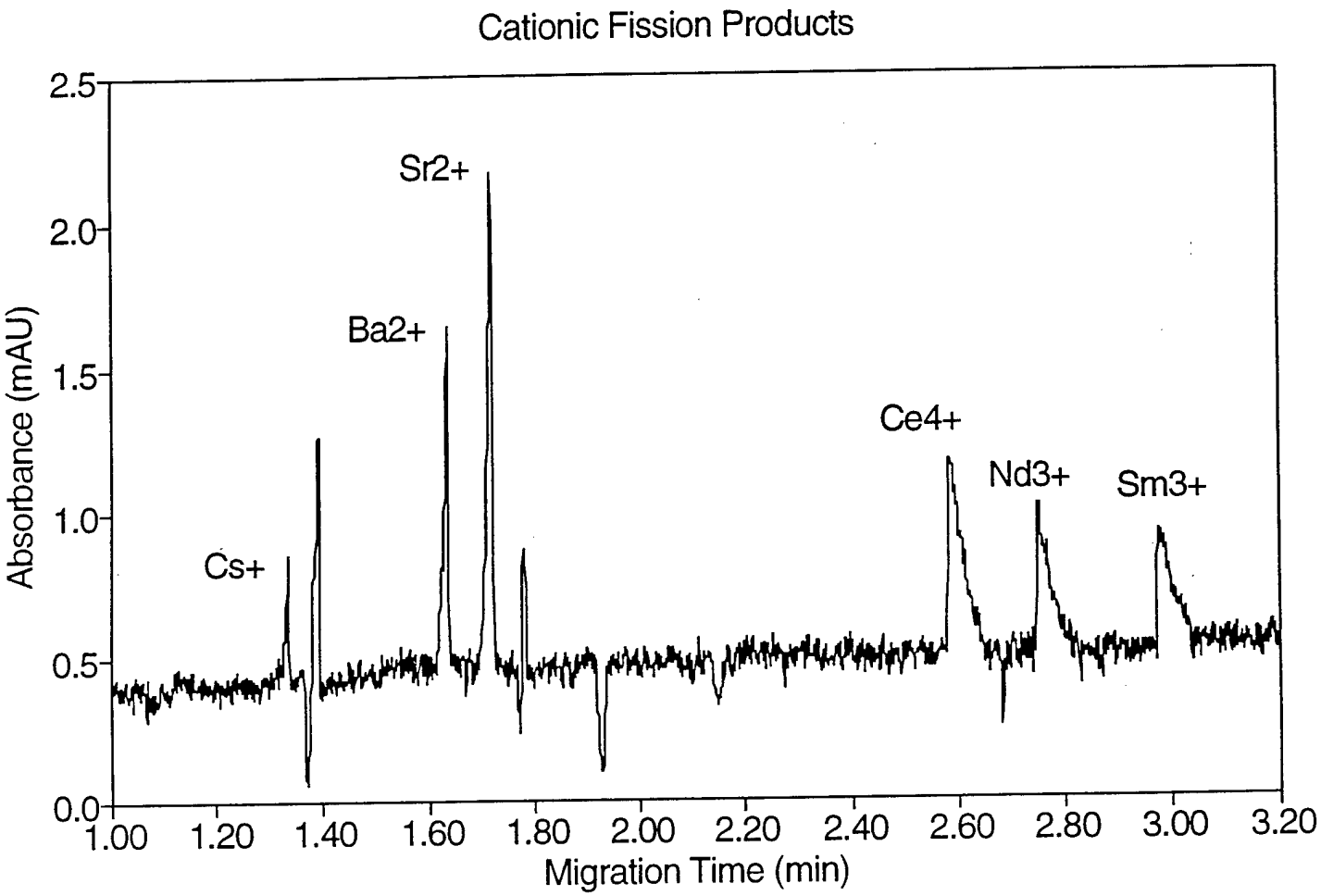
Cations

Background Electrolytes

Creatinine
Imidazole
Benzylamine
Pyridine
Ephedrine

Complexing Agents

α-HIBA
Citrate
Oxalate
Lactate
Acetate
Glycolate
Succinate


Cationic Fission Products
Absorbance (mAU)
2.5
2.0
1.5
1.0
0.5
0.0
Sr2+
Ba2+
Cs+
Ce4+
Nd3+
Sm3+
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
2.60
2.80
3.00
3.20
Migration Time (min)

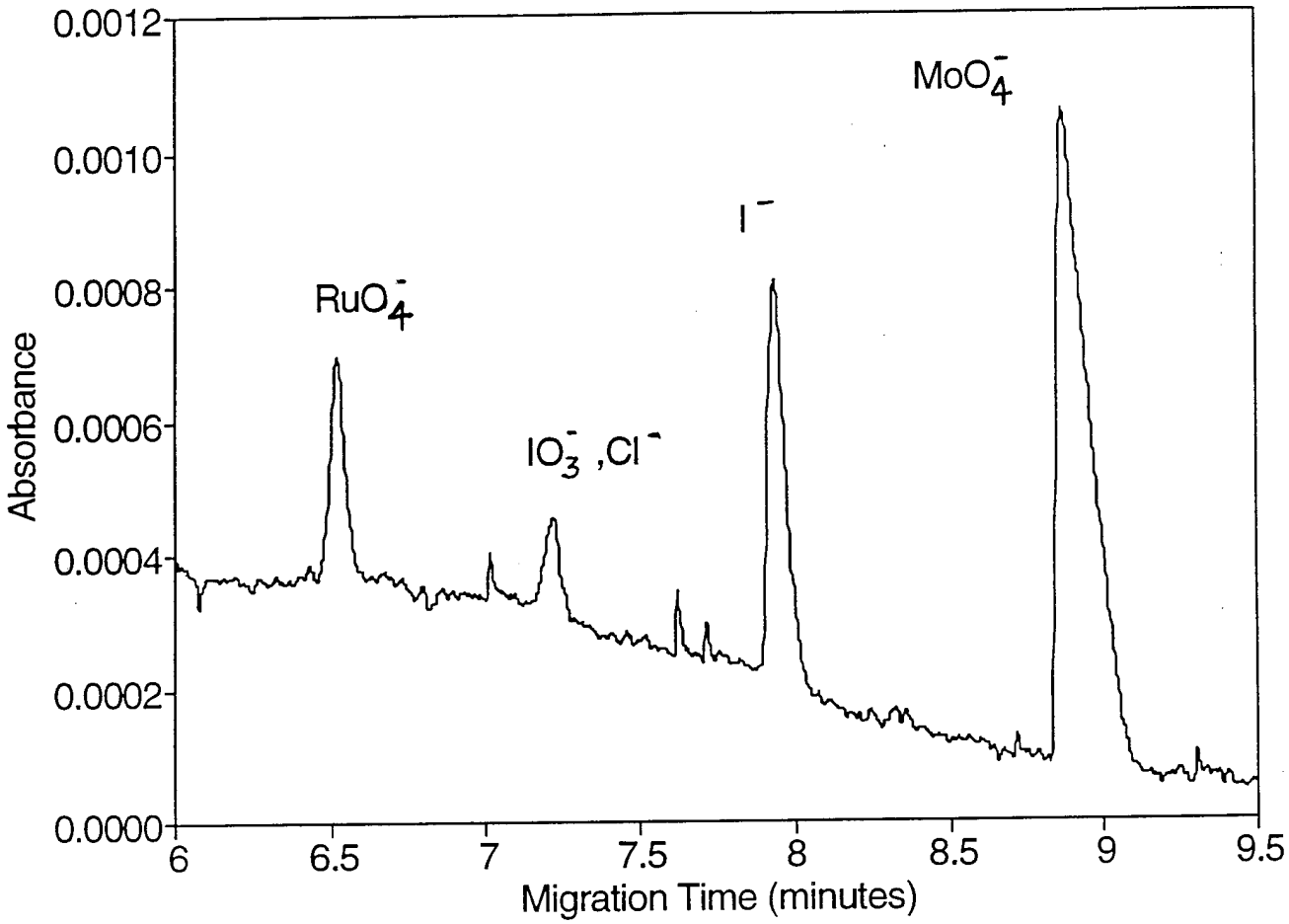
BUFFER SYSTEMS

Anions

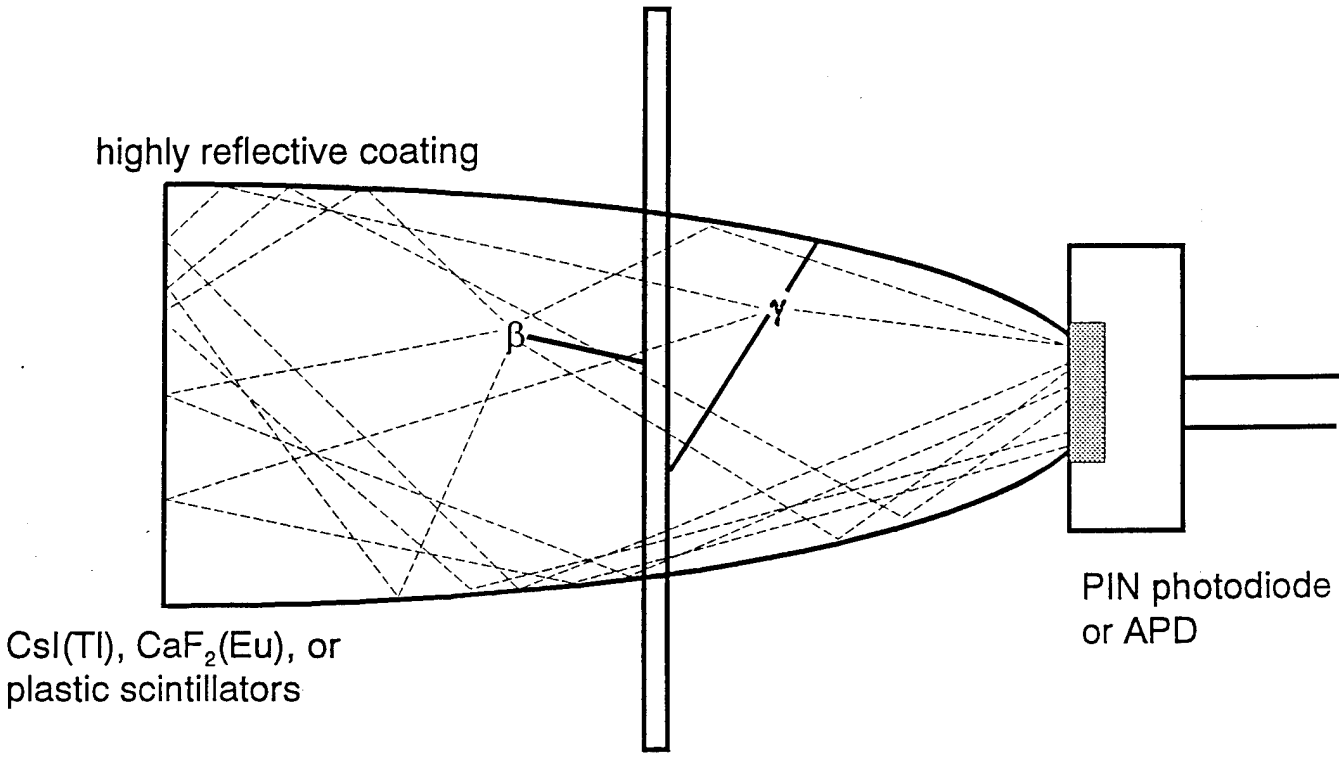
Electrolyte Buffers
Pyromellitic Acid
Phosphate
Tris
Borate
Chromate

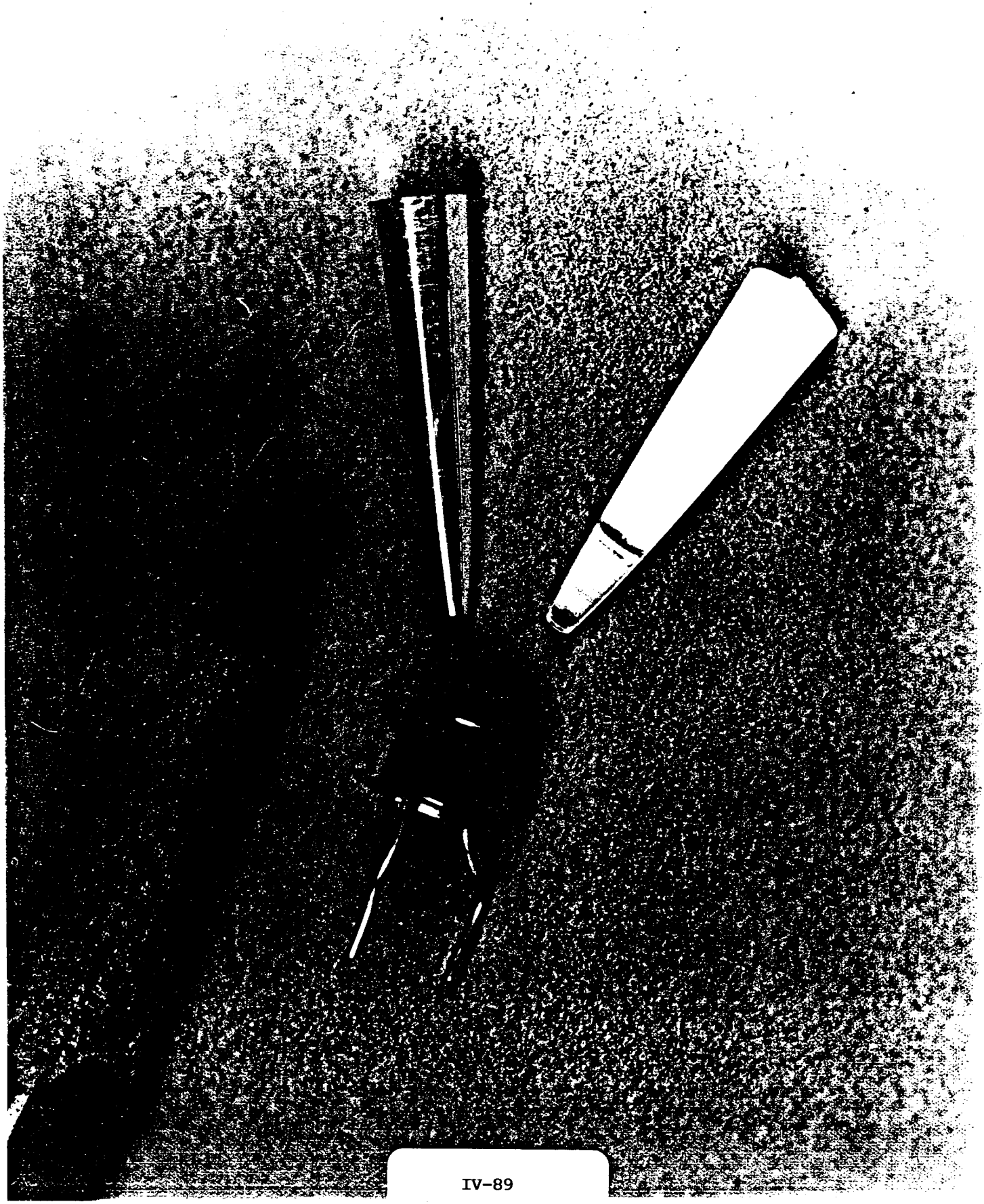
EOF Modifiers
TEA
SDS
CTAB
TTAB

Complexers
α–,β–,γ– cyclodextrins


0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
Absorbance
RuO_4^-
IO_3^- ,Cl^-
I^-
MoO_4^-
6
6.5
7
7.5
8
8.5
9
9.5
Migration Time (minutes)

Scintillation Detector for Capillary Electrophoresis





Estimated Limits of Detection

- Counting Efficiency (25%)
  - Collection efficiency (80%)
  - Conversion efficiency (45%)
  - Reflectivity (90%)
  - Quantum efficiency (70%)
- Statistics
  - 3 times background

ACTIVITY

$$\frac{dN}{dt} = -\lambda N$$

$$\lambda = \text{decay constant} = \frac{\ln 2}{t_{1/2}}$$

SPECIFIC ACTIVITY

$$\frac{\text{activity}}{\text{mass}} = \lambda \frac{A_V}{M}$$

RADIATION DETECTION LIMIT

25% efficiency relative to NaI(Tl)

$$\frac{4 \text{ disintegrations}}{1 \text{ detection}} \times \frac{2.7*10^{-11} \text{ Ci}}{\text{dps (Bq)}} \times 0.5 \text{ s} = 2.6*10^{-10} \text{ Ci}$$

e.g. ^{89}Sr $t_{1/2} = 50.5$ days

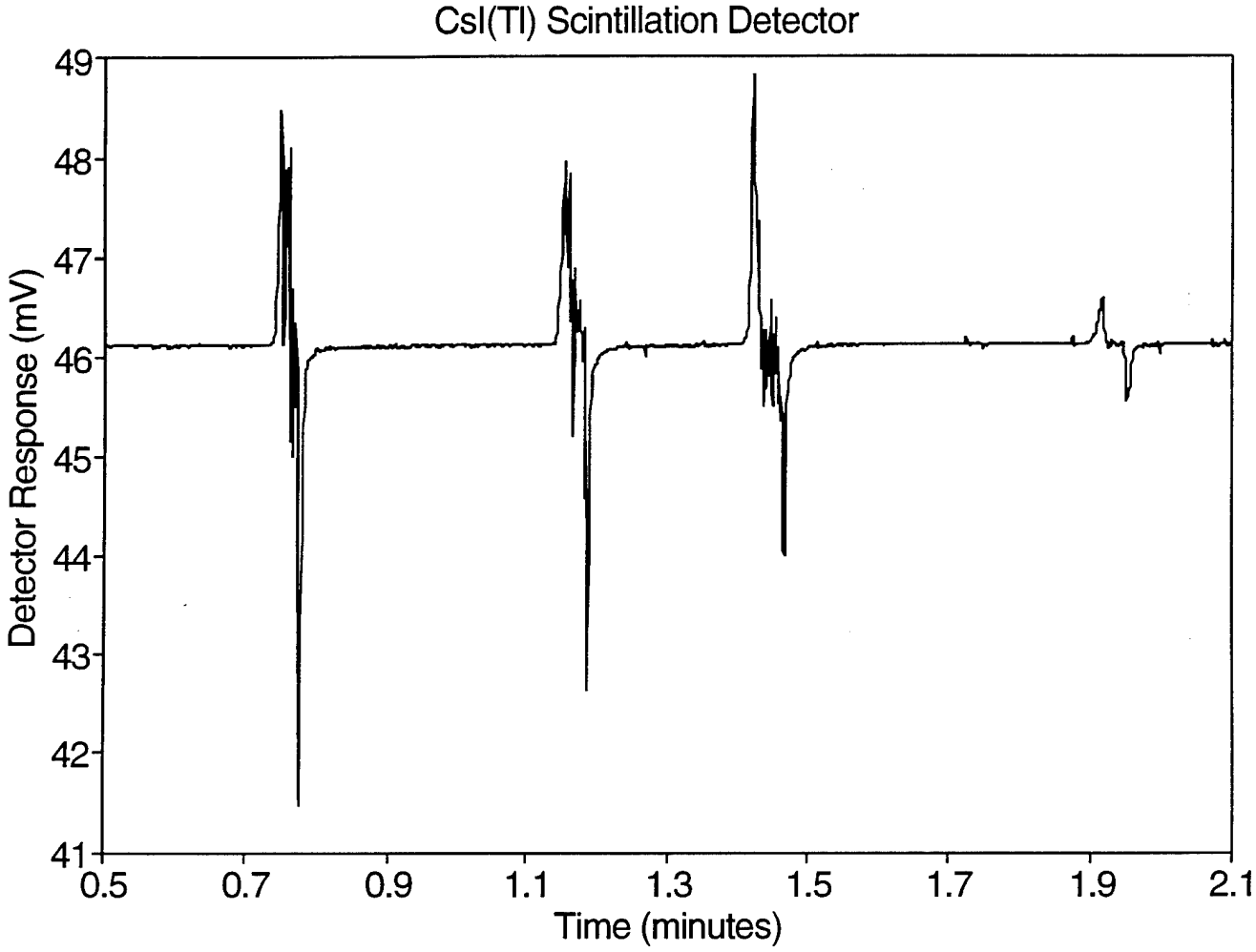
E(MeV) = 1.463

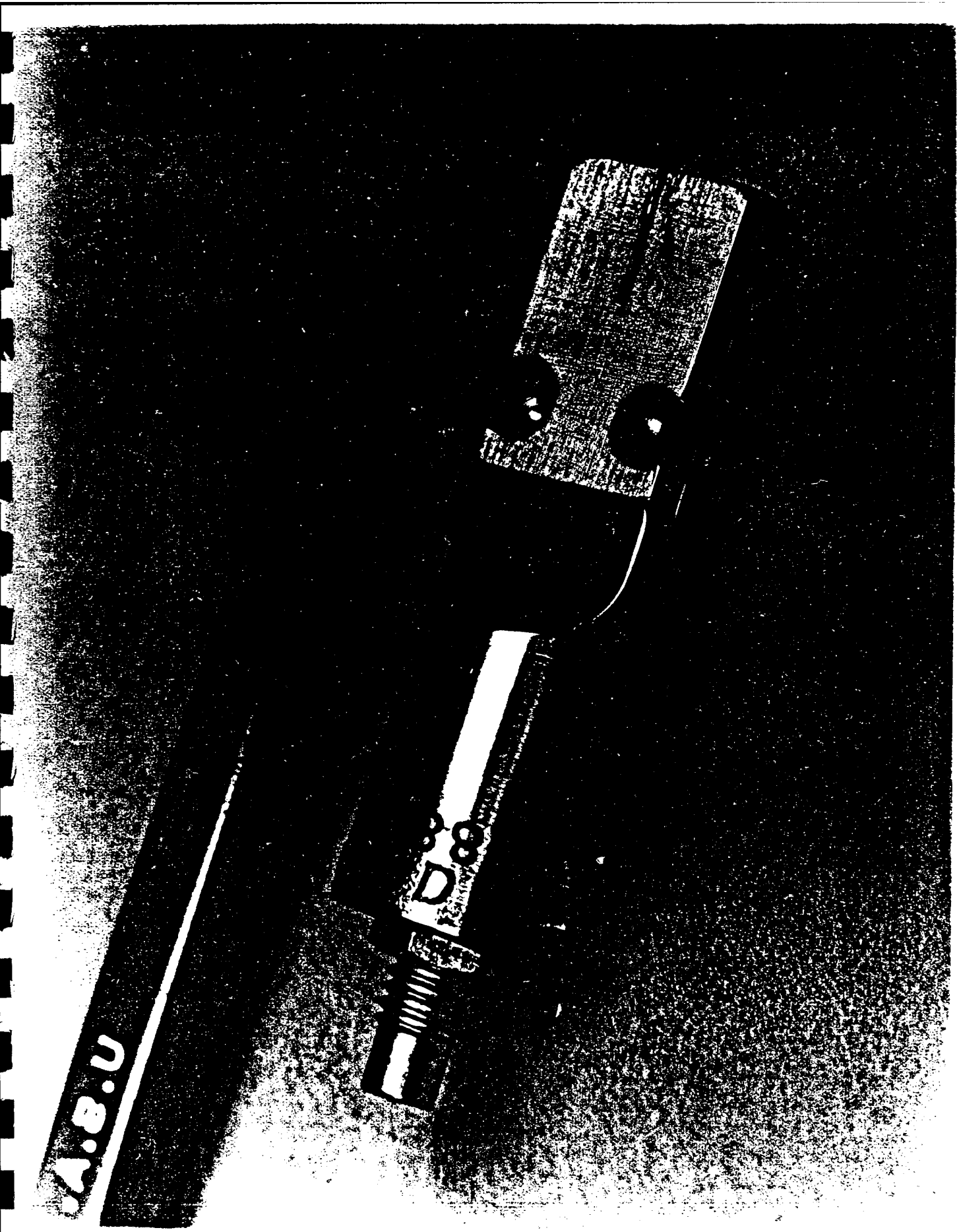
Specific Activity = $1.07*10^{15}$ Bq/g

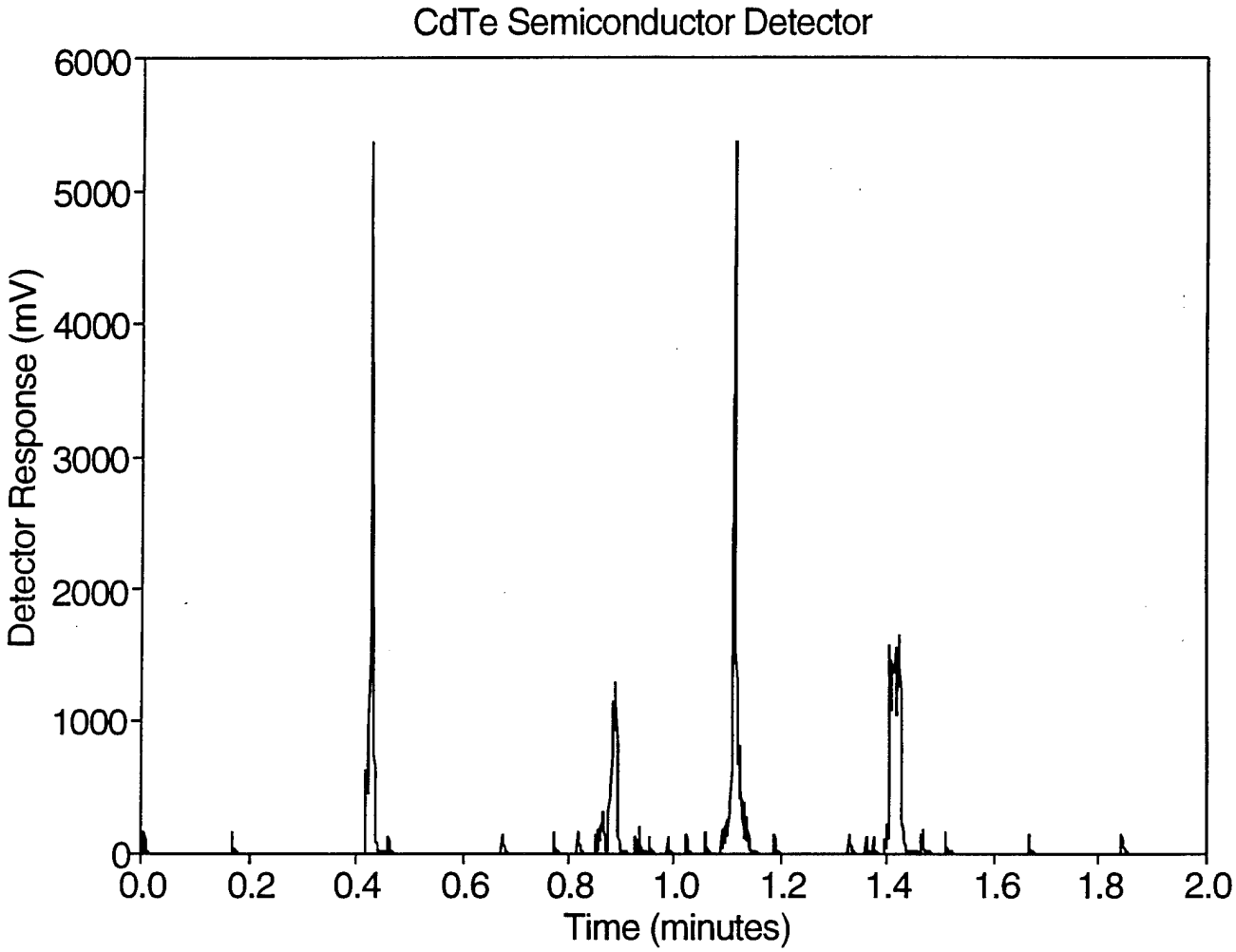
= $2.91*10^{4}$ Ci/g

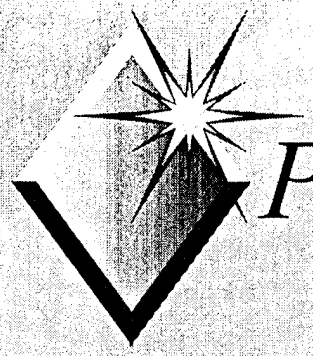
$8.36*10^{-17}$ g/detection

$9.40*10^{-19}$ moles


CsI(Tl) Scintillation Detector
Detector Response (mV)
49
48
47
46
45
44
43
42
41
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
Time (minutes)

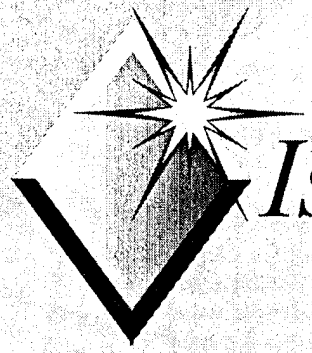

D8
A.B.U


CdTe Semiconductor Detector
Detector Response (mV)
6000
5000
4000
3000
2000
1000
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Time (minutes)



Preconcentration

- Ion-exchange beads
  - manual
  - milliliters to microliters
- Isotachophoresis
  - automated
  - microliters to nanoliters



Isotachophoresis

- Large bore capillaries (500μm)
- Large volume injections (50% column)
- Multiple fraction collection
- Preconcentration (1000 fold)

Acknowledgment

This work was funded by the U.S. Department of Energy, Office of Nonproliferation and National Security, NN-20.

MONITORING POINT SOURCES OF RADIOACTIVITY IN THE MARINE ENVIRONMENT: THE RUSSIAN SSBN YANKEE

(The *Hummingbird* Sampling System)

Principle Investigator:
Dr. Charles D. Hollister, Vice President and Senior Scientist
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
Phone: 508-289-2501
Fax: 508-457-2190

BACKGROUND

The environmental impact of radioactivity on the marine environment has been and continues to be a very controversial issue. Conjecture on this subject by environmental groups, especially Greenpeace, make international headlines usually under the banner of catastrophe or potential disaster and usually without scientific basis.

Carefully planned and executed monitoring expeditions to *Scorpion*, *Thresher*, and *Komsomolets* have, so far, failed to reveal any evidence to support these claims.[1]

Nevertheless the debate continues and the following program intends to add substantively to our understanding of the fate and effects of point sources of concentrated radioactivity on the ocean environment and its contained ecosystems.

Our strategy is to carefully study the *Yankee* site (500 miles east of Bermuda) which contains the single highest concentration of high level radioactive material found anywhere in the marine environment (32 nuclear warheads, 2 nuclear torpedoes, 2 old-dirty reactors).

---

[1] I.D. Spassky, International Symposium on the Discussion of Results of 1993 Expedition to SSN *Komsomolets* and on the working out of a common concept for further research held at Central Design Bureau for Marine Engineering Rubin, St. Petersburg, Russia, January 31 - February 2, 1994.

Richard B. Sheldon and John D. Michne, "Deep Sea Radiological Environmental Monitoring Conducted at the Site of the Nuclear-powered Submarine *Thresher* Sinking, Knolls Atomic Power Laboratory, Schenectady, New York, KAPL-4748.

Richard B. Sheldon and John D. Michne, "Deep Sea Radiological Environmental Monitoring Conducted at the Site of the Nuclear-powered Submarine *Scorpion* Sinking, Knolls Atomic Power Laboratory, Schenectady, New York, KAPL-4749.

Hugh D. Livingston (ed), "Proceedings of the conference Radioactivity and Environmental Security in the Oceans: New Research and Policy Priorities in the Arctic and North Atlantic, June 7-9, 1993, Woods Hole Oceanographic Institution, Woods Hole, MA.

I. Objective

To sample the most recent (age of years to decades) sediment deposited within cm to m of point sources of radioactivity.

Central to the problem of monitoring toxicity in the marine environment is sampling techniques. Sampling radioactive and other toxic cation metal species with fractionation (to sediment) coefficients of 10^3 or greater is an intrinsic problem of sampling the surficial "fluff layer." The sediment in the immediate vicinity of the source is the most likely place for adsorbing species to accumulate. Thus, precise sampling of this layer will allow prediction of release rates of these species which is essential for credible dosimetry.

II. The Problem

We are not now able to precisely sample the mm scale deposits that have accumulated against or on top of point sources of toxic material now resting on the sea floor. Most of these sources have been on the bottom of order 10s of years or less and most marine rates of sediment accumulation are measured in cm per thousand years. Thus the amount of material (the "fluff layer") that has settled near these sources since they were dumped is only of order mm or less in thickness and even the most precise of our modern sea floor core-type samplers "blow" away the upper "fluff layer" during the sampling process. Thus it is entirely conceivable that "we" have been trying to measure toxicity of sediment that is much older than the arrival date of the sources of contamination.

III. Approach

We propose to build a suction type "***Hummingbird***" sampler as a modification to a tethered ROV (JASON). The JASON platform has all the necessary capabilities for such work in addition we would add very high resolution cameras to JASON such that the sampling probe be visually "ground truthed" as to precise location of each sample vis-a-vis the source (read warhead and fuel rods).

Great care must be taken such that the ROV propulsion system not blow away this "fluff layer" before the sucker can sample. The eyeball for "ground truthing" the systems effectiveness will be done by a high resolution video cameras. Naturally the JASON and Hummingbird modifications would have to be dock side tested and then tested in deep water.

IV. How Results Will Help Guide Monitoring and Assessment

The release rate of toxic material into the environment from point sources is the basis for dosimetry, without which the impact of toxic materials in the environment cannot be predicted. Accurate determination of concentration gradients from the source is generally done using measurements of the amount of toxic material adsorbed onto particles because the difficulties of assessing dissolved ion concentrations, to obtain reliable gradients in a turbulent marine environment, is nearly impossible.

The challenge is one of multiple sampling very small areas, next to the source in a precise, non-disruptive way using the human eye (via video link) to know where and how well each sample was taken.

V. Other Applications

This sampler has broader applications than the monitoring of toxic materials. The ***Hummingbird*** system will be very useful for precise sampling and fine scale microphysiography of surface features, for geochemistry, micro-acoustics, vent systems and micro-organism identification and capture.

THE *YANKEE* SITE

The submarine sank in a region of the deep return flow of the Gulf Stream in the western north Atlantic gyre and although currents have not been measured near the bottom in this location, archival data suggests that there may be a possibility for a westward flow of water and suspended particles from the region of sinking toward Bermuda and eastern U.S.A. (see attached figures)

Data[2] suggests that large sediment drifts have been constructed down current or west of this site in the past and the question remains as to how fast and how recent this mud has been deposited. If there is any leakage of nuclear material (especially plutonium) from the submarine's reactors/weapons it will probably affix itself onto sediment particles and move with the currents at a concentration, direction and speed that we will determine from this proposed experiment.

We intend to deploy current meters and nephelometers in an array surrounding the submarine's debris field and to recover them at the end of the field working order to give us the boundary conditions on the "near field" of leaked radioactive material affixed to particles.

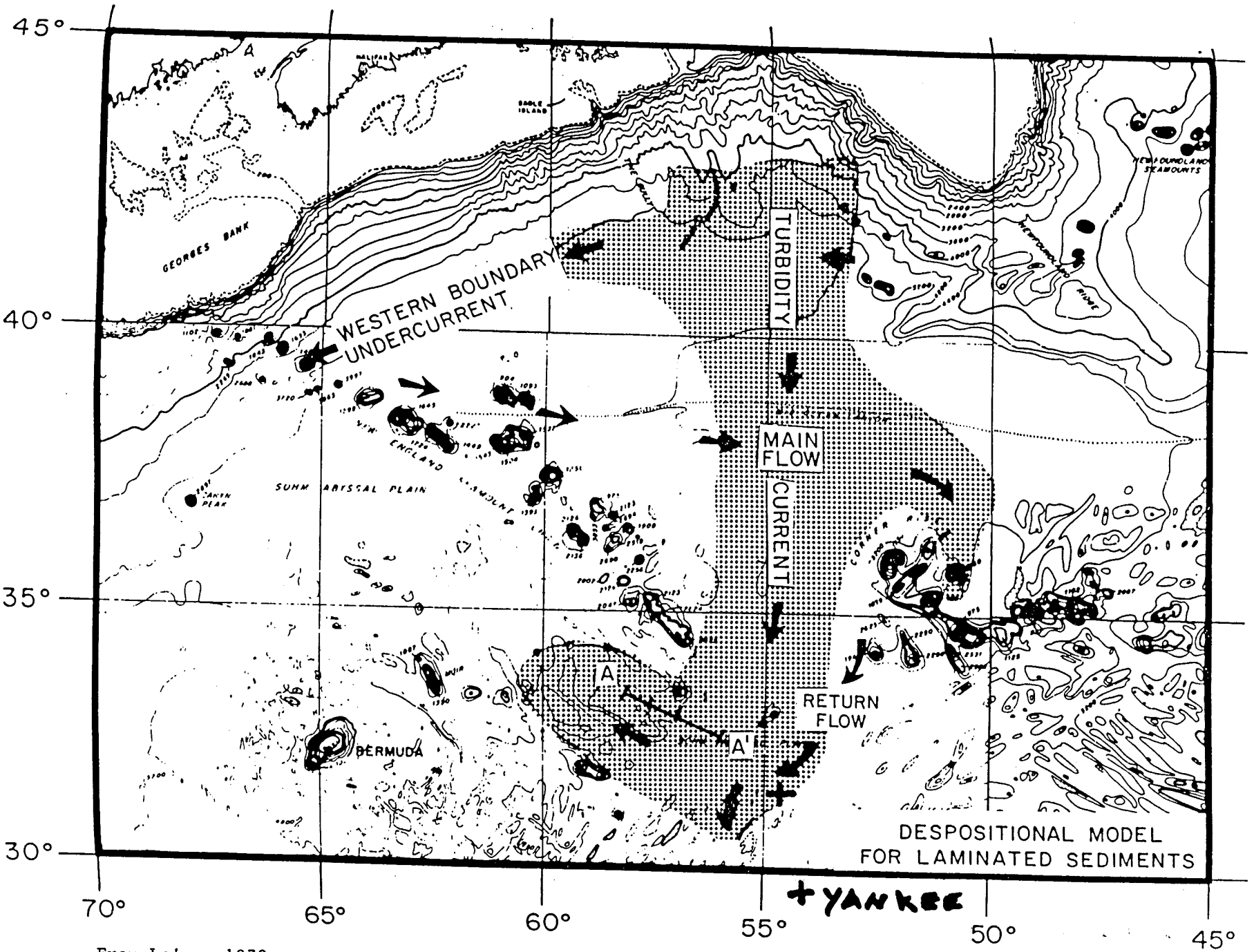
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[2] E. Laine and C. Hollister, Geologic Effects of the Gulf Stream on the Northern Bermuda Rise, Marine Geology, 39:277-310, 1981.

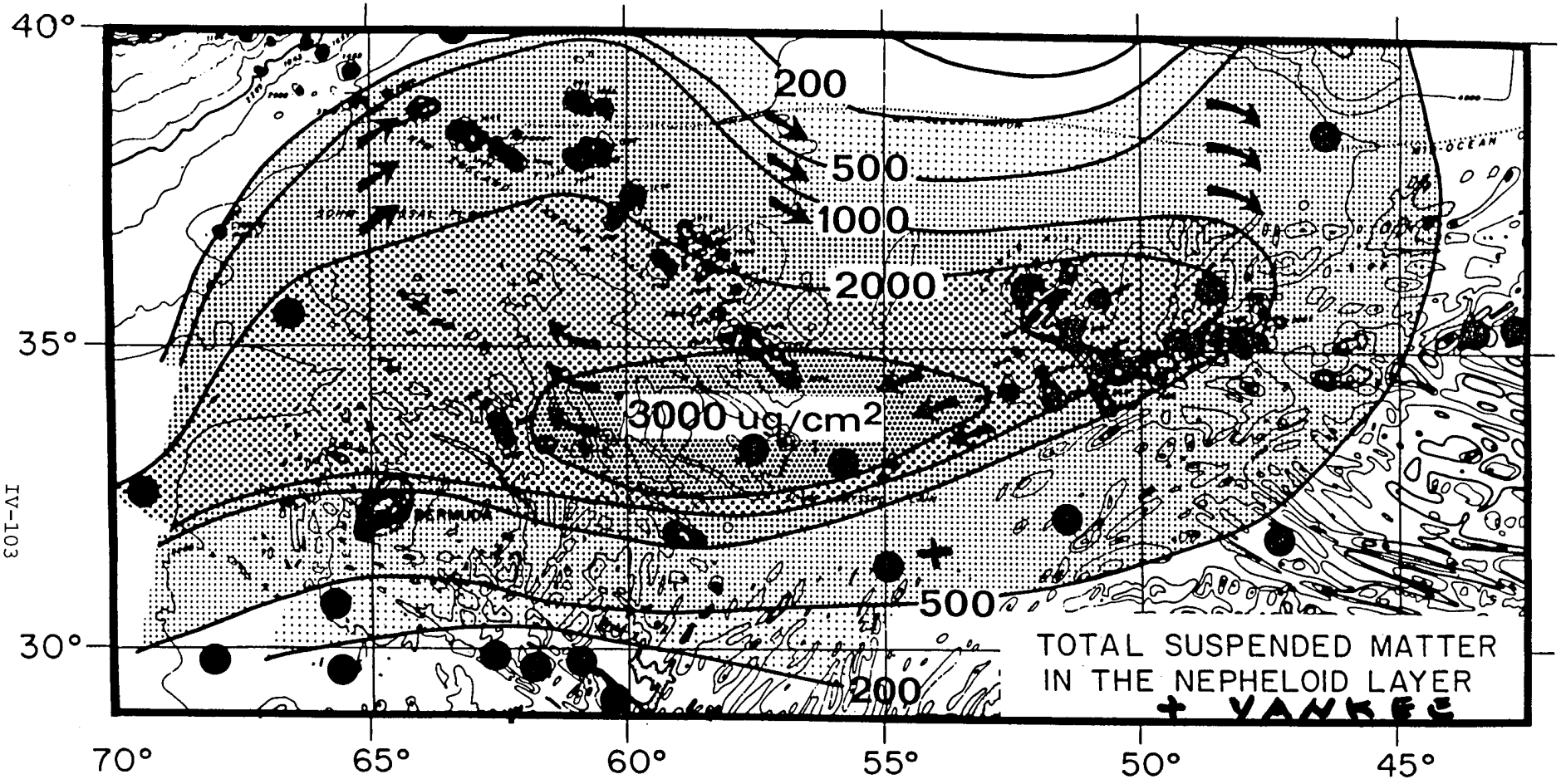
Since the Russians recently revealed the magnitude of their dumping of reactors and other radioactive waste onto the ocean floor particularly in the Arctic (Table 1), there has been an elevated concern about possible radiological impact of this activity. Much money and press have been focused on this particular issue. Regardless of this, the largest amount of high level radiological material, accidentally or on purpose, deposited in the marine environment, is the *Yankee* off Bermuda which has never been studied!.

There have been numerous expeditions to the Arctic, Kara and Barents Sea, looking for direct evidence of contamination from the materials that have been dumping in that region.[3] No evidence of contamination at dangerous levels have so far been obtained. The *Yankee* represents a much stronger signal and a much more important place to assess impact of radiation on the biofauna of the ocean floor and is an excellent place to determine what, if any environmental impact this material has on the marine environment.

[3] Lars Foyn and Alexander Nikitin, "Cruise Report of the Joint Norwegian/Russian Expedition to the Dump Sites for Radioactive Waste in the Abrosimov Fjord and the Stepovogo Fjord, August-September 1994.



From Laine, 1978.



From Laine, 1978.

A Very Rough Estimate of Point Sources of Nuclear Material on the Sea Floor

Compiled by C.D. Hollister/WHOI

A) Nuclear Weapons (50 ea.) and Reactors (9 ea.) Lost in the Deep Ocean

Date (m/d/y)	Est. of Nuclear Devices	Reactors w/ Fuel	Description
3/10/56	2		A U.S. Air Force B-47 bomber carrying two capsules of nuclear materials for nuclear bombs, en route from MacDill AFB, Florida, to Europe, fails to meet its aerial refueling plane over the Mediterranean Sea. An extensive search fails to locate any traces of the missing aircraft or crew.
4/18/59			The U.S. Navy dumps the sodium-cooled liquid metal reactor vessel and the reactor plant components of the USS Seawolf into 9,000 feet of water about 120 miles off the Delaware–Maryland coast in the Atlantic Ocean.
6/4/62	1		A nuclear test device atop a Thor rocket booster falls into the Pacific Ocean near Johnston Island after the rocket has to be destroyed as part of the United States' first high altitude atmospheric nuclear test attempt.
6/20/62	1		A second attempt to detonate a nuclear device in the atmosphere fails when a Thor booster is destroyed over Johnston Island, and the nuclear device falls into the Pacific Ocean.

Date (m/d/y)	Est. # of Nuclear Devices	# w/ Fuel	Description
4/10/63		1	The USS Thresher implodes and sinks 100 miles east of Cape Cod, Massachusetts, in approx. 8,500 feet of water.
12/5/65	1		An A-4E Skyhawk attack jet loaded with a B43 nuclear bomb rolls off an elevator of the aircraft carrier USS Ticonderoga and sinks in 16,000 ft. of water about 250 miles south of Kyushu Island.
4/11/68	5	2	A Soviet Golf class ballistic missile submarine with three SS-N-5 missiles and probably two nuclear torpedoes sinks in the Pacific, about 750 miles northwest of the island of Oahu, Hawaii.
5/21–27 /68	2	1	The USS Scorpion sinks 400 miles southwest of the Azores in more than 10,000 feet of water. The ship was reportedly carrying two ASTOR nuclear torpedoes.

Compiled by C.D. Hollister/WHOI

Date (m/d/y)	Est. # of Nuclear Devices	Reactors w/ Fuel	Description
4/12/70	2	2	A Soviet November class nuclear-powered attack submarine experiences a nuclear propulsion casualty while operating in heavy seas approx. 300 naut. miles northwest of Spain. After failing to rig a tow line to a Soviet bloc merchant ship which was standing nearby, the submarine apparently sank. The submarine was probably carrying two nuclear torpedoes.
10/6/86	34	2	A Soviet Yankee I class nuclear-powered ballistic missile submarine with 16 SS-N-6 multiple warhead missiles and probably two nuclear torpedoes sinks 500 miles east of Bermuda. A fire and explosion, originating in the liquid fuel of a ballistic missile on 3 October, led to the sinking.
4/7/89	2	1	A Soviet Mike class nuclear-powered submarine with cruise missiles and 2 nuclear torpedoes sank in 1670 meters of water 118 miles SW of Norway's Bear Island. A fire in a stern compartment led to the sinking.
Totals	**50 (45 Soviet weapons)**	**9**	

Compiled by S.D. Hollister/WHO

B) Reactors (22 ea.) on the Shallow Sea Floor of the Eastern Arctic

Date (year)	Reactors w/o Fuel	Reactors w/ Fuel	Description
1965–66	5	3	Four submarine reactor compartments (5 w/o fuel, 3 w/fuel) dumped in Abrosimov Gulf, location: 71°56'N, 55°21'E, depth 20-40 meters.
1967		1	Atomic icebreaker *Lenin* dumped at 74°21' N, 58°42' E in Sivolky Gulf at depth of 50 meters.
1967	3		Three reactors w/o fuel from atomic icebreaker *Lenin* dumped at 74°26' N, 58°37' E in Sivolky Gulf at depth of 50 meters.
1972		1	Barge with reactor from submarine dumped at 72°40' N, 58°10' E at depth of 300 meters in open Kara Sea.
1982		2	Atomic submarine K-27 after emergency dumped at 72°31' N, 55°34' E at depth of 50 meters in Stepovov Gulf.
1988	1		One reactor w/o fuel dumped at 75°59' N, 66°18' E at depth of 50 m in Techeniya Gulf.
1960–70		2	Submarine reactor section disposed of Eastern Barents Sea.
1960–70		4	Four reactors disposed in Eastern Barents Sea.
Totals	***9***	***13***	

Compiled by C.D. Hollister/WHOI

C) Nuclear Non-Reactor Waste Dumping by Russia near Novaya Zemlya

Date (year)	***Description***
1964–90	11,000-17,000 waste containers off E. coast of Novaya Zemlya, approximately 2,272,060 GBq (61,407 ci) *(37 GBq = 1 curie).*
1961–90	165,000 cubic meters liquid waste in Barents Sea west of Novaya Zemlya, approximately 490,795 GBq (13,264 ci).

For rough comparisons:
Chernobyl = 86 million ci; of which about 6 million ci of Cs-137 with 30 year half life; total of all bomb fallout is 34 million ci Cs-137; one large power reactor contains order 10 million ci of Cs-137.

Compiled by C.D. Hollister/WHOI

NEW DETECTORS FOR MONITORING

Steven E. King, Gary W. Phillips, and Robert A. August
Code 6616
Naval Research Laboratory
Washington, DC 20375

Ulf R. Aakenes
Oceanor
Pir-Senteret
N-7005 Trondheim, Norway

Robert C. Mania
Division of Math and Sciences
Kentucky State University
Frankfort, KY 40601

Abstract:

Recent advances in gamma-ray sensor technology have opened a new opportunity for improving the capabilities of in-situ measurements of environmental radiation in the marine environment. The goal is to determine the most suitable sensor system for long term monitoring of radioactivity areas such as the Kara Sea, Ob and Yenisey Rivers. Parameters of importance for monitoring are power consumption, ruggedness, energy resolution, detector efficiency, background rejection and overall sensitivity. The approach has been to obtain devices from commercial detector manufacturers packaged in rugged, waterproof housings for evaluation. Semiconducting radiation detectors such as CdZnTe, GaAs or hybrid detectors using semiconducting photodiodes offer potential advantages in energy resolution, power consumption and lack of sensitivity to magnetic fields. In addition, the performance of the Oceanor RADAM NaI sensor will be presented. The Oceanor sensor is packaged with both analog and digital electronics including multichannel analyzer and communication capabilities. The present status of this evaluation is discussed.

NEW DETECTORS FOR MONITORING

Steven E. King

Naval Research Laboratory

Outline

- Advances in NaI Sensors
- Semiconducting radiation detectors
- GaAs Research

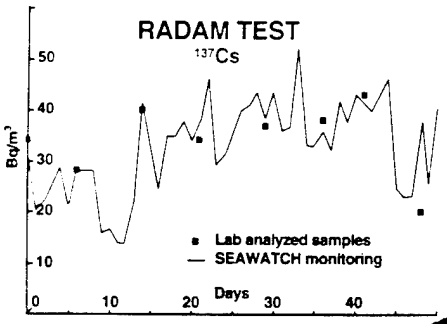
Researchers

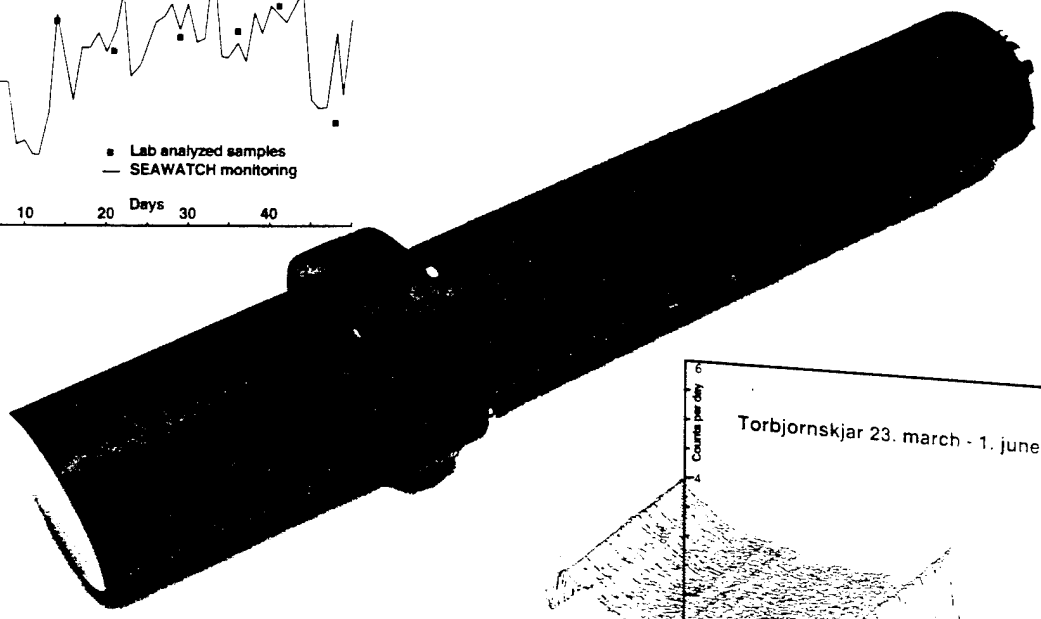
- U.R. Aakenes
  Oceanor, Norway
- R.A. August, G.W. Phillips
  NRL
- R.C. Mania
  Kentucky State U.

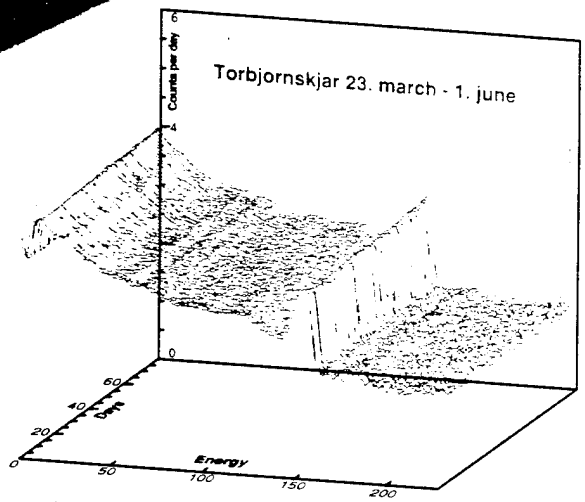
Opportunity

- NaI - Advances in ruggedization, electronics and power
- Semiconducting Detector Potential
  - » Better resolution
  - » Lower power consumption
  - » Compactness
  - » Ruggedness
  - » Stability

RADAM







3-D plot of RADAM spectra

Sea and onshore radioactivity sensor with spectrometer.

Possible pollution from nuclear powered vessels, power plants, test sites and waste deposits increase the need for radioactivity surveillance. *RADAM* is developed to provide accurate and updated information about radioactivity in the environment, whether on land or in water.

RADAM is a 3"x3" NaI scintillator with a 1024 channel analyzerattached to the miniatyrized *GENI* computer with communication link, all assembled within the same robust housing. The internal temperature is measured, and a gain control loop eliminates temperature drift in the spectrum.

General specifications

Input voltage:	11 - 33V
Power consumption:	1W
Container tube:	Pom
Overall length:	58 cm
Overall diameter:	12 cm
Depth	on request

Operational alternatives

Moored or drifting buoys
Standalone sea/land unit
Vertical/horizontal profiling

Gamma ray sensor

3"x3" NaI scintillator
Resolution at 662 KeV: 7%
Energies from 50 KeV
Spectral presentations of energies between 50-3500 KeV

Detection limit of ^{137}Cs, with 95% level of confidence:
24 hrs. observ. period: 19 Bq/m^3
7 days observ. period: 7 Bq/m^3
30 days observ. period: 4 Bq/m^3

Processing unit

GENI miniatyrized computer
Analyzer with temperature controlled gain compensation
Analyzing software
Graphical presentation software
Communication software

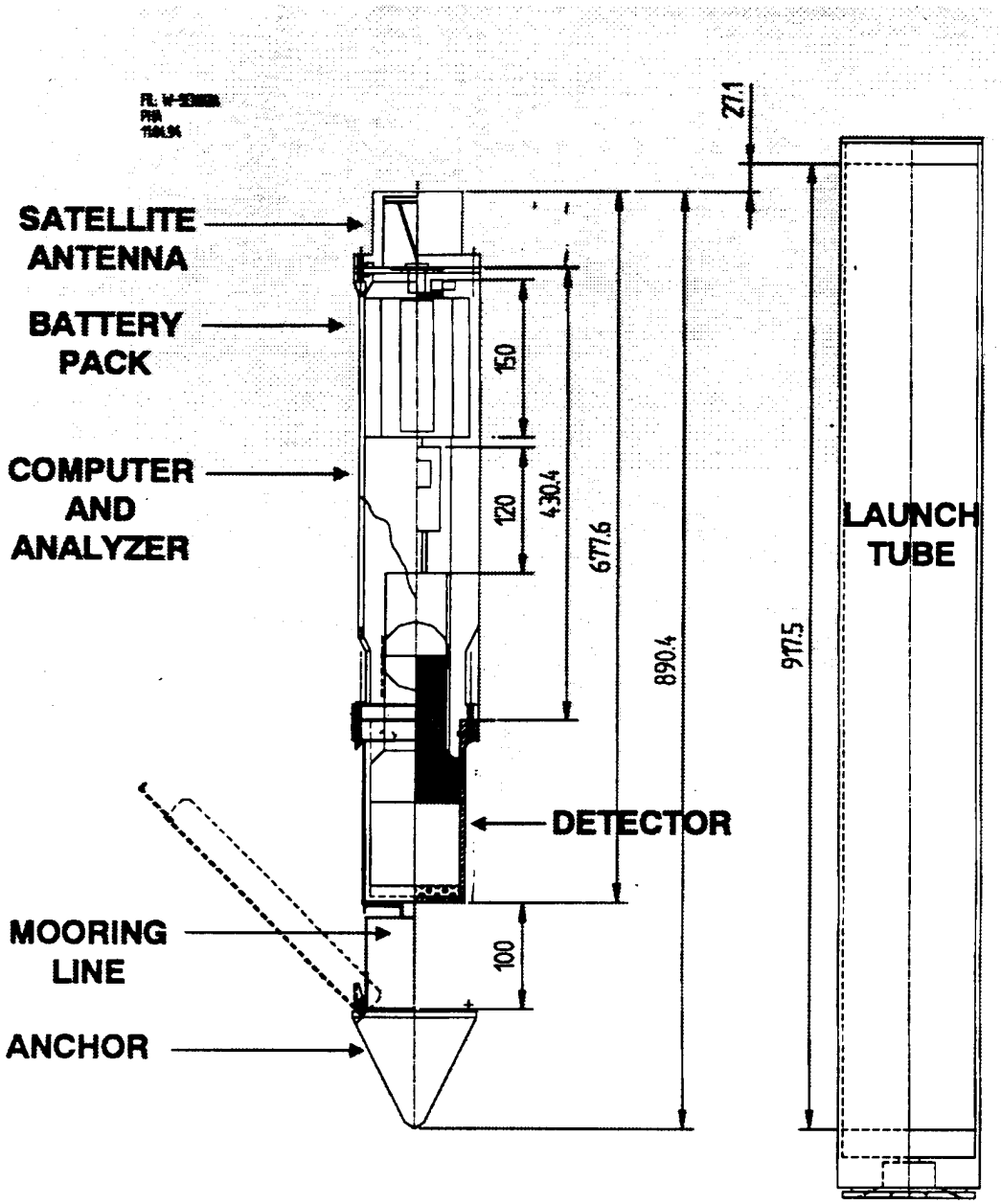
Communication

ARGOS / INMARSAT
UHF / VHF
Fixed or mobile telephone
RS 232 / RS 485

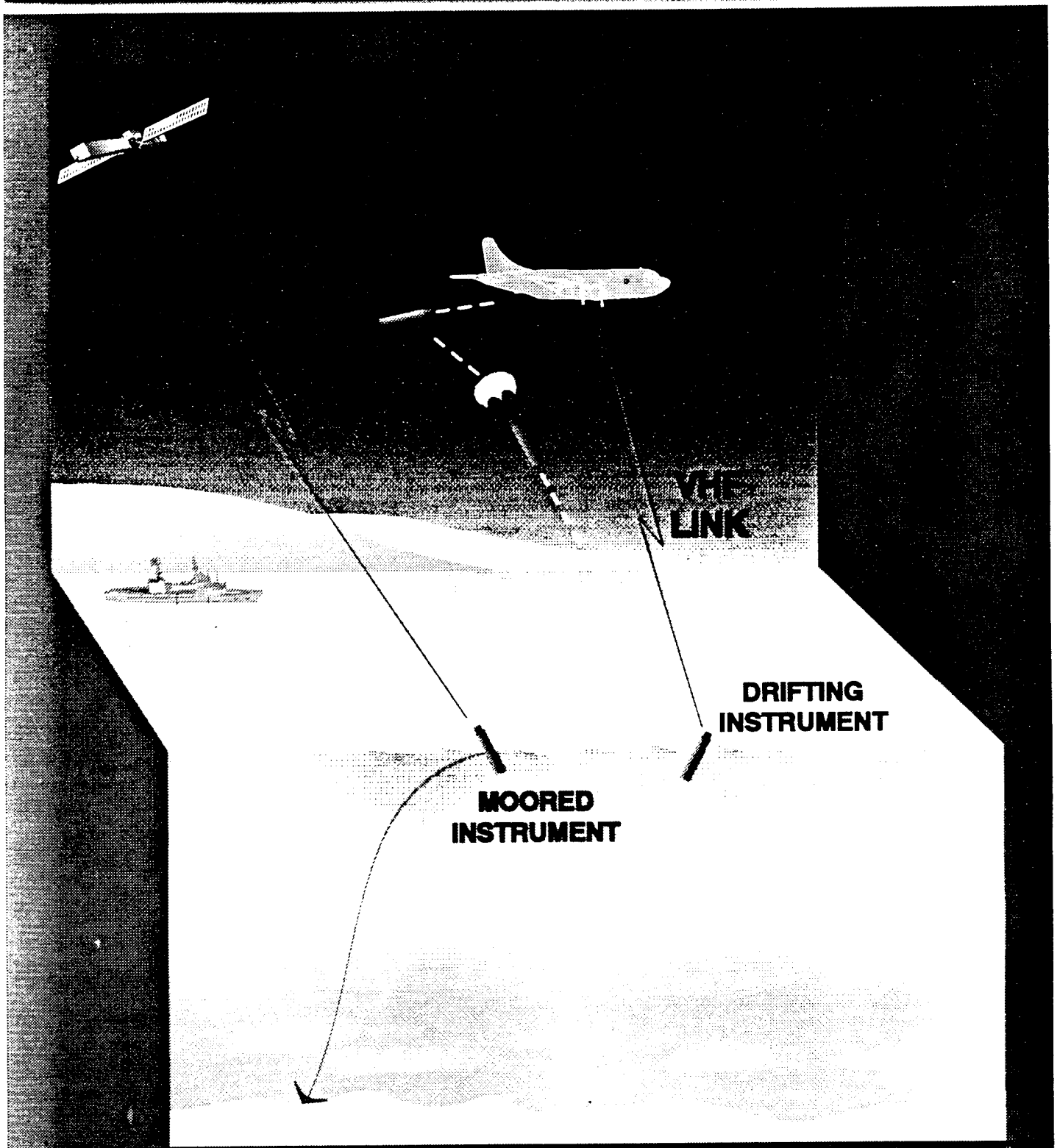
OCEANOR
Oceanographic Company of Norway A/S

Press AS Print: Bjerum AS 02/1994

RADAM



OCEANOR



OCEANOR

Approach

- Acquire prototype devices packaged for
  - » Ruggedness
  - » Waterproofness
- Performance Evaluation
  - » Energy Resolution, Efficiency
  - » Compton Scattering
  - » Power consumption
  - » Stability, Reliability and Ruggedness
  - » Sensitivity

Semiconducting Detectors

- Advantages
  - » Better energy resolution and stopping power
  - » Lower power consumption
  - » Elimination of potentially fragile PMT
  - » Lack of sensitivity to changes in magnetic field

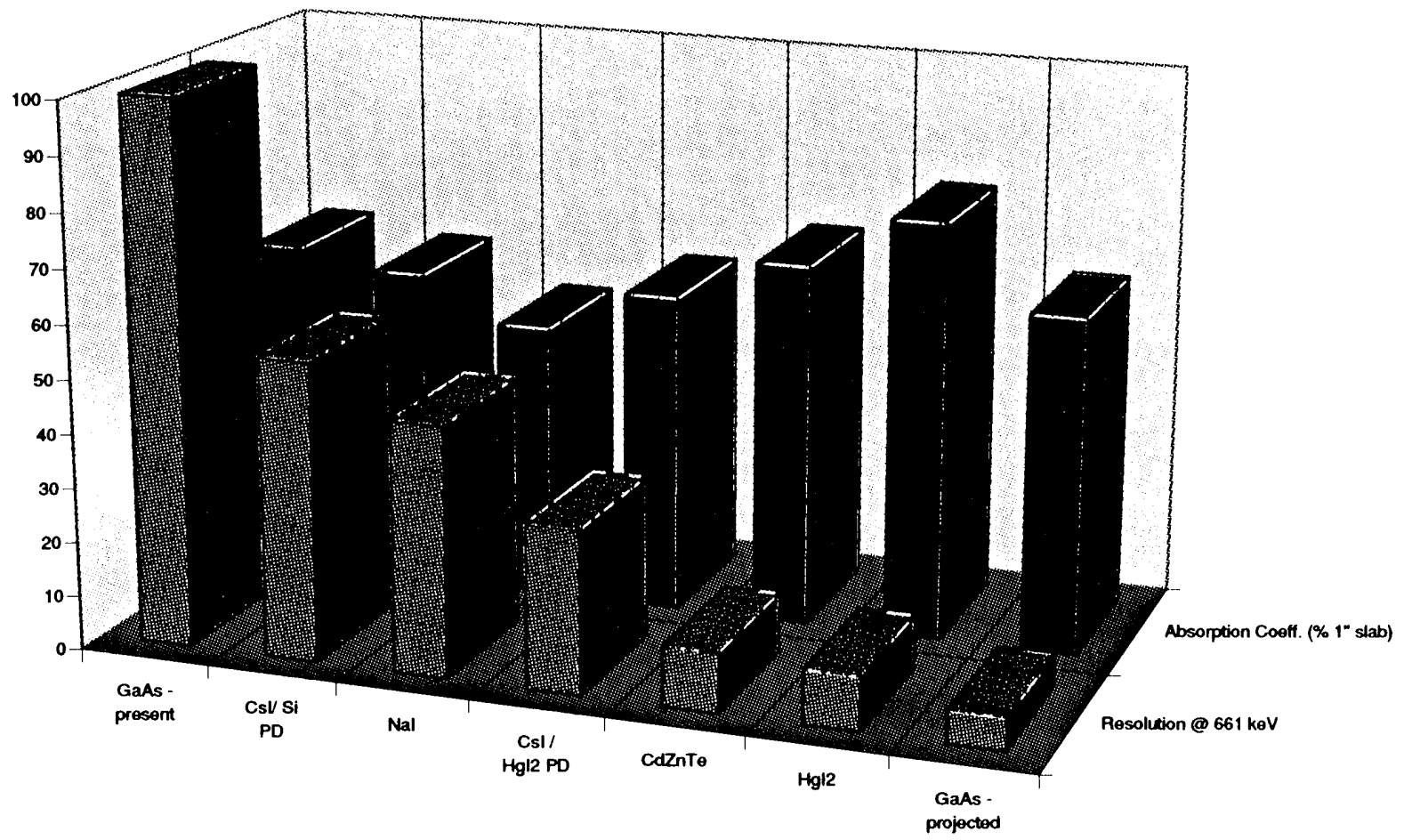
Semiconducting Detectors

- Disadvantages
  - » New technologies - difficult to predict ultimate potential
  - » Size limitations limit sensitivity
  - » Cost

Semiconducting Detectors

- CdTe - small crystals, good res.
- CdZnTe - Larger than CdTe, good res.
- HgI_2 - Small, good res.
- GaAs - Preliminary research
- Hybrid Scintillators/ semiconducting photodiode - Moderate res., higher efficiency

Detector Comparison

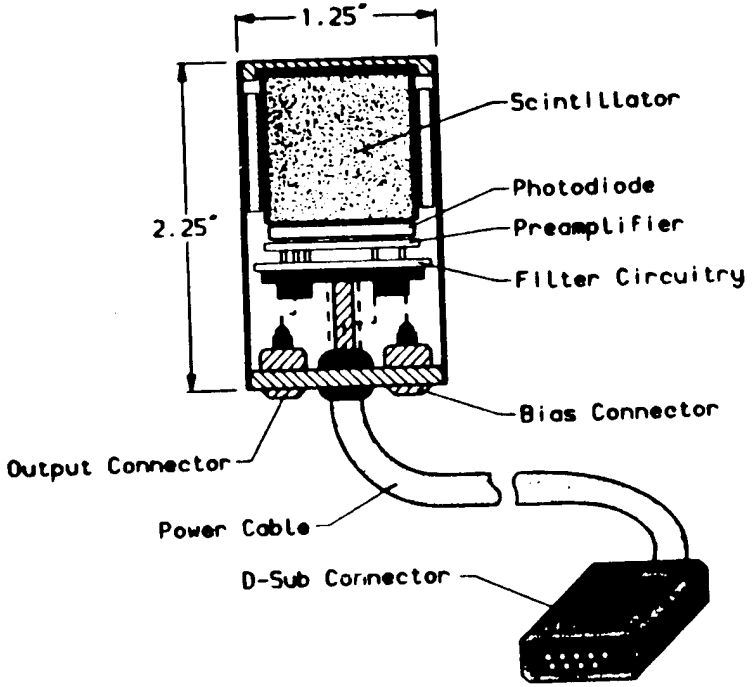


Semiconducting Detectors

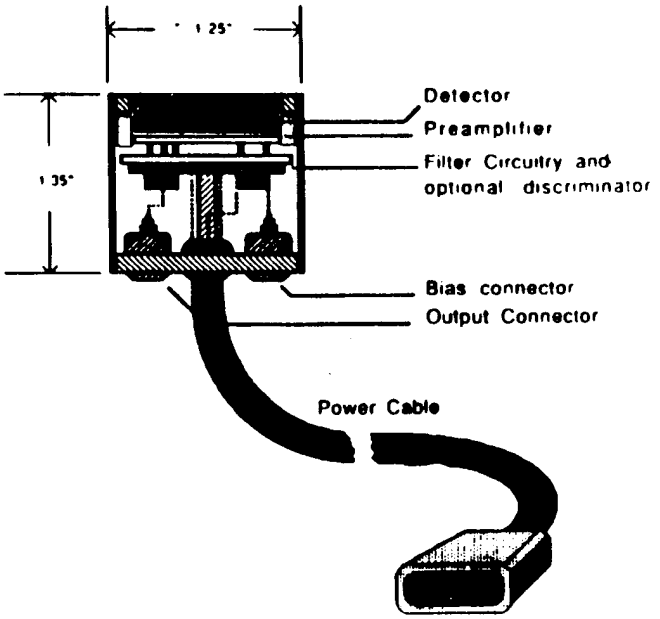
- eV Products
  - » CdZnTe - 5 x 15 x 15 mm
  - » CsI / Si photodiode - 28 x 28 x 28 mm
- RMD
  - » CdTe - 2 x 2 x 2 mm
- Aurora
  - » CdZnTe - 5 x 10 x 10 mm

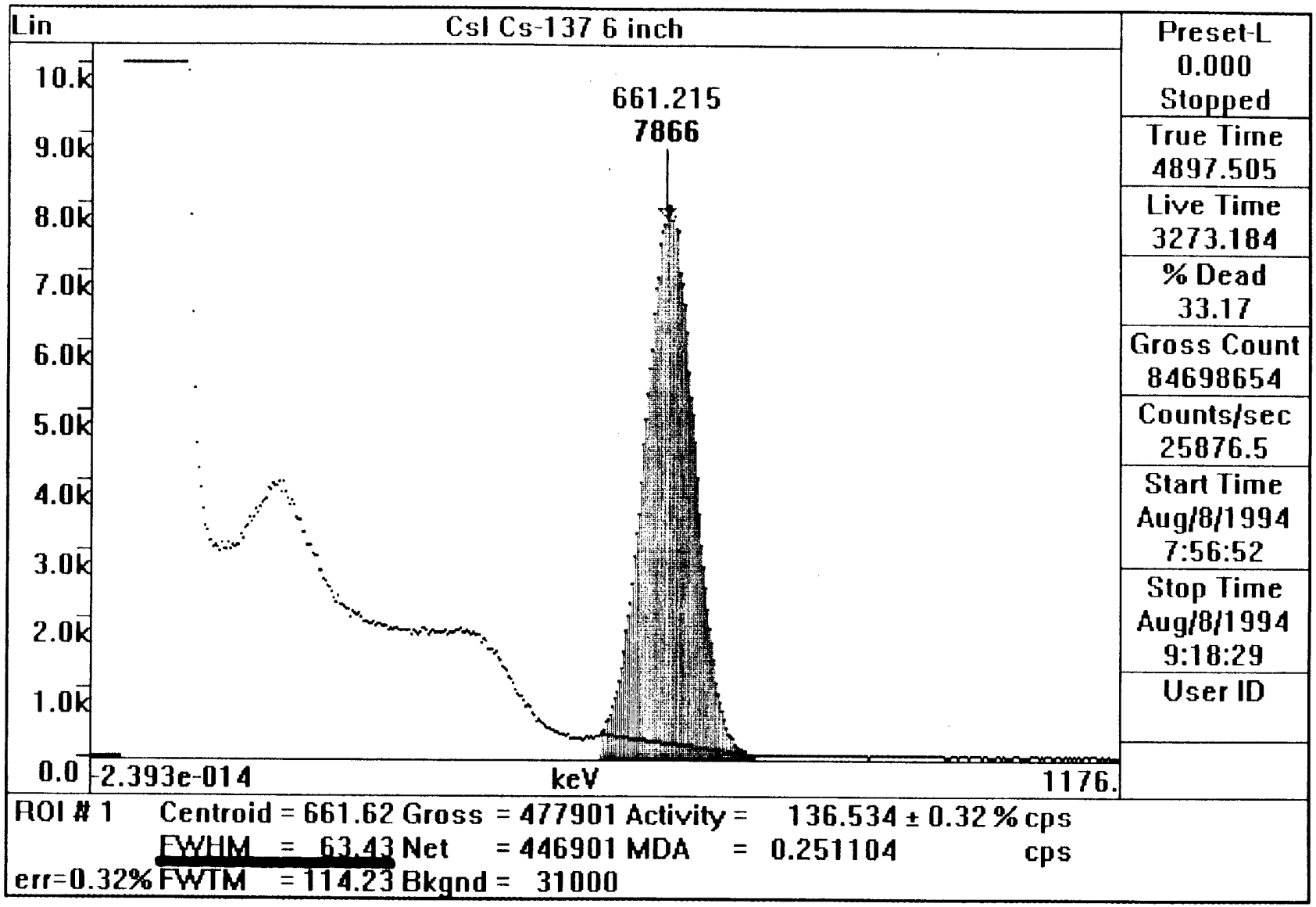
New Technologies

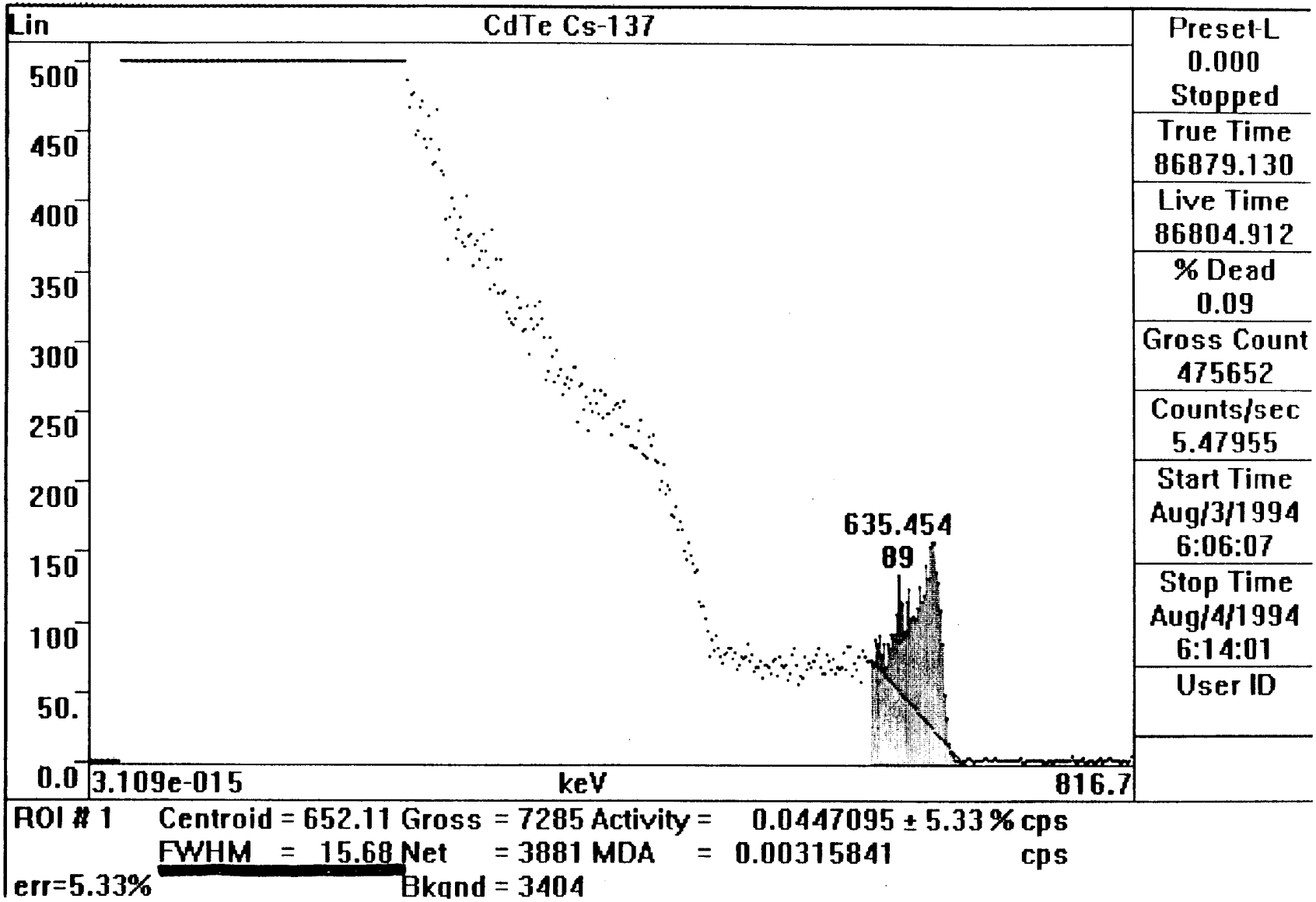
CsI / PIN Diode

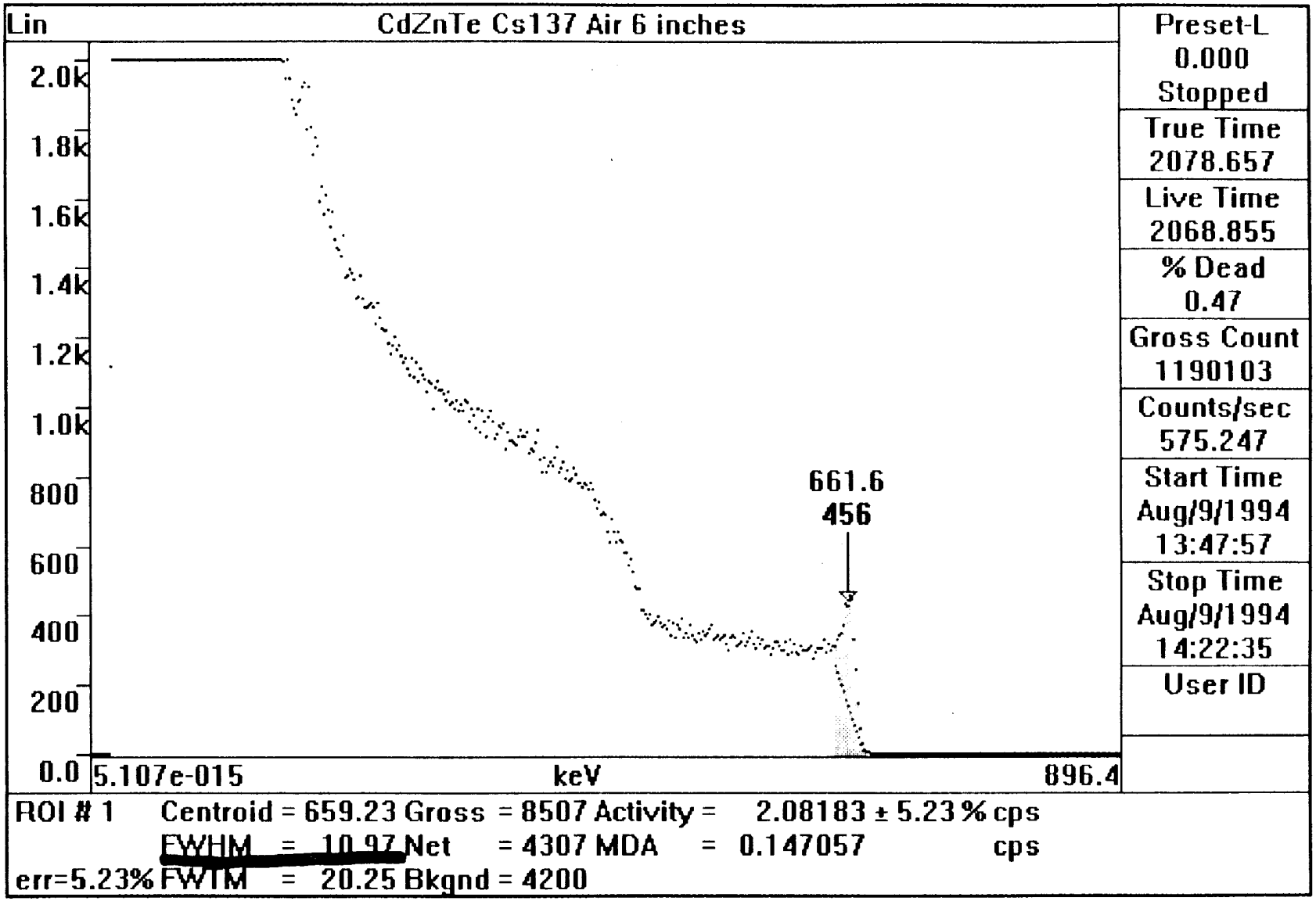


CdZnTe




Lin
CsI Cs-137 6 inch
661.215
7866
10.k
9.0k
8.0k
7.0k
6.0k
5.0k
4.0k
3.0k
2.0k
1.0k
0.0
-2.393e-014
keV
1176.
Preset-L
0.000
Stopped
True Time
4897.505
Live Time
3273.184
% Dead
33.17
Gross Count
84698654
Counts/sec
25876.5
Start Time
Aug/8/1994
7:56:52
Stop Time
Aug/8/1994
9:18:29
User ID
ROI # 1 Centroid = 661.62 Gross = 477901 Activity = 136.534 ± 0.32 % cps
FWHM = 63.43 Net = 446901 MDA = 0.251104 cps
err=0.32% FWTM = 114.23 Bkgnd = 31000


Lin
CdTe Cs-137
500
450
400
350
300
250
200
150
100
50.
0.0
635.454
89
3.109e-015
keV
816.7
Preset-L
0.000
Stopped
True Time
86879.130
Live Time
86804.912
% Dead
0.09
Gross Count
475652
Counts/sec
5.47955
Start Time
Aug/3/1994
6:06:07
Stop Time
Aug/4/1994
6:14:01
User ID
ROI # 1 Centroid = 652.11 Gross = 7285 Activity = 0.0447095 ± 5.33 % cps
FWHM = 15.68 Net = 3881 MDA = 0.00315841 cps
err=5.33% Bkgnd = 3404


Lin
CdZnTe Cs137 Air 6 inches
Preset-L
0.000
Stopped
True Time
2078.657
Live Time
2068.855
% Dead
0.47
Gross Count
1190103
Counts/sec
575.247
Start Time
Aug/9/1994
13:47:57
Stop Time
Aug/9/1994
14:22:35
User ID
2.0k
1.8k
1.6k
1.4k
1.2k
1.0k
800
600
400
200
0.0
661.6
456
5.107e-015
keV
896.4
ROI # 1 Centroid = 659.23 Gross = 8507 Activity = 2.08183 ± 5.23 % cps
FWHM = 10.97 Net = 4307 MDA = 0.147057 cps
err=5.23% FWTM = 20.25 Bkgnd = 4200

GaAs

- GaAs - potential room temperature, high resolution detector
- Epitaxial growth - 1.5-2.5% resolution @122 keV
- Bulk crystal, commerical GaAs - 30% resolution

New GaAs Initiative

- Use techniques developed to produce high purity GaAs to grow bulk crystal for gamma-ray detectors
- Zone Refining
- Control of E2 defects

Summary

- NaI instrumentation is in an advanced state ready for Arctic applications
- Present semiconducting devices are not yet reliable and rugged, microphonic problems
- Promising Potential for New Solid State Detectors

Detection of Alpha Contamination via Ionization

James E. Koster
Los Alamos National Laboratory
Nonproliferation and International Security /
Environmental Applications
Mail Stop J561
Los Alamos, NM 87545

An abstract submitted to the Workshop on Monitoring of Nuclear Contamination in Arctic Seas, Naval Research Laboratory, Washington, D.C., January 18-19, 1995.

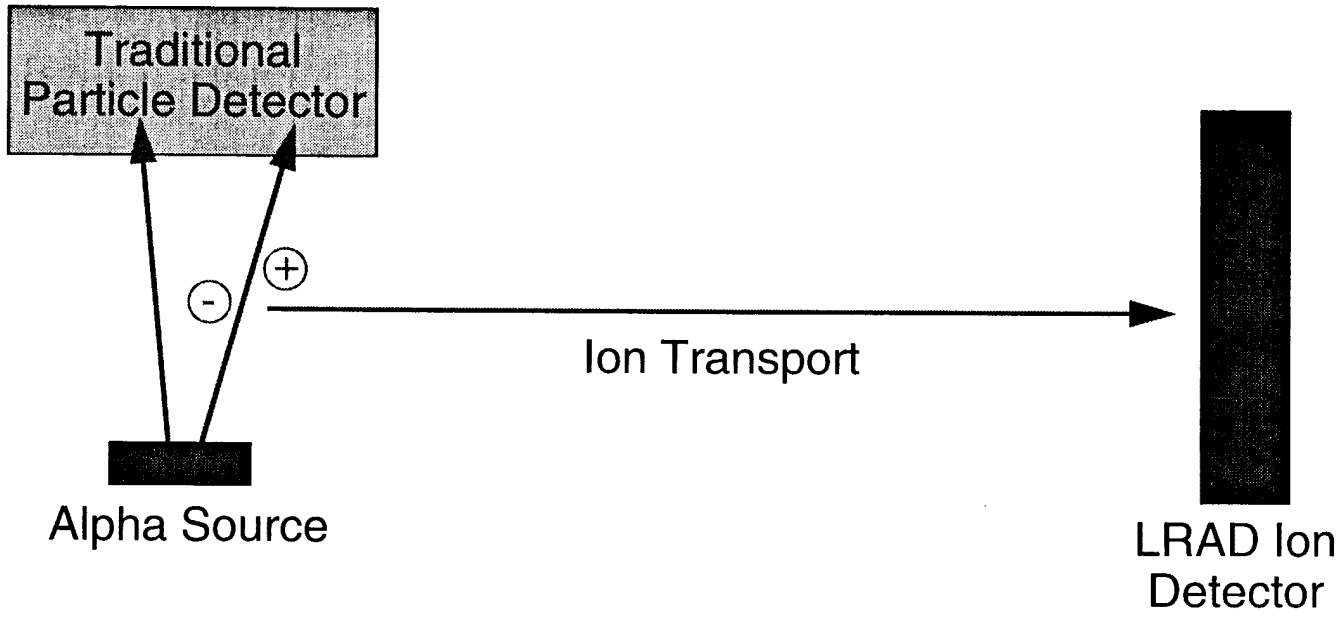
Nuclear material has been injected into rivers and seas of the Eurasian continent that feed the arctic seas for decades, both by dumping of nuclear waste and by accident. The nuclear material typically consists of actinides such as uranium and plutonium. Most actinides alpha decay - thus alpha particles are a good indicator of the presence of such contamination. If the alpha particles are emitted into air, each produces 10^5 ion pairs. The ions can be detected much easier than the original alphas. This technique can be used for detection of contamination underwater, at the water's surface, or on the shores and riverbanks. The latter two applications have been demonstrated in the field. These and related techniques will be described as a means of *in-situ* monitoring for nuclear contamination in arctic seas.

Detection of Alpha Contamination via Ionization

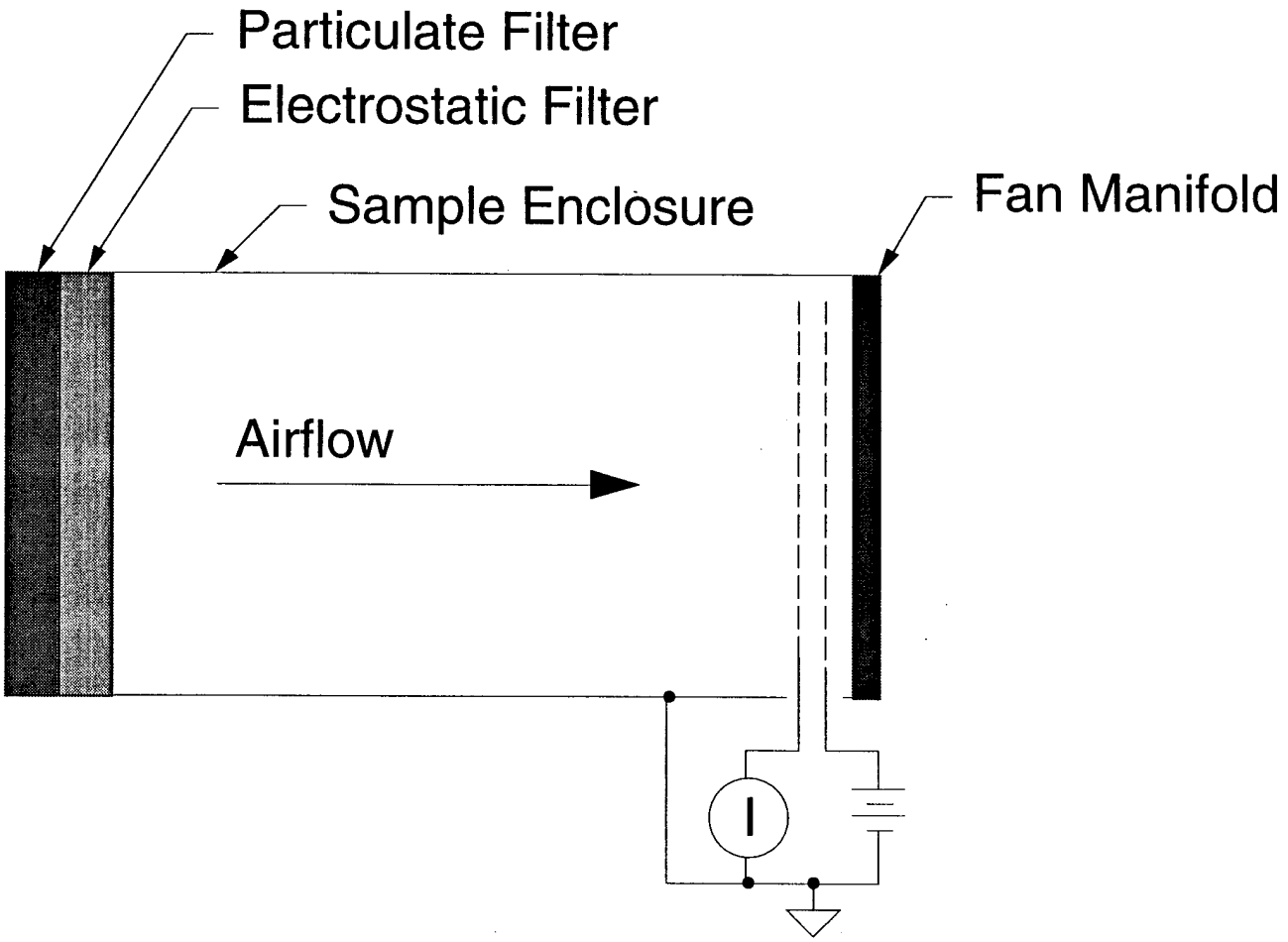
James E. Koster

Advanced Nuclear
Technology / Environmental
Applications
LANL

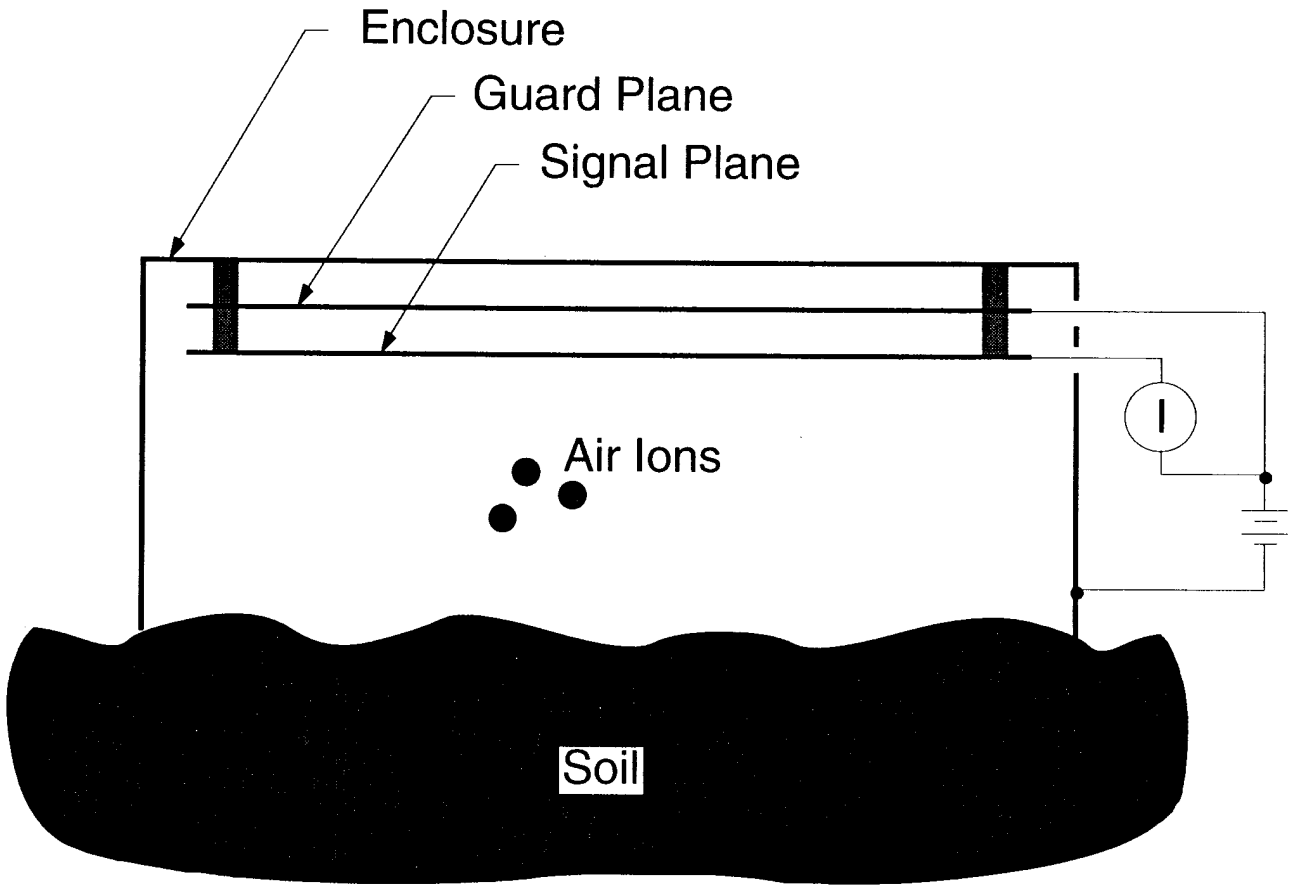
Alpha Detection Technology



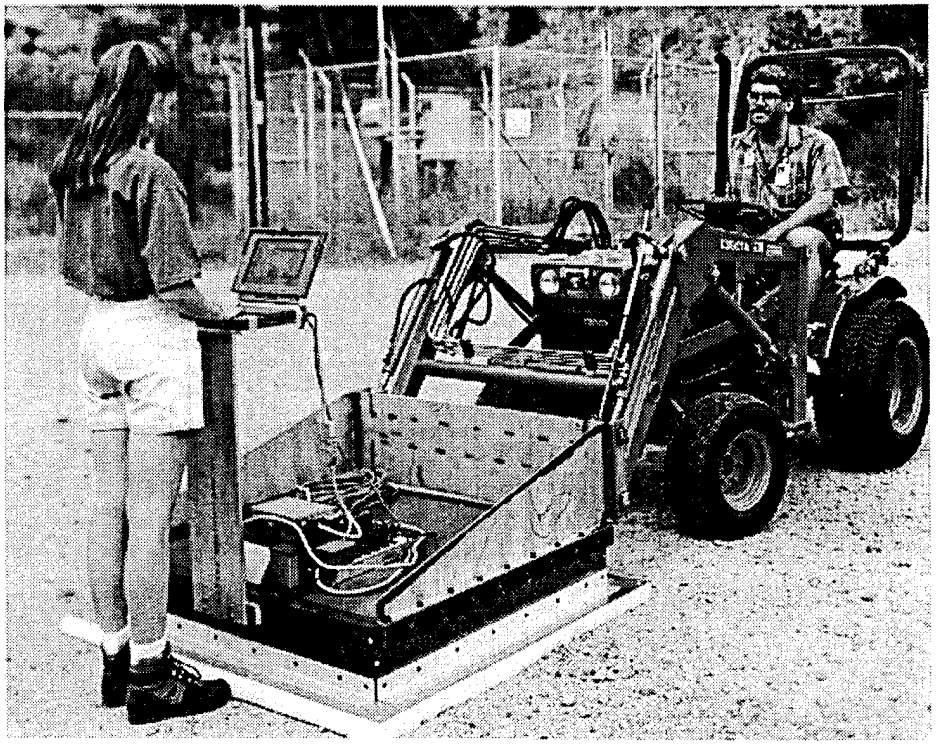
Airflow Ion Transport



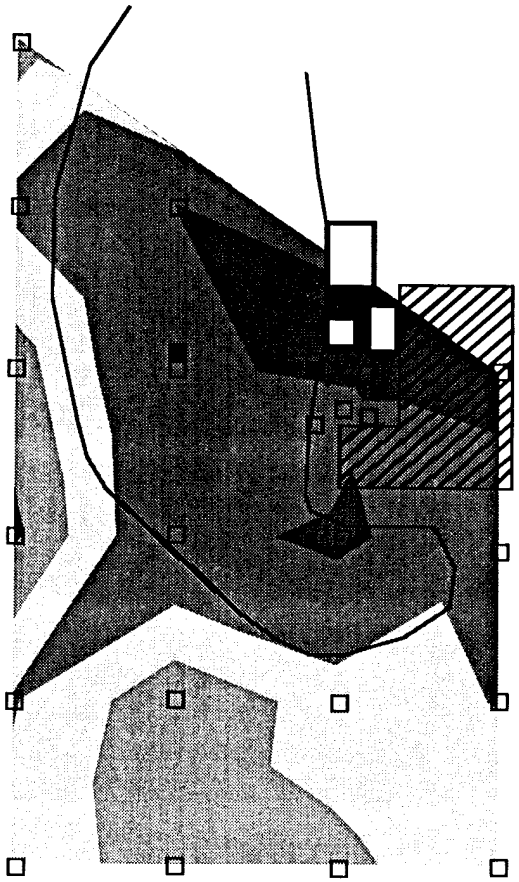
Electrostatic Ion Transport

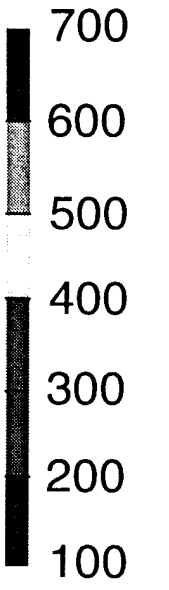


1 m^2 Tractor-mounted surface monitor



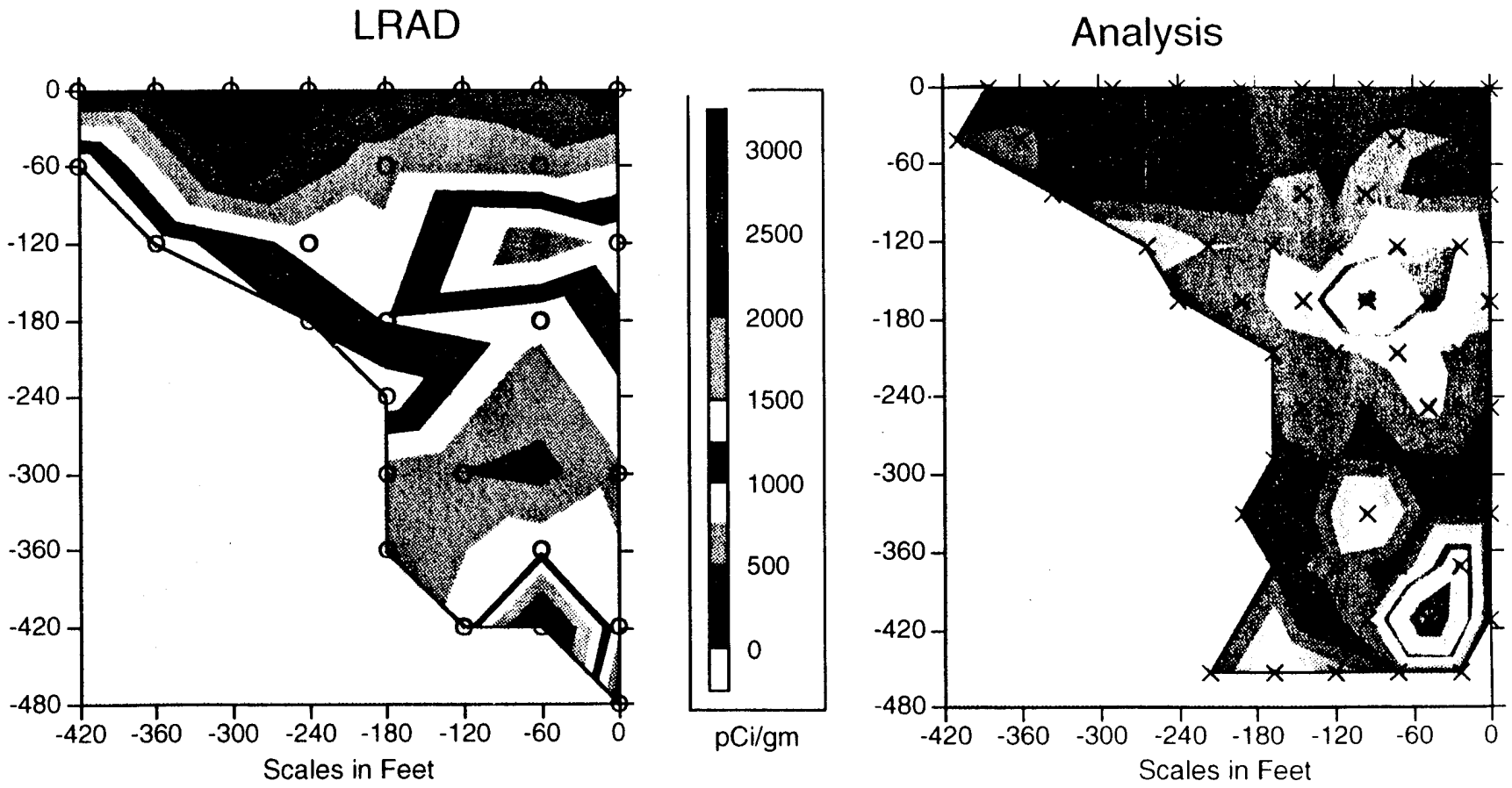
LANL: TA - 15 Ector Site





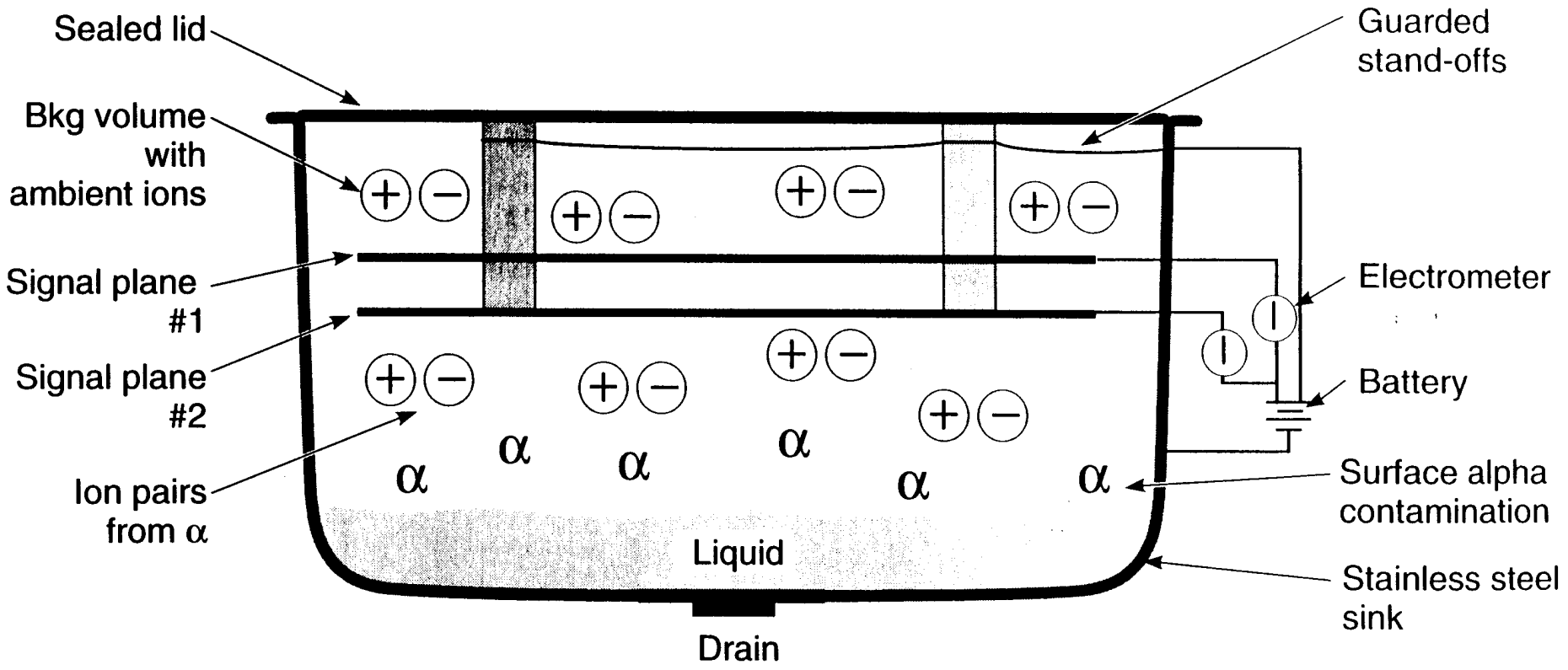
dpm/100cm^2

Comparison of Techniques at D&D

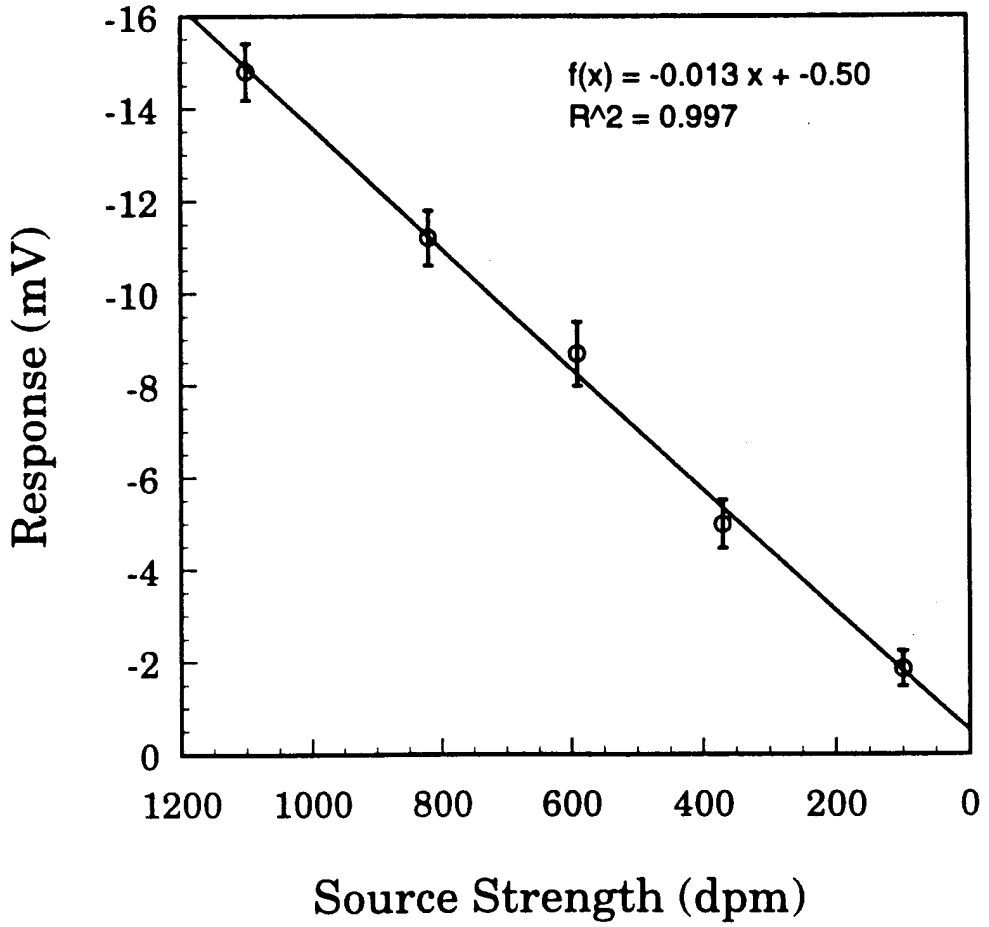


Hand-held surface monitor photo

Liquid Waste Monitor



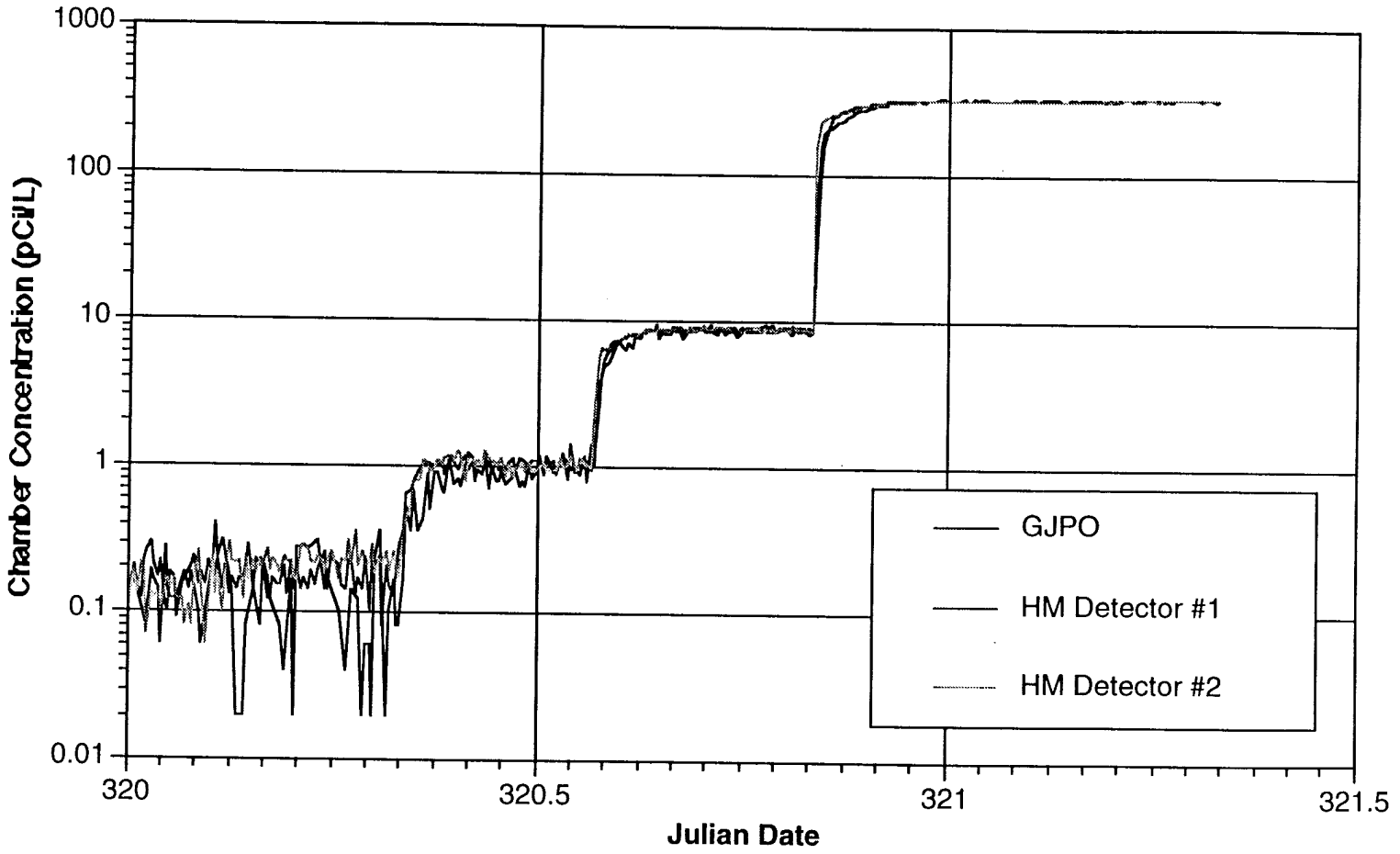
LWM data



John Johnson, LANL

Implementation in Seas

Radon Detection



Summary

- CAPABILITIES
  - Specific to alpha emitters
  - Real-time response
  - Improved sensitivity
  - Increased distance from source
  - Ruggedness

- ISSUES for Implementation
  - Data transfer
  - Power (esp. for data transfer)
  - Environment (temperature, humidity & condensation)

Other Applications

- Environmental Monitoring
  - Soil (Fernald, DNA, WSRC, LANL; hybrid monitors)
  - Surface (Liquid waste stream, roofing, swipes/smears)
  - Waste minimization
- Decontamination and Decomissioning
  - Pipe monitors
  - Glovebox monitors
  - Concrete monitors
  - Sewers
- Personnel Safety
  - Archival logbooks
  - Arm, hand, working level
- NORM Monitoring
- Radon/Air Quality Monitoring (EPA, EM-50, etc.)
- Nonproliferation and Safeguards

Advanced Nuclear Technology EA

Krag Allander
Aron Beasinger
Rick Bolton
John Bounds
John Conaway
Scott Garner
Jeff Johnson
John Johnson
Jim Koster
Duncan MacArthur
Mohini Rawool-Sullivan
Steve Rojas
Larry Sprouse
Peter Steadman
Joe Vaccarella
Lorraine Vigil
Trung Vu
Steve Walters
Harry Williams
Kevin Williams

ACCUMULATION OF RADIONUCLIDES BY BIVALVE MOLLUSCS AND SEA STARS: IMPLICATIONS FOR CONTAMINATED ARCTIC WATERS

Nicholas S. Fisher, David A. Hutchins, and Ian Stupakoff

Marine Sciences Research Center, State University of New York,
Stony Brook, NY 11794-5000

Disposal of radioactive wastes in the Kara Sea has raised major questions about their mobility in polar marine food chains. Experiments were performed to assess the bioaccumulation and retention of three gamma-emitting radioisotopes -- ^{57}Co, ^{137}Cs, and ^{241}Am -- in marine invertebrates typical of the dominant forms found in the benthos of the Kara Sea. Both dissolved and particulate (food) source terms were evaluated as potential routes of radionuclide uptake in the clam *Macoma balthica* and the sea star *Asterias forbesii*. Both animals were able to accumulate Co and Am from food and from the dissolved phase. There was minimal effect of temperature on the accumulation of isotope in the clam from either food or water. Assimilation efficiencies for ingested Am and Co in clams were typically 20% to 30%, and biological half-lives of assimilated Am and Co were only about 1 week at 2 C. The biological half-lives of Am and Co accumulated in clams from the dissolved phase were very long ($\geq$ 12 weeks). Sea stars also concentrated radioisotopes from dissolved and particulate sources and released them very slowly. The low temperatures prevailing in the Arctic greatly increase the retention of radionuclides obtained from food (the biological half-life of ^{241}Am increased from 31 days at 12 C to ∞ at 2 C), indicating that results of previous radioecological studies conducted at warmer temperatures may not be applicable to polar environments. The appreciable assimilation and generally long retention of radionuclides suggest that bivalves and especially sea stars would make effective bioindicators of radioactivity releases in polar waters.

BIOLOGICAL MONITORING FOR LONG-LIVED RADIONUCLIDES USING MARINE BIVALVE MOLLUSCS AND ECHINODERMS

Nicholas Fisher, David Hutchins, & Ian Stupakoff

Marine Sciences Research Center
State University of New York
Stony Brook, NY 11794-5000

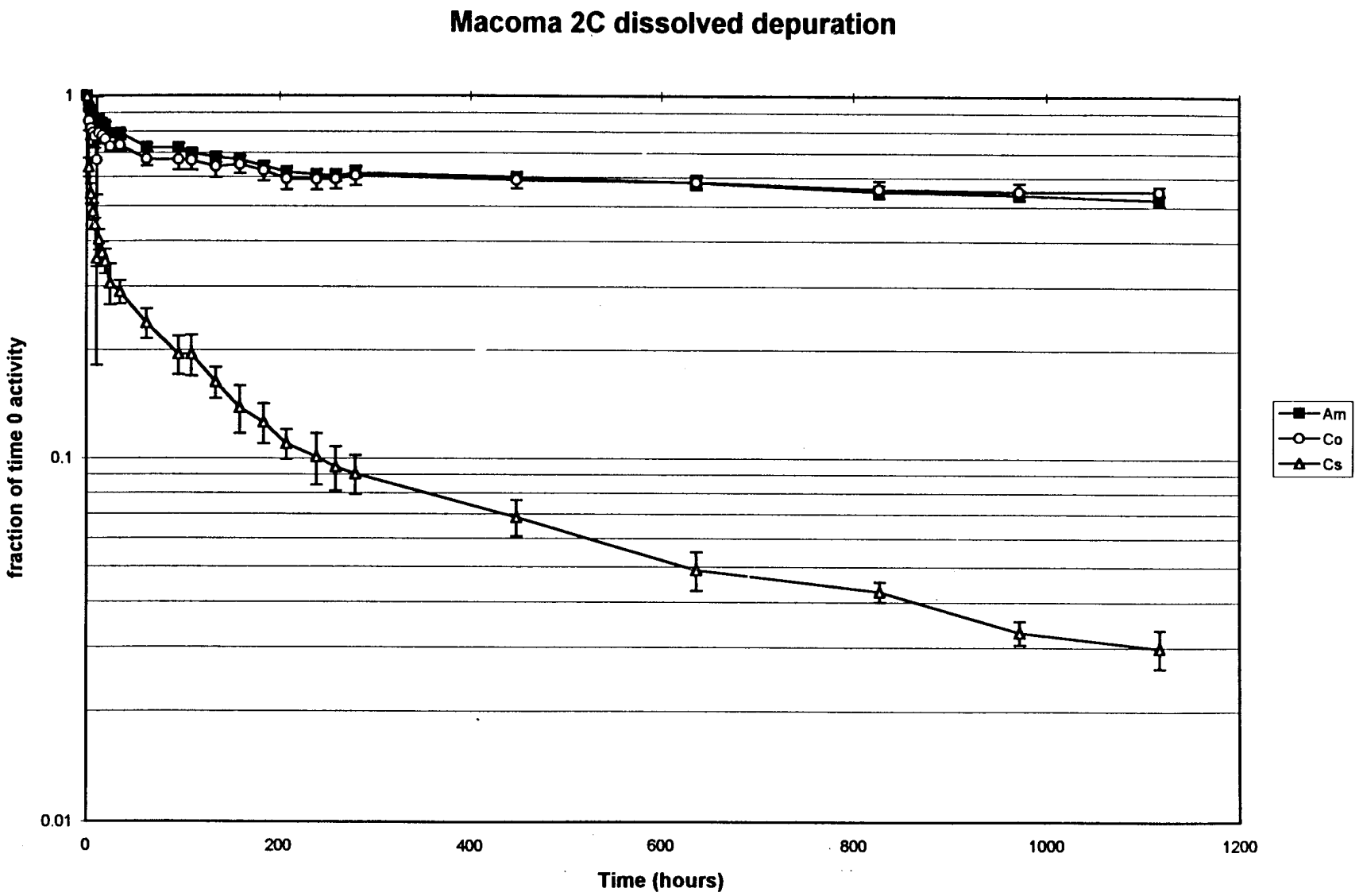
Questions:

(1) Can marine bivalve molluscs and sea stars (starfish) accumulate radionuclides from the dissolved phase? from ingested food?

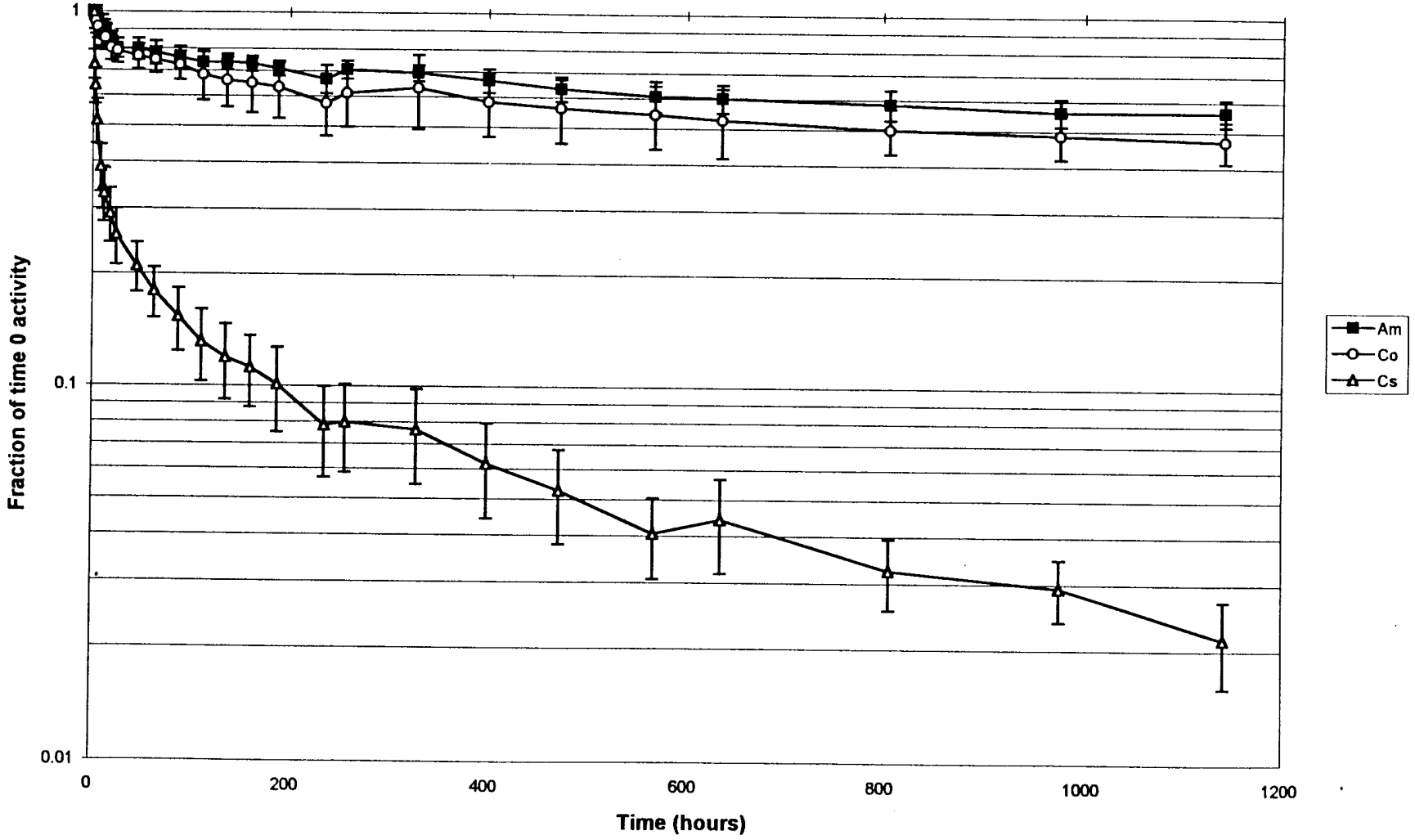
(2) What is the biological retention of accumulated radionuclides in these organisms?

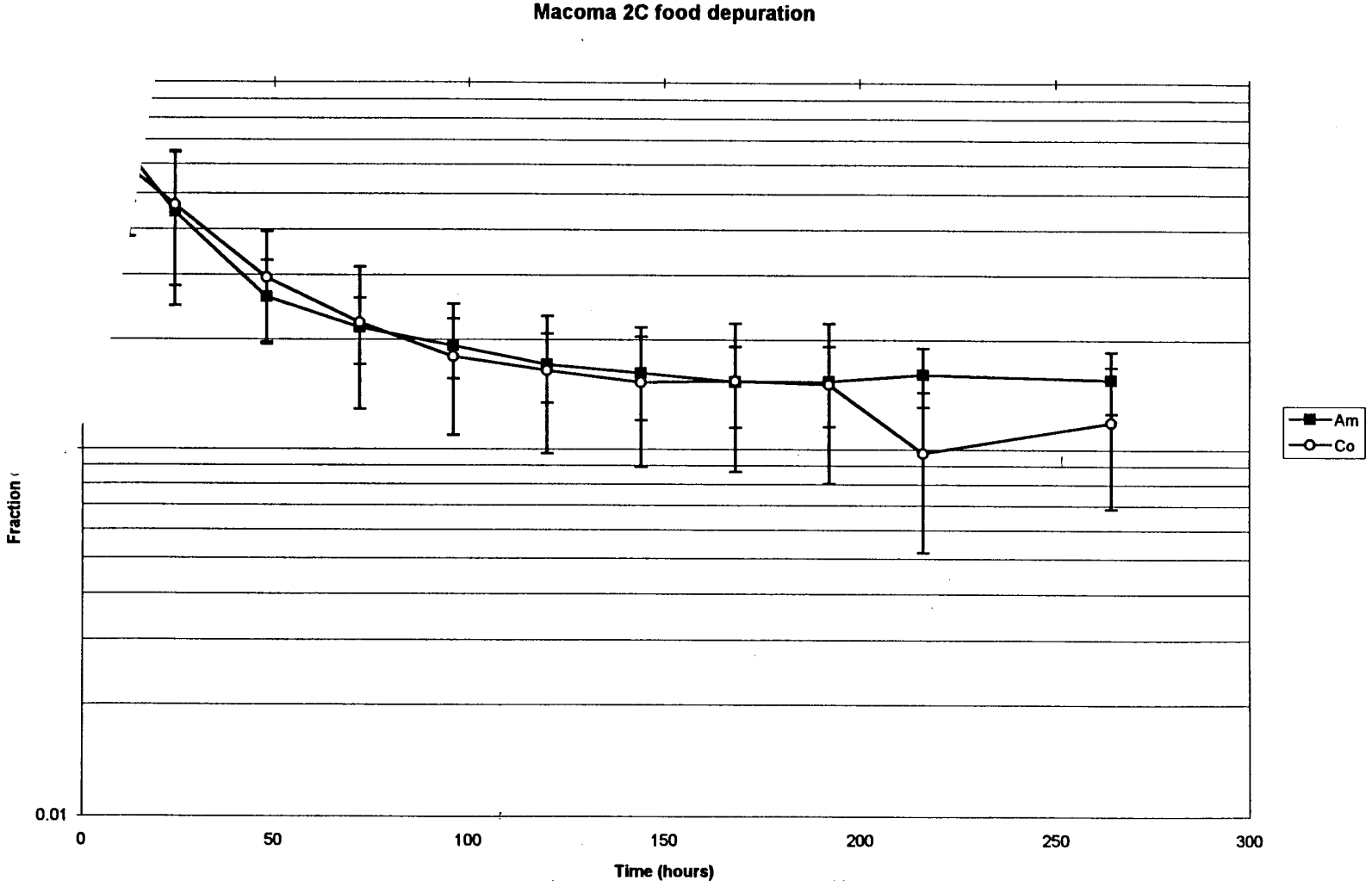
(3) Do Arctic temperatures influence accumulation/retention of radionuclides?

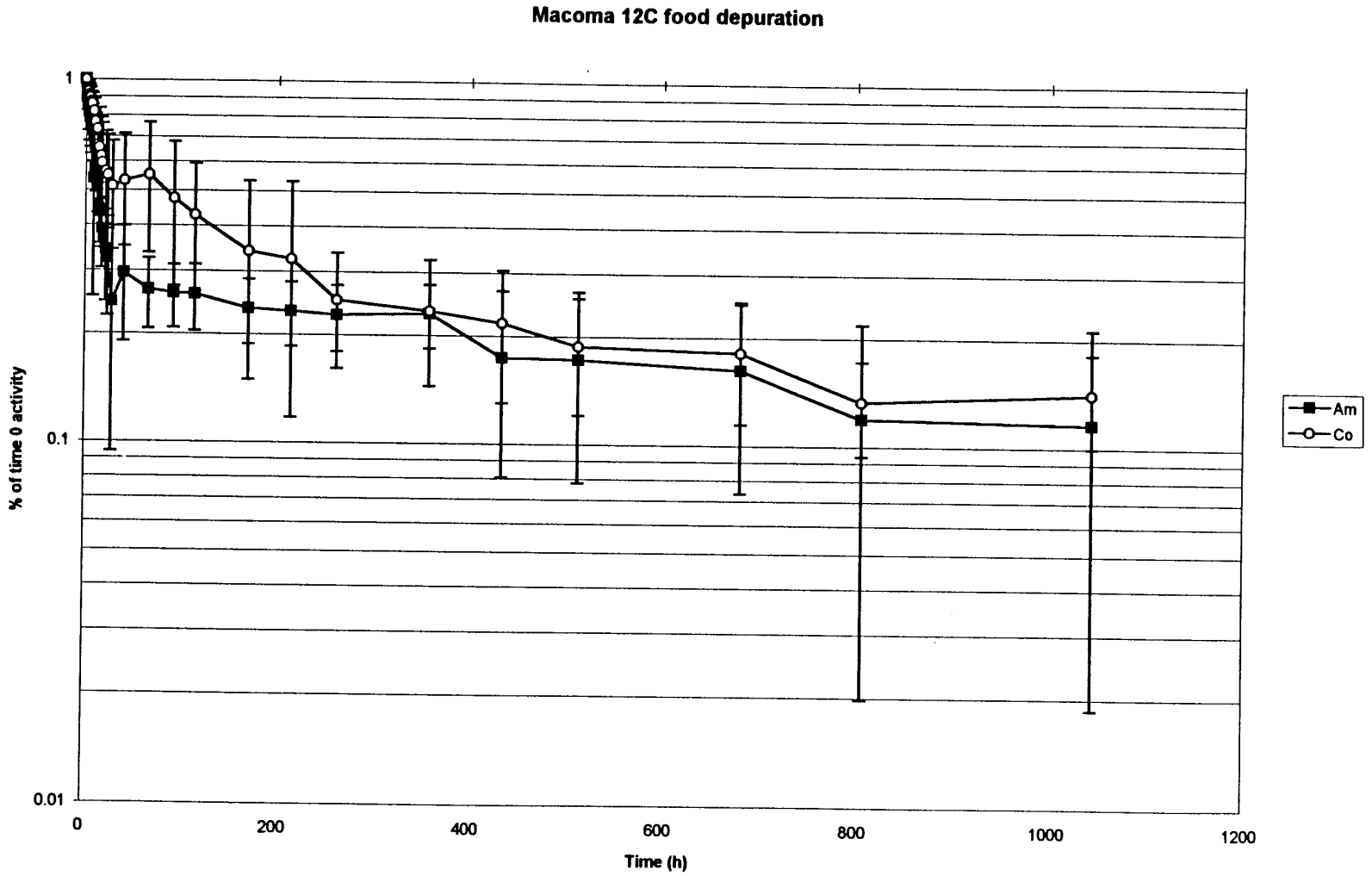
(4) How do different radionuclides differ in their biological interactions? We compared: ^{57}Co, ^{137}Cs, ^{241}Am.


Macoma 2C dissolved depuration
fraction of time 0 activity
1
0.1
0.01
0
200
400
600
800
1000
1200
Time (hours)
Am
Co
Cs

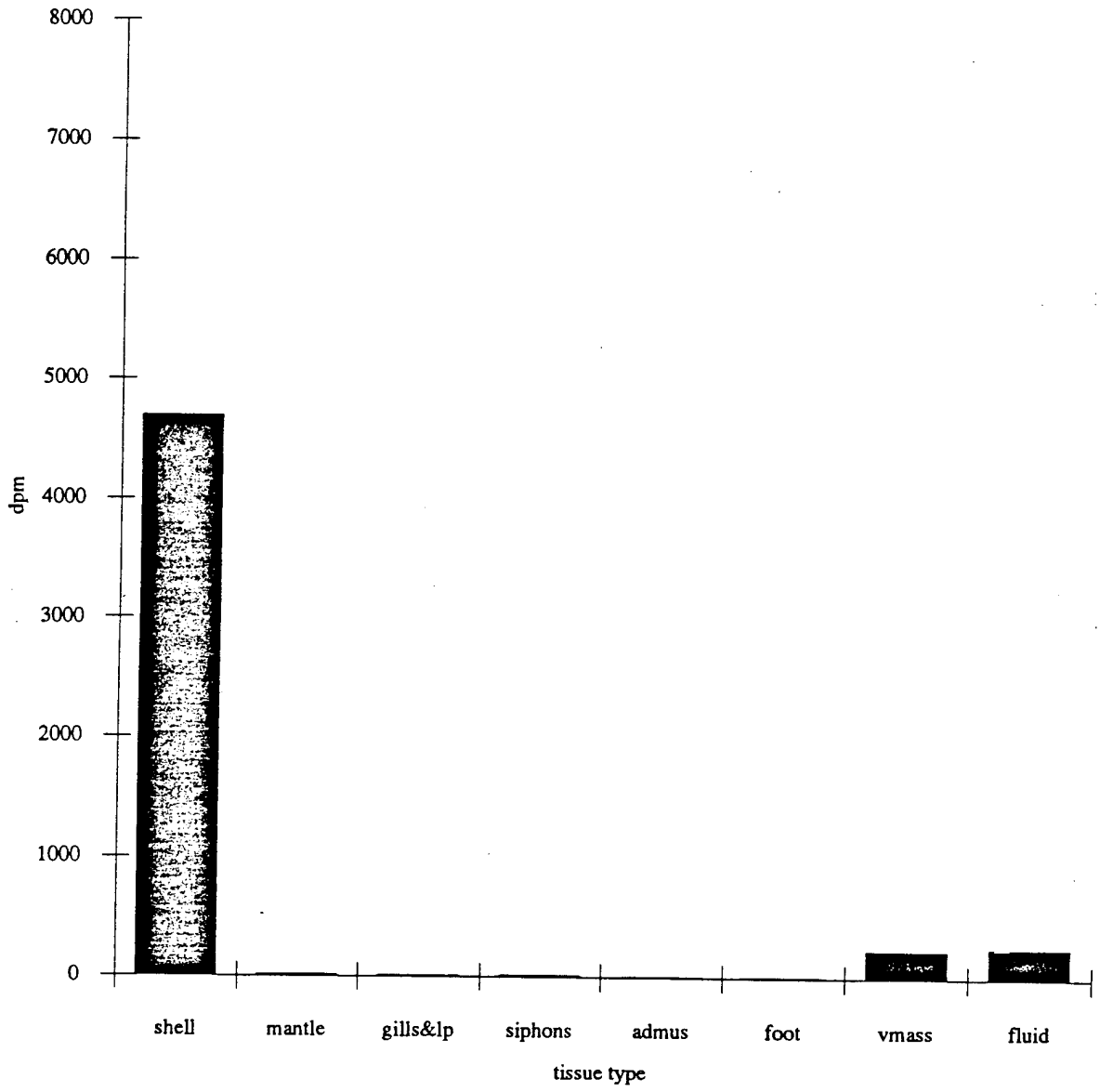
Macoma 12C Dissolved Depuration



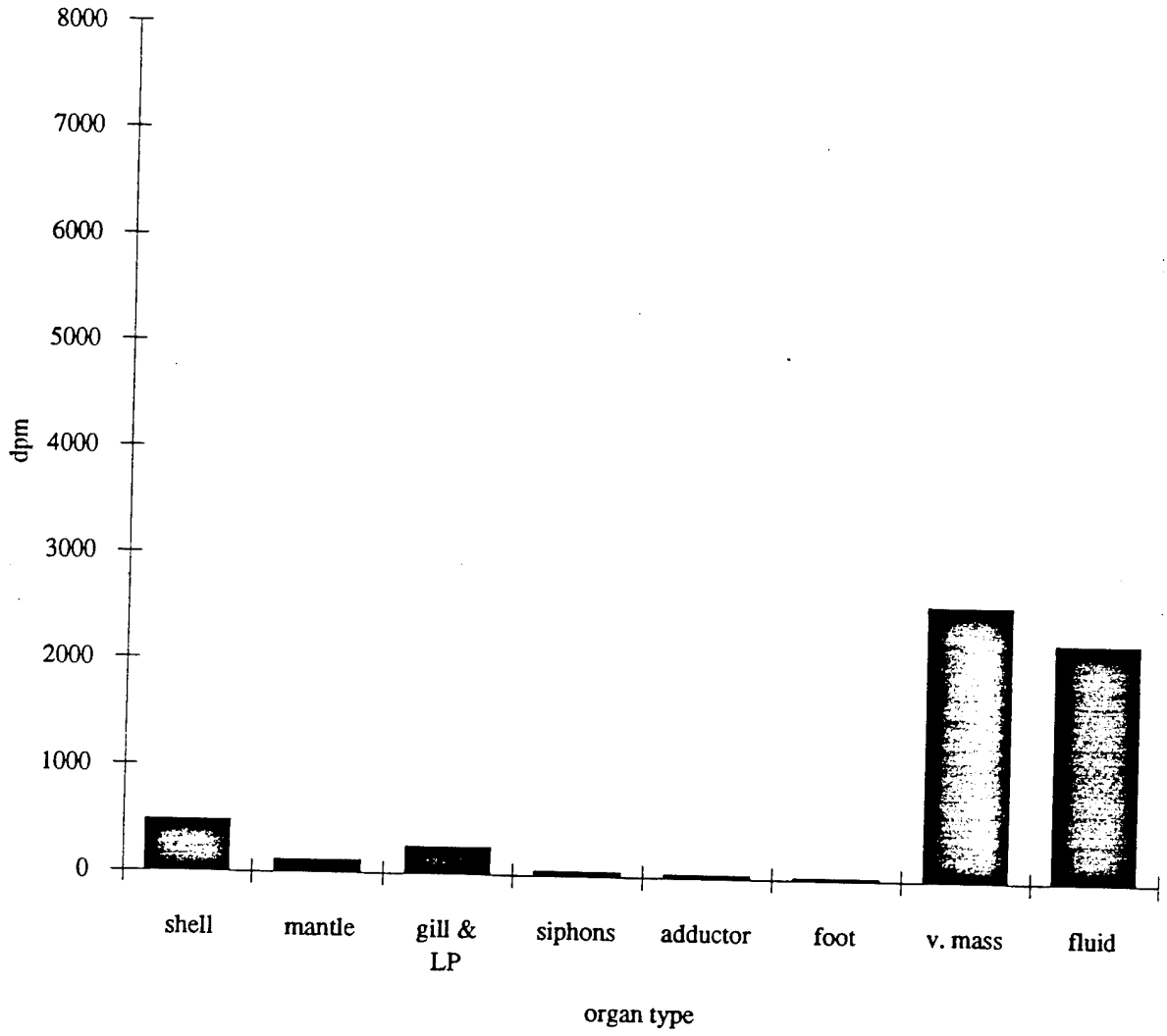

Macoma 2C food depuration
Fraction
0.01
0
50
100
150
200
250
300
Time (hours)
Am
Co

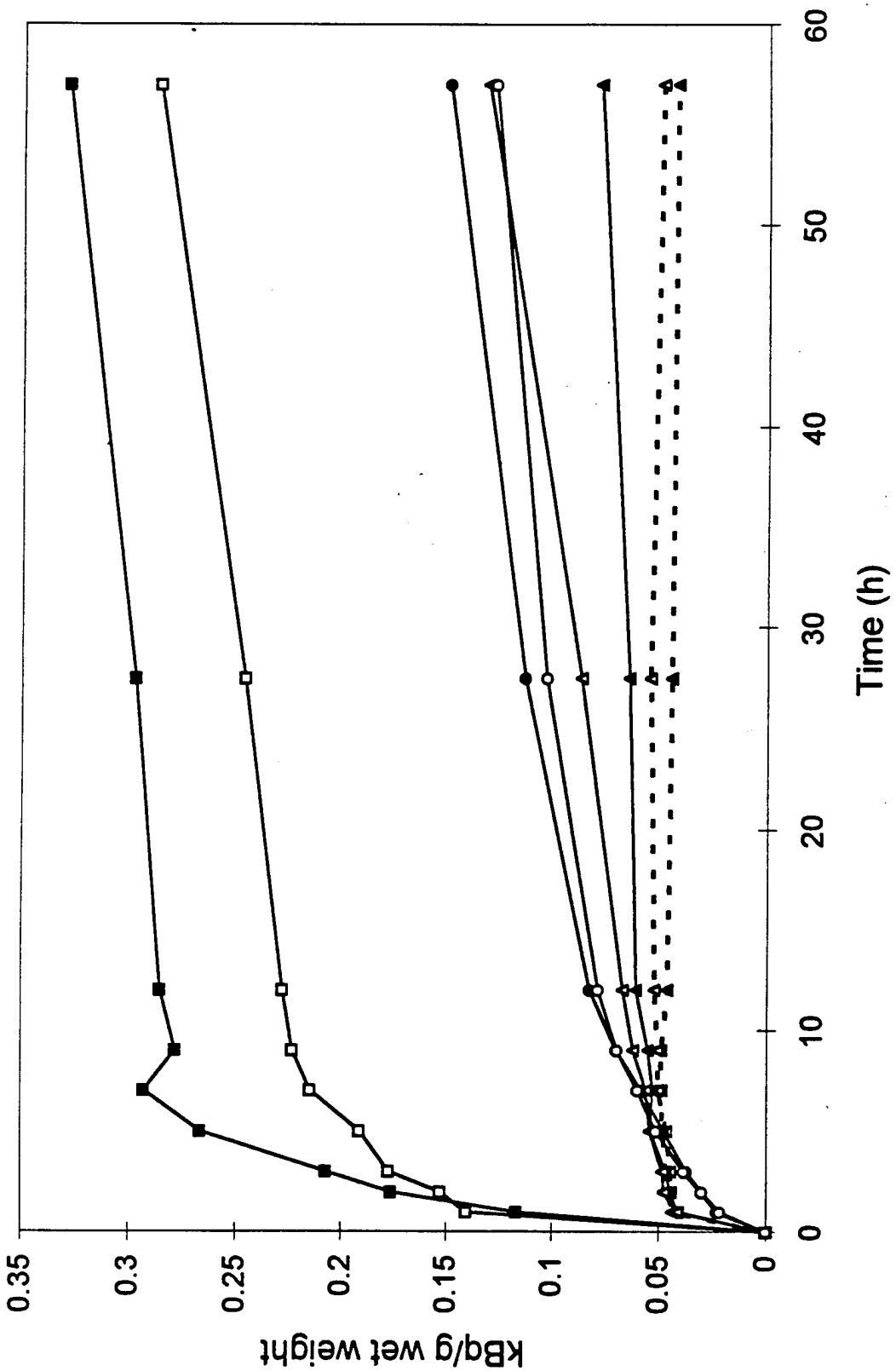

Macoma 12C food depuration
1
0.1
0.01
% of time 0 activity
0
200
400
600
800
1000
1200
Time (h)
Am
Co

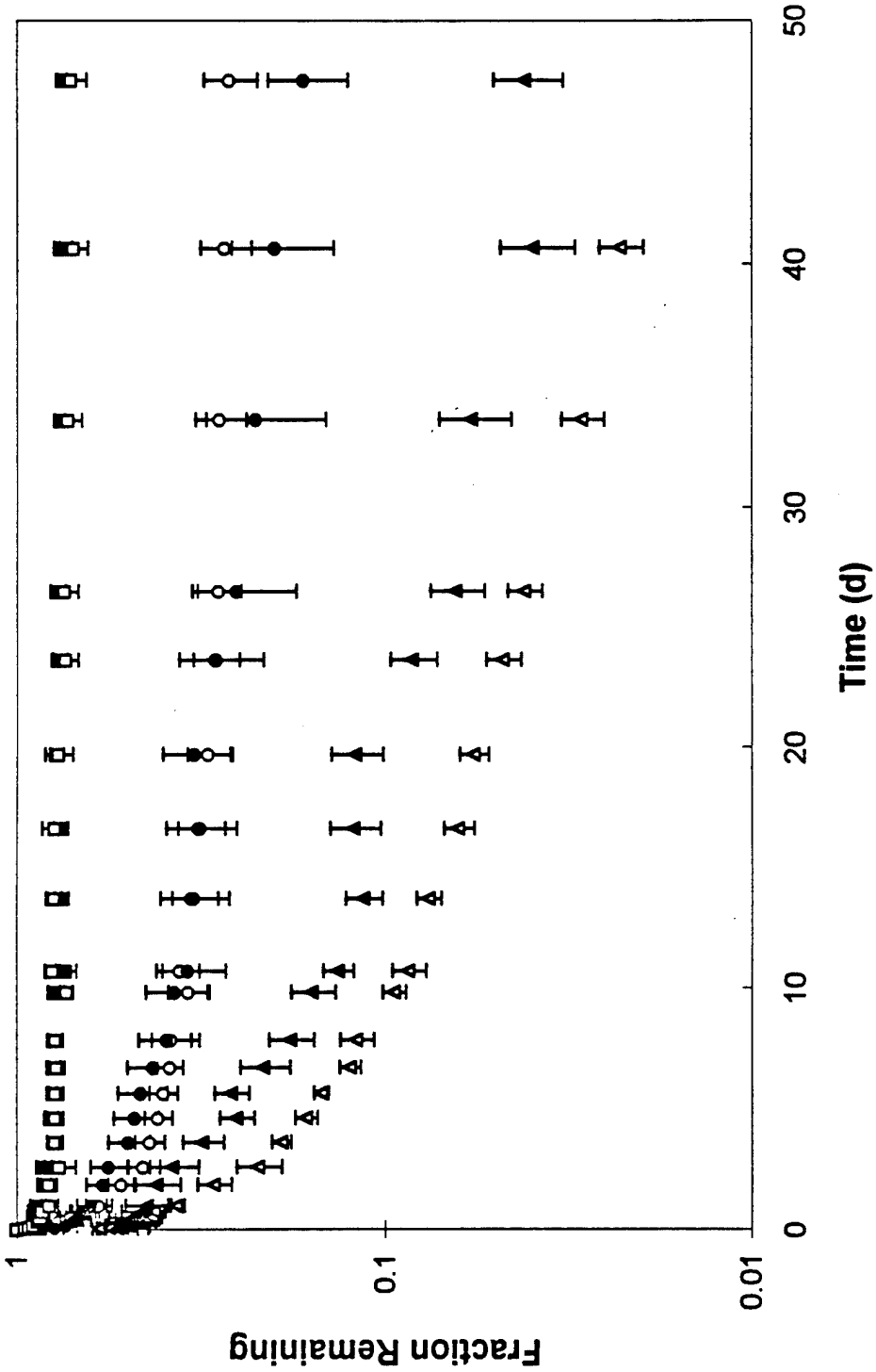
distribution of am at t=o from dissolved uptake at 12 degrees

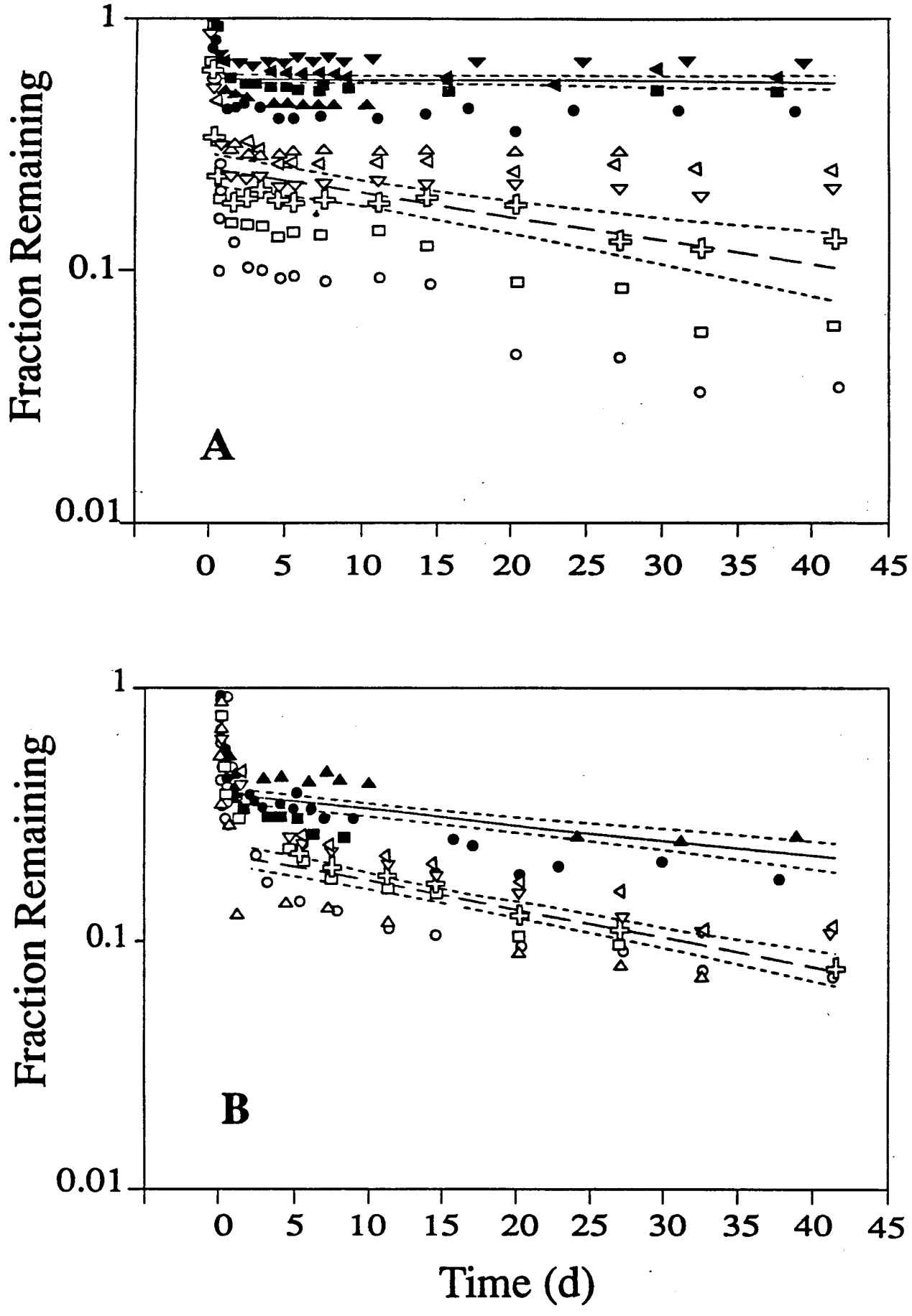


distribution of Am from particulate uptake at 2 degrees, t=0




kBq/g wet weight
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Time (h)
0
10
20
30
40
50
60


Fraction Remaining
1
0.1
0.01
0
10
20
30
40
50
Time (d)


Fraction Remaining
1
0.1
0.01
A
0
5
10
15
20
25
30
35
40
45
Fraction Remaining
1
0.1
0.01
B
0
5
10
15
20
25
30
35
40
45
Time (d)

animal	source	temp.	Co	Cs	Am
M.b.	diss.	2	289	21	160
M.b.	diss.	12	96	20	28
M.b.	food	2	6	-	8
M.b.	food	12	19	-	31
A.f.	diss.	2	41	21	1155
A.f.	diss.	12	92	15	187
A.f.	food	2	41	-	∞
A.f.	food	12	26	-	31

Biological half-lives (in days) of Co, Cs, and Am in the clam *Macoma balthica* (M.b.) and the sea star *Asterias forbesii* (A.f.) under different experimental conditions.

TOWARD HIGH-RESOLUTION COMPACT SCINTILLATION INSTRUMENTS

Bradley E. Patt, Y.J. Wang and J.S. Iwanczyk
Xsirius, Inc.,
1220 Avenida Acaso, Camarillo, CA 93012
Phone: (805) 484-8300

The status and fate of radionuclides in the Arctic and North Pacific, and in their adjacent rivers and overlying atmosphere are of great interest because of the threat that they pose to, amongst others, on-shore residents and sea life. Several dump sites for nuclear reactors and other wastes have been identified in the Barents and Kara Sea, and many of the rivers discharging into the Arctic may be contaminated. Accurate assessments of the radionuclide concentrations and transport pathways in the marine system, adjoining river systems, coastal regions and the overlying atmosphere need to be performed.

Thus there is a need for new detector systems with improved performance that also are capable of more sophisticated measurements including mobile field measurements and continuous un-manned monitoring. Low-grade radioactive material assay has historically been accomplished by using a collimated gamma-ray detector with associated electronics. The principle detector in use has been the NaI(Tl) scintillator/photomultiplier (PMT) gamma-ray detector. These systems have several drawbacks associated with the PMT light sensor which have limited their performance beyond what is possible with the scintillators. Consequently, there has been some effort to find suitable alternatives to replace the PMT for gamma-ray spectrometry.

The mercuric iodide (HgI_2) photodetectors (PD) developed by Xsirius, when coupled to a CsI(Tl) scintillator, has demonstrated perhaps the best energy resolution attained by any solid state light sensor [1-3]. The spectral responsivity of HgI_2 PD's is very well matched to the light spectrum produced by CsI(Tl) scintillators, and operates with almost 100% quantum efficiency [4]. Compared to the most widely used scintillation material, NaI(Tl), CsI(Tl) has a higher density (4.51 gm/cm^3 for CsI(Tl) and 3.67 gm/cm^3 for NaI(Tl)) and higher effective atomic number, and therefore the response function for this material shows a greater detection efficiency and photofraction. CsI(Tl) has the largest scintillation yield (photons per unit energy deposited) of any known inorganic scintillating crystal, ≈35% greater than that of NaI(Tl) (room temperature, gamma-ray excitation) [5]. Therefore, spectrometers using a combination of CsI(Tl) scintillators and HgI_2 PDs offer the best energy resolution and detection efficiency for gamma ray spectroscopy at ambient temperature today. A value of 4.58% at 662 keV was measured with a 0.5"-diameter HgI_2 PD coupled to a 0.5"-diameter by 0.5" high CsI(Tl) scintillator. In order to take full advantage of scintillation detectors for high energy gamma-rays, larger size scintillators we have considered a novel tapered scintillator geometry. The response of a large conical frustum (top-2", bottom-1", 2" high) CsI(Tl) scintillator coupled with a 1"-diameter HgI_2 PD was measured. The energy resolution of the 662 keV peak was 5.57%.

The above results show the potential for using this technology as the basis of new radiation monitoring instruments in both portable and stationary unmanned formats. Portable instruments based upon the CsI(Tl)/HgI_2 detectors would be smaller and more lightweight than those using the standard NaI/PMT detectors. They would also have better performance.

[1] J. Markakis, C. Ortale, W. Schnepple, J. Iwanczyk and A. Dabrowski, "Mercuric Iodide Photodetectors for Scintillation Spectroscopy," *IEEE Trans. on Nucl. Sci.* Vol. NS-32, No. 1, 559-562, (1985).

[2] J.M Markakis, "Mercuric Iodide Photodetector-Cesium Iodide Scintillator Gamma Ray Spectrometers," *IEEE Tans. on Nucl. Sci.* NS-35(1), 356 (1988).

[3] Y.J. Wang, J.S. Iwanczyk and B.E. Patt, "New Concepts for Scintillator/HgI_2 Gamma Ray Spectroscopy," *IEEE Trans. on Nucl. Sci.* V.41, No. 4 (1994) 910.

[4] J.S. Iwanczyk, J.B. Barton, A.J. Dabrowski, J.H. Kusmiss, W.M. Szymczyk, G.C. Huth, J. Markakis, W.F. Schnepple and R. Lynn, *Nucl. Instr. and Meth.*, 213 (1983) 123-126.

[5] I. Holl, E. Lorenz, and G. Mageras, "A measurement of the light yield of common inorganic scintillators," *IEEE Trans. on Nucl. Sci.*, vol. 35, No. 1, pp. 105-109, 1988.

TOWARD HIGH-RESOLUTION COMPACT SCINTILLATION INSTRUMENTS

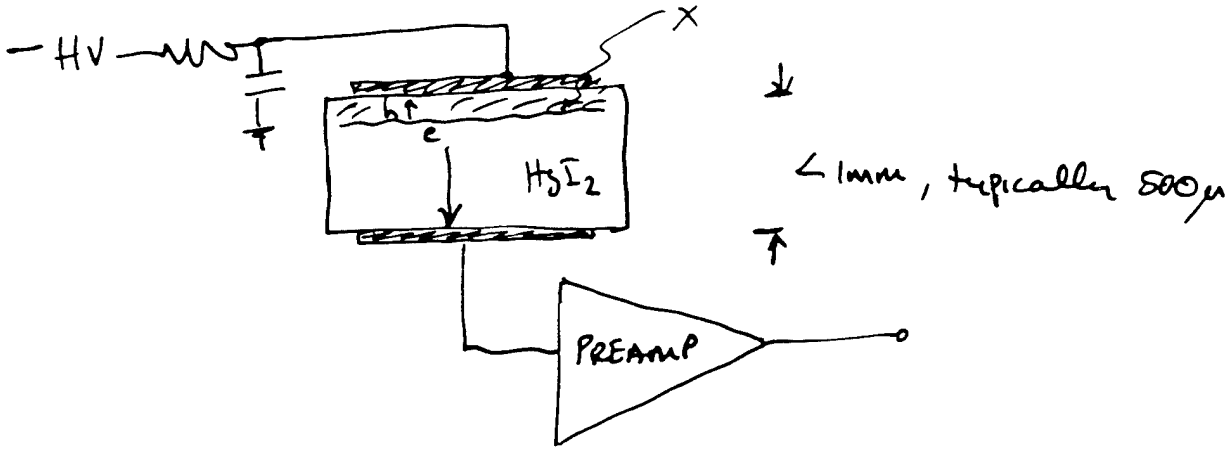
BRADLEY E. PATT, Y.J. WANG AND J.S. IWANCZYK
XSIRIUS, INC.,
1220 AVENIDA ACASO, CAMARILLO, CA 93012
(805) 484-8300

PROPERTIES OF HgI_2 CRYSTALS

Property	Value
Crystal Structure	Tetragonal (low T, red) Orthorhombic (high T, yellow)
Lattice Parameters	a = b = 4.361 A, c = 12.450 A
Density	6.4 g/cm^3
Melting Point	259°C
Phase Transition Temperature	127°C
Dielectric Constant	8.80-1.2i (at 5461 A)
Index of Refraction	2.71 (at 5890 A), 2.62 (at 6328 A)
Band Gap	2.13 eV
Electrical Resistivity	~10^{13} ohm-cm
Electron Mobility	~ 100 cm^2/Vs at 300K
Hole Mobility	~ 4 cm^2/Vs at 300K
$(\mu\tau)_e$	$\leq 10^{-3}$ cm^2/V
$(\mu\tau)_h$	$\leq 10^{-5}$ cm^2/V
Energy per e-h pair	4.2 eV (measured)
Fano factor	0.1

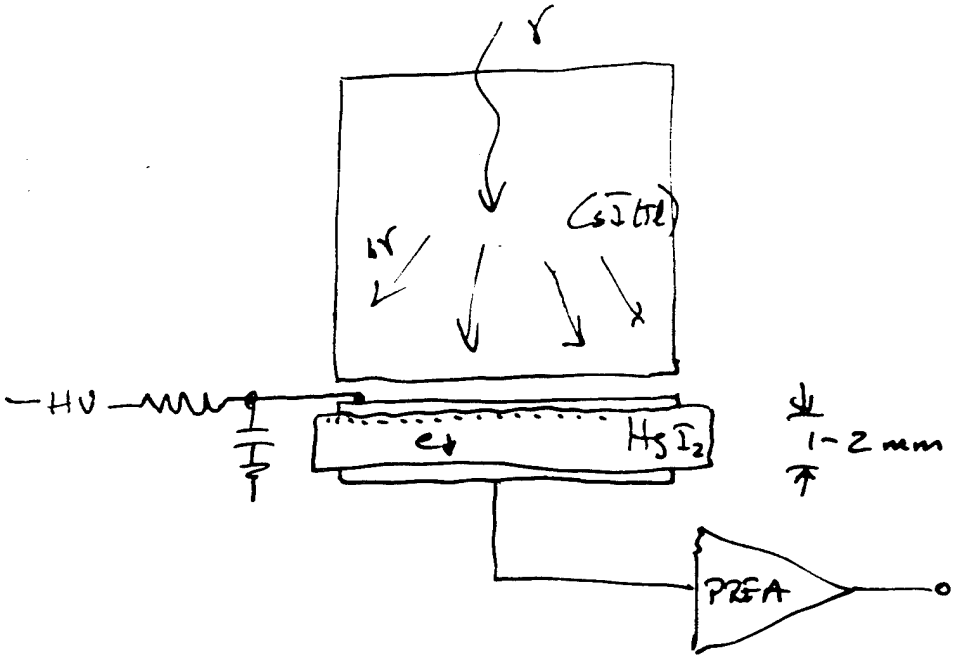
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CAMARILLO, CA 93012
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X-RAY DETECTORS (DIRECT)



< 1mm, typically 500μ

PHOTODETECTORS (INDIRECT)



1-2 mm

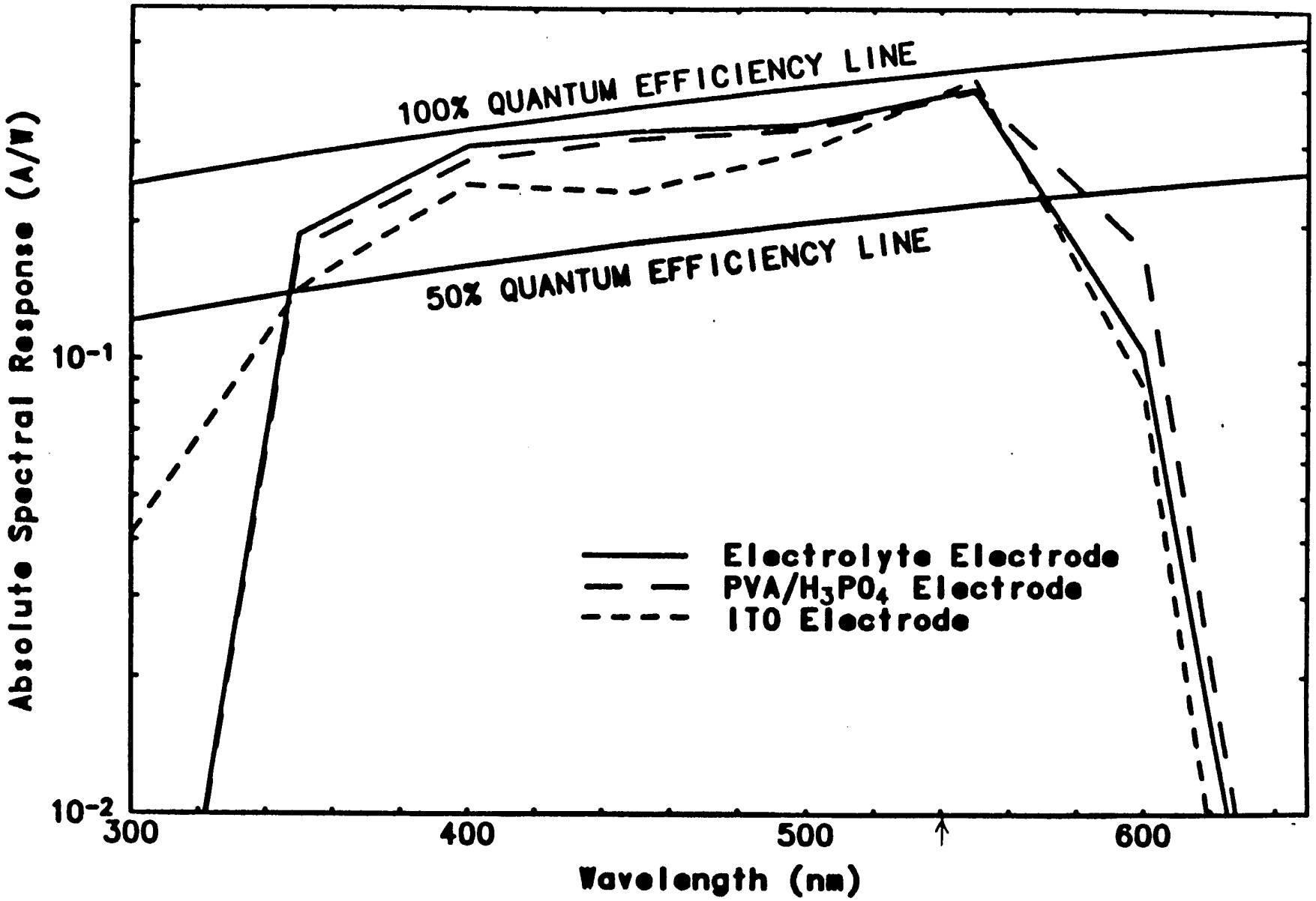
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INTRODUCTION

- The scintillator/PMT system has been used as a high efficiency gamma-ray spectrometer for many years
- Disadvantages: relatively poor energy resolutions; bulky and fragile; lacks immunity from magnetic fields

  $\Rightarrow$ to replace PM tubes with solid-state devices
- HgI_2 photodiode/CsI(Tl) as a gamma-ray detector:
  - ◊ good energy resolution: 4.58% FWHM for 662 keV gamma-ray photons
  - ◊ room temperature
  - ◊ compact size
- Recent progress has been made on large size HgI_2/CsI(Tl) spectrometers with high energy resolutions and detection efficiency:
  - ◊ detector structure optimization
  - ◊ low noise input amplification stage
  - ◊ scintillator geometry optimization

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Spectral response of HgI_2 with various entrance electrode materials.

From: J.M. Markakis and A.Y. Cheng, Nucl. Instr. & Meth. in Phys. Res., A283 (1989) 236-239.

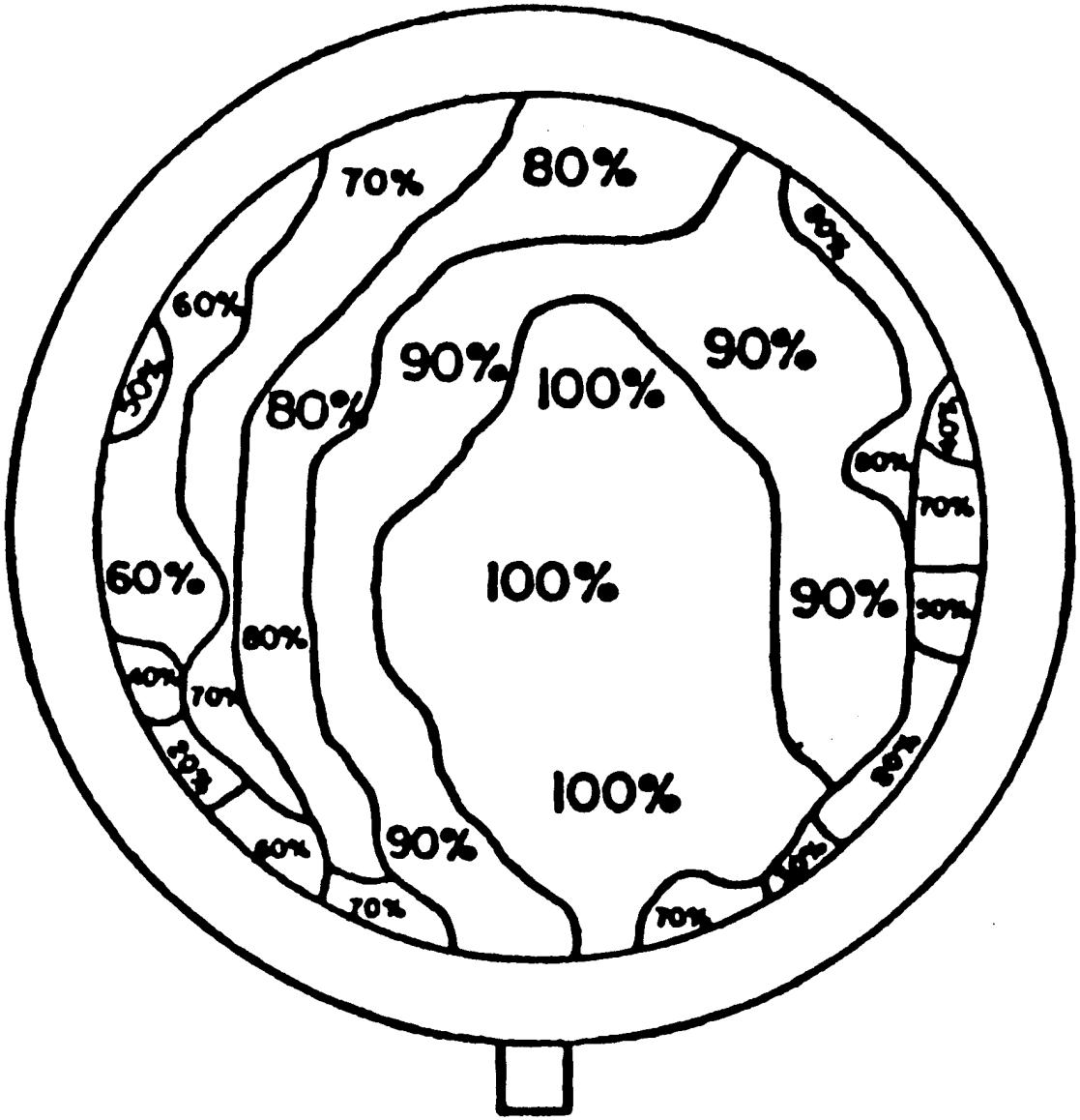
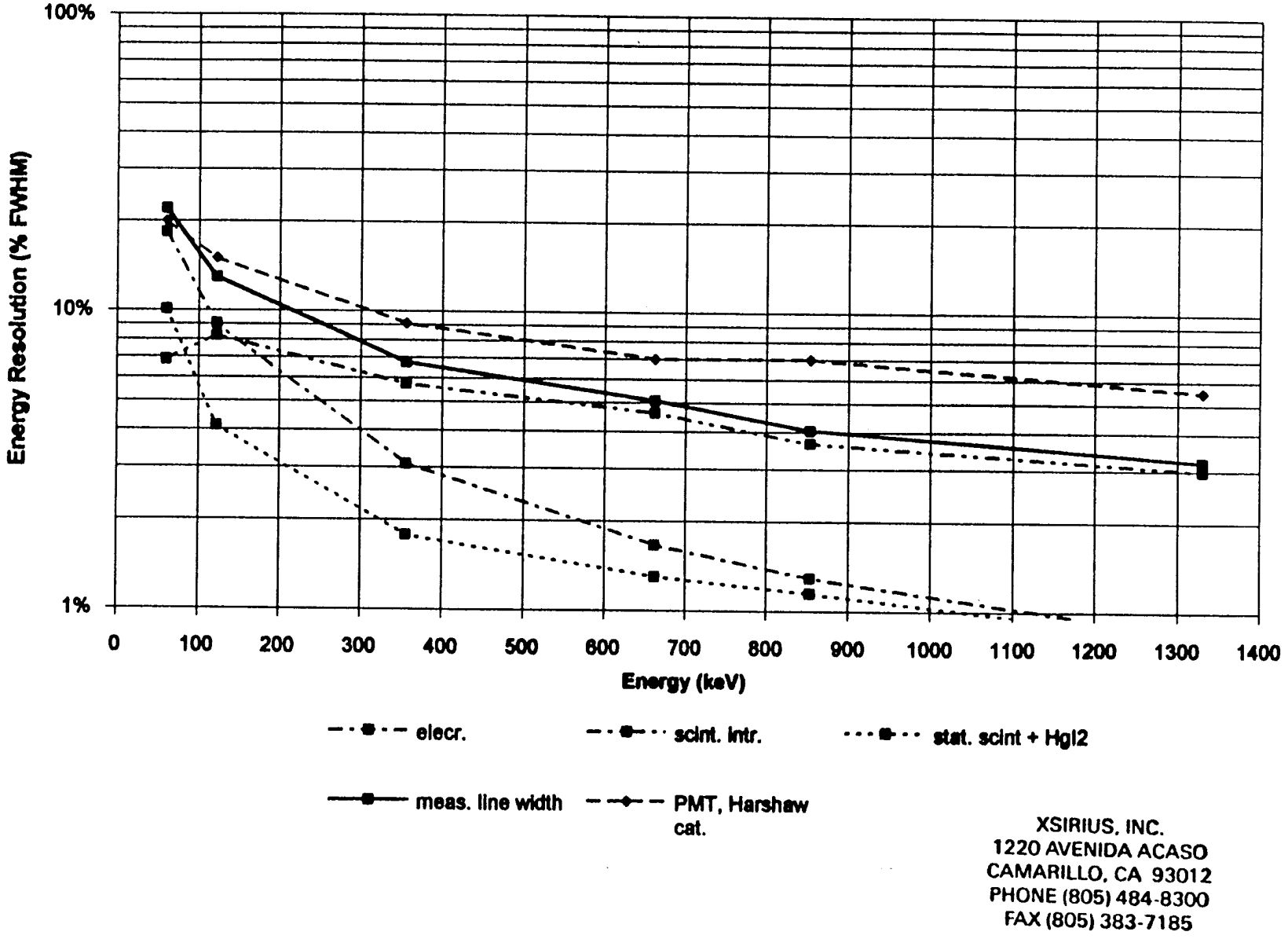
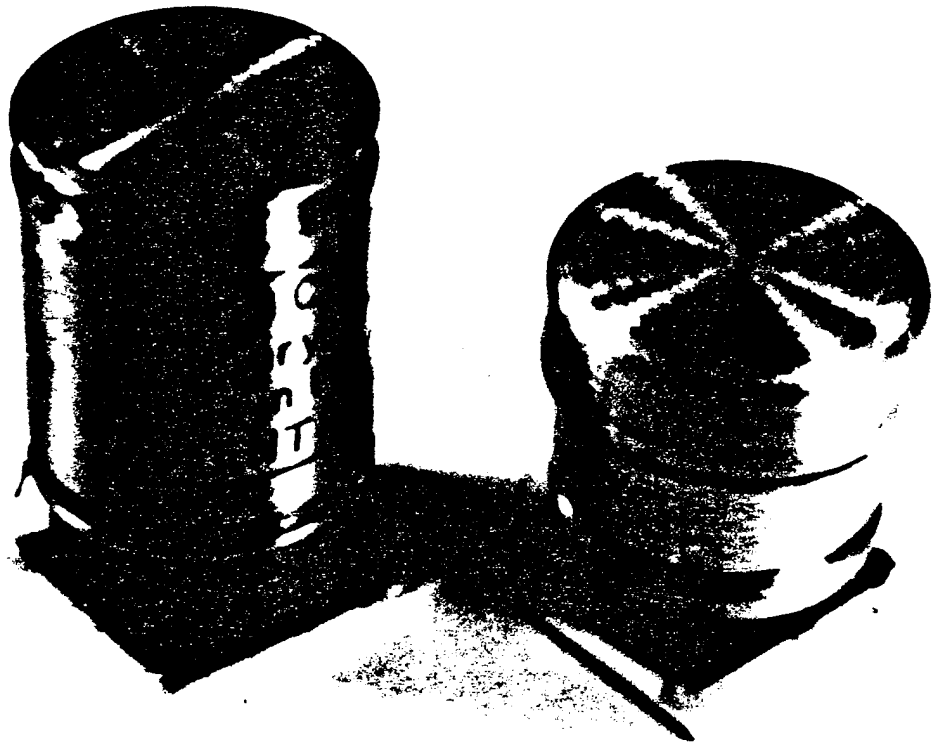


FIGURE 21:
Relative sensitivities for an RCA 2 in. diameter photomultiplier, Type 6342 A.



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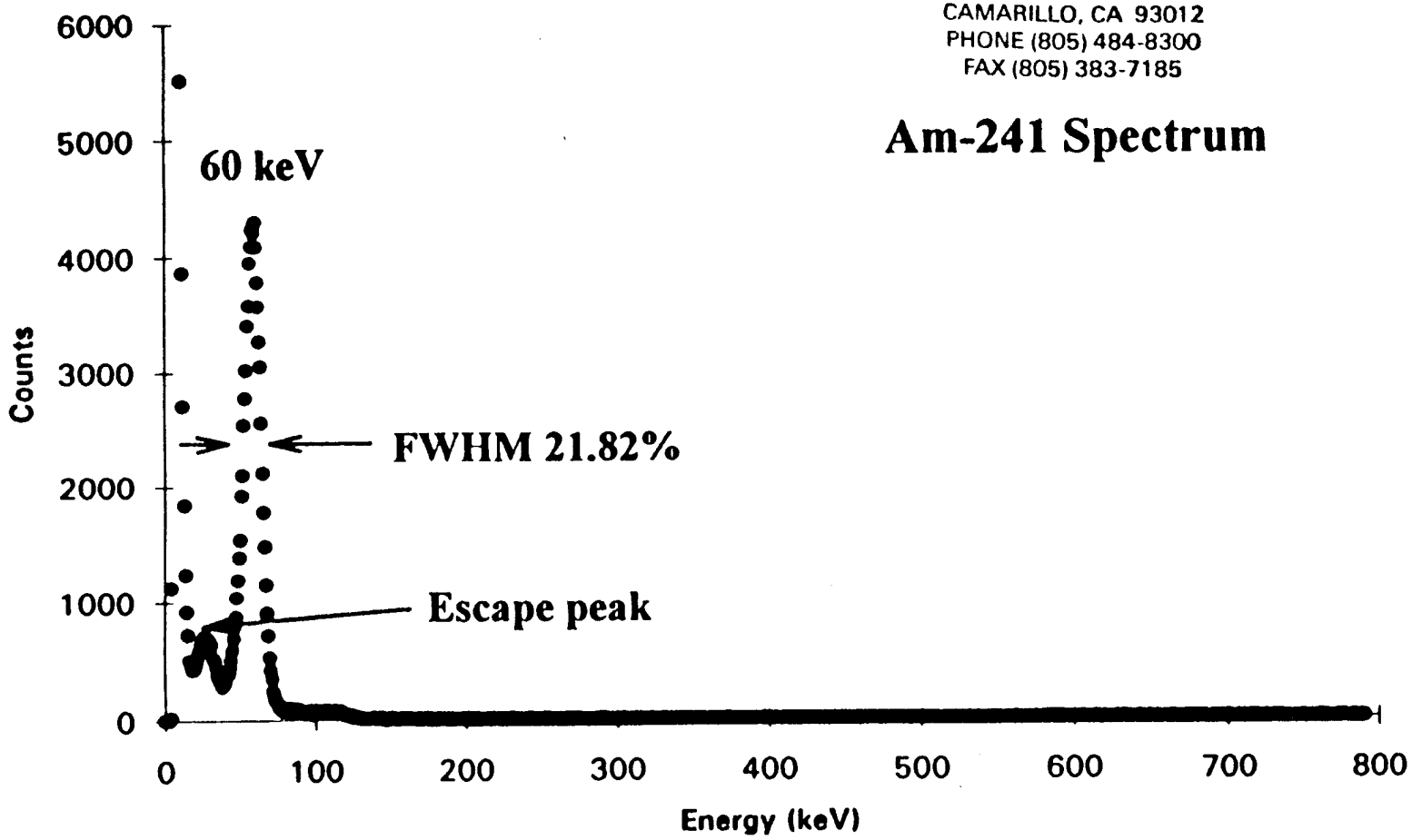


Combinations of mercuric iodide photodetectors and scintillation crystals for gamma-ray detection.

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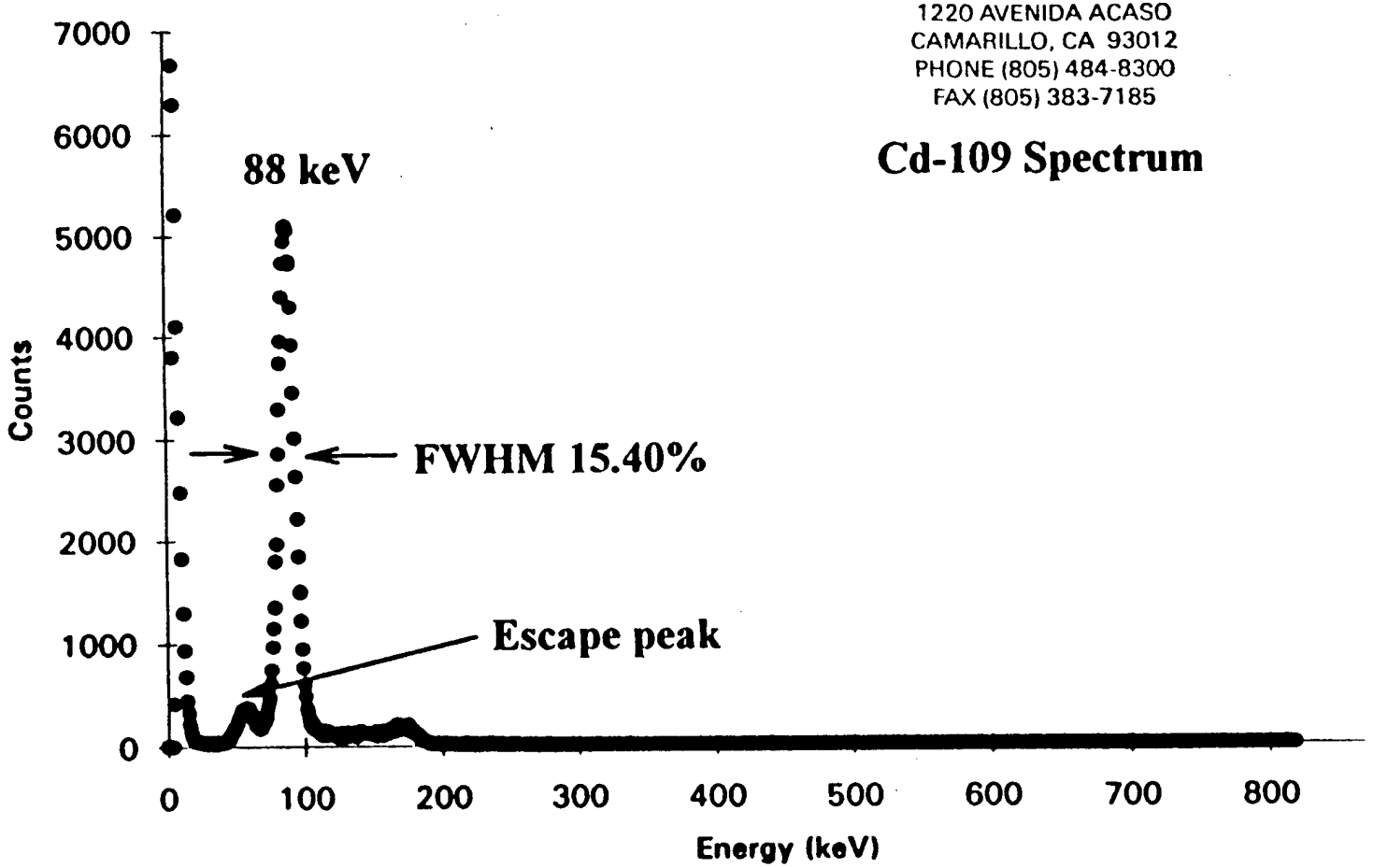
Am-241 Spectrum



The spectrum taken with a 1.5cmx1.5cm HgI_2 PD coupled to a 0.5"x0.5" CsI(Tl) scintillator for gamma-rays from a ^{241}Am source. The FWHM energy resolution for 60 keV is 21.82%.

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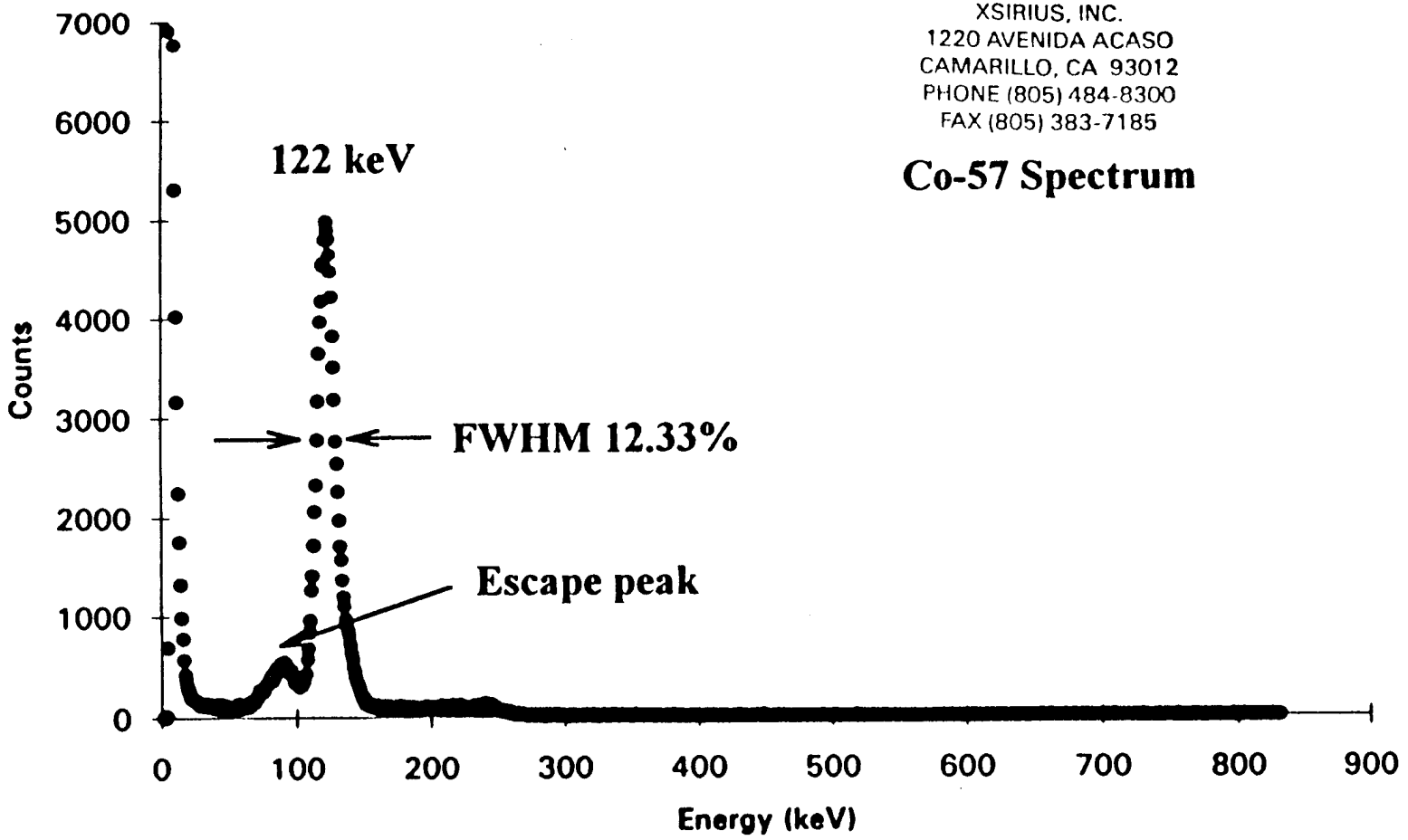
Cd-109 Spectrum



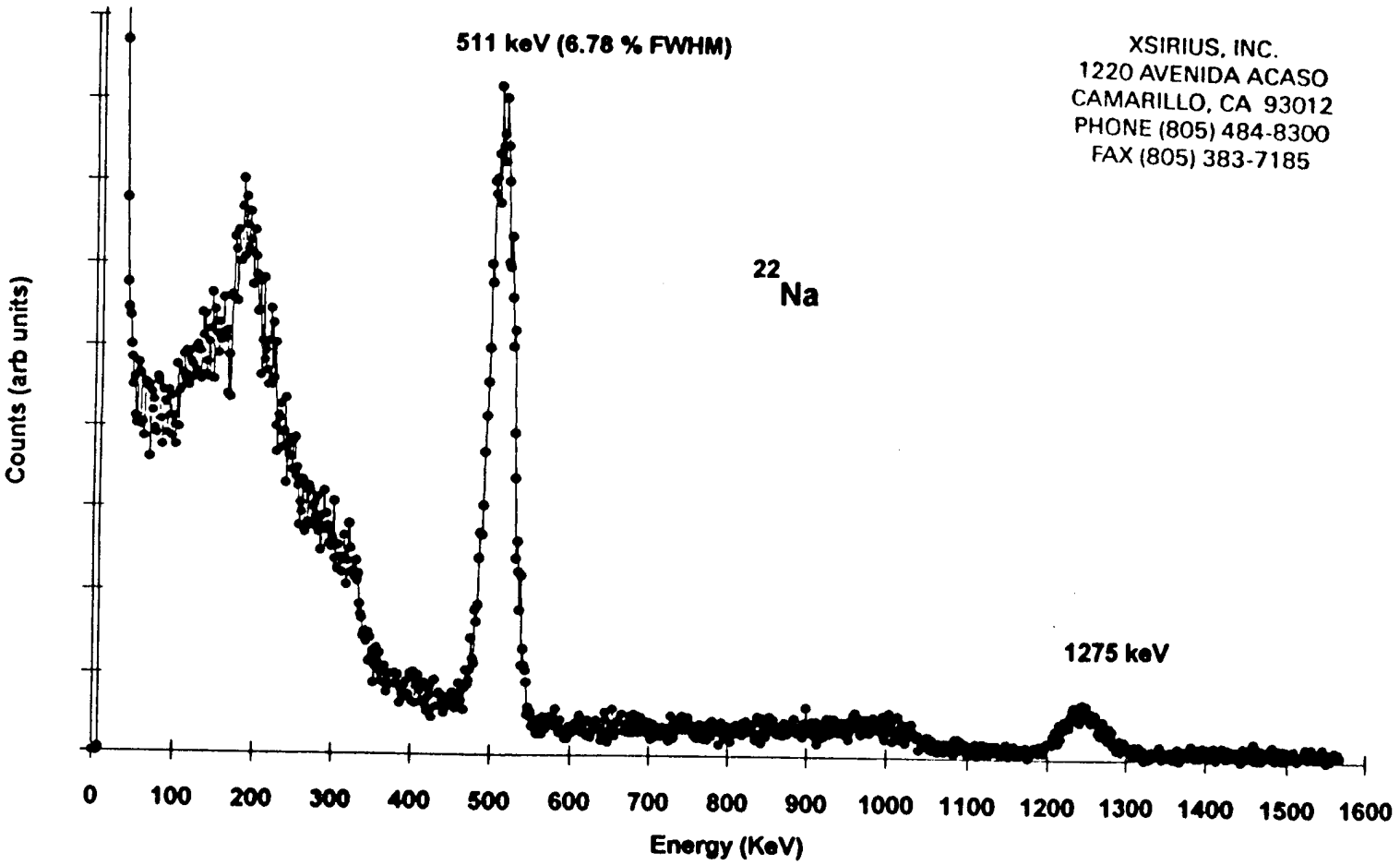
The spectrum taken with a 1.5cmx1.5cm HgI_2 PD coupled to a 0.5"x0.5" CsI(Tl) scintillator for gamma-rays from a ^{109}Cd source. The FWHM energy resolution for 88 keV is 15.40%.

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Co-57 Spectrum

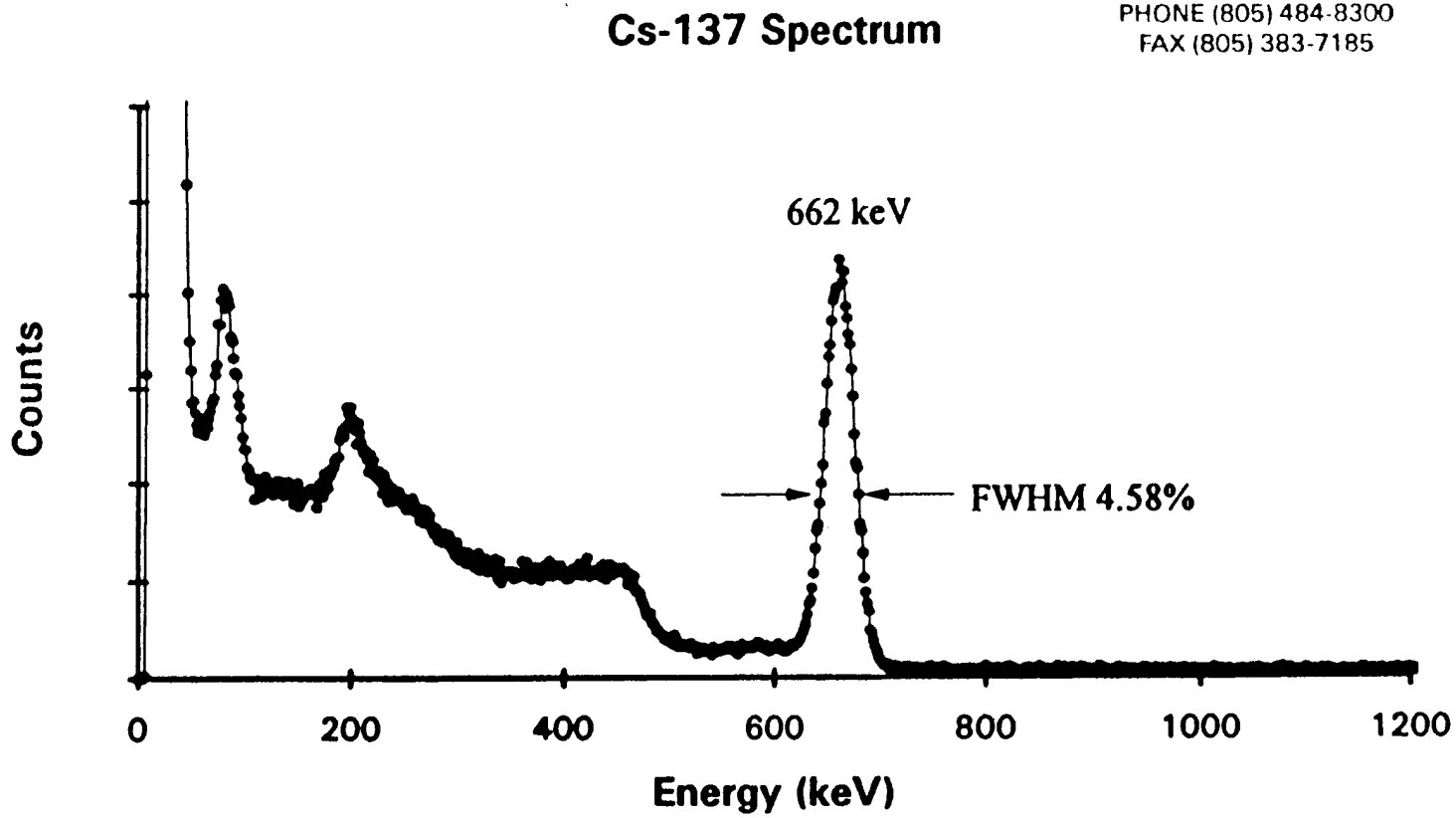


The spectrum taken with a 1.5cmx1.5cm HgI_2 PD coupled to a 0.5"x0.5" CsI(Tl) scintillator for gamma-rays from a ^{57}Co source. The FWHM energy resolution for 122 keV is 12.33%.

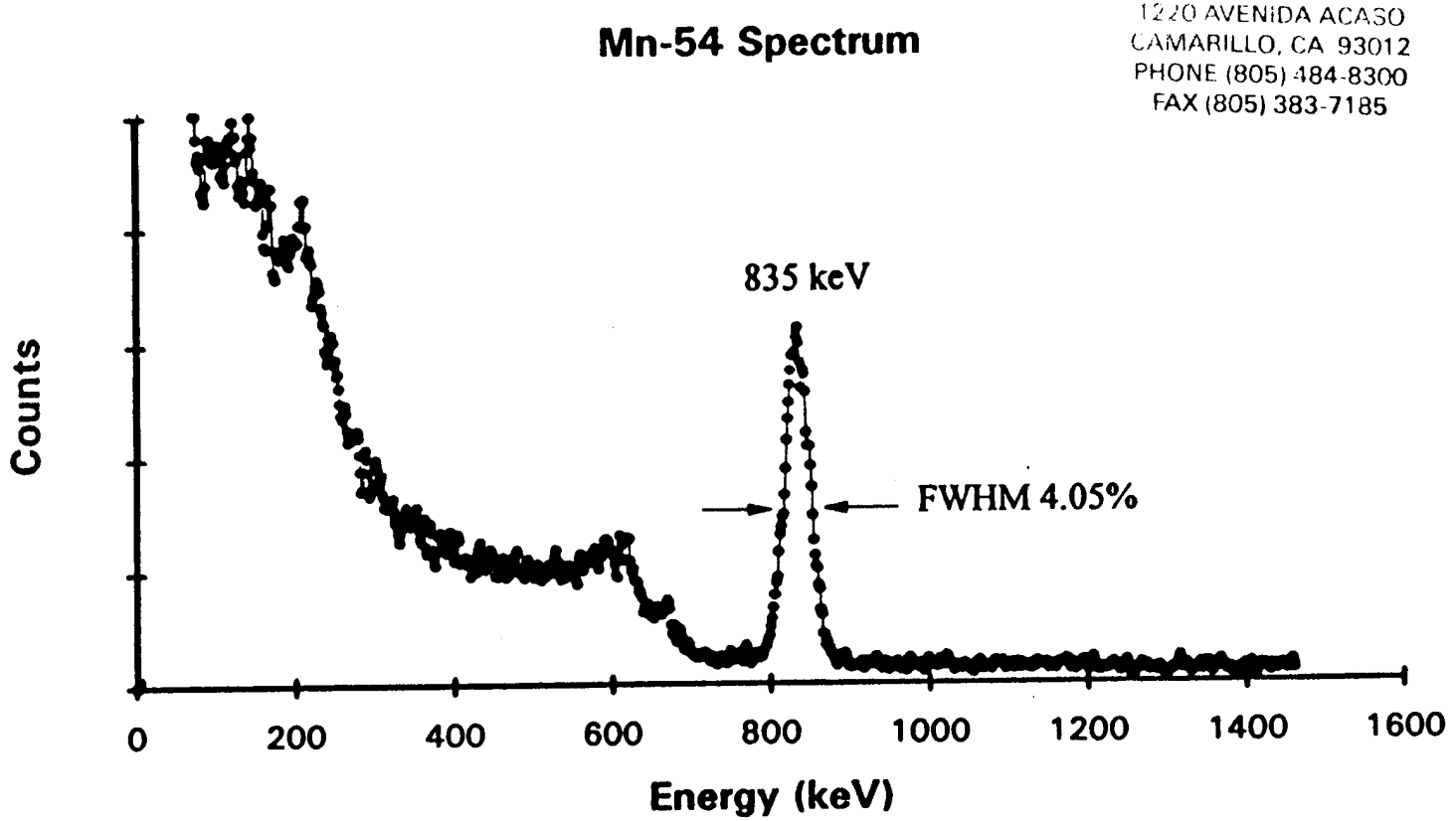


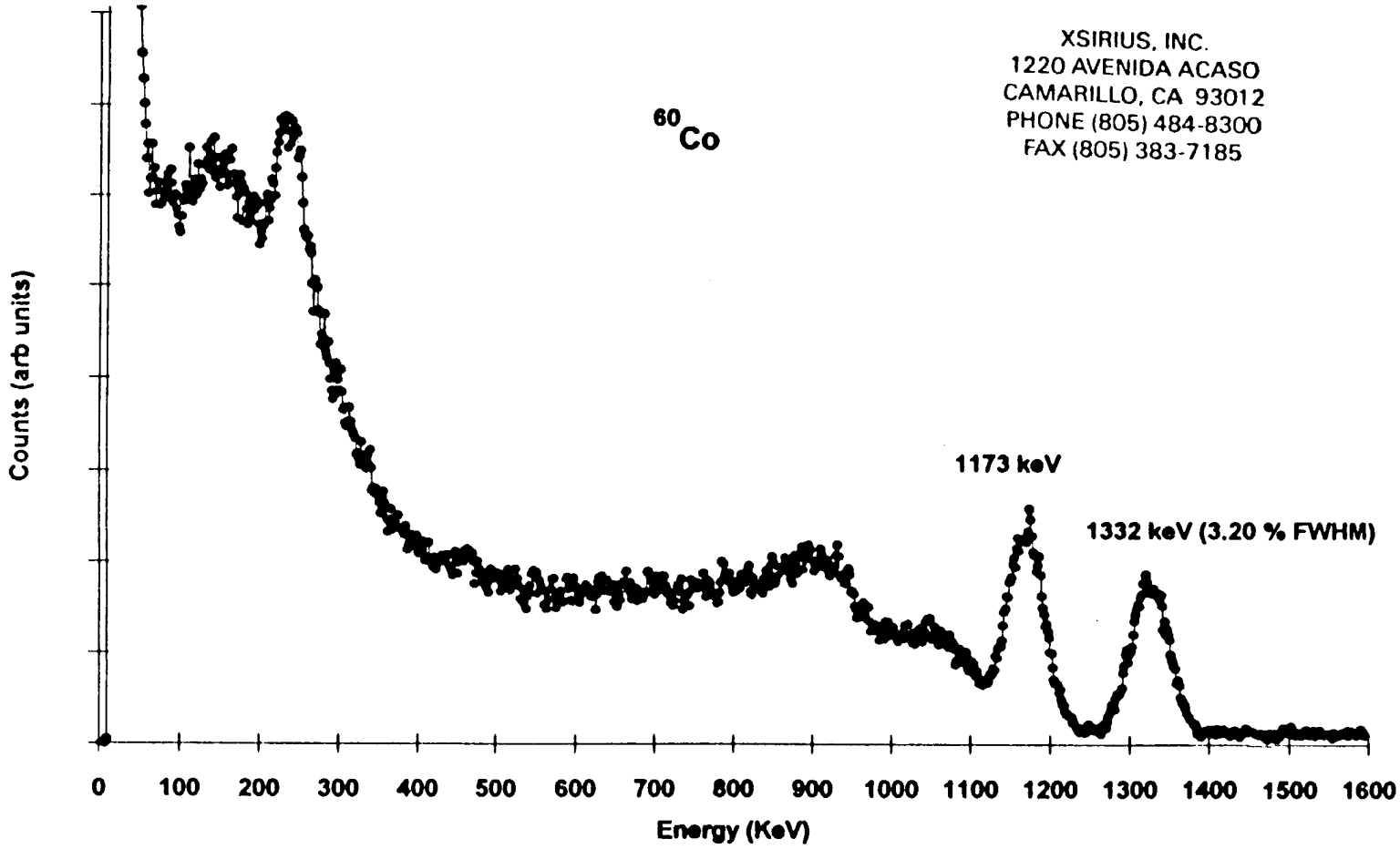
The spectrum taken with a 0.5" HgI_2 coupled to a 0.5"x0.5" CsI(Tl) scintillator for gamma rays from a ^{22}Na source. The FWHM energy resolution for 511 keV is 6.78%.

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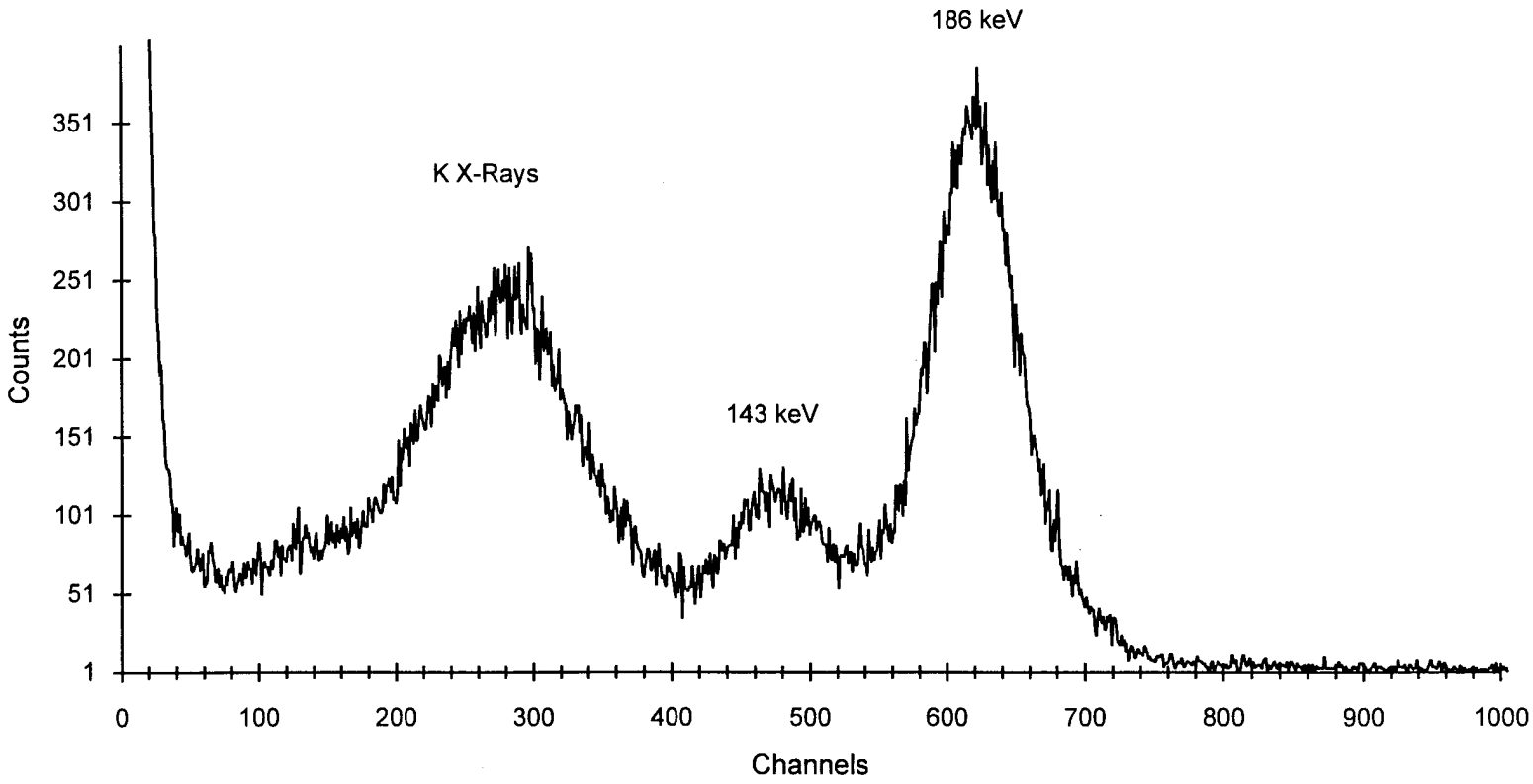
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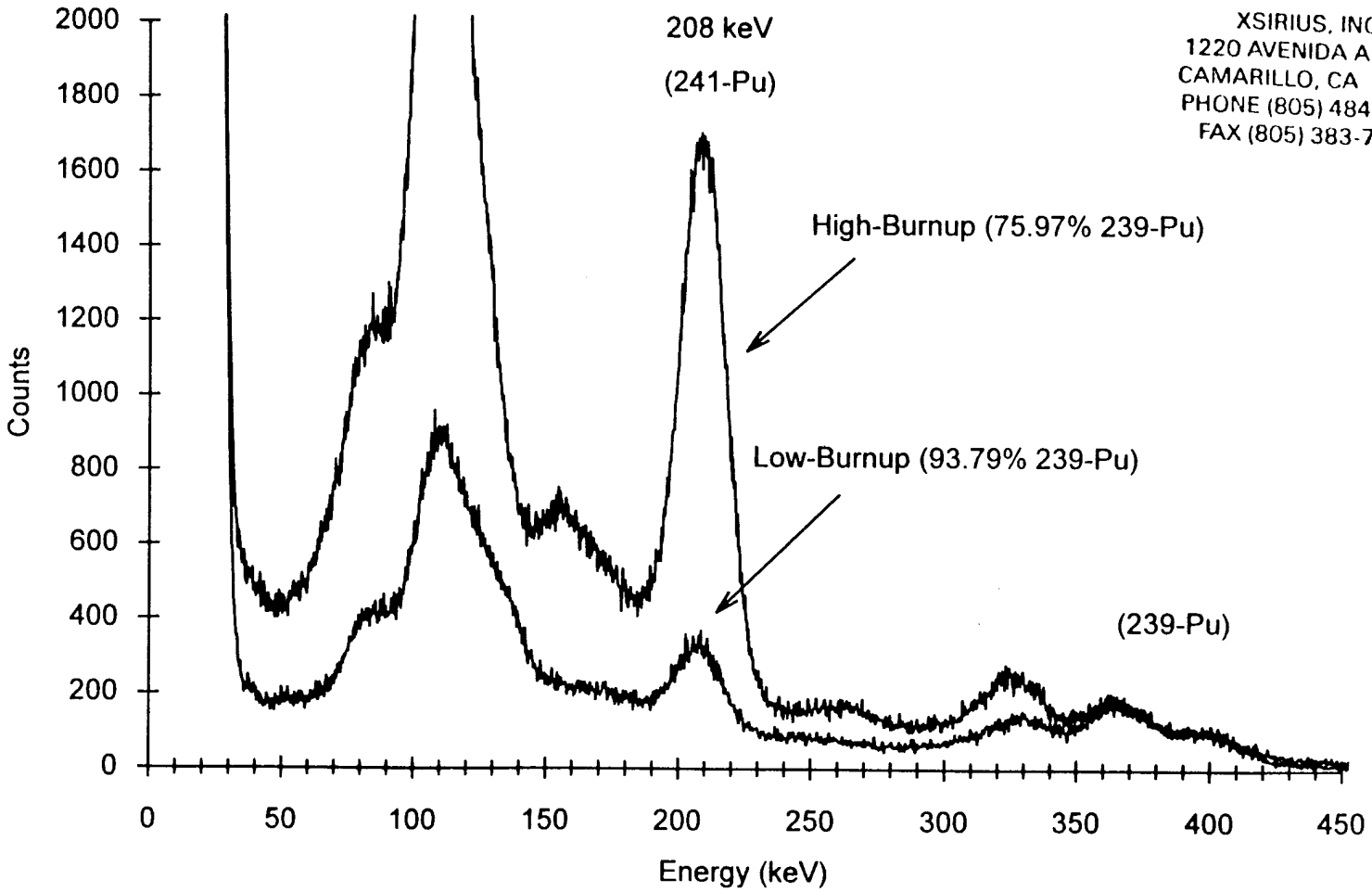


The spectrum taken with a 0.5" HgI_2 coupled to a 0.5"x0.5" CsI(Tl) scintillator for gamma rays from a ^{60}Co source. The FWHM energy resolution for 1332 keV is 3.20%.

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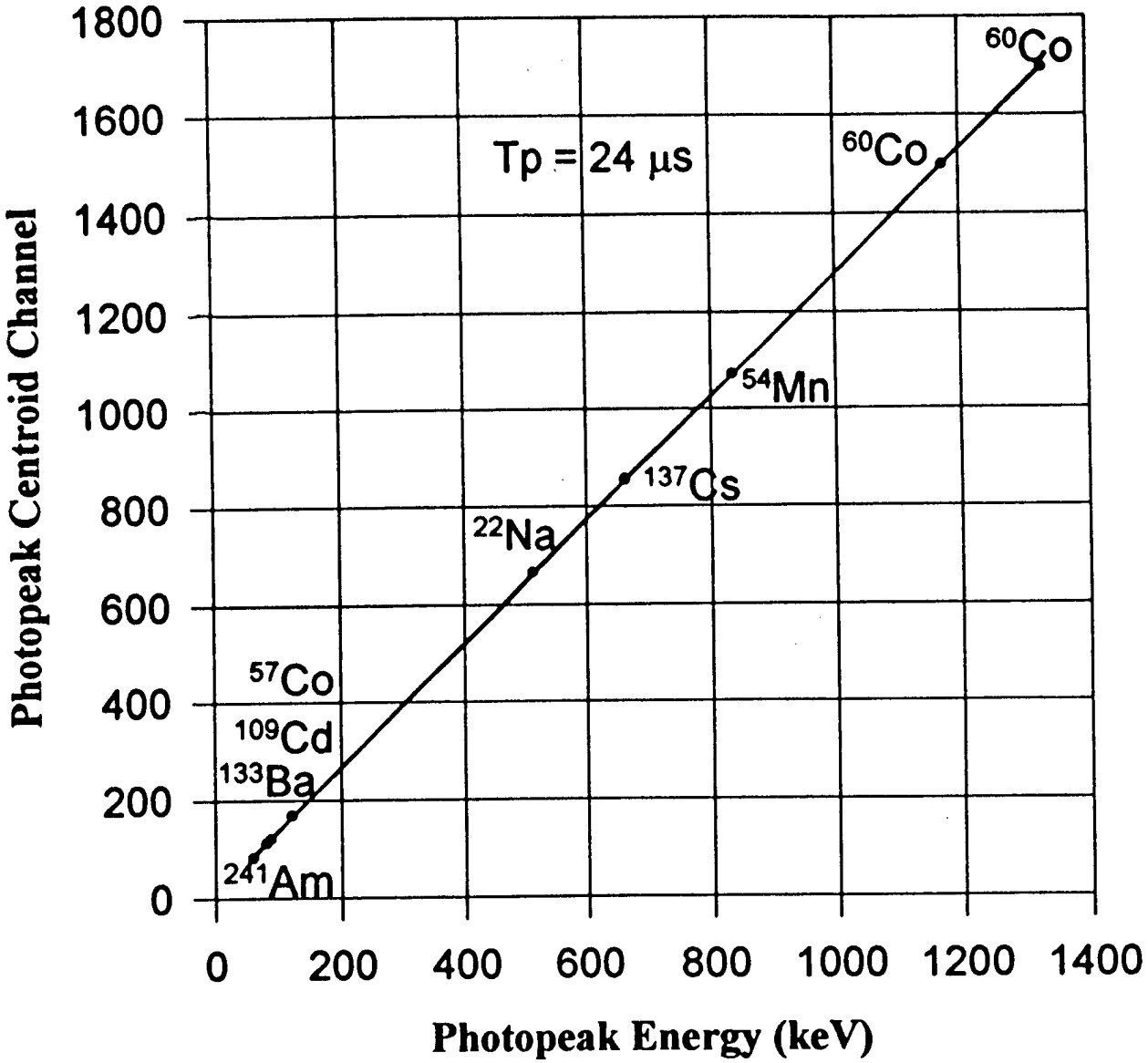


Comparison of Spectra: Low and High Burnup Pu Samples

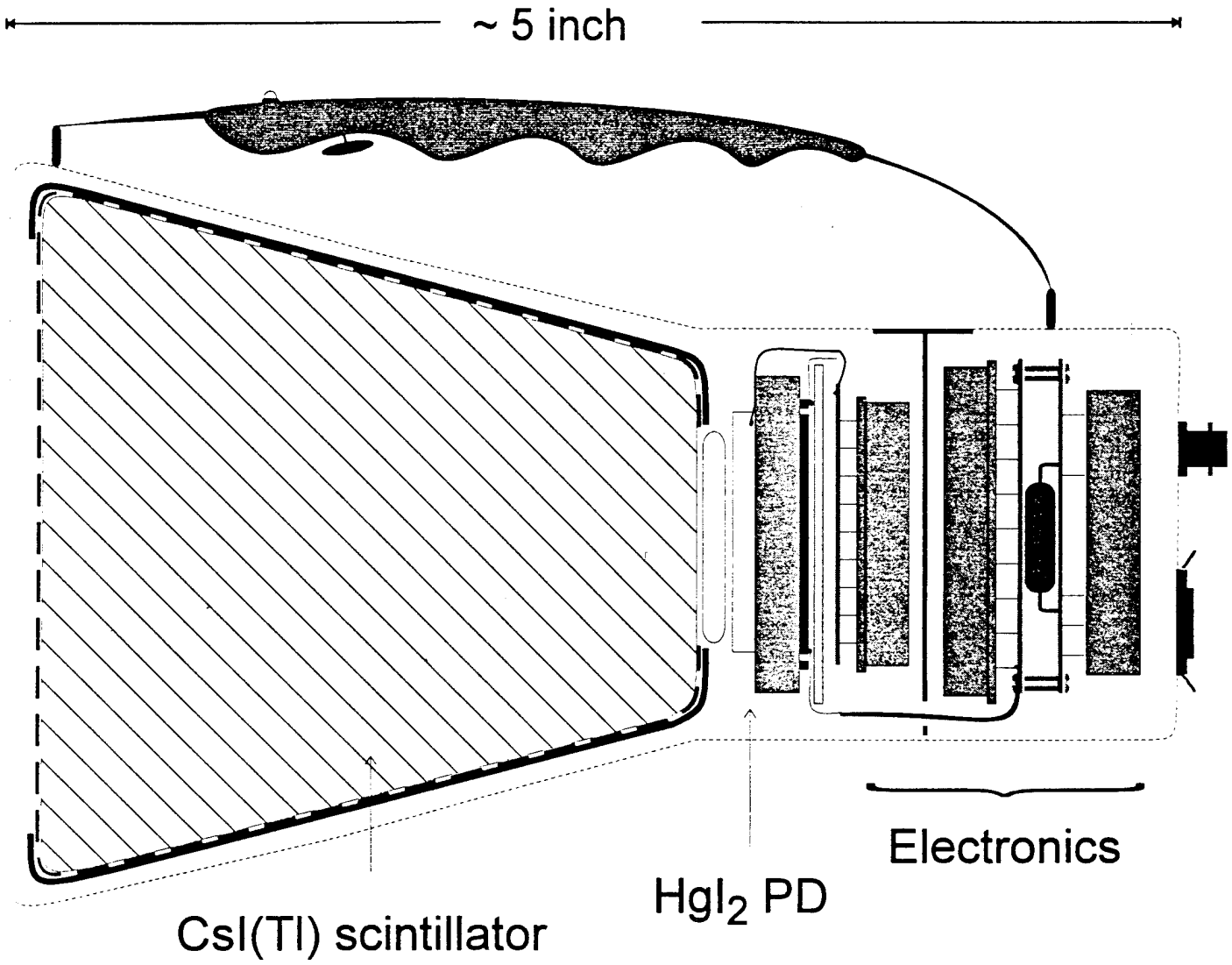


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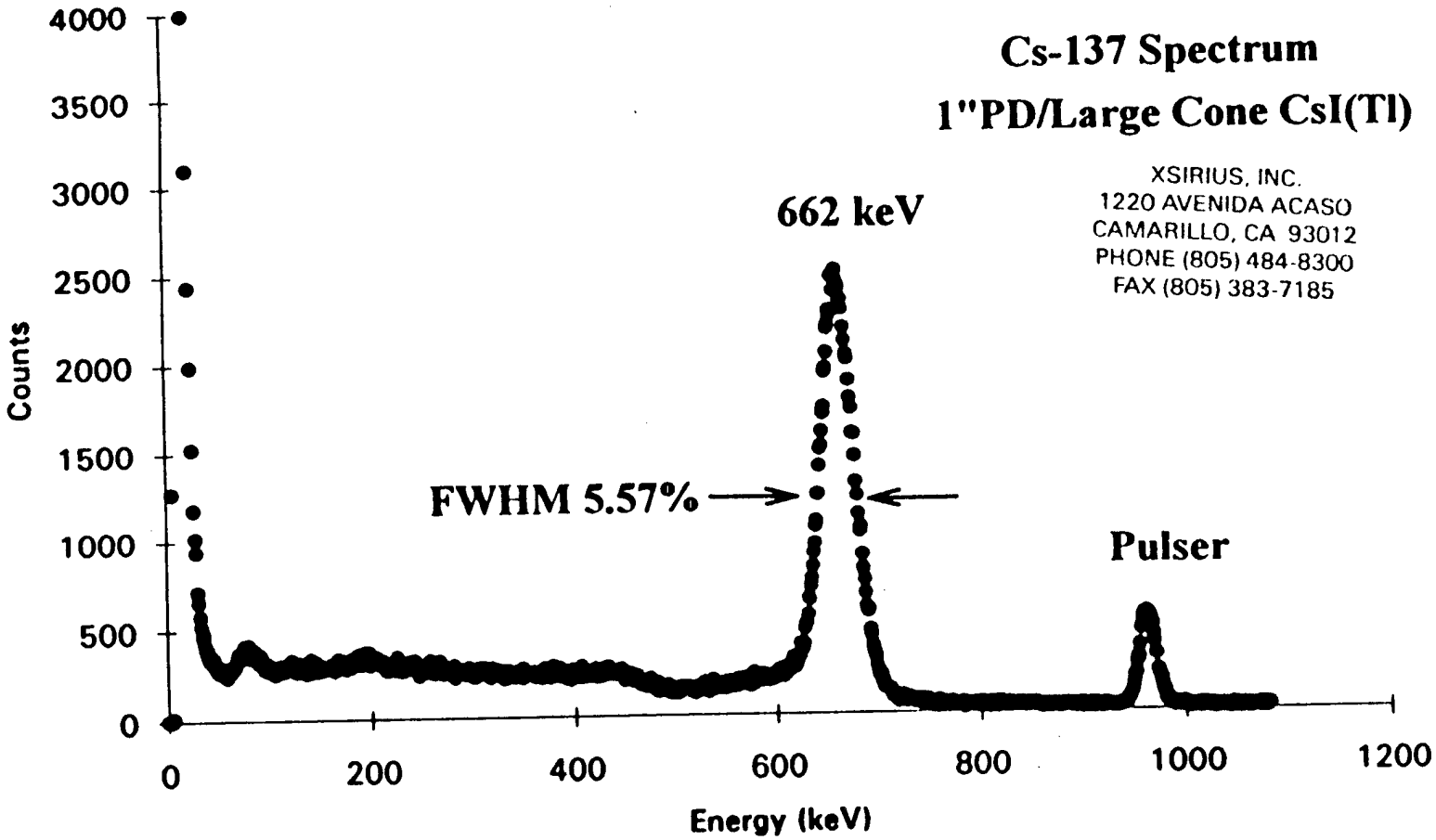
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Gamma response linearity of 0.5" HgI_2 photodetector coupled to a 0.5"x0.5" CsI(Tl) scintillator. Radiation sources ^{241}Am, ^{133}Ba, ^{109}Cd, ^{22}Na, ^{137}Cs, ^{54}Mn and ^{60}Co were used.



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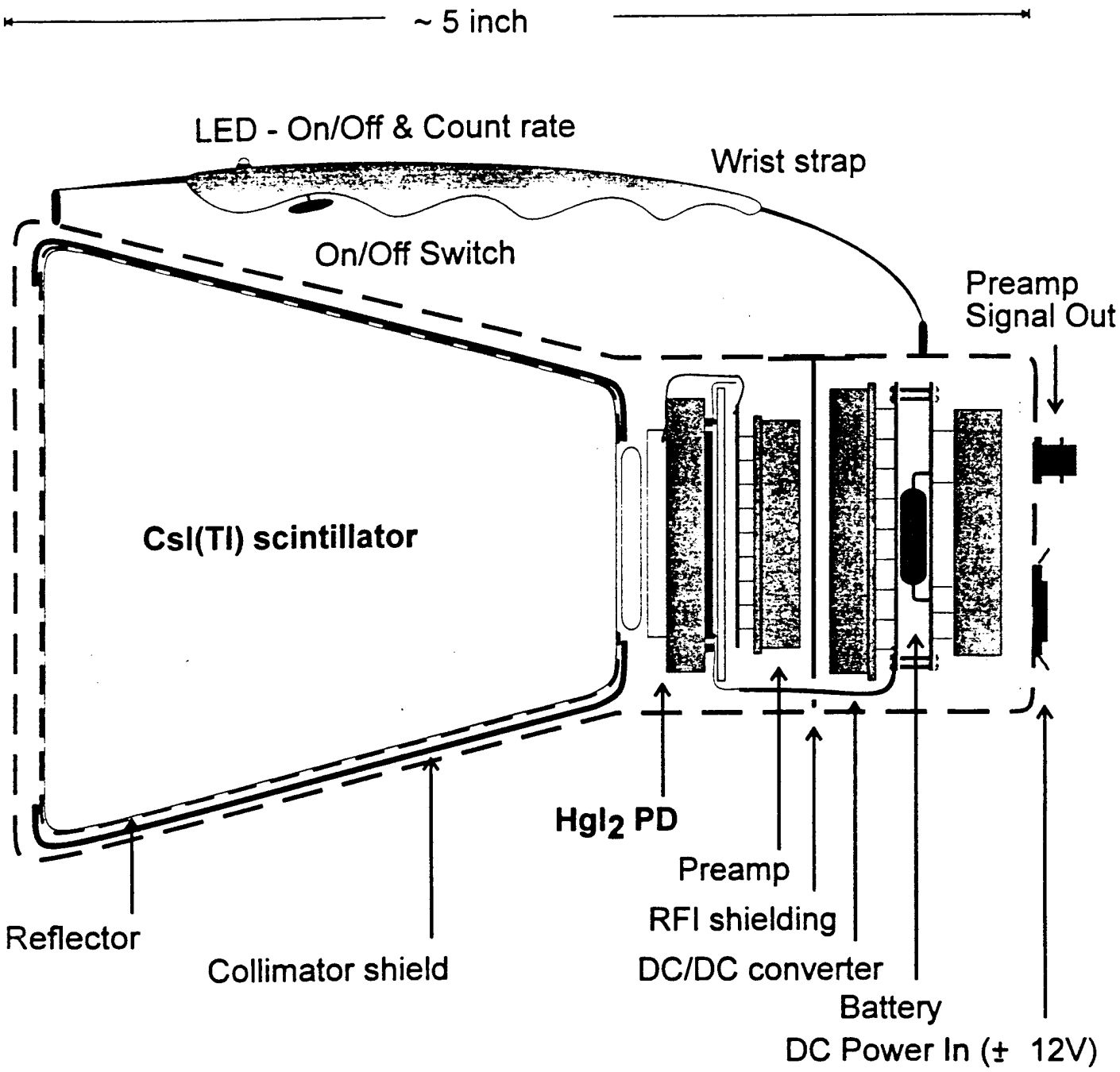


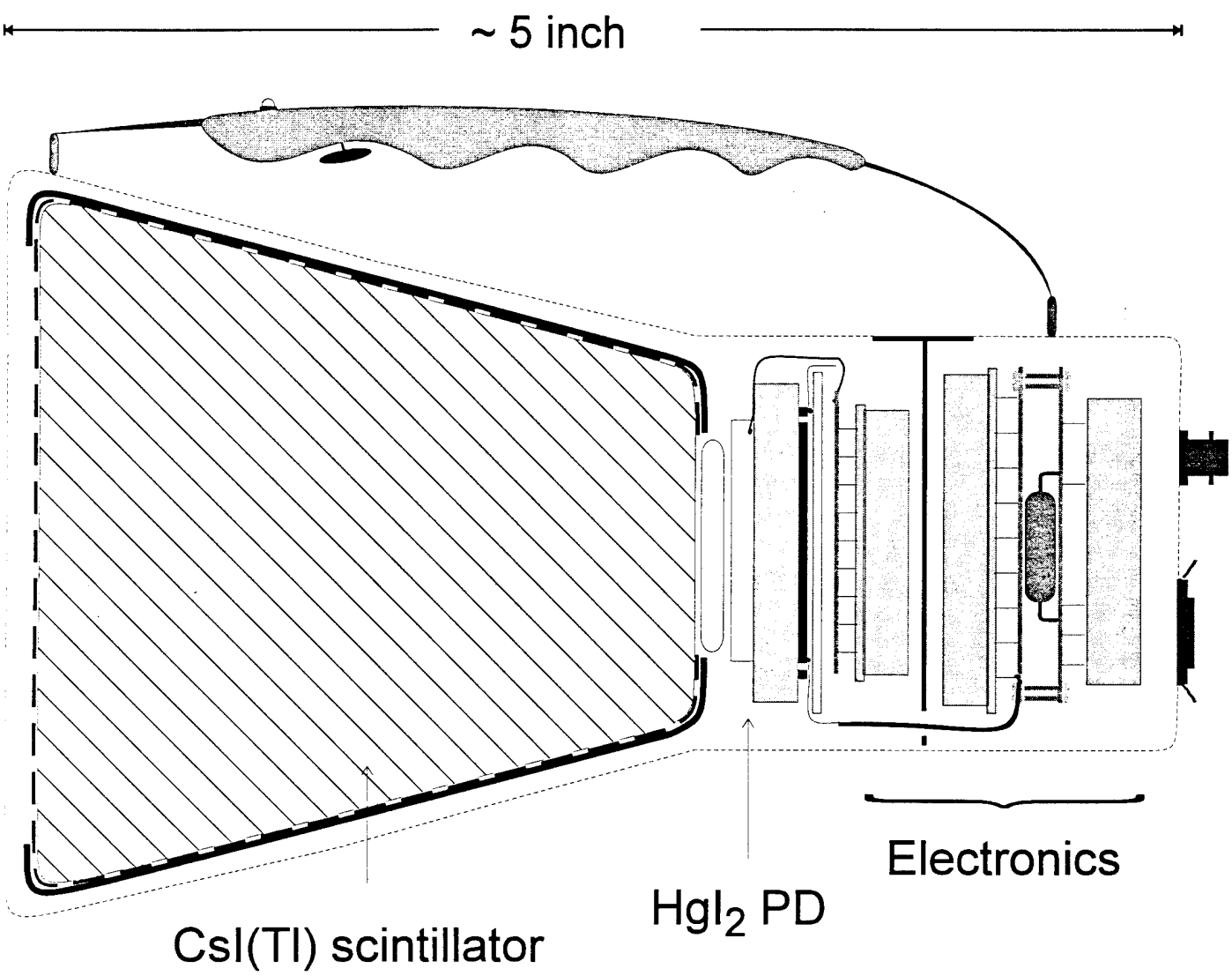
The spectrum taken with a HgI_2 PD (1" diameter) coupled to a cone shaped CsI(Tl) scintillator (top diameter: 2", bottom diameter: 1", height: 2") for gamma-rays from a ^{137}Cs source. The FWHM energy resolution for 662 keV is 5.57%.

CONCLUSIONS

- **$CsI(Tl)/HgI_2$ gamma-ray spectrometers have shown good energy resolutions (4.58% FWHM for 662 keV gamma-ray photons was found with a 0.5" detector)**
- **Large size HgI_2 PD ($\geq$ 1" diameter) coupled to cone shaped CsI(Tl) can be used as high efficiency gamma-ray spectrometer (5.57% FWHM for 662 keV gamma-ray photons was found with a 1" HgI_2 PD coupled to a big cone shaped scintillator)**
- **Advantages of $CsI(Tl)/HgI_2$ detectors (good energy resolution; high efficiency; compact size; no cryogenic cooling requirements) open a broad future for the use of these units in many applications.**

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~ 5 inch
LED - On/Off & Count rate
Wrist strap
On/Off Switch
Preamp
Signal Out
CsI(Tl) scintillator
HgI2 PD
Preamp
RFI shielding
DC/DC converter
Battery
DC Power In (± 12V)
Reflector
Collimator shield


~ 5 inch
Electronics
HgI2 PD
CsI(Tl) scintillator

V. Related Technologies Session

Satellite Data Relay For Remote Monitoring Of Nuclear Contamination

Joseph A. Goldstein
Naval Research Laboratory
Information Technology Division
Code 5554
Washington, D. C. 20375-5337
202-767-3029
FAX 202-767-3377
goldstein@itd.nrl.navy.mil

This presentation describes the development of technology to relay data from remote, unattended, often environmentally hostile locations to data fusion centers for display, analysis and often, wide dissemination via the Internet. The data relay technology is applicable to situations where the use of wires and/or fibers is not possible or practical. The choice of data relay connectivity is determined from the operational requirements of the particular application. NRL has a long history of involvement in RF data connectivity activities across the frequency spectrum from MF to EHF. NRL has extensive involvement in MF communications operations, in association with the U. S. Navy's ICEX exercises in the Lincoln and Beaufort Seas.

NRL has been involved with remote monitoring systems for the past three years. Initial efforts were directed toward a battery powered, low data rate system that used the U.S. Navy UHF Fleet Satellite (FLTSAT) system for both data relay and command and control. The current year's effort are directed toward the use of commercial satellites for much higher data relay rates (1 MBPS) and a generator-powered deployable system with a built-in Local Area Network (LAN) capability. The LAN consists of several nodes in the remote system. The LAN implementation will allow direct connectivity between the various controllers on the deployed system and the researchers at global locations via the Internet. Future expansion of satellite services holds great promise for increased capabilities and flexibility in system applications.

The technology being developed incorporates state-of-the art hardware and software to provide remote sensor interfaces and data relay via the optimum RF path, for wide data dissemination (Internet) and display to the global user. This technology is well suited for Nuclear monitoring, allowing for real-time or store-and-forward type data relaying from remote monitoring sites to global data analysis centers, as well as system command, control, and diagnostic troubleshooting from the control and operations center.

SATELLITE DATA RELAY FOR REMOTE MONITORING OF NUCLEAR CONTAMINATION

JOSEPH A. GOLDSTEIN

U. S. NAVAL RESEARCH LABORATORY

Information Technology Division

Transmission Technology Branch

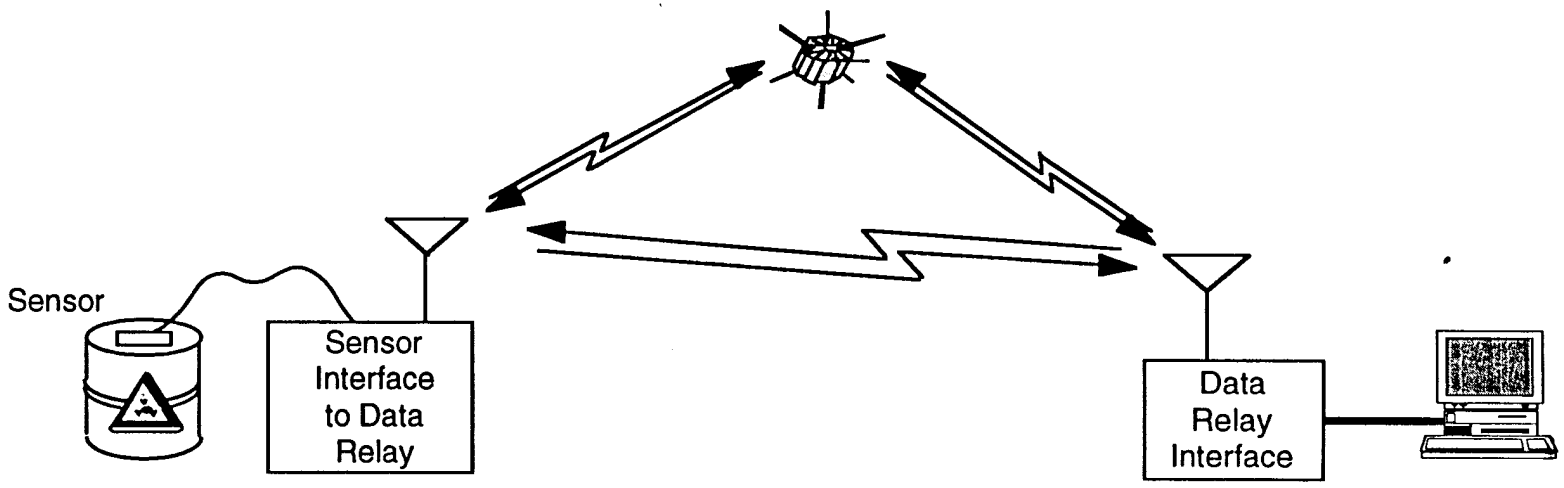
CODE 5554

202-767-3029

goldstein@itd.nrl.navy.mil

19 JANUARY 1995

SATELLITE DATA RELAY



- **State-of-the-Art Data Connectivity for Situations Where Wires or Fibers are Not Available**
- **Specific Application Drives Choice**

RF Path **Frequency Band**

Quantity of Data **Continuous / Intermittent**

SATELLITE DATA RELAY

Naval Research Laboratory Colleagues

Mike Rupar **Code 5554**
rupar@itd.nrl.navy.mil
202-767-3155

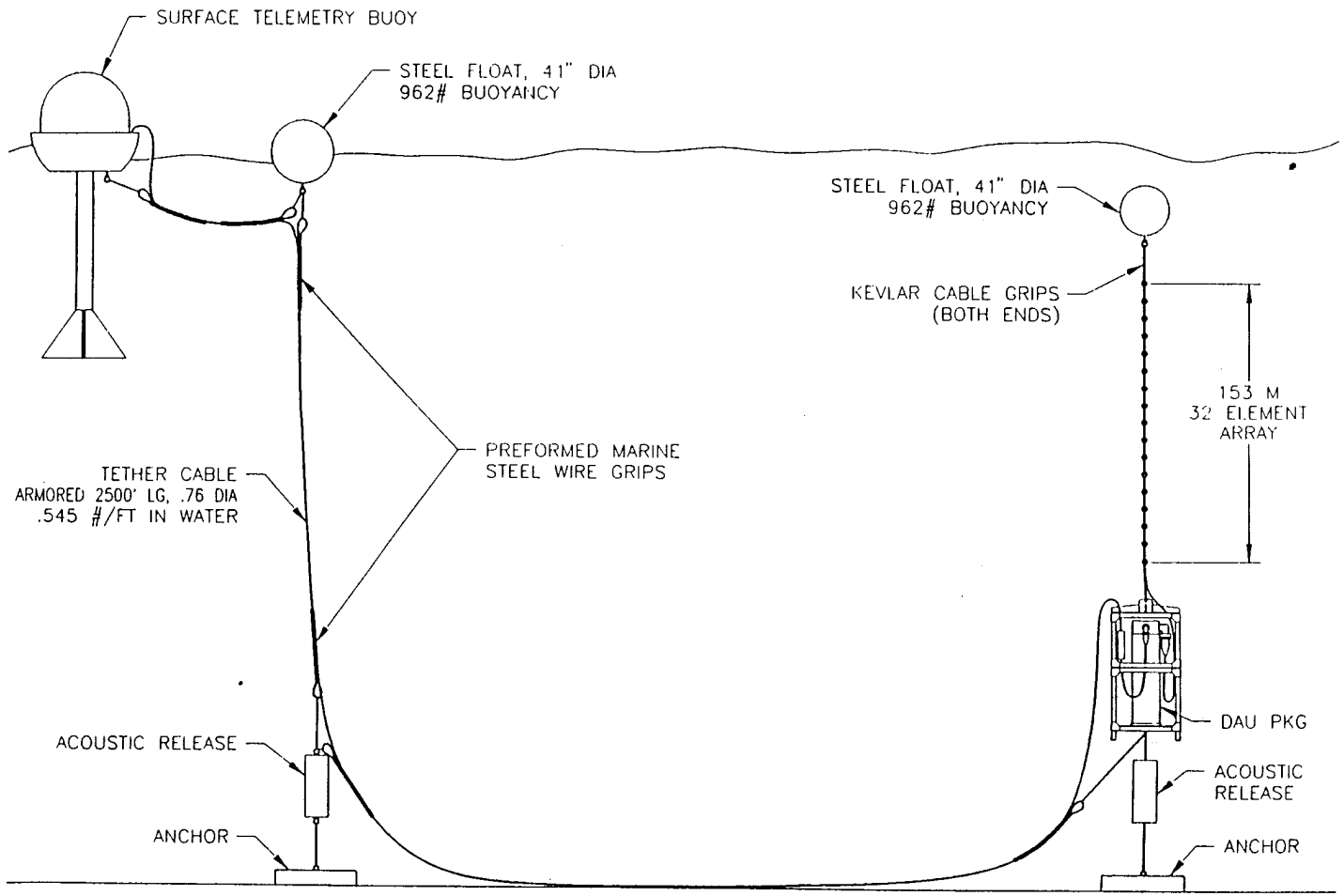
Tim Krout **Code 7140**
krout@abyss.nrl.navy.mil
202-767-5769

TESPEX

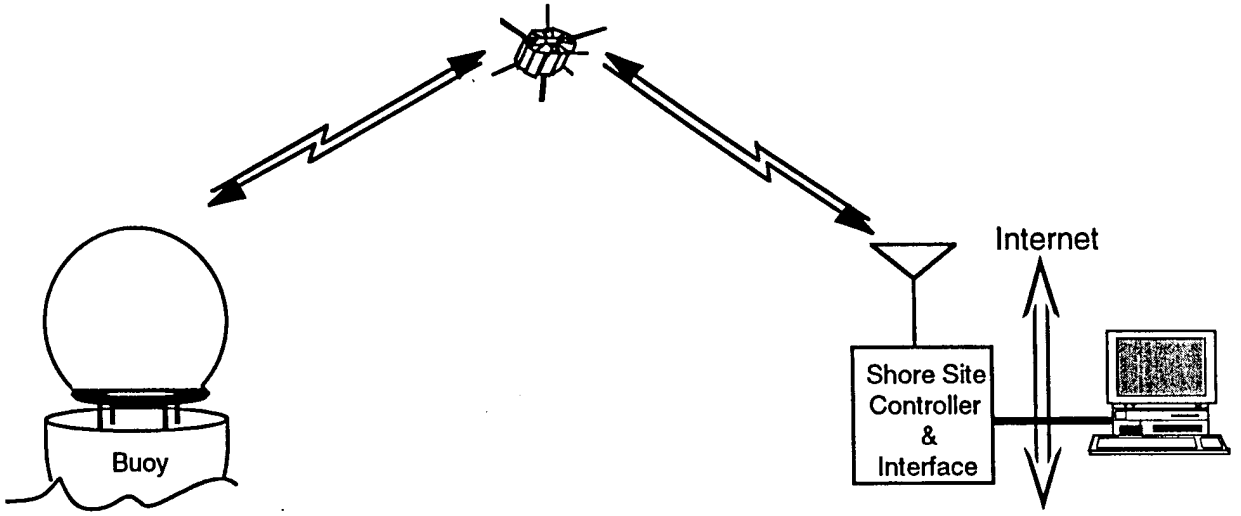
TTCP Environmental Signal Processing Experiment
TTCP - The Technical Cooperation Program
U. S. Canada U. K.
Australia & New Zealand

SATELLITE DATA RELAY

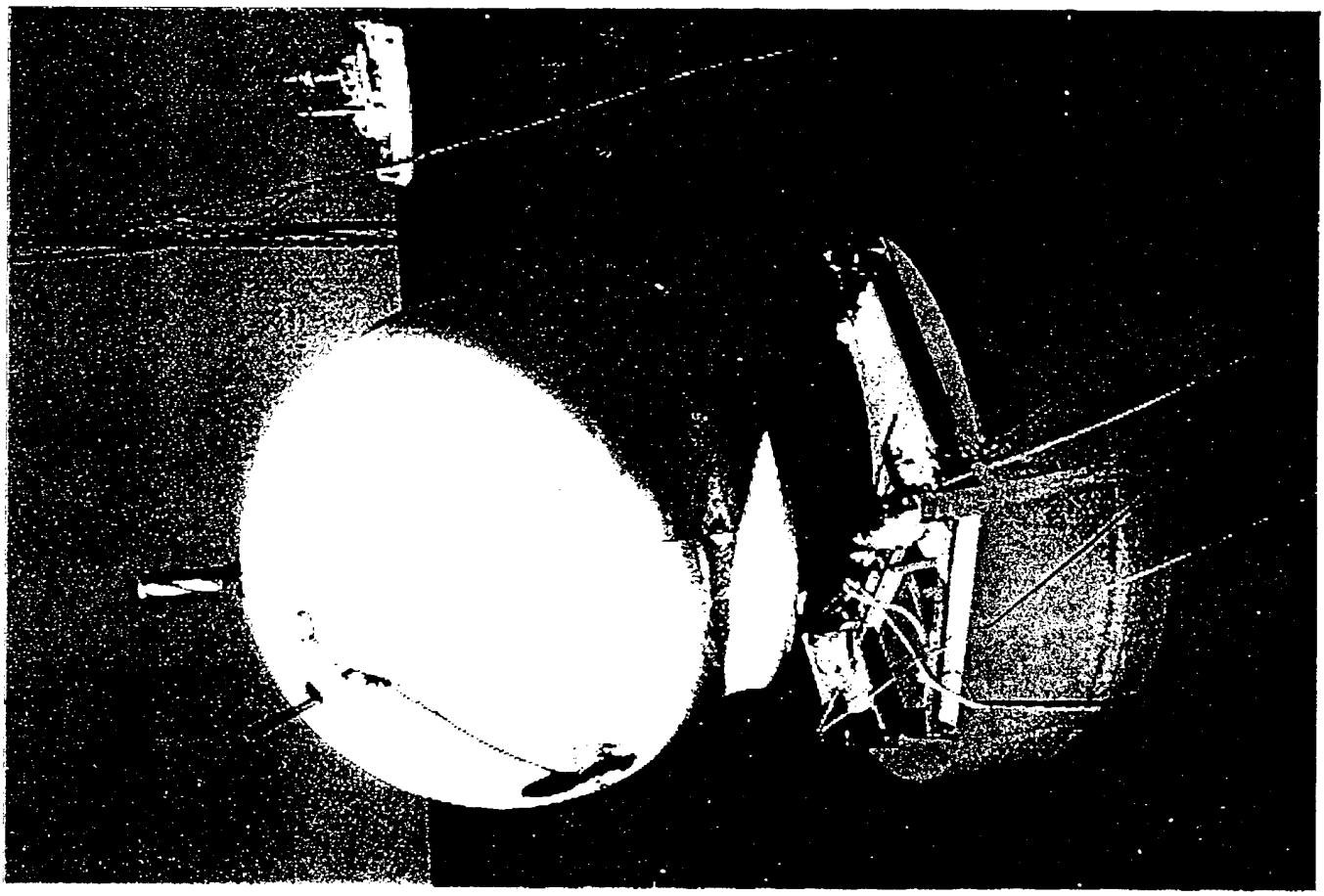
UHF **Cellular** **L Band** **C and/or Ku band**

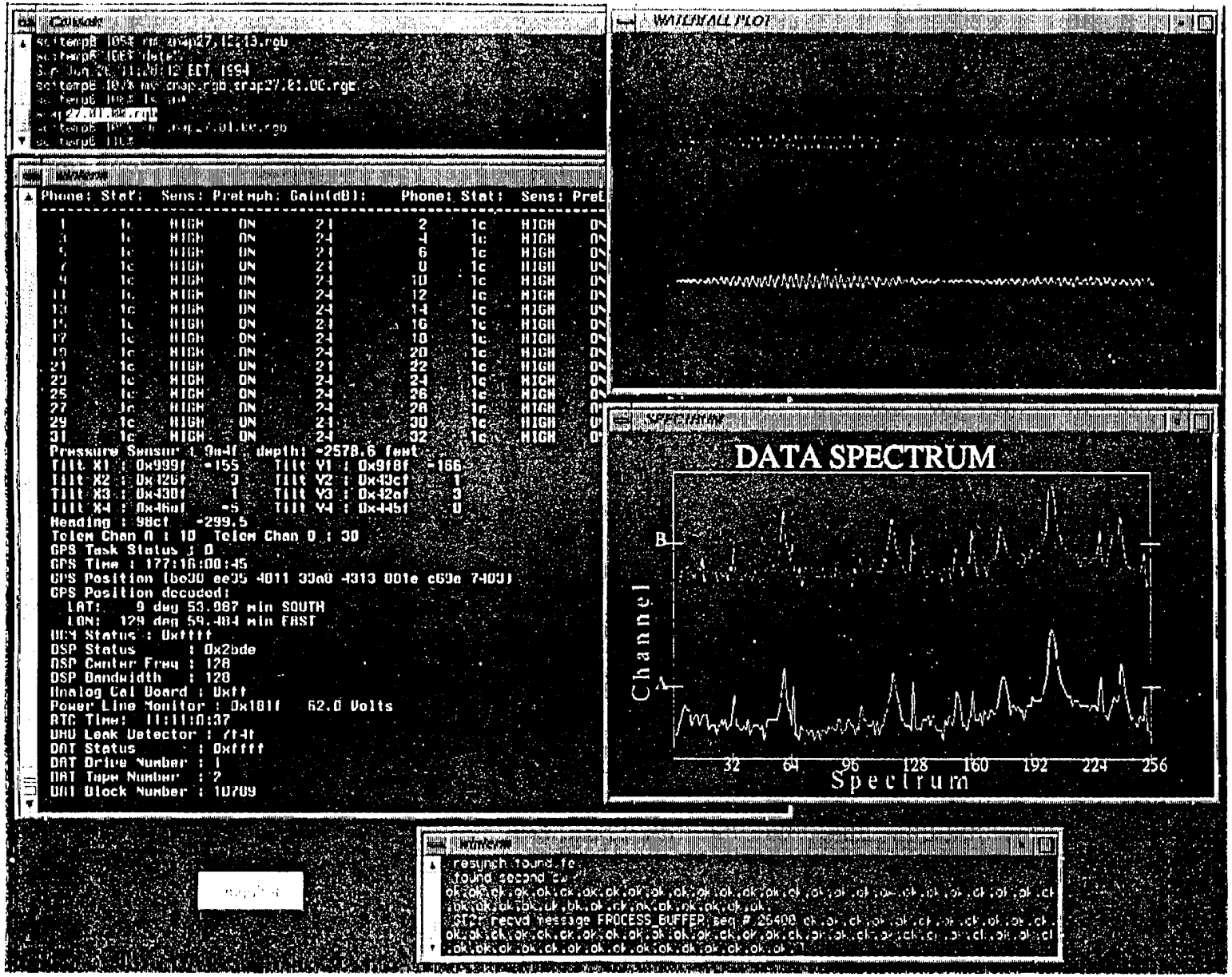


Satellite linked Vertical Line Array Program



- Data Transfer at 19.2 KBPS from the Buoy - 1993 & 1994
- Data Transfer at 1 MBPS (Data) and 600 BPS (Control) - 1995
- Complete Data Relay System Control from Shore
- UHF FLTSAT Satellite used - 1993 & 1994
- Omni-Directional Antenna - Mobile, Dynamic Platform - 93 & 94
- Commercial Satellite - 1995 - Ku & L Bands
  - Pointing Antenna System - Ku Band
- Modular System Design for Application to Unattended Operations





Source : 8.5 km due N
259 m deep

SATELLITE DATA RELAY

Links for RF Data Connectivity Between Sensor and User

• MF	Medium Freq	Ground Wave
• HF	High Freq	Ground Wave & Sky Wave
• VHF	Very High Freq	Line of Sight (LOS)
• UHF	Ultra High Freq	LOS & Satellite
• S Band		LOS & Satellite

LOS and Satellite Links (Geostationary)

• UHF Band	Military Satellites	FLTSAT
• L Band	Commercial Satellites	INMARSAT
• S Band	Commercial Satellites	
• C band	Commercial Satellites	
• X Band	Military & Commercial Satellites	
• Ku Band	Commercial Satellites	
• EHF Band	Commercial Satellites	
- Ka Band (subset of EHF)	Commercial Satellites	

Other Satellite Links

• LEO	Low Earth Orbit Satellites	Low Data Rates
• HEO	High Earth Orbit Satellites	

SATELLITE DATA RELAY

- **INMARSAT is an Ideal Medium For Data Relay From Global Locations**
  Coverage to About 75^0 North and South Latitude

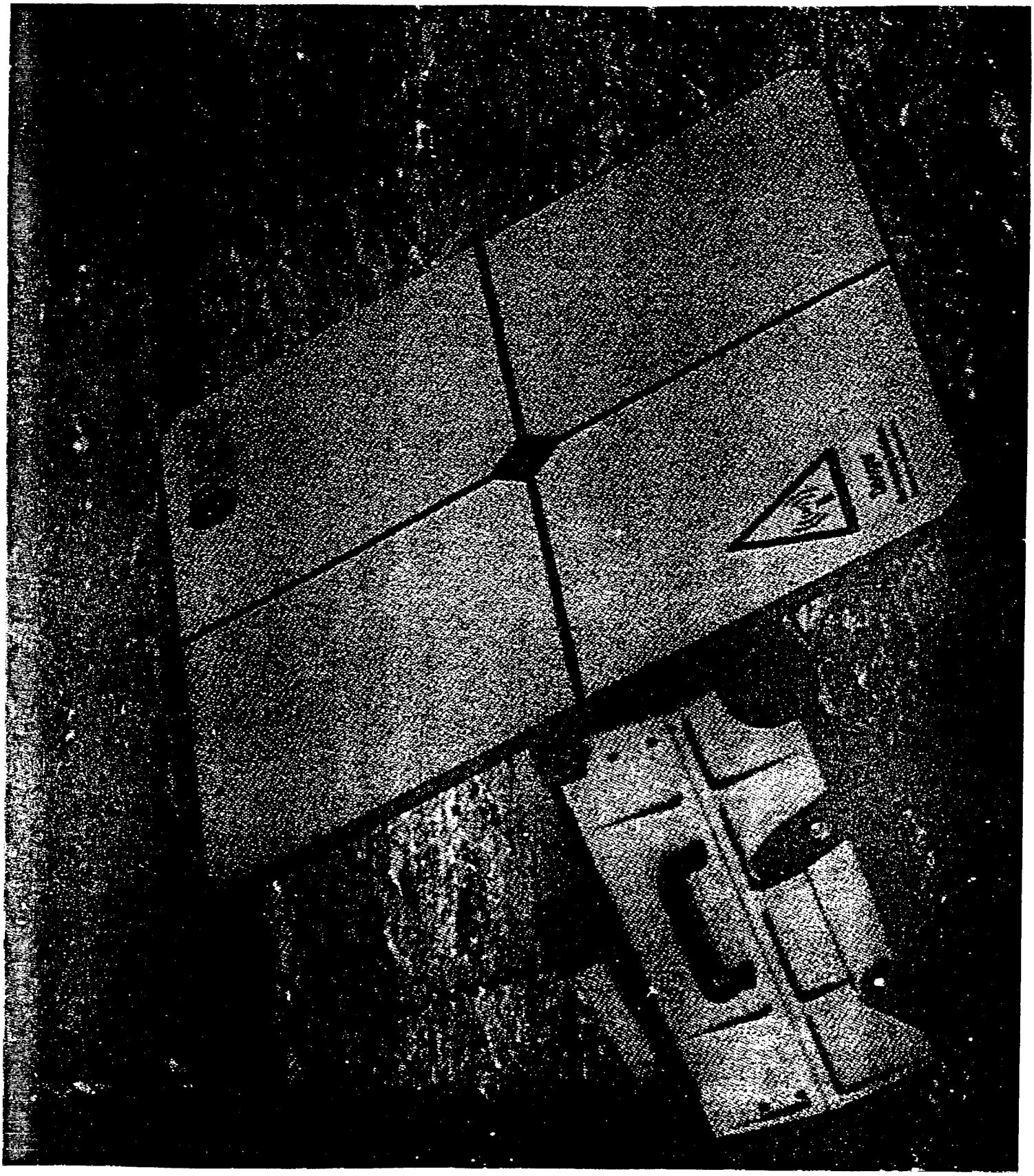
- **Can be Used On-Demand as an Order Wire System**
  - **Including a Modem Connection to an Internet Computer**
  - **Or Direct Modem Connection to Computer**

- **Cost Effective Solution**

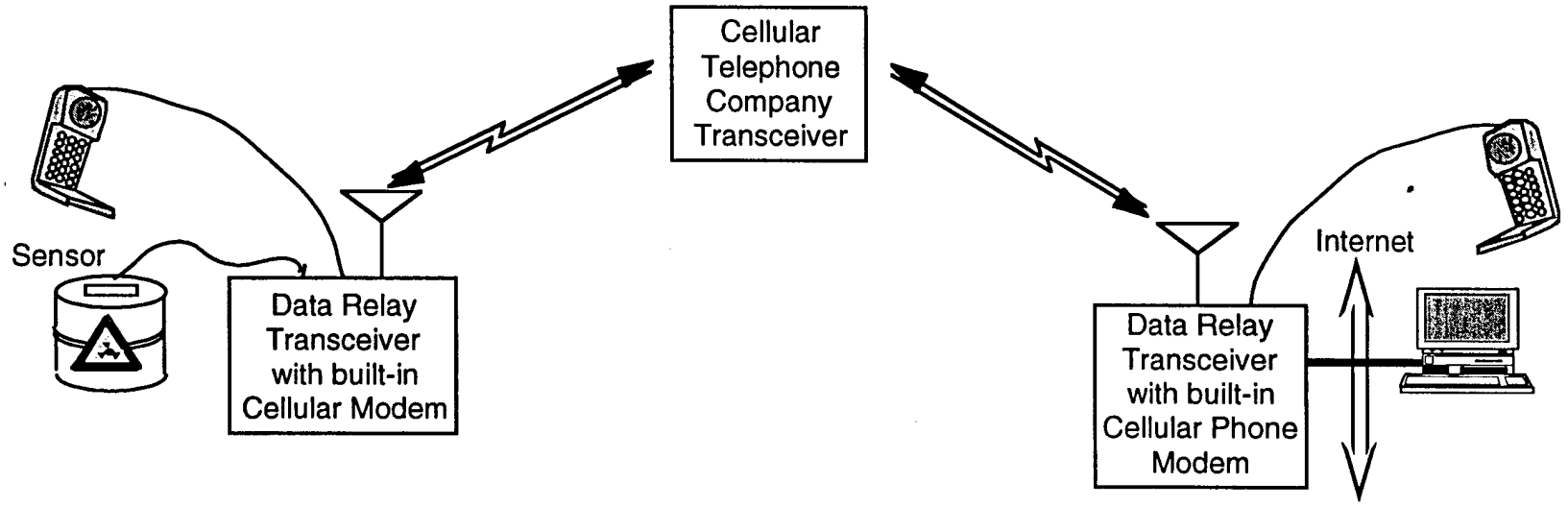
- **Data Transfer - Accomplished via Standard Protocols**
  - **TCP/IP FTP ISDN etc.**

- **Extension to Networks - Straightforward**
  - **Remote System Becomes an Internet Node via the Satellite**
  - **With All of the Advantages of the Internet**
    Wide Data Dissemination

- **INMARSAT Protocol and Overhead Data Completely Transparent to User**



CELLULAR TELEPHONE DATA RELAY



- **Low Data Rate**
- **Highly Portable**
- **Limited Geographic Coverage (Existing Services)**
- **Data Relay Techniques - Extension to Future Satellite Systems!**

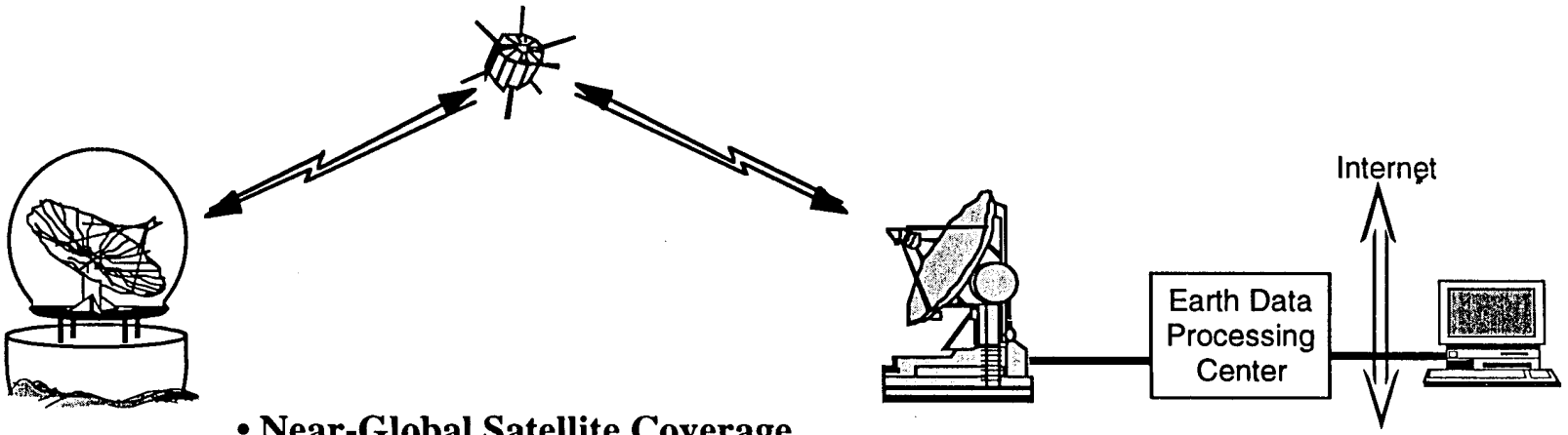
SATELLITE DATA RELAY

Future LEO Satellite Services

ARIES	ELLIPSO	GLOBSTAR	IRIDIUM	ODYSSEY
Global	*Global*	Global	Global	Global
1996	1997	1997	1998	1998
48 Satellites	15	48	66	12
Voice, FAX, & Data	Voice, FAX, Paging, & Data	Voice, FAX, Paging, & Data	Voice, FAX, Paging, & Data	Voice, FAX, Paging, & Data

SATELLITE DATA RELAY

C & Ku Band Commercial Satellite Services



- Near-Global Satellite Coverage
- Coverage to Approximately 75^0 North and South Latitude
- Data Rates of 1 to 10 MBPS - Continuous - Uncompressed
- For Practical Unattended System
  - Transmitter Power Amplifier Limited to < 50 Watts
  - Antenna Size Dependent on Data Rate & Satellite
- Ku Bandwidth More Readily Available Than C Band
- Implementation on Mobile, Dynamic Platforms

SUMMARY

- **UHF Data Relay Demonstrations - 1993 & 1994**
- **Cellular Telephone Data Relay - Internet Connectivity - 1995**
- **INMARSAT - Internet Connectivity - 1995**
- **Commercial Ku Development - Demonstrations - Sept 1995**
- **Remote Sensor Interface - Data Relay - Data Dissemination - Display**
  - **Utilize State-of-the-Art H/W & S/W**
    - **Provide Connectivity for Remote Applications**

Monitoring Suspended Sediment with In-Situ Acoustic Backscattering Systems

Marshall H. Orr
Code 7120
The Naval Research Laboratory

The spatial and temporal distributions of sediments suspended from the ocean bottom by wave and/or current interactions and other processes such as turbidity currents must be quantitatively measured to permit the estimate of sediment bound radionulcide or chemical transport from their source points to ocean basins. Radinulcide detectors and chemical measurements are usually made at fixed points in space and provide no information about the vertical distribution of suspended sediments such that the measurements can be integrated to estimate total mass transport.

High frequency acoustic backscattering systems can be used to **remotely** detect the temporal and spatial variability of the vertical distribution of suspended sediments near the ocean bottom. With proper calibration multi-frequency acoustic systems can be used to estimate suspended particle mass and size distributions. These measurements can be integrated with point measures of radionulcide or chemical species measurements to estimate total mass transport by hydrodynamic resuspension and mean current flows.

Incoherent Rayleigh backscattering theory is presented to illustrate the dependence of the backscattered acoustic signals on the acoustic wave number and particle radius. Acoustic backscattering data taken in a test tank for 1.5 and 5 MHz is presented to illustrate the detection of solid glass beads of 20-25; 30-37;44-66; 62-88 and 88-125 μm diameter. The intensity of the backscattered signals followed the predicted slope of incoherent Rayleigh backscattering in regions where incoherent scattering assumptions were considered to be valid. Vertical resolution of the measurements was about 5 mm.

An acoustic data set taken during the Hebble experiments in 1980 with a 5 MHz acoustic backscattering system mounted on a tripod resting at a depth of about 3600m on the Scotian Rise is presented. The 80 hr long time series of acoustic backscattering showed considerable variability in the scattering amplitude. The intensity of the acoustics scattering correlated with beam attenuation measurements made a transmissometer (Zanfeld) also mounted on the tripod.

ACOUSTIC DETECTION OF SUSPENDED MARINE SEDIMENTS

Marshall Orr
NRL
Code 7120

M. Orr
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8:26 AM

SEDIMENTS

- Radionuclides/Chemicals Bind to Sediments
- Understanding Dispersion of Sediment Bound Pollutants Requires
  - Measurement of Suspended Particle
    - » Concentration
    - » Size Distribution
    - » Spatial/Temporal Distributions
  - Understanding Fluid Dynamic Processes of Resuspension/Transport

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Scattered Acoustic Signal

- Visualization of Fluid Processes
  - Mixing Processes
  - Dynamics
- Sediment Transport and Dispersion
  - Benthic Boundary Layer Sediment Suspension and Transport by Wave/Current Interactions

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Three Components

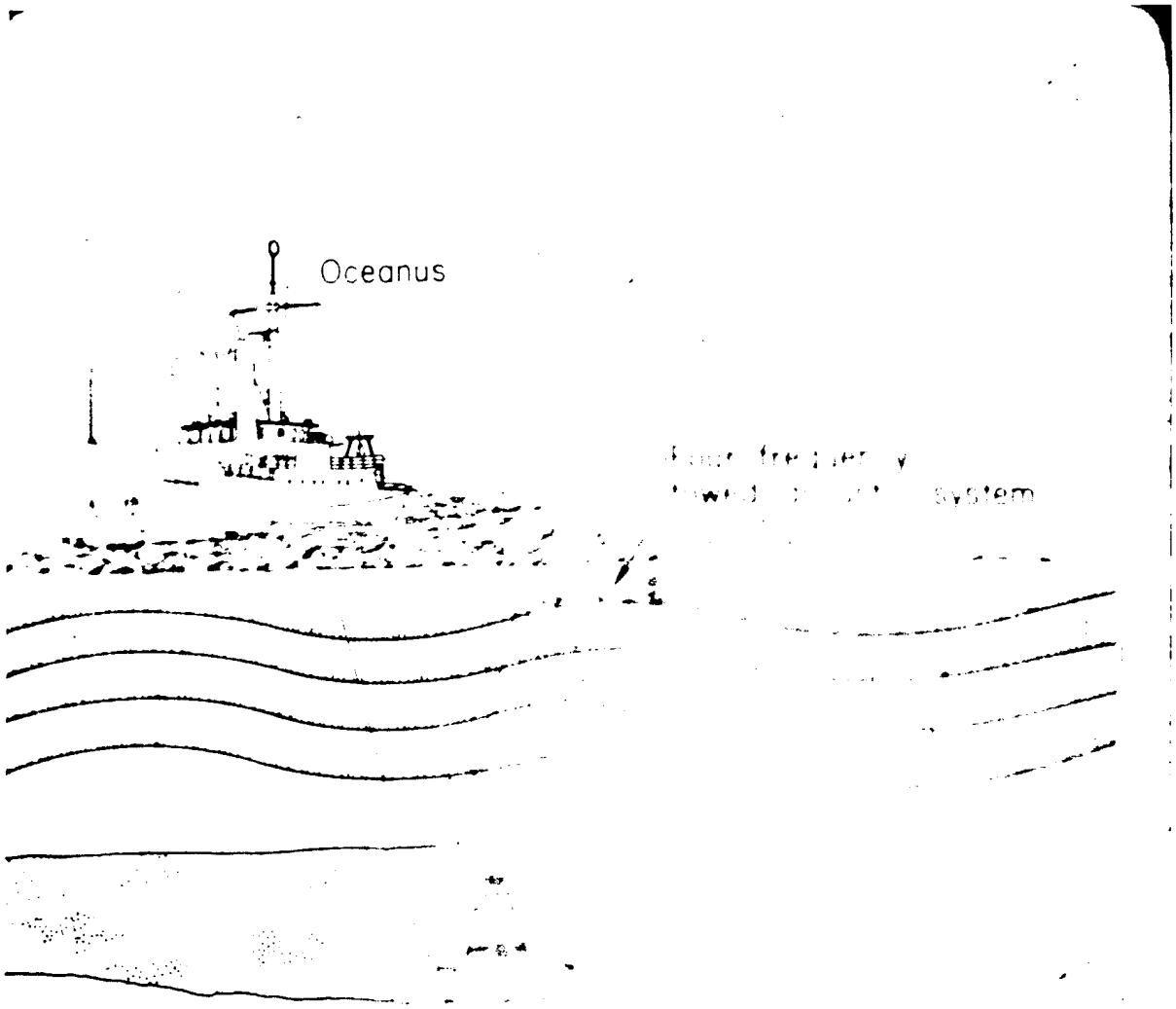
- Multi-Frequency ***Towed*** Acoustic System
- High Frequency ***Moored*** Acoustic System (ABSS)
- Laboratory Test Tank Facility to Calibrate ABSS

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High Frequency ***Moored*** System (ABSS)

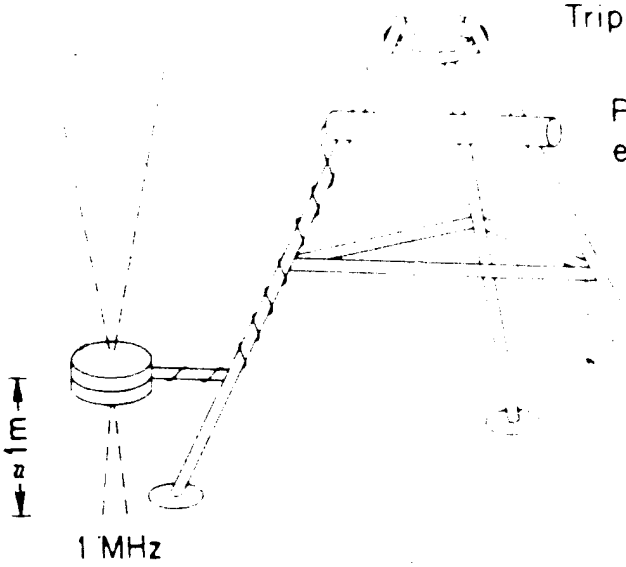
- Designed to study boundary layer wave/current interaction with the bottom sediments and fluid processes in water column
- Quantitative measure of particle concentrations and estimate of size distributions
- Multi-frequency
  - 200 KHz, 1 MHz and 5 MHz
- Laboratory facilities to calibrate against
  - particles of known size distribution
  - particles from specific geomorphological settings

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HUDSON
EXPL

200 kHz

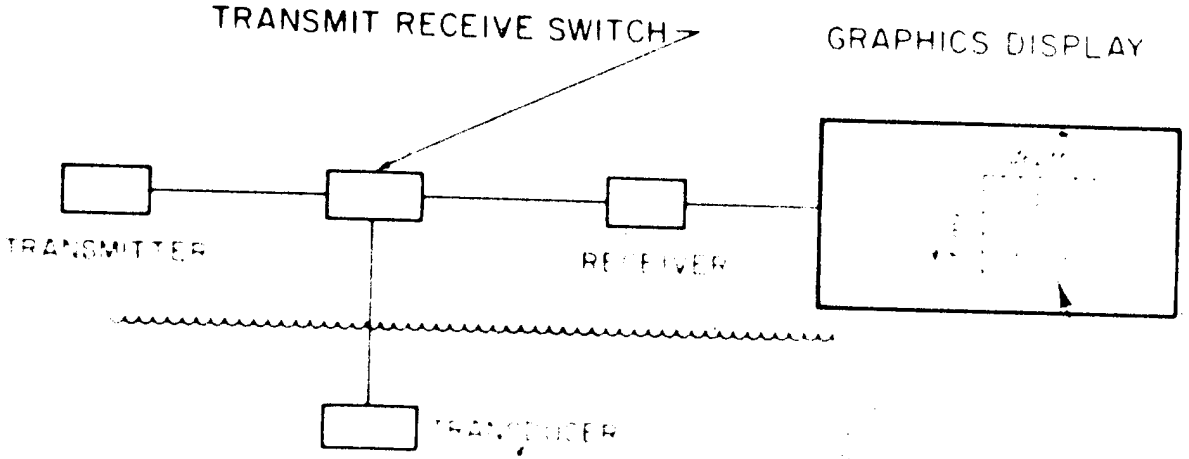


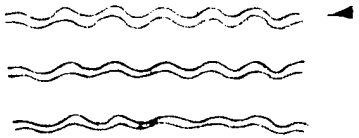
Data storage rate
one ping every

120 sec
1 hr
2 hrs

Duration

SIMPLE ACOUSTIC BACKSCATTERING SYSTEM



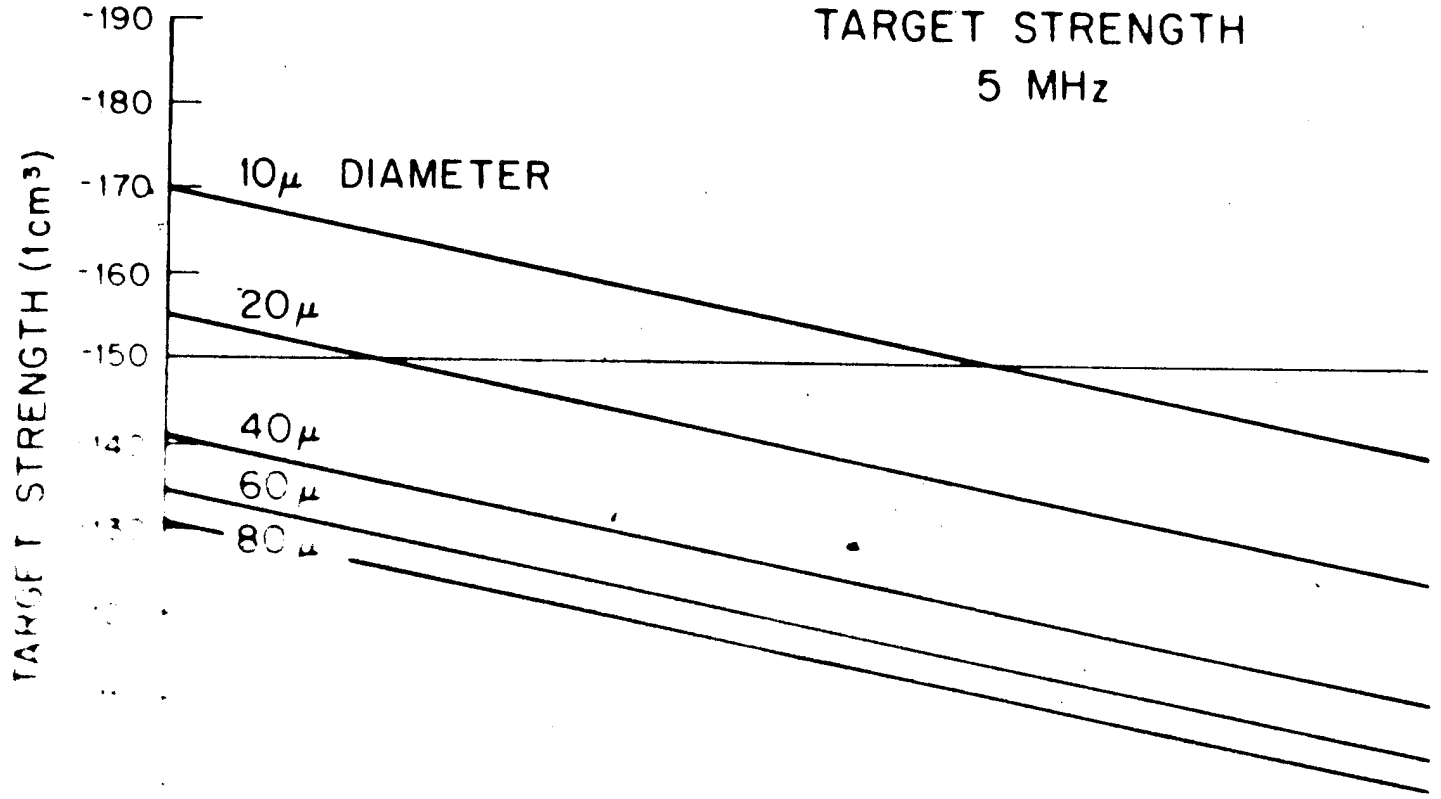


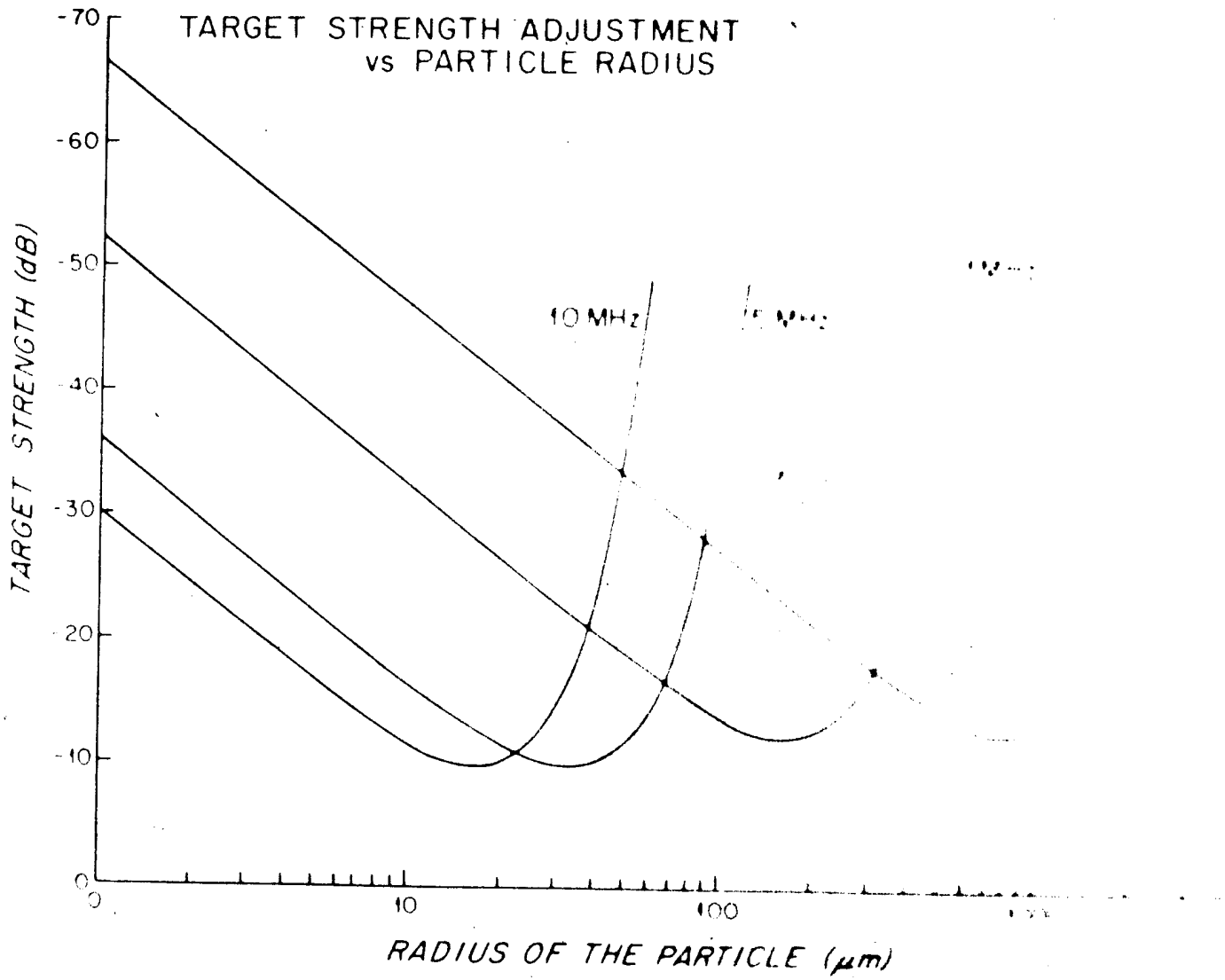
INCOHERENT RAYLEIGH BACKSCATTERING THEORY

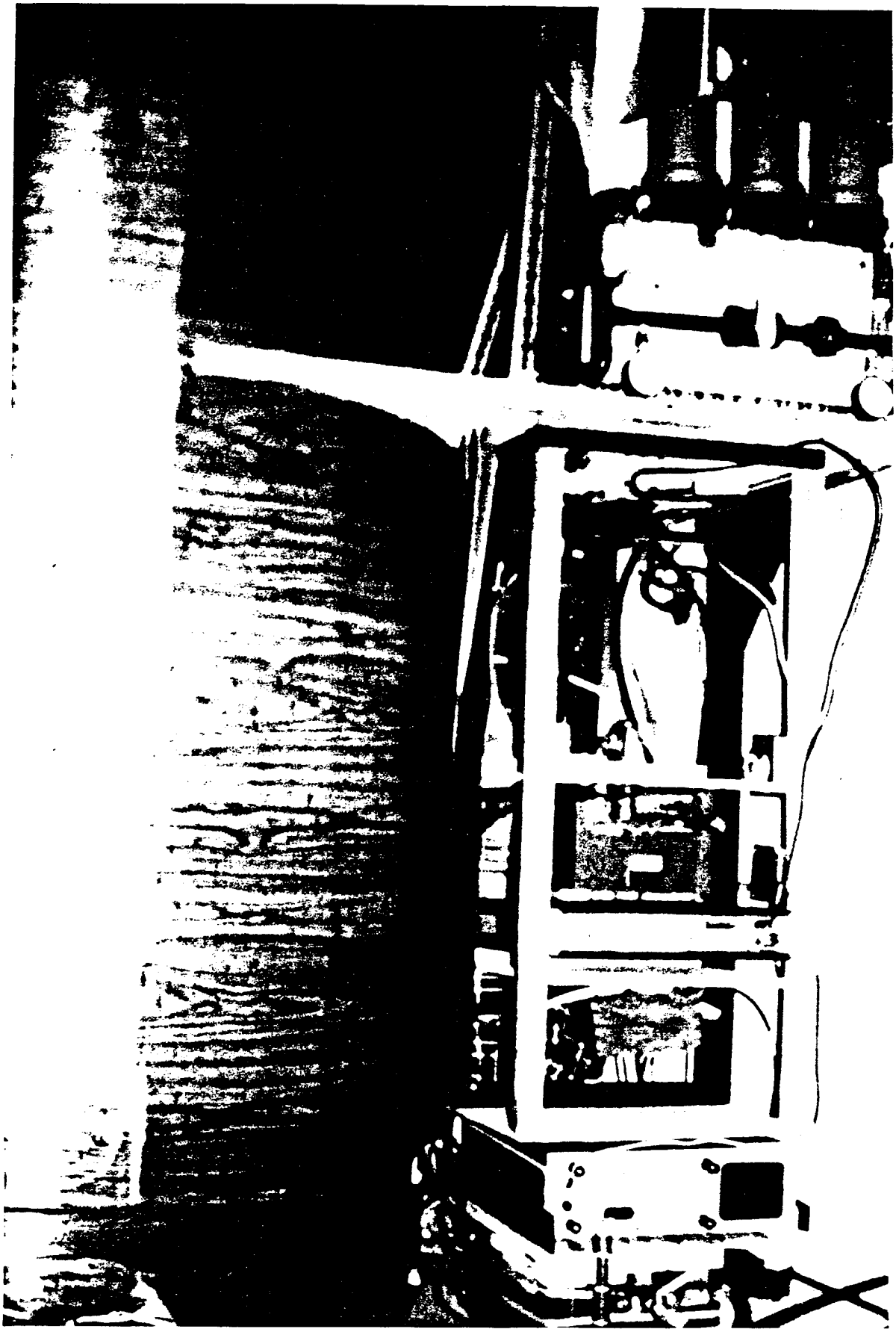
$$\frac{I_{is}}{I} \sim \frac{\sqrt{2\pi}}{72} \, NV \, \frac{k^6 a^8}{r^2} \, |\gamma_\kappa + \gamma_\rho|^2 \, e^{-2k^2a^2}$$

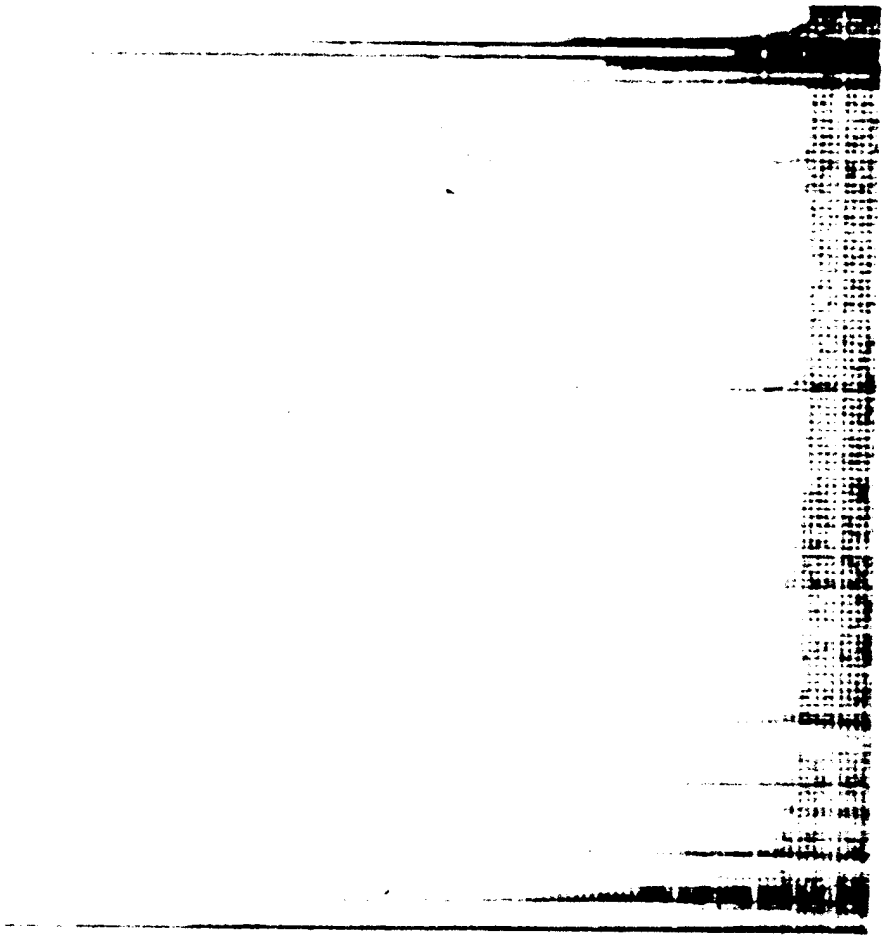
$$\gamma_\kappa = \frac{\kappa_e - \kappa}{\kappa}$$

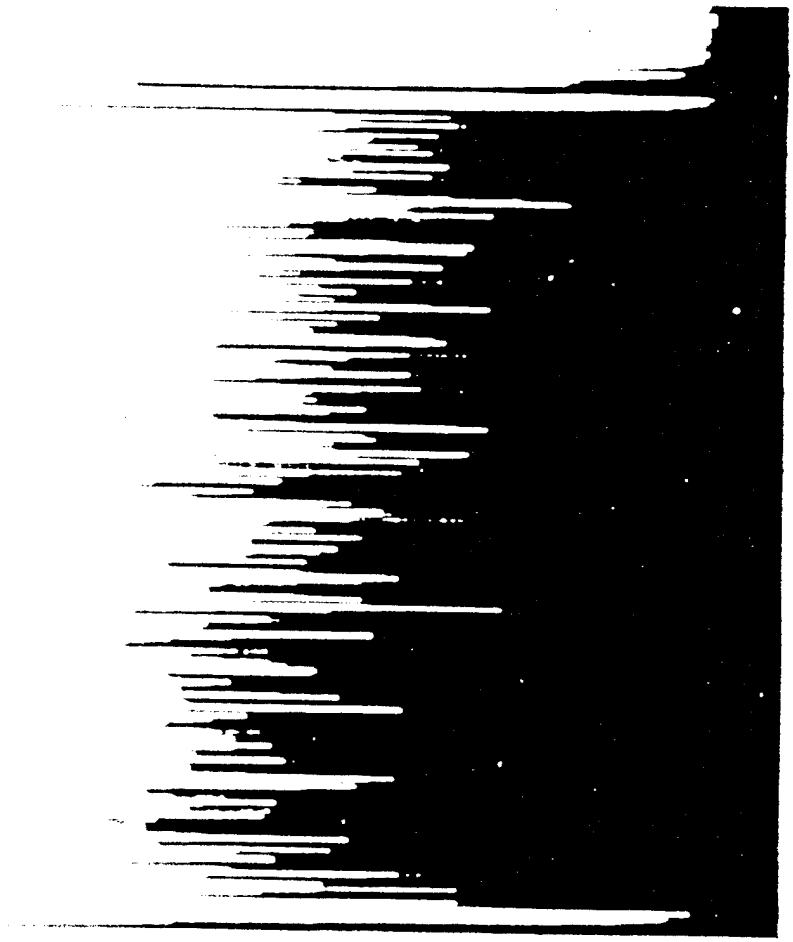
$$\gamma_\rho = \frac{3\rho_e - 3\rho}{2\rho_e + \rho}$$


TARGET STRENGTH
5 MHz
-190
-180
-170
-160
-150
10μ DIAMETER
20μ
40μ
60μ
80μ
TARGET STRENGTH (1cm³)


TARGET STRENGTH ADJUSTMENT
vs PARTICLE RADIUS
-70
-60
-50
-40
-30
-20
-10
0
10 MHz
TARGET STRENGTH (dB)
0
10
100
RADIUS OF THE PARTICLE (μm)



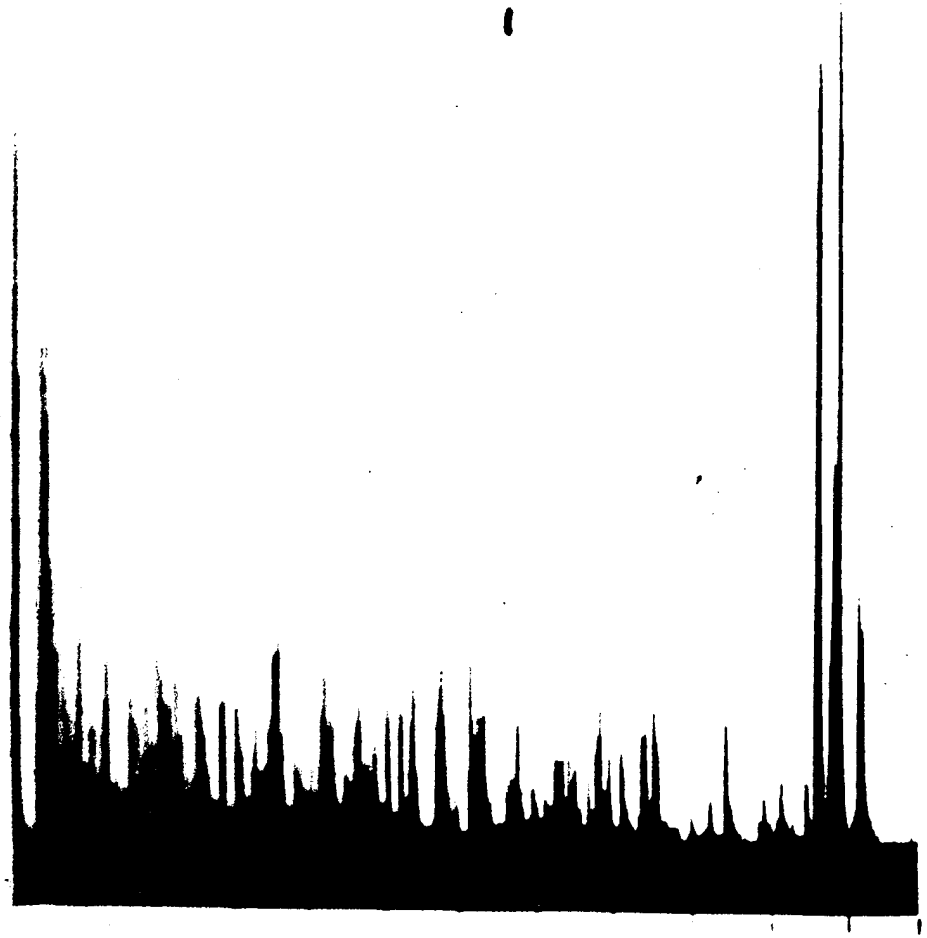


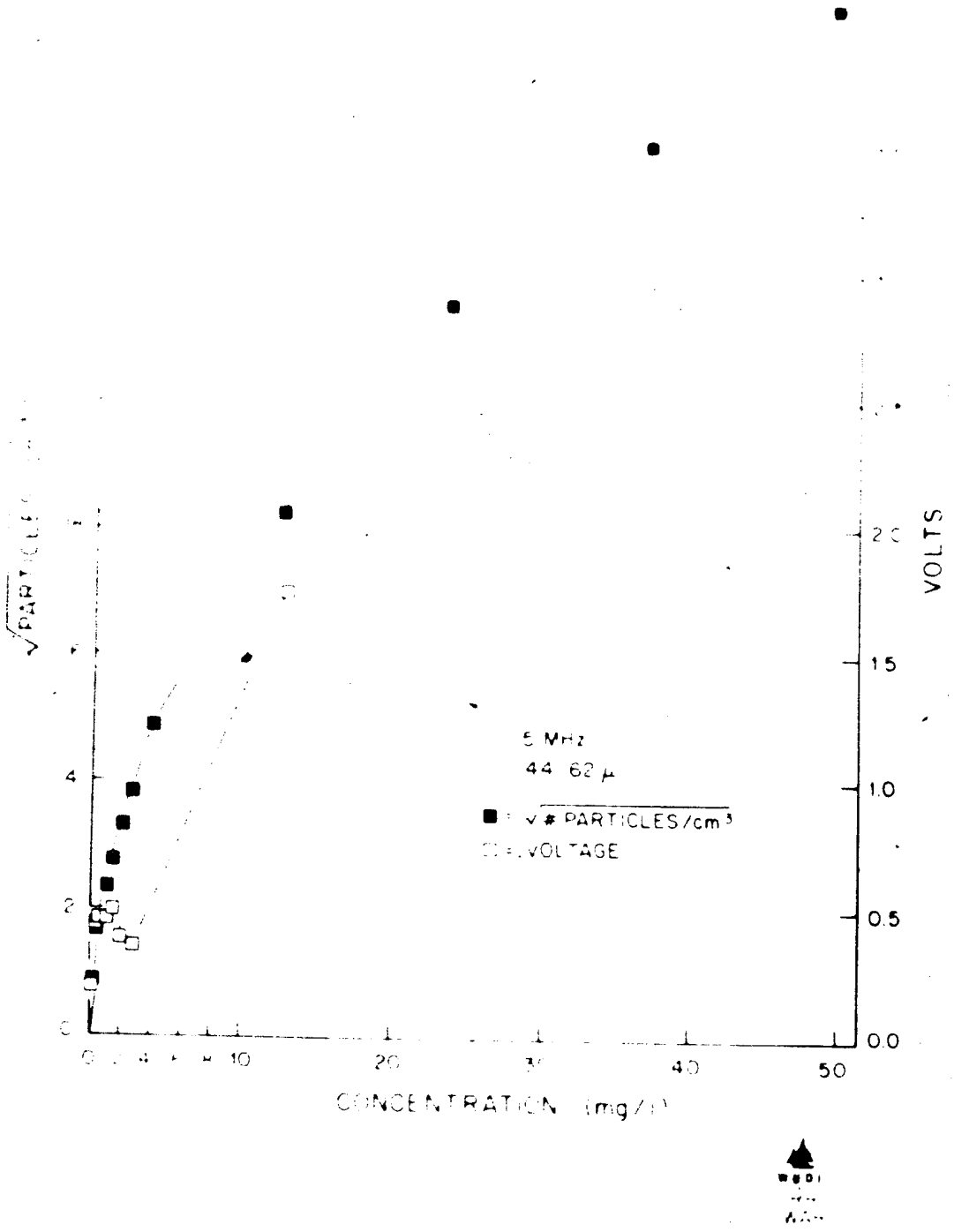


DEPTH vs. VOLTAGE

5 MHz
9 μsec pulse width
glass beads:
ρ = 2.4 g/cm^3
size: 44-62 μsec

1,161 μg/l




VOLTS
2.0
1.5
1.0
0.5
0.0
4
2
0
10
20
40
50
5 MHz
44 62 μ
■ = √# PARTICLES/cm³
□ = VOLTAGE
CONCENTRATION (mg/l)

Particles

	Diameter (microns)
• 6	0-10
• 5	20-25
• 4	30-37
• 3	44-62
• 2	62-88
• 1	88-125

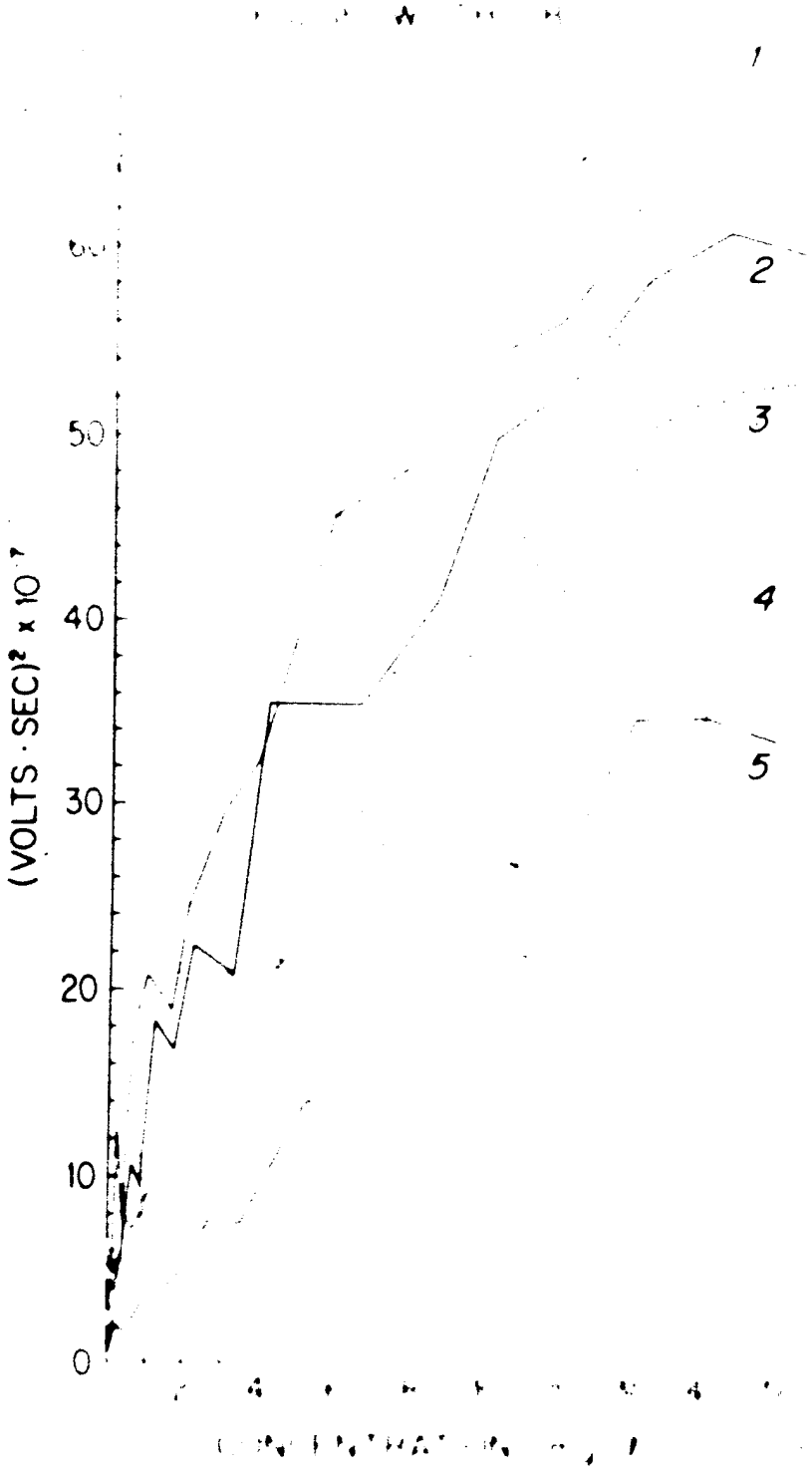
Soda-lime plate glass microbeads

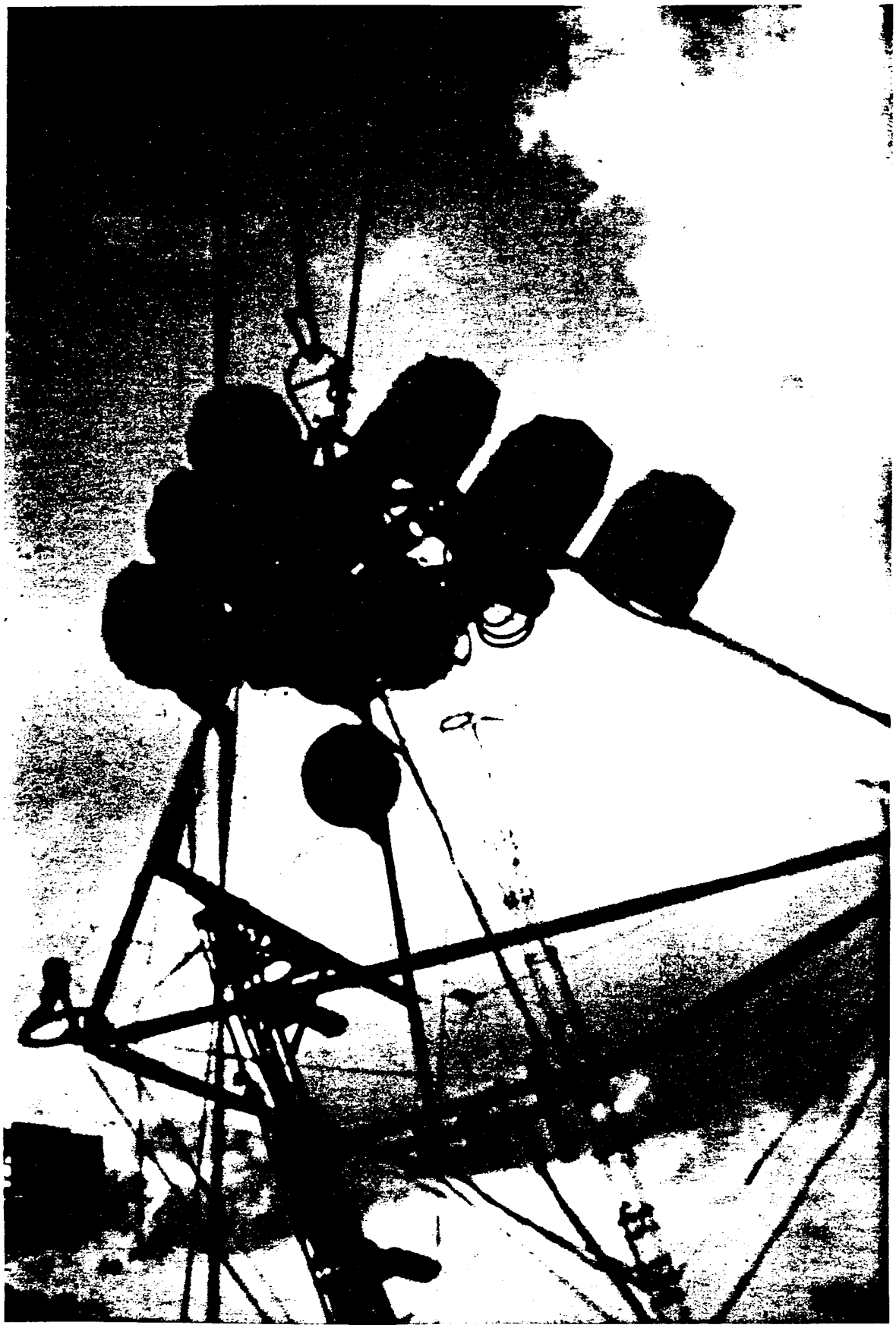
density 2.42-2.50 g/cm^3

Gaussian distribution about center size

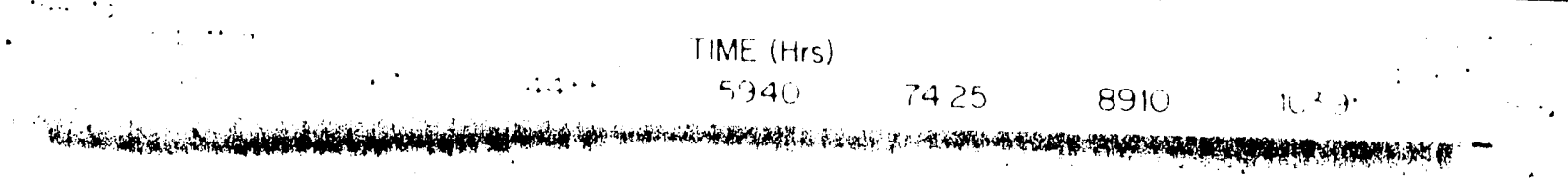
20 microsec pulse

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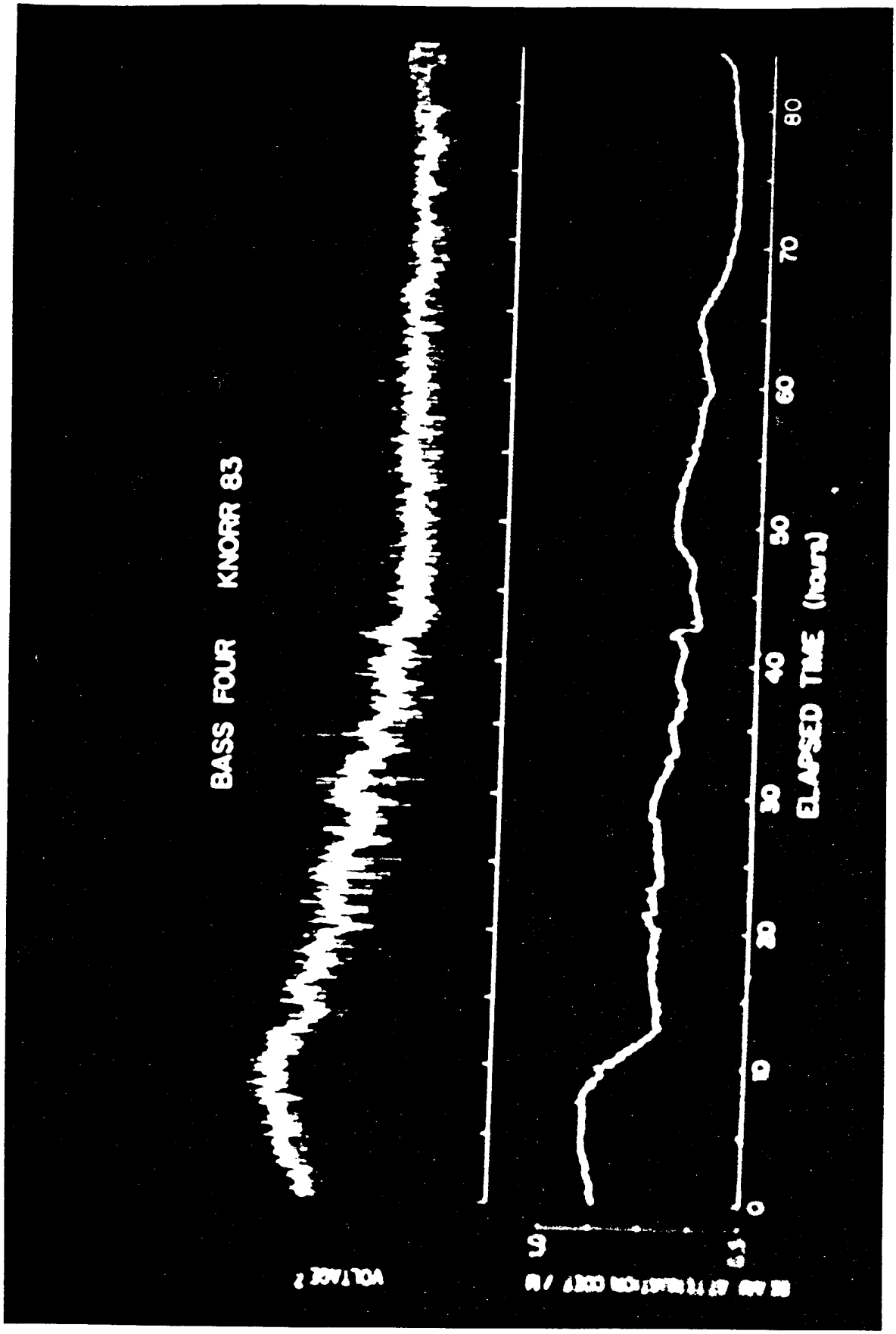

(VOLTS · SEC)² x 10⁻⁷
50
40
30
20
10
0
1
2
3
4
5

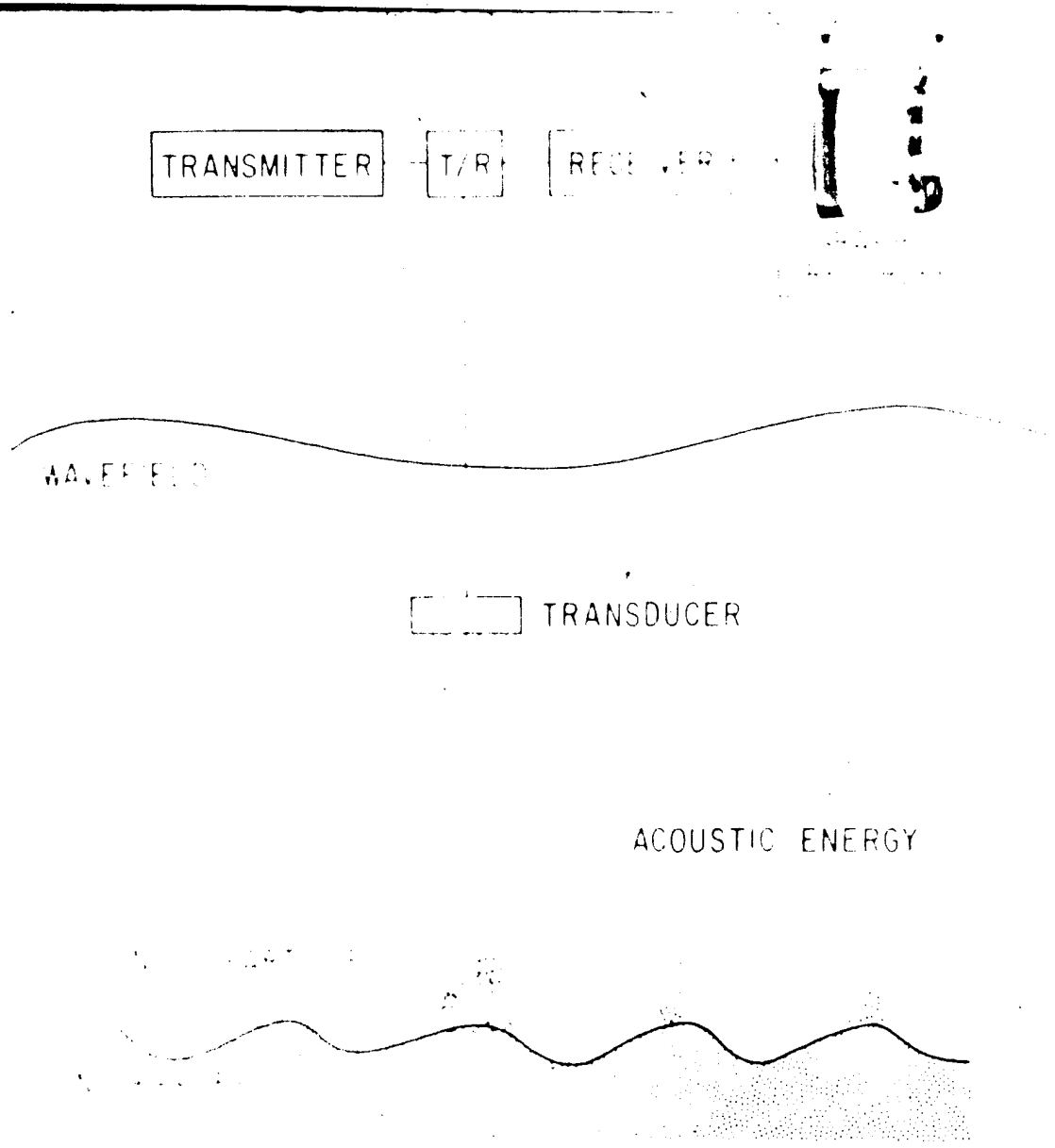


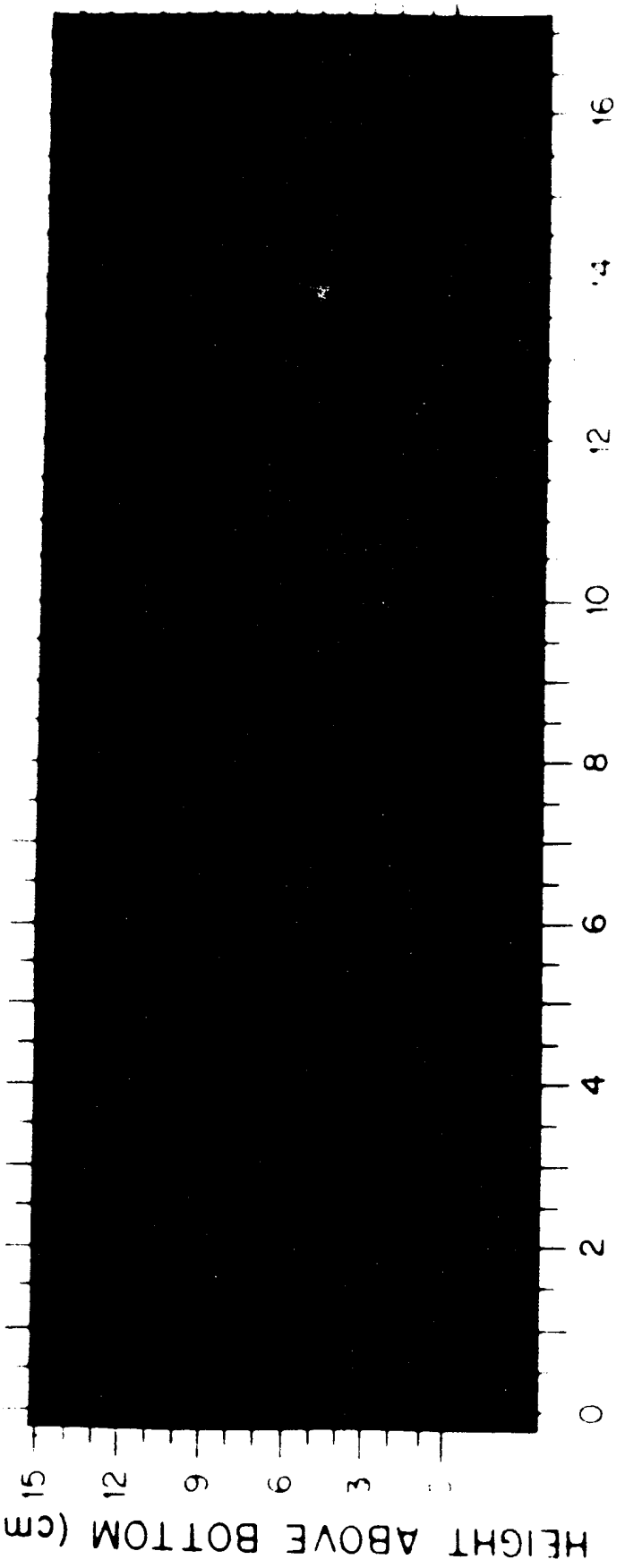
[redacted]



[redacted]


BASS FOUR KNORR 83
ELAPSED TIME (hours)
0
10
20
30
40
50
60
70
80


TRANSMITTER
T/R
TRANSDUCER
ACOUSTIC ENERGY


HEIGHT ABOVE BOTTOM (cm)
15
12
9
6
3
0
2
4
6
8
10
12
14
16
TIME (sec)

Conclusions

- The Dispersion, Concentration and Size Distribution of Particles in the Marine Environment Can Be Estimated Using Acoustic Scattering Physics
- Success Requires Sufficient Supporting Environmental Measurements to Permit Interpretation of the Acoustics Data
  - Navigation
  - Current, Shear, Atmospheric Forcing, Wave Directional Spectra
  - Temperature and salinity
  - Broadband acoustic measurements

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Conclusion

- Scattering Theory
  - Flocs
  - Irregular
- Laboratory Measurements
  - Flocs
  - Irregular

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MONITORING OF RADIOACTIVE CONTAMINATION IN ARCTIC SEAS: DATA LINKS THROUGH WATER AND ICE

Ronald T. Miles, Neptune Sciences, Inc., Slidell, LA

ABSTRACT

The former Soviet Union disposed of radioactive wastes and disused reactors at numerous seafloor dump sites near Novaya Zemlya in the Barents and Kara seas. Radioactive material is also being transported to the Arctic seas as part of the pollutants carried by river systems such as the Ob an Yenisei rivers that empty into the Kara Sea. Results of survey cruises have, so far, shown no indication that levels of fission products are exceeding any radiological hazard standards. However, future release of radionuclides due to container or reactor deterioration, or accidental release from industrial storage ponds could pose a potentially serious problem. It is important to monitor the levels of fission products at these potential sources, to acqire the data necessary to understand the transport mechanisms and to predict ultimate destination of these materials.

Because of the extreme environment, survey cruises are possible only during the 2-3 month period when these areas are free of ice. In order to fully understand and characterize the environment it may be necessary to conduct continuous, long term monitoring of radioactivity and water column parameters at dump sites and at outflows of river sources. If near real time data via satellite is required, it will be necessary to transmit data from a seafloor sensor package through the ice cover to a shore station or ice buoy for re-transmission via satellite.

This paper discusses the various methods that might be used to transmit data across the water-ice-air interface in order to provide near realtime monitoring of radionuclides and oceanographic parameters in potential problem areas. These methods include standard cable data transmission, transmission via acoustic telemetry, and transmission via Magneto-Inductive (MI) communications. The paper shows proposed ways in which each technology may be used, typical expected performance, and advantages and disadvantages of each method. The complicating effects of major environmental and political issues are discussed as they relate to the suitability of each transmission method.

MONITORING OF RADIOACTIVE CONTAMINATION IN ARCTIC SEAS: DATA LINKS THROUGH WATER AND ICE

Ronald T. Miles, Neptune Sciences, Inc., Slidell, LA

BACKGROUND

The former Soviet Union disposed of radioactive wastes and disused reactors at numerous seafloor dump sites near Novaya Zemlya in the Barents and Kara seas. Radioactive material is also being transported to the Arctic seas as part of the pollutants carried by river systems such as the Ob an Yenisei rivers that empty into the Kara Sea. Results of survey cruises have, so far, shown no indication that levels of fission products are exceeding any radiological hazard standards. However, future release of radionuclides due to container or reactor deterioration, or accidental release from industrial storage ponds could pose a potentially serious problem. It is important to monitor the levels of fission products at these potential sources, to acqire the data necessary to understand the transport mechanisms and to predict ultimate destination of these materials.

Because of the extreme environment, survey cruises are possible only during the 2-3 month period when these areas are free of ice. In order to fully understand and characterize the environment it may be necessary to conduct continuous, long term monitoring of radioactivity and water column parameters at dump sites and at outflows of river sources. If near real time data via satellite is required, it will be necessary to transmit data from a seafloor sensor package through the ice cover to a shore station or ice buoy for re-transmission via satellite.

This paper discusses the various methods that might be used to transmit data across the water-ice-air interface in order to provide near realtime monitoring of radionuclides and oceanographic parameters in potential problem areas. These methods include standard cable data transmission, transmission via acoustic telemetry, and transmission via Magneto-Inductive (MI) communications. The paper shows proposed ways in which each technology may be used, typical expected performance, and advantages and disadvantages of each method. The complicating effects of major environmental and political issues are discussed as they relate to the suitability of each transmission method.

POLITICAL AND ENVIRONMENTAL ISSUES

As shown in figure 1, radioactive dump sites abound near Novaya Zemlya and the Kara sea. Since many of these sites are located close to the shoreline, it should be a relatively straightforward task to monitor these sites using in situ seafloor sensor systems and either shore receiving stations or moored buoys to transmit data to satellite. However, two major issues greatly complicate this task: (1) difficulties in obtaining permission from the Russian Federation (former Soviet Union) to locate such facilities in their territorial waters, and (2) the fact that these waters are ice covered for at least 8 months of the year. The first issue (political) may prevent use of shore receiving stations, leaving only offshore methods of data retrieval, which during the prolonged period of ice cover may prove to be impractical. The second issue (environmental) severely limits the options for transmitting data from seafloor

sensor packages to either shore stations or buoys. The ice cover can be expected to move in roughly the same patterns as the predominate ocean currents in the area. Figure 2 shows the ocean currents in the Kara sea area adjacent to Novaya Zemlya. It can be expected that ice will be continuously moving over areas where seafloor sensor packages must be located to provide long term monitoring of dump sites. Data cables from these seafloor packages to shore receiving stations or to surface buoys cannot be expected to survive under these conditions. Furthermore, surface buoys can be expected to move out of range of any acoustic telemetry systems used to transmit data from the seafloor. The presence of ice cover from November until June will predictable, whereas experience has shown that the political issue is not.

CABLE TRANSMISSION OF DATA

Transmission of data from in situ sensor packages to shore stations by cable for re-transmission to satellite presents problems that are difficult if not impossible to overcome in the severe Arctic winter environment. During the winter ice moving close to shore will make cable survival impossible. Even cables in back-filled trenches used by the Canadian Hydrographic Service have been destroyed by ice movement. The Japanese Antarctic coastal base SYOWA STATION used iron pipe installed in the land-fast ice to protect tide measurement data cables. Though this may have been somewhat successful it presents significant problems related to logistics and construction in a severe environment. Other more reliable methods may be available for this task and should be investigated.

ACOUSTIC TELEMETRY

Underwater digital acoustic telemetry of data has, until recently, been extremely limited in data rates and range, and has exhibited considerable unreliability due to its dependence on environmental conditions. The underwater acoustic channel is prone to high reverberation, multipath, signal fading and high noise levels. Recent work by Woods Hole Oceanographic Institution and Datasonics Corp. has utilized Digital Signal Processing (DSP) methods and Multiple Frequency Shift Keying (MFSK) protocol to overcome many of these problems. This has resulted in commercially available acoustic telemetry able to reliably transmit and receive digital data at a rate of 1200 bits/second over horizontal ranges exceeding 2000 meters.

During ice-free periods in arctic seas this improved acoustic telemetry could certainly be used as a data link between in situ seafloor sensor packages and either shore stations or moored buoys for further relay by satellite. However, during the 7-8 month period that ice cover is present, the use of acoustic telemetry is greatly complicated by the fact that the receiving hydrophone must be placed in the water below the ice cover. If a shore receiving station is used, the hydrophone cable will be subjected to mechanical stress and abuse and will almost certainly fail due to ice movement in the shallow water. Use of an ice buoy as a satellite data relay, as shown in figure 3, presents significant logistics problems associated with buoy deployment. Such a scheme may also be short lived due to movement of the ice and subsequent loss of signal as the buoy moves out of range of the acoustic telemetry transmitter. Short of periodically re-positioning or replacing the ice buoy this method is not likely to provide a reliable solution.

MAGNETO-INDUCTIVE (MI) COMMUNICATIONS

Magneto-inductive communications is another method that might be used to transmit near realtime data from seafloor sensor packages through the ice cover to shore stations or ice buoys for relay to satellite. This communication system, developed by a Canadian company, Correpro Atlantic, Ltd., makes use of a low frequency digitally modulated quasi-static magnetic field to transmit data at low data rates from a submerged transmitter to a shore receiver. Prototypes of this system have been built and successfully demonstrated for the Canadian Hydrographic Service, which plans to use this system for long term monitoring and transmission of data from tide gages beneath Arctic ice.

. An MI system is capable of transmitting data at a rate of 30 bits/second over a range greater than 250 meters using 200 peak watts of transmit power. Peak transmit power is only required during very short transmit times (i.e. for 60 seconds or less, depending on quantity of data in each transmission). Equipment to receive the magnetic signal and re-transmit it to satellite is available from Socomar International who is working with Correpro on producing the Canadian Hydrographic service tide measurement system. This shore station has already been proven under severe Arctic conditions as part of other environmental measurement programs.

At river outflows an MI system can be used to transmit data directly to a shore receiver. For offshore dump sites an underwater cable may be used to transmit data from the sensor package to an MI transmitter module closer to shore (minimum distance depends upon bottom slope and expected ice thickness) which will transmit the data through the ice cover to a shore receiver (figure 4). This will avoid the problems associated with cable survival at the ice/shoreline interface. MI communications is not affected by ice noise or variations in the acoustic environment.

If permission is not obtained for location of shore stations, it may be possible to deploy relatively inexpensive satellite relay ice buoys by aircraft. These buoys would receive the MI signal through ice cover and re-transmit to satellite (figure 5). Feasibility of this method would depend on expected speed of ice movement and the economics of periodic buoy replacement.

CONCLUSIONS

Based on the foregoing information it is concluded that the method most likely to provide reliable long term monitoring of radioactive contamination in the arctic seas during the ice covered period is Magneto-inductive communications transmitting data to a shore receiving station for relay to satellite.Use of Acoustic telemetry with the attendant requirement for a hydrophone under the ice is seen to present significant problems related to logistics and deployment. Use of data cables to shore is completely unreliable due to the likelihood that the cable will not survive ice movement in shallow water. Instllation of cables in back-filled trenches or steel pipes for protection is unacceptable from a logistics standpoint. However, the success of any method selected will be subject to the political issue of obtaining necessary permission from the Russian Federation.

REFERENCE BIBLIOGRAPHY

1. Environmental Radioactivity In the Arctic, Antarctic, ST Conference Report, Sea Technology, December, 1993.

2. DSP-Based Acoustic Telemetry Modems, Steve Merriam and Dave Porta, Sea technology, May, 1993.

3. Mixing It Up: Electromagnetic Communications Via Multiple Media, Paul Wrathall, Sea Technology, May, 1991.

4. Forcaster's Handbook for the Arctic, F. S. Sechrist, R.w. Felt, D.C. Perryman, Naval Environmental Prediction Research Facility, Monterey, CA, TR 89-12, October, 1989.

5. Water Level Measurements in the Polar Regions: Status and Technology, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NOS OMA 54, September, 1990.

Radioactive Waste Dump Sites In The Kara Sea

Neptune Sciences, Inc.

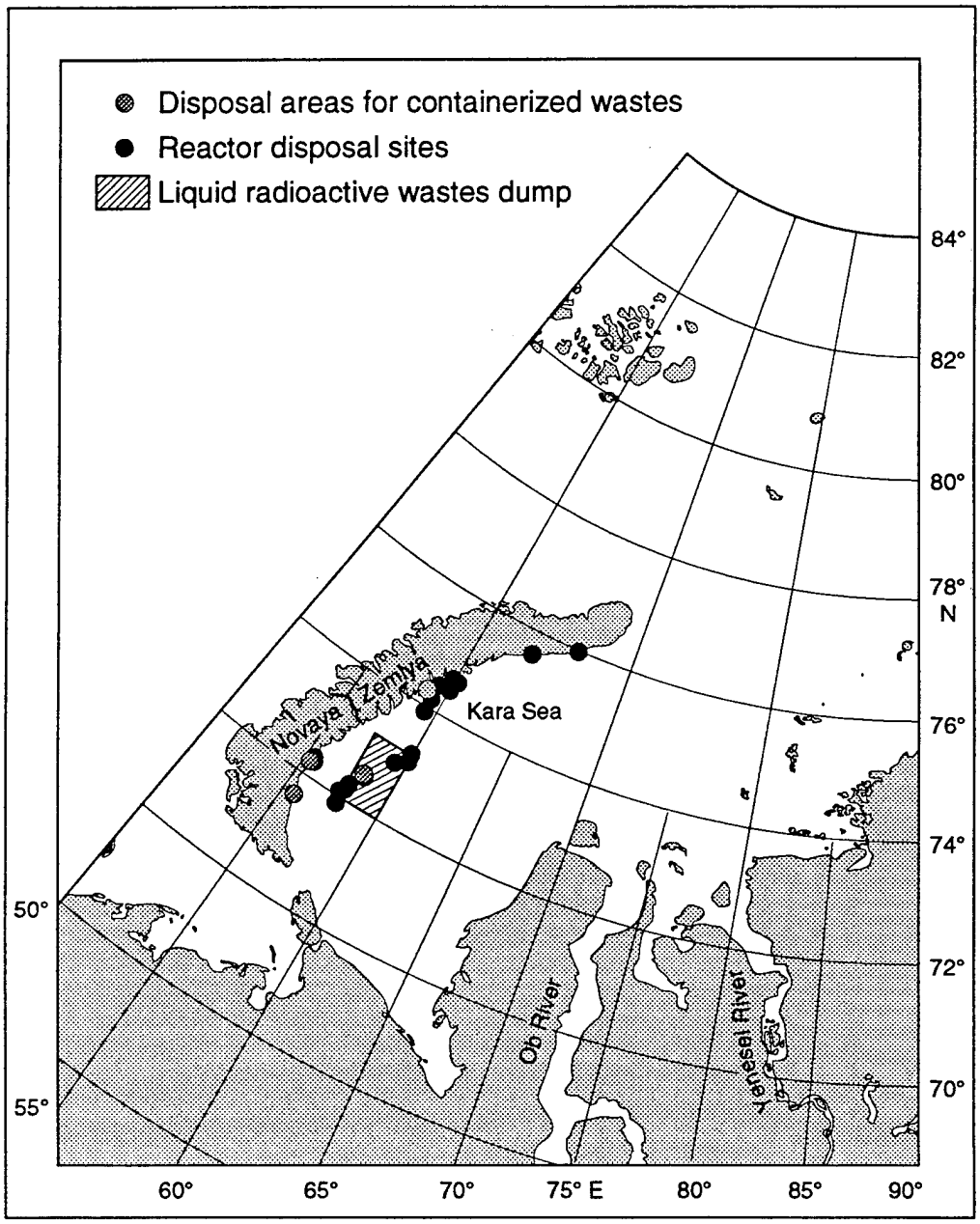


FIGURE 1

VG95028

Ocean Currents In The Kara Sea Area

Neptune Sciences, Inc.

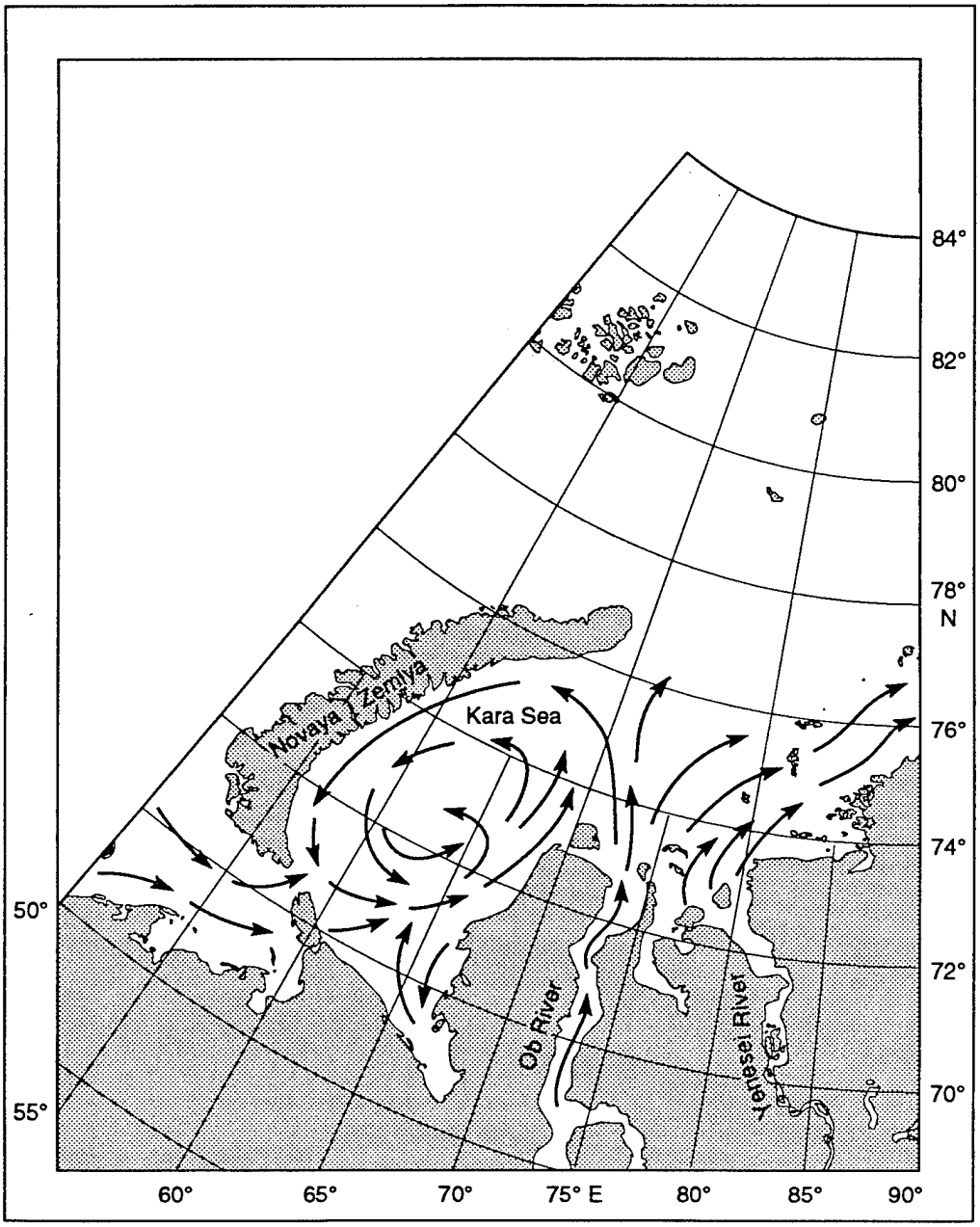


FIGURE 2

VG95029

Acoustic Data Links

Neptune Sciences, Inc.

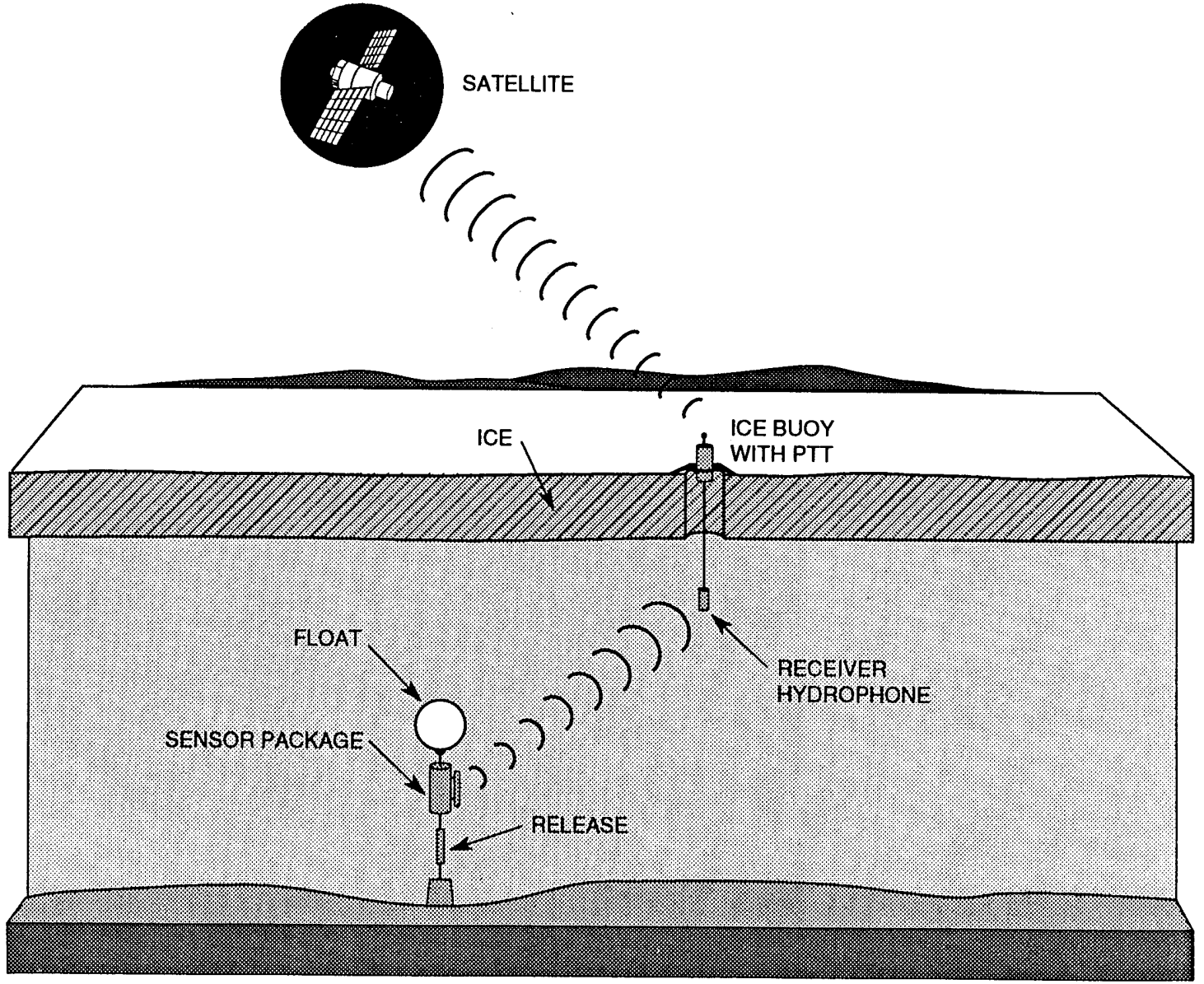


FIGURE 3

MI Data Link To Shore Station

Neptune Sciences, Inc.

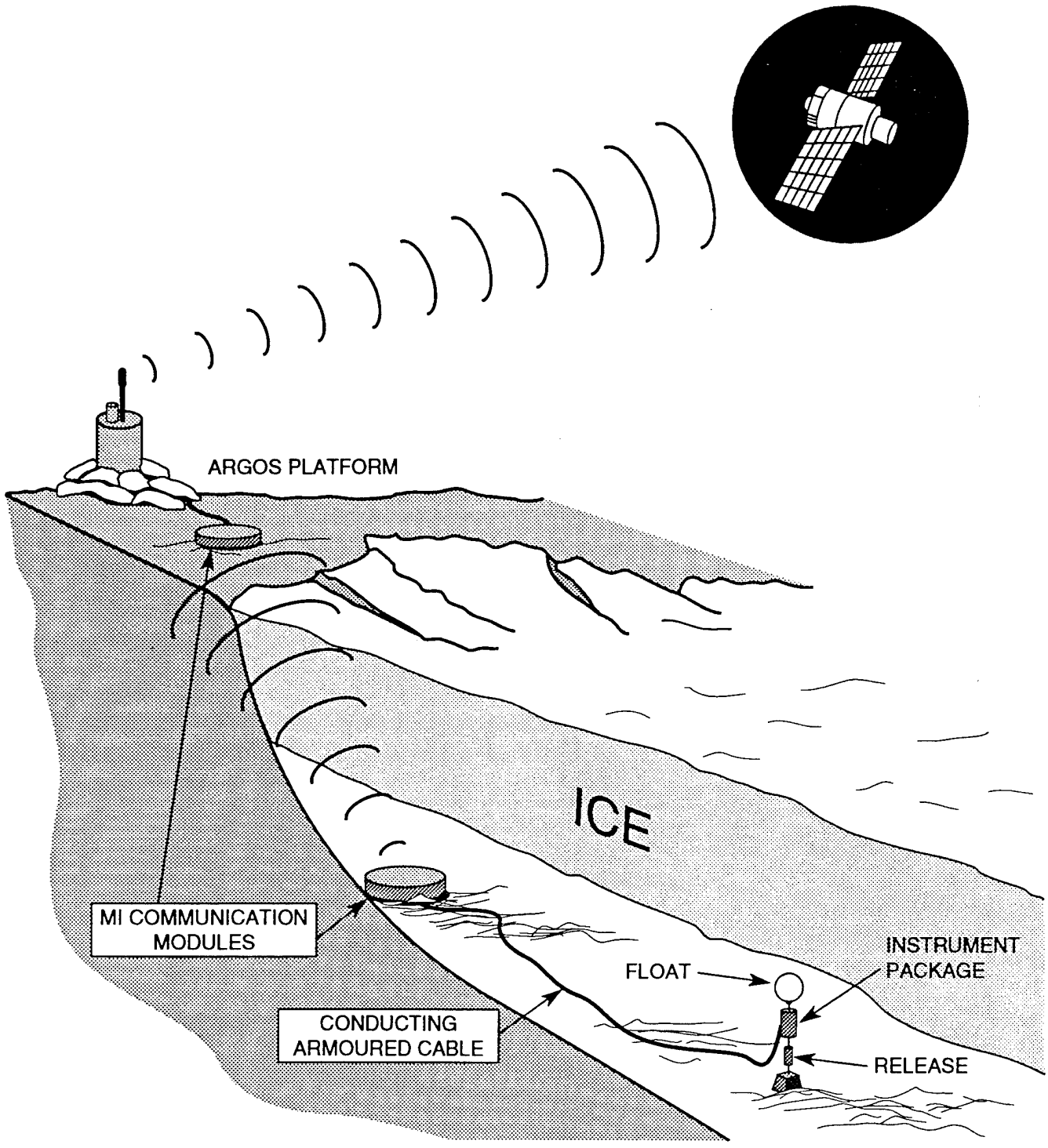


FIGURE 4

VG95037

Magneto-Inductive (MI) Data Link

Neptune Sciences, Inc.

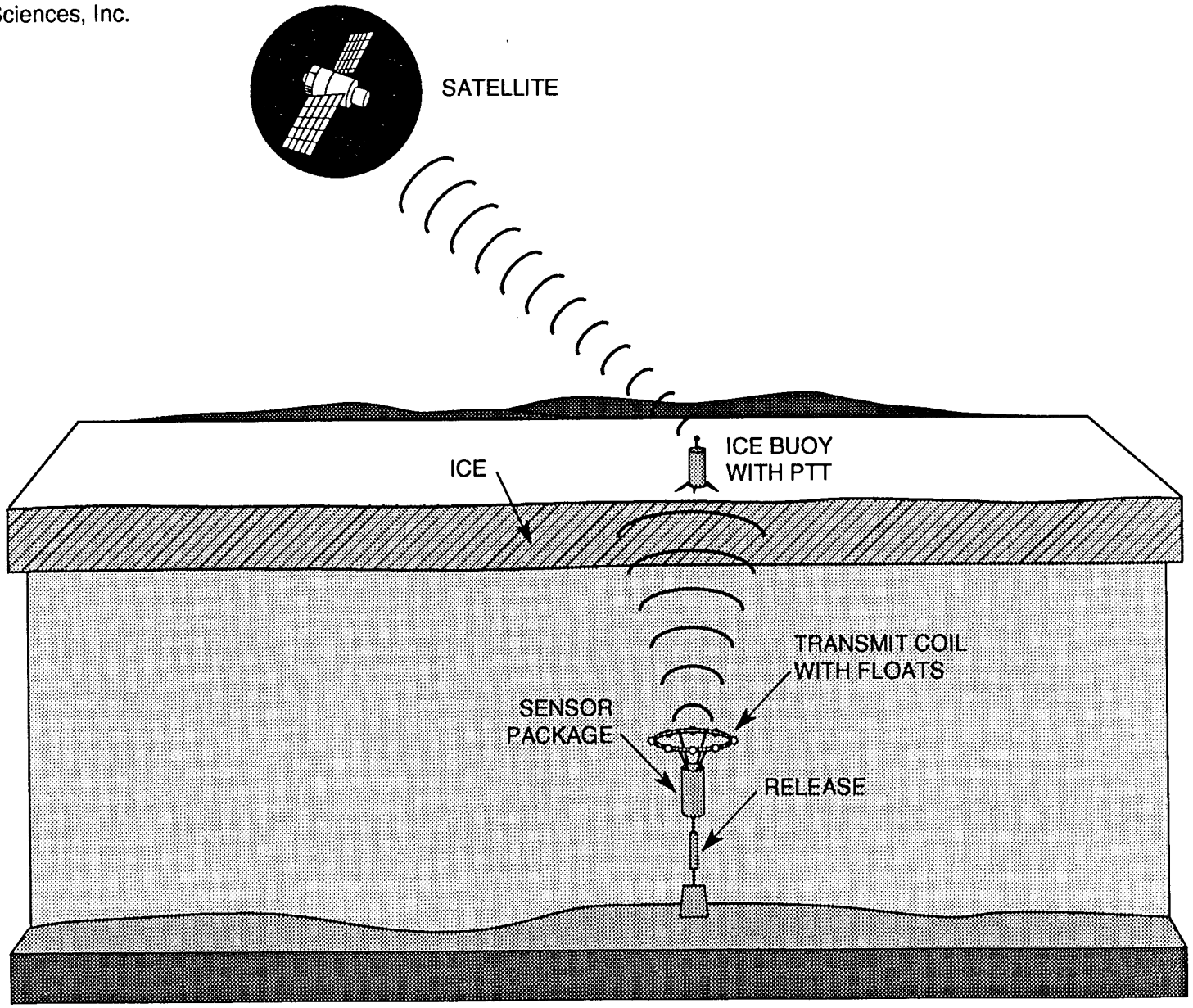


FIGURE 5

Monitoring Of Radioactive Contamination In Arctic Seas: Data Links Through Water And Ice



VG95025

Major Complicating Issues

Neptune Sciences, Inc.

- Political
  - Permission for establishing shore based data receiving/satellite relay stations
  - Permission for overflights to deploy satellite ice buoys
- Ice movement
  - Long term reliability of data cables to shore
  - Acoustic or MI receivers on ice buoys move out of range of seafloor instruments

VG95027

Data Link Alternatives

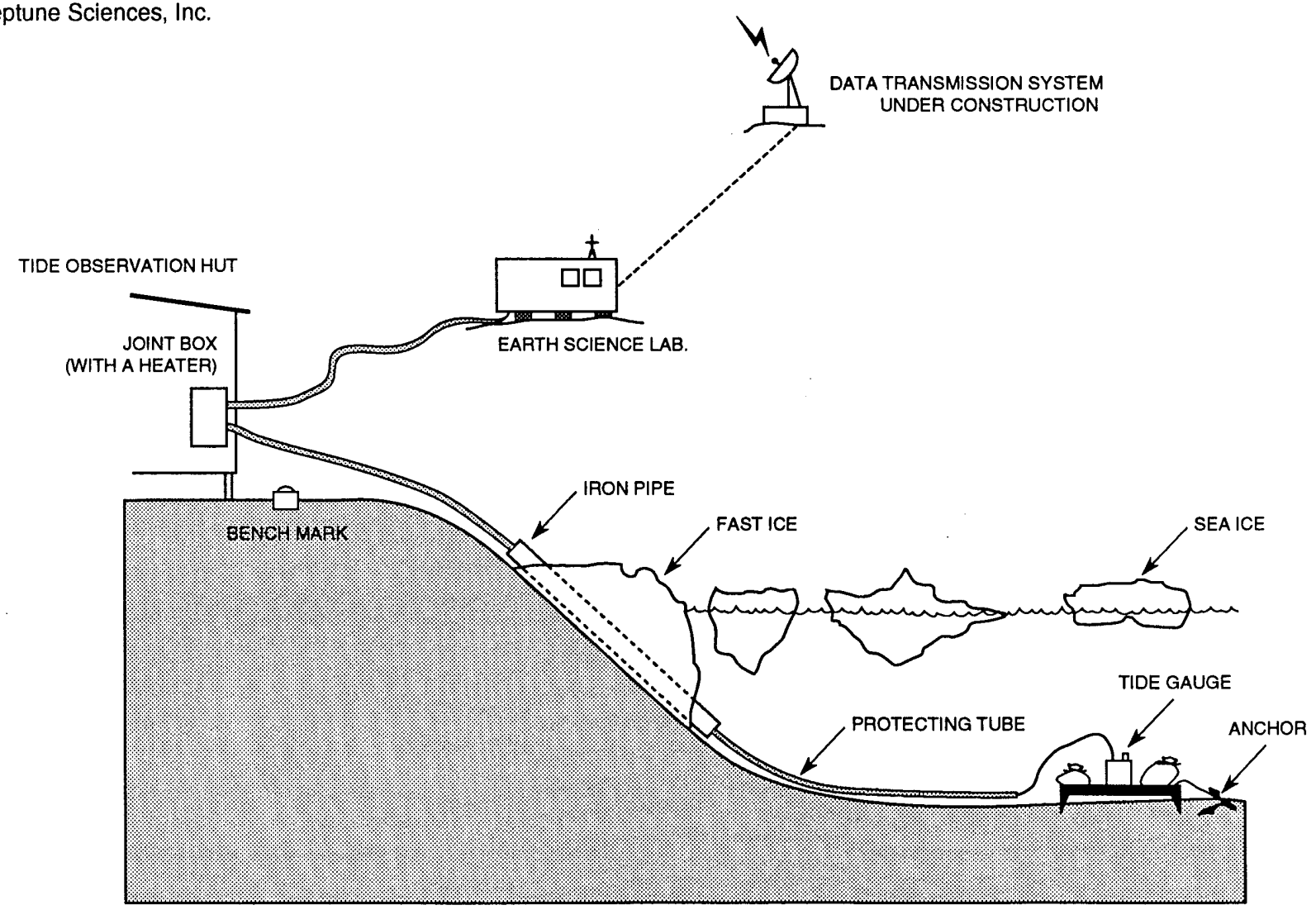
Neptune Sciences, Inc.

- Cable to shore-based SATCOM
- Acoustic link to shore station or ice buoy for relay to satellite
- Magneto-inductive (MI) link to shore station or ice buoy for relay to satellite

VG95026

The Present System Of Tidal Observation At The Japanese SYOWA Station

Neptune Sciences, Inc.



Acoustic Data Links

Neptune Sciences, Inc.

- Well developed technology
- Greater data rates than MI
- Requires deployment of receiving hydrophone through ice cover
- Reliability dependent upon acoustic environment (multi-path, signal fading affected by underice morphology)

VG95031

Typical Acoustic Telemetry Performance (Datasonics)

Neptune Sciences, Inc.

- Transmit and receive bit rate: 1200 band
- Range: 2000 meters max.
- Frequency: 15 - 20 kHz
- DSP based error detection/correction

VG95033

Magneto-Inductive (MI) Data Link

Neptune Sciences, Inc.

- Uses the modulated magnetic component of a quasi-static electromagnetic field as the communication channel
- Prototype units have been built and demonstated
- Transmits data through water, ice, rock or air - no need to deploy a receiving element through the ice cover
- Limited range ($\simeq$ 250 meter) at moderate output power

VG95034

Typical MI Link Performance

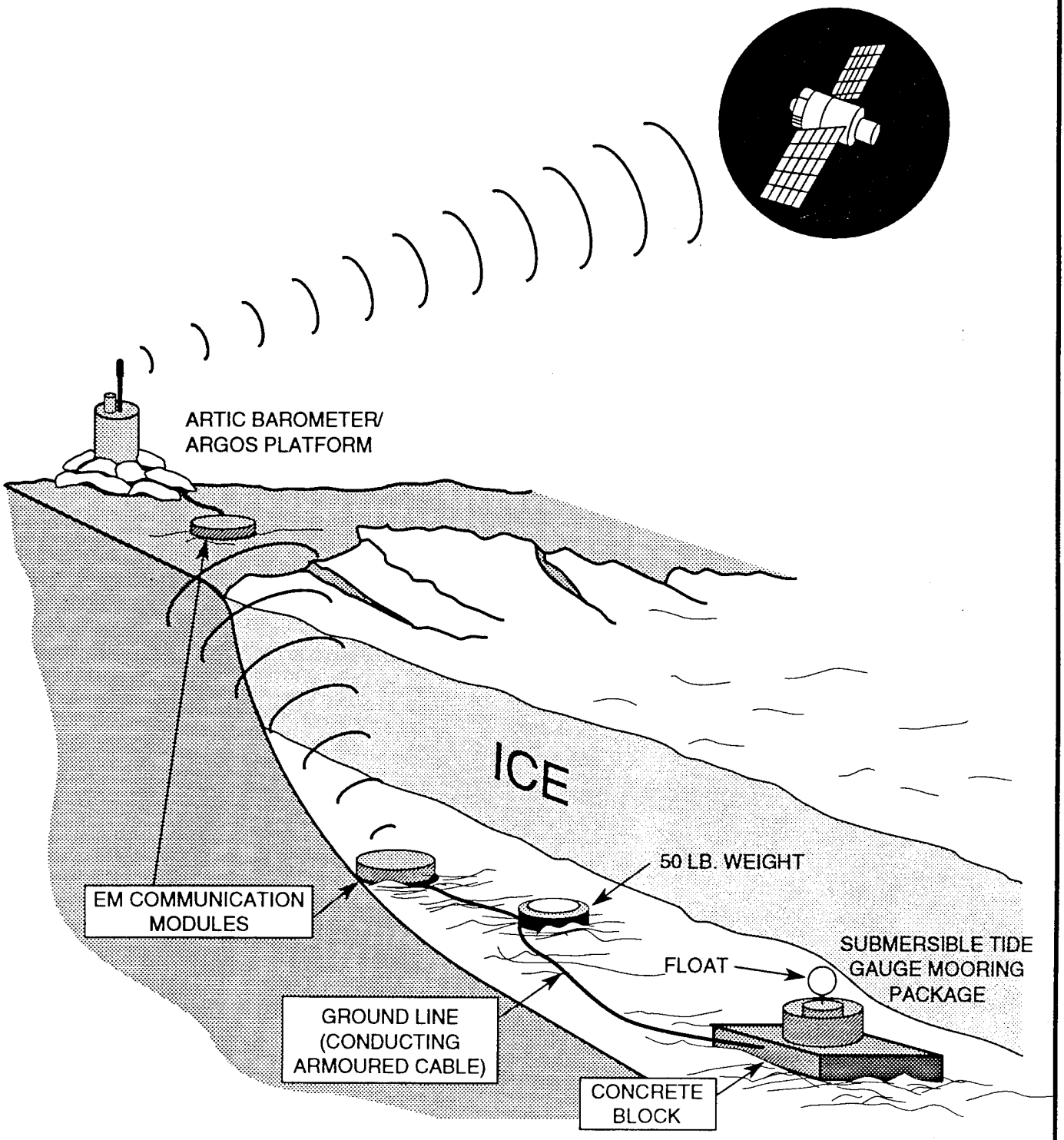
Neptune Sciences, Inc.

- Power Output: 200 watts
- Depth: 10 meters
- Range: 250 meters
- Data rate: 30 bits/sec

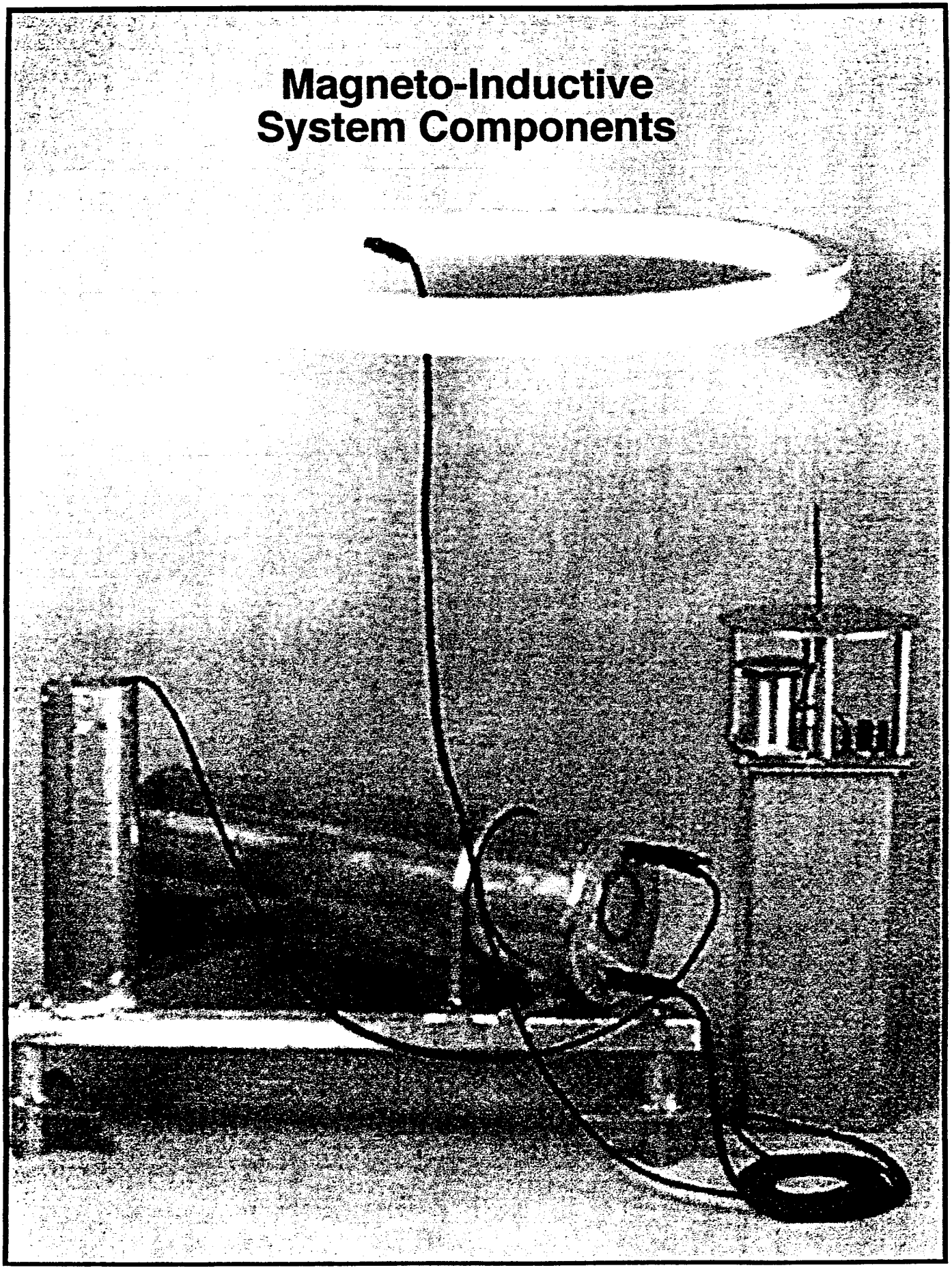
VG95036

Canadian Developments
MI Data Link To Shore Station

Neptune Sciences, Inc.



Magneto-Inductive System Components



Radionuclide Transport through the Arctic Ocean: Monitoring Strategies

J.N. Smith and K.M. Ellis
Bedford Institute of Oceanography
Dartmouth, N.S., Canada

L. Polyak and S. Forman
Ohio State University
Columbus, Ohio

D. Matishov and G. Matishov
Murmansk Institute of Marine Biology
Murmansk, Russia

G. Ivanov
Okeangeologia
St. Petersburg, Russia

S. Dahle
Akvaplan-niva
Tromso, Norway

L. Kilius
University of Toronto
Toronto, Ont., Canada

Abstract:

Radionuclide results relevant to monitoring strategies are reported for three current projects in the Arctic Ocean associated with, (1) contamination of Chernaya Bay on the Novaya Zemlya coastline from underwater nuclear weapons tests, (2) potential releases of radioactivity to the Novaya Zemlya Trough from a barge containing radioactive wastes, and (3) inputs of ^{129}I and ^{137}Cs to North American arctic waters from European sources.

Sediments in Chernaya Bay are distinguished by high levels of $^{239,240}Pu$ (>10,000 Bq/kg in surface sediments) owing to releases from at least two underwater nuclear weapons tests conducted in 1955 and 1957. A unique feature of the Chernaya Bay plutonium contamination is the atom ratio, $^{240}Pu/^{239}Pu$ of 0.0304 that is much lower than values (0.18) typical of global fallout, but is consistent with ratios measured for fallout from the early (1951-55) series of weapons tests at the Nevada Test Site. The timing of the Chernaya Bay source term, estimated from the $^{241}Am/^{241}Pu$ ratio, is consistent with the timing of the 1955 and 1957 underwater nuclear tests. Relatively low initial yields of ^{241}Pu ($^{241}Pu/^{239}Pu$ atom ratio = 0.00123) in these tests have resulted in $^{241}Am/^{239,240}Pu$ activity ratios (0.05) in recent sediments in Chernaya Bay that are low compared to

ratios of 0.3-0.4 typical of sediments contaminated by global fallout. The low $^{240}Pu/^{239}Pu$ and $^{241}Am/^{239,240}Pu$ ratios in Chernaya Bay sediments can be exploited to trace Chernaya Bay particle contamination throughout the Barents Sea. However, the $^{241}Am/^{239,240}Pu$ ratio is probably a more cost-effective tracer from a monitoring perspective because it can be measured using alpha spectrometry and does not require access to the thermal ionization mass-spectrometry technology required to resolve the ^{240}Pu and ^{239}Pu activities.

Sediment and seawater measurements for a range of artificial and natural radioisotopes have been conducted near a sunken vessel in the Novaya Zemlya Trough. This vessel is situated near the coordinates of a site identified in the Yablokov Report as the location of a barge loaded with 118 Ci (^{90}Sr equivalents) of solid radioactive wastes that was scuttled in 1980. The activities of ^{137}Cs and $^{239,240}Pu$ in bottom water and surface sediment samples collected near the sunken vessel are typical of those in other regions of the Kara Sea and show no indication of local releases from the dumpsite. Radionuclide tracer profiles in cores from this and other regions of the Kara and Barents Seas have been simulated using a two-layer biodiffusion model characterized by rapid, near-homogeneous mixing in the surface mixed layer and reduced mixing in the deep layer. ^{210}Pb sediment-depth profiles are consistent with a wide range of sedimentation and mixing rates in the deep sediment layer. However, the ^{137}Cs and $^{239,240}Pu$ results further constrain the model parameters and indicate that the downward transport of radionuclides in the sediments is governed primarily by sediment mixing, with sediment burial playing a secondary role. The implication of sediment mixing to monitoring is that it reduces the quantity of information on the history of anthropogenic inputs that can be resolved through the analysis of sediment contaminant profiles.

^{137}Cs measurements in the Central Arctic Ocean are reported for several ice stations including FRAM 3 (1981), CESAR (1983) and the Canadian Ice Island (1985, 1986 and 1989). In 1993, seawater samples were collected for ^{137}Cs analyses in the Chukchi and East Siberian Seas from the Canadian icebreaker, CSS Henry Larsen. Elevated ^{137}Cs levels (>10 Bq/m^3) measured in surface waters of the East Siberian Sea are evidently associated with the transport into this region of Atlantic water contaminated by releases from European reprocessing plants. Elevated levels of ^{129}I were also detected in these water samples, indicating that both ^{137}Cs and ^{129}I are unambiguous tracers of Atlantic water in the Western Arctic Ocean. These two radionuclides together provide critical information on radionuclide source terms and their measurement should be a key element in the design of a radionuclide monitoring program for North American Arctic waters.

VI. Poster Session

Concentrations and Inventories of ^{137}Cs & $^{239,240}Pu$ in Sediment and Biological Samples from Ob & Yenisey Rivers and Kara Sea

M. Baskaran[1], Shaunna Asbill[1], Peter Santschi[1], Tamara Davis[2], James Brooks[2], Mike Champ[2], Vyacheslav Makeyev[3] and Vladimir Khlebovich[4]

[1] Department of Oceanography, Texas A & M University at Galveston, Galveston, TX 77553-1675, USA

[2] Geochemical and Environmental Research Group, College Station, TX 77845, USA

[3] Research Institute for Nature Conservation of the Arctic and North, St. Petersburg, Russia

[4] Zoological Institute of St. Petersburg, St. Petersburg, Russia

Paper Presented at the Workshop on Monitoring of Nuclear Contamination in Arctic Seas
Sponsored by the Office of Naval Research
January 18-19, 1995
Naval Research Laboratory, Washington, DC

Abstract:

The major sources of plutonium and radiocesium isotopes in the environment are from nuclear weapons testing via global and close-in (debris) fallout, nuclear fuel reprocessing and fabrication plant effluents. Measurements of differences in the Pu isotopic ratios have yielded information not only on the time horizons for sedimentary deposits but also on the sources of Pu. We have measured ^{238}Pu, $^{239,240}Pu$ and ^{137}Cs concentrations in the surficial sediments as well as in sediment cores from the Ob and Yenisey Rivers (Russia) and the Kara sea. A comparison of the sediment core inventories of $^{239,240}Pu$ and ^{137}Cs along with the $^{238}Pu/^{239,240}Pu$ activity ratios with those expected from global fallout at the study sites allows us to estimate the relative amounts of reactor-derived ^{238}Pu and $^{239,240}Pu$ from the dumped reactor sites in the study area.

In surficial sediment samples, the $^{239,240}Pu$ concentrations vary between 0.32 and 51.4 dpm kg^{-1}, with a mean of 14.8 dpm kg^{-1}. The $^{238}Pu/^{239,240}Pu$ activity ratios vary between 0.010 and 0.069 with an average value of 0.0347. This range can be compared to the average $^{238}Pu/^{239,240}Pu$ activity ratio of 0.030 for the year 1993 from nuclear weapons testing and SNAP fallout obtained from soil studies, indicating very little ($\leq$ 5%) additional sources of ^{238}Pu to the sediments in the study area. The inventories of Pu in the 5 sediment cores from the study area vary between 0.016±0.004 and 0.147±0.013 dpm cm^{-2}, with a mean value of 0.053 dpm cm^{-2}. The ^{137}Cs concentrations in the upper 3 cm of the sediments vay between below detection limit to 4121 dpm kg^{-1} with a mean of 891 dpm kg^{-1}. The ^{137}Cs inventories in the 5 sediment cores vary between 0.94±0.17 and 9.60±0.92 dpm cm^{-2}, with a mean value of 3.50 dpm cm^{-2}. The mean ratio of inventories of Pu to that of ^{137}Cs , 0.015, is compared to the values in other places in the Arctic region.

MATERIALS AND METHODS:

- 83 SURFACE SEDIMENT SAMPLES
- 5 SEDIMENT CORES

- ^{238}Pu, $^{239,240}Pu$ - ALPHA SPECTROMETRY
- ^{137}Cs - GAMMA RAY SPECTROMETRY (GERMANIUM WELL DETECTOR)

TABLE 1: $^{239, 240}Pu$ inventories in the Water samples and sediments from the Arctic Regions.

Location and Nature of Sample	Water Depth (m)	Year of Collection	$^{239,240}Pu$ (Bq m^{-2})*	Source
76.6° N; Thule, Greenland Soil Sample	-	1971	12.2	*Hardy, 1973*
71.3° N; Barrow, Alaska Soil Sample	-	1971	14.8	*Hardy, 1973*
64.8° N, Fairbanks, Alaska Soil Sample	-	1971	31.5	*Hardy, 1973*
65°55.7 N; 27°27.0 W Water Samples	646	1972	20	*Livingston, 1985 Data reported in Aarkrog, 1989*
74°56.2 N; 1°7.2 W Water Samples	3740	1972	54	*Livingston, 1985 Data reported in Aarkrog, 1989*
89° N; 89° W Water Samples	2497	1979	35.0	*Livingston et al., 1984*
89° N; 111° W Water Samples	3000	1979	24.2	*Livingston et al., 1984*
89° N (Expected from Fallout)	-	-	5.13	*Livingston et al., 1984*
68° - 76° N; 67° - 84° E Sediment Cores from Ob and Yenisey Rivers and Kara Sea	7-290	1993	8.85 (2.61 - 24.4)	*Baskaran et al. 1995 (in press)*

* Numbers in parenthesis denote the range of values reported.

TABLE 2: $^{238}Pu/^{239,240}Pu$ activity ratios in nuclear effluents from Sellafield and Cap de la Hague, dissolved, particulate phases, surficial sediments and terrestrial samples in the Arctic Region.

Nature of Sample	Location	Number of Samples	Year of Collection	^{238}Pu / $^{239,240}Pu$ * Activity Ratios in 1993	Source
Effluents from Sellafield	Irish Sea	7	1978-1984	0.29±0.02	*British Nuclear Fuels 1985*
Effluents from Cap de la Hague	English Channel	7	1962-1982	0.46	*Calmet and Guegueniat, 1985*
Dumped Reactors in Kara Sea	Kara Sea	Estimate	-	0.26-0.49	*Mount et al. 1993*
Global Fallout (+SNAP)	Northern Hemisphere		1982	0.021 (0.030)	*Aarkrog, 1989*
Water samples- Dissolved phase	Barents, Greenland, Norwegian and North Seas	41	1980	0.060±0.010 (0.037±0.016 - 0.078±0.012)	*Holm et al. (1986)*
Water samples- Particulate phase	Barents, Greenland, Norwegian and North Seas	41	1980	0.052±0.018 (0.019±0.025 - 0.084±0.066	*Holm et al. (1986)*
Terrestrial samples (Lichen, Moss, Soil)	Svalbard Isfjord, NE Greenland	12	1980	0.042±0.007 (0.036±0.005 - 0.055±0.005)	*Holm et al. (1986)*
Surficial sediments	79.2-82.3°N; 25.3-33.7°E	10	1980	0.062±0.006	*Holm et al. (1986)*
Surficial Sediments	Ob, Yenisey Rivers and Kara Sea	55	1993	0.036±0.003 (0.009-0.065)	*Baskaran et al. (1995) (In press)*

* Numbers in parenthesis denote the range of values reported.

TABLE 3: Water depths, Locations, and Inventories of ^{238}Pu, $^{239,240}Pu$ and ^{137}Cs in sediment samples from Ob and Yenisey Rivers and Kara Sea.

Sample Code	Location	Water Depth (m)	239, 240Pu (dpm cm^{-2})	238Pu (dpm cm^{-2})	137Cs (dpm cm^{-2})
62	72°00.00'N-73°09.15'E	14.9	0.147±0.013	0.0050±0.0017	9.60±0.92
64A	75°32.73'N-72°59.89'E	38.1	0.065±0.008	0.0052±0.0026	2.38±0.42
64B	75°32.73'N-72°59.89'E	38.1	0.0157±0.004	BD	1.50±0.26
66	75°45.02'N-72°43.06'E	76.2	0.0161±0.0027	0.0007±0.0004	0.940±0.172
4413	Ob River	15	0.0219±0.0036	0.0010±0.0010	3.09±0.16

NM: Not measured.
BD: Below detection limit

TABLE 4 : Concentrations of ^{238}Pu, $^{239,240}Pu$ and ^{137}Cs in biological samples from Ob and Yenisey Rivers and Kara Sea.

Sample Code	Sample	$^{239,240}Pu$ (dpm kg^{-1})	^{238}Pu (dpm kg^{-1})	^{137}Cs (dpm kg^{-1})
8	Isopods	1.98	BD	BD
15	Bivalves		BD	BD
16	Isopods	4.8	BD	BD
	Wormtubes	9.69	BD	642
17	Amphipods	2.88	BD	BD
20	Bivalves	BD	BD	BD
9, 10	Liver	2.76	BD	BD
10	Isopods	4.02	BD	BD
14	Bivalves	6.01	BD	420
10A	Fat	3.72	BD	BD
5	Liver	1.86	BD	BD
2	Liver	4.86	BD	BD
24	Liver	0.96	BD	BD
31	Isopod	11.0	BD	BD

NM: Not measured.
BD: Below detection limit

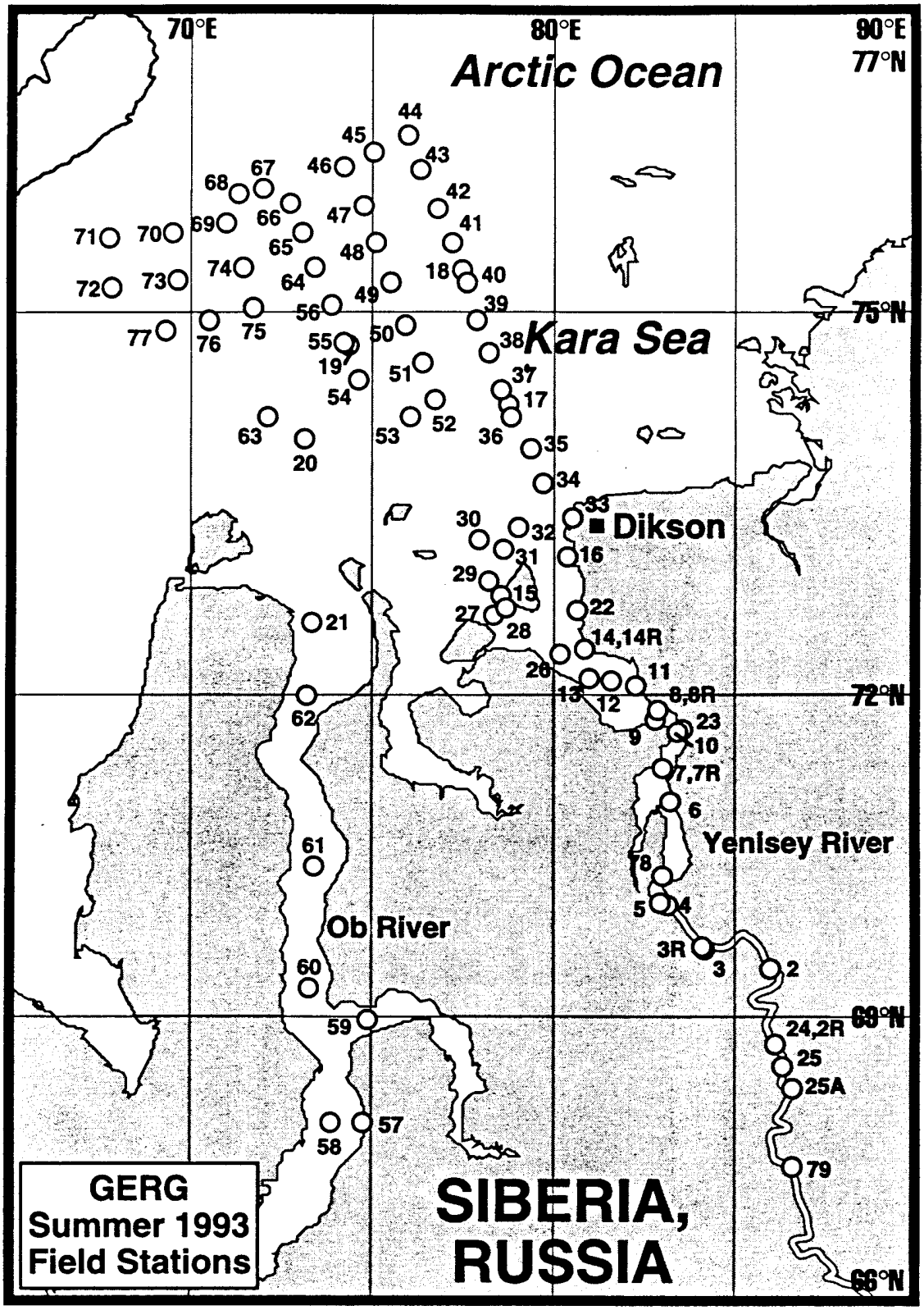


Figure 1. Sample locations in the Kara Sea.

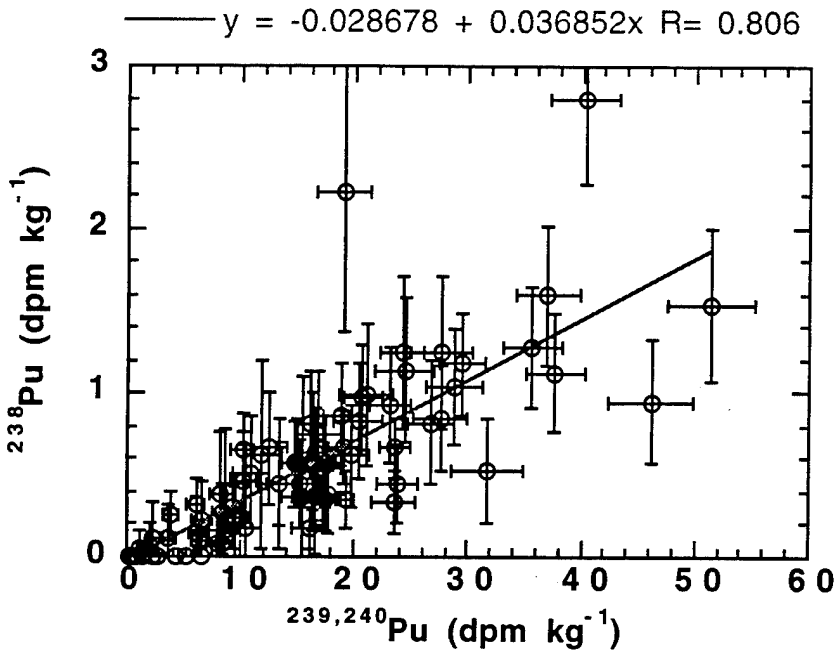


FIGURE 2 : ^{238}Pu VERSUS $^{239,240}Pu$: THE SLOPE VALUE (= $^{238}Pu/^{239,240}Pu$ ACTIVITY RATIO) SUGGESTS THAT MOST OF THE PU ARE DERIVED FROM GLOBAL FALLOUT.

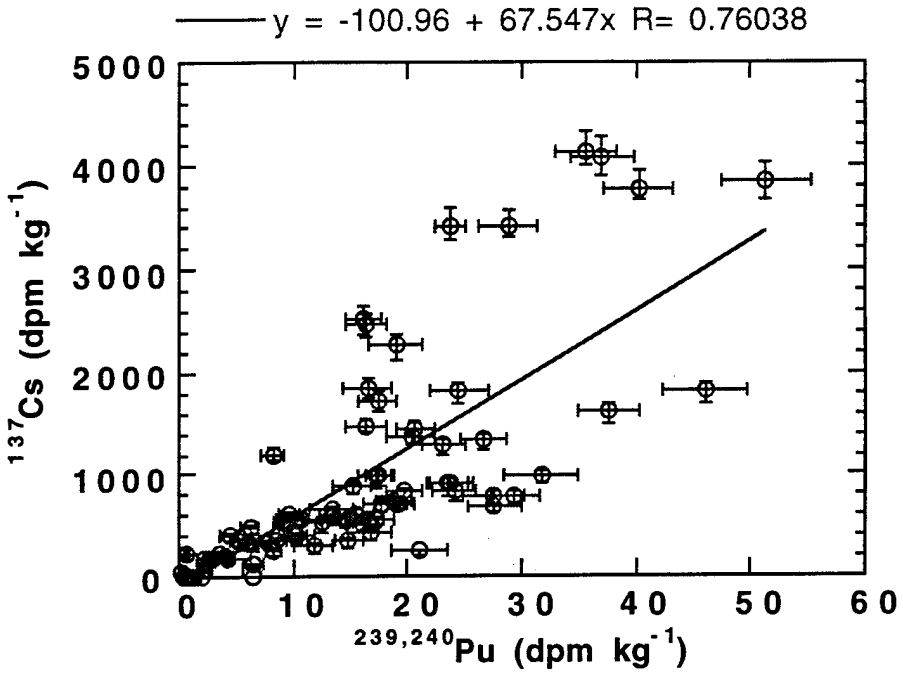


FIGURE 3 : ^{137}Cs VERSUS ^{239,240}Pu: THE ACTIVITY RATIO OF ^{239,240}Pu/^{137}Cs SUGGESTS THAT MOST OF THE PU AND RADIOCESIUM ARE DERIVED FROM GLOBAL FALLOUT.

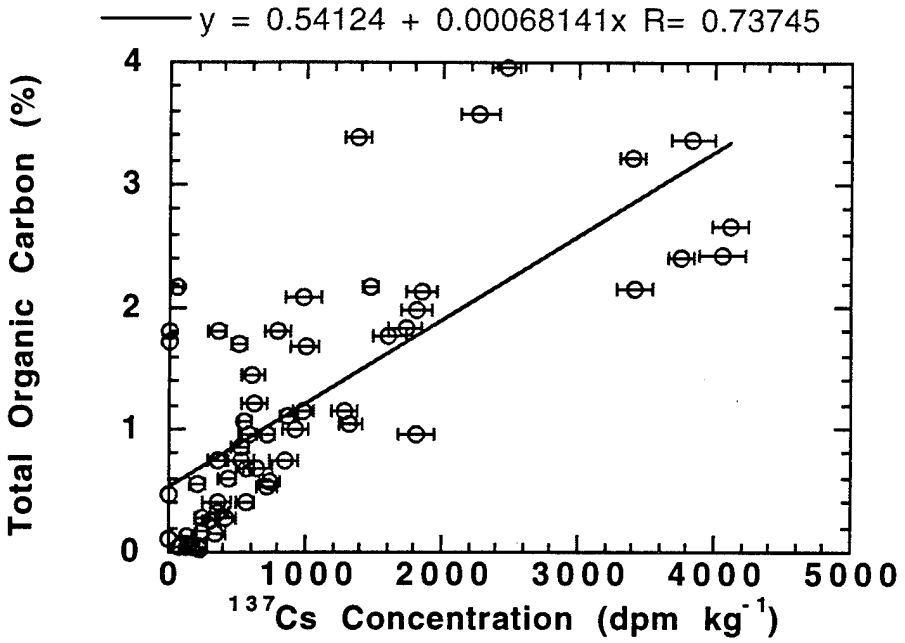


FIGURE 4 : TOTAL ORGANIC CARBON VERSUS ^{137}Cs CONCENTRATION. ORGANIC CARBON APPEARS TO CONTROL ^{137}Cs CONCENTRATION.

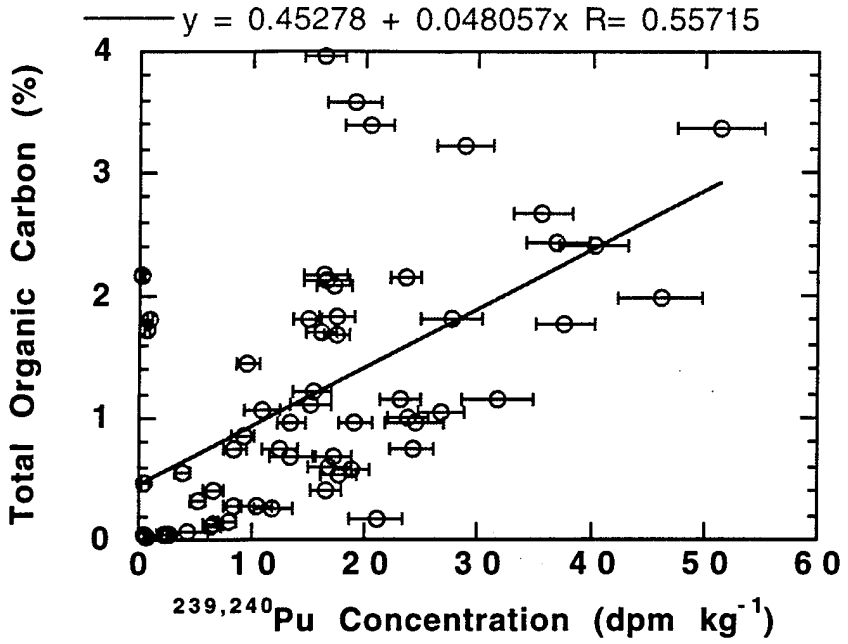


FIGURE 5 : TOTAL ORGANIC CARBON VERSUS $^{239,240}Pu$ CONCENTRATION. ORGANIC CARBON APPEARS TO CONTROL THE $^{239,240}Pu$ CONCENTRATION.

CONCLUSIONS

We have measured the ^{238}Pu, $^{239,240}Pu$, and ^{137}Cs concentrations from the surficial sediments, as well as selected core samples from the Ob and Yenisey Rivers and Kara Sea, to quantitatively evaluate the contribution of Pu and from the nuclear reactors dumped in the Kara Sea. From this present investigation, the following conclusions are drawn.

1. The $^{239, 240}Pu$ concentrations in the surficial sediments (upper 3 cm) vary from 0.32 to 51.4 dpm kg^{-1}, with a mean of 14.8 dpm kg^{-1}. The ^{238}Pu concentrations in these sediments vary from below the detection limit to 2.79 dpm kg^{-1}, with a mean of 0.52 dpm kg^{-1}. The ^{137}Cs concentrations varied between below detection limit to 6,555 dpm kg^{-1}, with a mean of 2,217 dpm kg^{-1}.

2. The $^{239,240}Pu$ inventory in the five sediment cores from the Ob and Yenisey Rivers and Kara Sea varies between 0.016 and 0.147 dpm cm^{-2}, with a mean value of 0.053 dpm cm^{-2}. This value is comparable to the value, 0.089 dpm cm^{-2}, reported for a soil sample collected from Barrow, Alaska. Also, this value is significantly lower than the anticipated additional inventory, 0.118 - 0.290 dpm cm^{-2}, if all the Pu from the dumped reactors in the Kara Sea were released and redistributed uniformly to the Kara Sea sediments. The ^{137}Cs inventory varied between 0.94 and 9.60 dpm cm^{-2} with a mean value of 3.50 dpm cm^{-2}.

3. The $^{238}Pu/^{239,240}Pu$ activity ratios in the surficial sediment samples vary between 0.0096 and 0.069. The best-fit-line between ^{238}Pu and $^{239,240}Pu$ concentration in these samples yields an activity ratio of 0.037±0.003. Comparing this value with the published values on the European nuclear effluents discharged into the coastal waters, fallout values

of the nuclear weapons tests, and the estimated Pu inventories in the dumped reactors in Kara Sea, we conclude that there is virtually no detectable input from either the European nuclear effluents or from the dumped nuclear reactors in the Kara Sea or the input from these are below detection limit. The $^{239,240}Pu/^{137}Cs$ activity ratio in the surficial sediment samples suggests that most of the radiocesium and Pu are derived from global fallout.

4. From the average value of the measured inventory of Pu in the sediments of Ob and Yenisey Rivers and Kara Sea, 0.053 dpm cm^{-2}, the total inventory of Pu in the Kara Sea is estimated to be 5.3×10^{14} dpm.

5. There is a fairly good correlation between Organic Carbon content and the concentrations of $^{239,240}Pu$ and ^{137}Cs, suggesting that organic carbon primarily controls the variations in the concentrations of these nuclides.

Measurement of Long-Lived Radionuclides in Marine Environs

by

D.M. Beals,
J.M. Pochkowski,
and
W.G. Winn

MEASUREMENT OF LONG-LIVED RADIONUCLIDES IN MARINE ENVIRONS

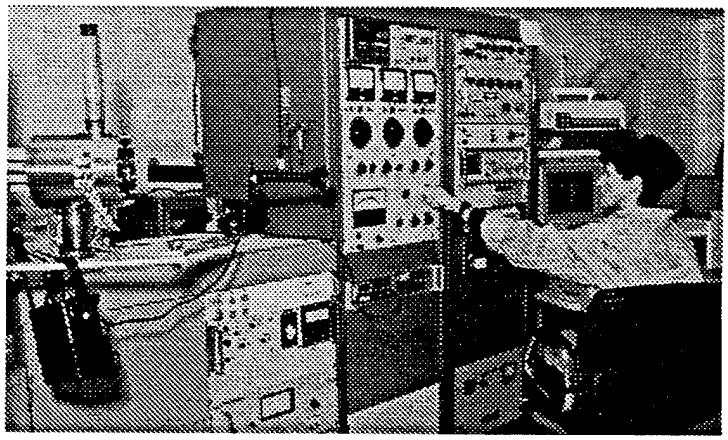
D. M. Beals, J.M. Pochkowski and W.G. Winn
Savannah River Technology Center, Bldg 735A
Westinghouse Savannah River Co., Aiken SC 29808

The Environmental Technology Section (ETS) of the Savannah River Technology Center has established techniques to measure radionuclides in environmental samples at very low detection limits. By studying the concentration and distribution of various radionuclides in the environment conclusions can be made about the sources and transport mechanisms of those elements through the geosphere. Plutonium, technetium and radioisotopes of cesium are primarily manmade elements and isotopes. They are found worldwide at very low concentrations due to fallout from weapons testing. Elevated concentrations of these elements and isotopes, and especially unique isotopic ratios, can be indicative of nuclear waste, such as may be entering the Arctic from the Former Soviet Union. To differentiate between fallout and other inputs to a marine system high sensitivity and high precision measurements are required.

The ETS uses isotope dilution/thermal ionization mass spectrometry (TIMS) to measure the concentration and determine the isotopic distribution of plutonium in environmental samples (Buesseler and Halverson, 1987). The ETS also uses isotope dilution TIMS to determine the concentration of Tc-99 in environmental samples (Pochkowski and Beals, 1993). Cesium-137, and Cs-134, are determined by high resolution gamma spectrometry in the ETS underground counting facility (Winn, 1987).

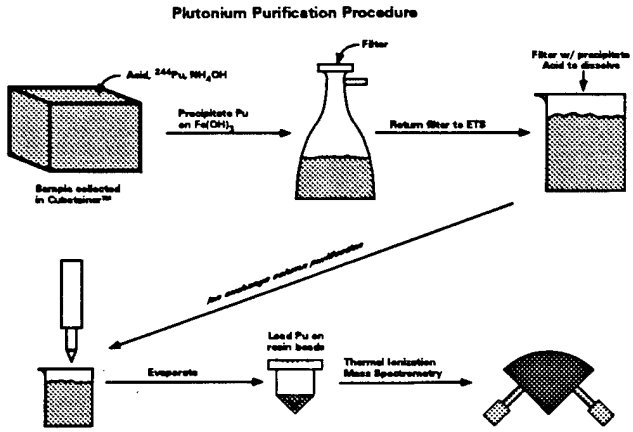
Of these three elements discussed, technetium is expected to be the most mobile in the marine environment. In groundwater systems at the Savannah River Site, Tc-99 flows at nearly the velocity of the groundwater (Carlton, et al., 1993); it does not appear to be very particle reactive. In the marine environment both Pu and Cs are adsorbed by particles and thus would be expected to remain more localized near the source of the input. However, due to the longer half life of the plutonium isotopes, they may be regenerated to the dissolved phase and readsorbed to particles many times before decaying, thus allowing farther migration of the plutonium than the cesium. By studying the distribution of these three elements in the marine environment, using the above ultra-sensitive techniques, it will be possible to determine the sources and transport mechanisms of these radionuclides in the Arctic Ocean.

Abstract



The Environmental Technology Section (ETS) of the Savannah River Technology Center has established techniques to measure radionuclides in environmental samples at very low detection limits. By studying the concentration and distribution of various radionuclides in the environment, conclusions can be made about the sources and transport mechanisms of those elements through the geosphere. Plutonium, technetium, and radioisotopes of cesium are primarily man–made elements and isotopes. They are found worldwide at very low concentrations due to fallout from weapons testing. Elevated concentrations of these elements and isotopes, and especially unique isotopic ratios, can be indicative of nuclear waste, such as may be entering the Arctic from the former Soviet Union. To differentiate between fallout and other inputs to a marine system high sensitivity and high precision measurements are required.

Plutonium



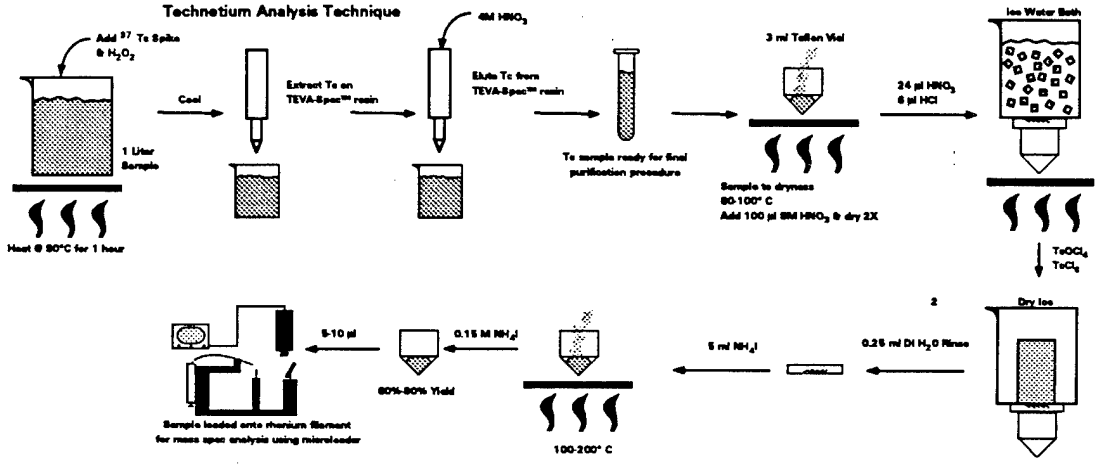
The Environmental Technology Section uses isotope dilution/TIMS to measure the concentration and determine the isotopic distribution of plutonium in environmental samples (Buesseler and Halverson, 1987). For sea water, a large water sample is brought on board a sampling platform. The sample is acidified, spiked with a ^{244}Pu tracer and then the plutonium is precipitated with iron hydroxide. The precipitate is returned to the laboratory for purification of the plutonium by ion exchange and TIMS analysis.

A total Pu sample size of 1 fg is needed to obtain a reliable Pu isotopic signature, including ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{242}Pu. For typical open ocean samples this requires 20 to 100 L of water to be collected and processed. The atom percent of ^{239}Pu versus ^{240}Pu varies with the source of the plutonium; plutonium produced in nuclear reactors has a different isotopic ratio than fallout. This ratio information is unavailable when alpha spectrometry is used to detect plutonium, which is the reason for the use of TIMS by the ETS. Using TIMS, we should be able to determine the source of the plutonium in the Arctic Ocean.

Technetium

The ETS uses isotope dilution thermal ionization mass spectrometry (TIMS) to determine the concentration of ^{99}Tc in environmental samples (Pochkowski and Beals, 1993). For water samples, freshwater or sea water, a ^{97}Tc tracer is added to a one liter sample. After equilibration the technetium is extracted onto an extraction chromatography resin. The technetium is eluted and further concentrated by a microdistillation technique prior to final loading on a rhenium filament for TIMS analysis.

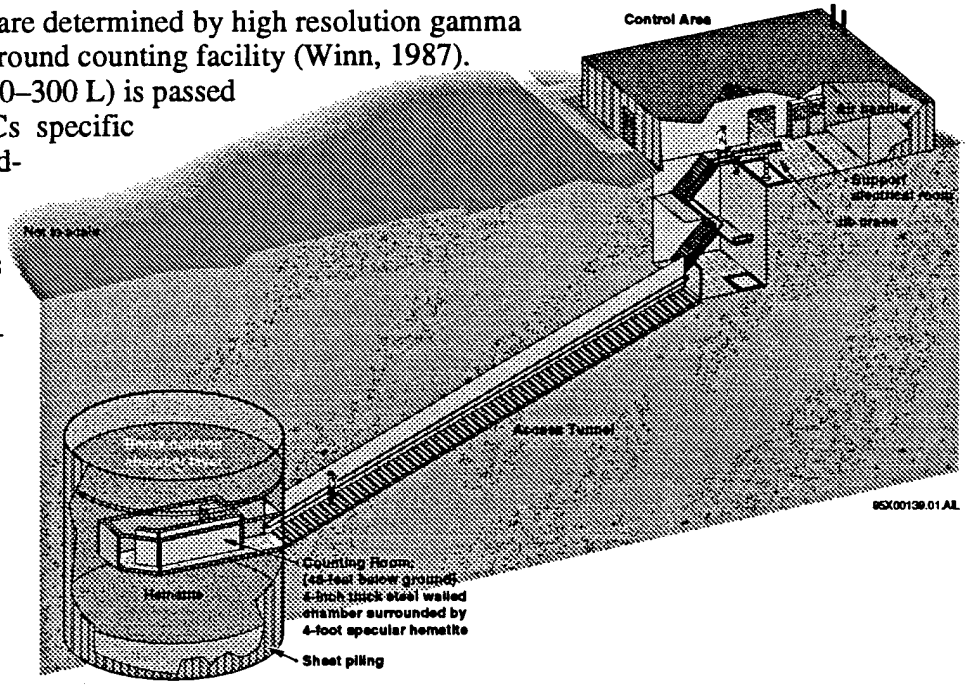
For suspended particulate analyses, the filter with attached particles is placed in a microwave digestion bomb. The ^{97}Tc tracer is added along with 4M nitric acid. The bomb is sealed and then heated in the microwave oven. After cooling the bomb is opened and the acid diluted with DI water.



The pH is adjusted to 5–7 using ultrapure ammonium hydroxide and the sample processed identically to water samples. The procedural detection limit for a one liter sample is 0.55 pg./L (9fCi/L).

Cesium

Cesium-137 and cesium-134 are determined by high resolution gamma spectrometry in the ETS underground counting facility (Winn, 1987). A large volume water sample (20–300 L) is passed through a column containing a Cs specific material. The resin is then extruded into an ETS standard counting vial and counted, The detection limit for a 20 liter sample is 5 fCi/L for a 24–hour count using a 30% efficient HPGe detector in the ETS underground counting facility. This detection limit can be significantly reduced by using the 90% efficient detector currently operating or using a new 164% efficient detector, to be delivered early in 1995.



Conclusion

Of the three elements discussed(plutonium, technetium, and cesium), technetium is expected to be the most mobile in the marine environment. In groundwater systems at the Savannah River Site, ^{99}Tc flows at nearly the velocity of the groundwater (Carlton, et al., 1993); it does not appear to be very particle reactive. In the marine environment both Pu and Cs are adsorbed by particles and thus would be expected to remain more localized near the source of the input. However, due to the longer half-life of the plutonium isotopes, they may be regenerated to the dissolved phase and readsorbed to particles many times before decaying, thus allowing farther migration of the plutonium than the cesium. By studying the distribution of these three elements in the marine environment, using these ultra-sensitive techniques, it will be possible to determine the sources and transport mechanisms of radionuclides in the Arctic Ocean.

ETS Procedural Detection Limits

Analysis	Sample Size	Instrument	Detection Limits (pCi/L)
^{239}Pu ^{240}Pu ^{241}Pu ^{242}Pu	20 L	TIMS	3.5 x 10-6 1.1 x 10-6 1.9 x 10-5 8.1 x 10-11
^{99}Tc	1 L	TIMS	9.2 x 10-3
^{137}Cs	20 L	HPGe	5.0 x 10-3

Buesseler, K.O. and J.E. Halverson, 1987, "Mass Spectrometric Determination of Fallout Pu-239 and Pu-240 in Marine Samples." J. Environ. Radioact., (United Kingdom) v 5:6, p 425-444.

Pochkowski, J.M. and D.M. Beals, 1993, "Determination of Subpicogram Quantities of Technetium-99 in Environmental Samples by Positive Thermal Ionization Mass Spectrometry." Proceedings of the 41st ASMS conference on Mass Spectrometry and Allied Topics, San Francisco.

Winn, W.G., 1987, "Ultra-sensitive Examination of Environmental Samples by SRL Underground Counting Facility." Trans. Am. Nuc. Soc., v 54, n 34.

Carlton, W.H., M. Denham and A.G. Evans, 1993, "Assessment of Technetium in the Savannah River Site Environment." WSRC-TR-93-217, Westinghouse Savannah River Co., Aiken SC.

What Does Near-Alaska Radionuclide Data Indicate about Future Monitoring Strategies?

Lee W. Cooper*, Jacqueline M. Grebmeier*, I.L. Larsen

Environmental Sciences Division, Oak Ridge National Laboratory, PO Box 2008, Oak Ridge, Tennessee 37831-6038, U.S.A.

*also at: Graduate Program in Ecology, University of Tennessee, Knoxville, Tennessee 37996-1191, U.S.A.

ABSTRACT

The concentrations of radioactive anthropogenic contaminants in the near-Alaskan marine environment are relatively low and an order of magnitude lower than activities concurrently measured in more polluted ecosystems (e.g. Black Sea, Kara Sea). Nevertheless, there is evidence for contaminants in the near-Alaskan marine environment potentially originating from North Atlantic (Sellafield) and former Soviet Union sources. These indications include subsurface maxima in Laptev, Beaufort and Chukchi Sea iodine-129 concentrations, elevated cesium-137 concentrations in Arctic Ocean sea ice, and plutonium-240/239 ratios in deep Canada basin and Laptev Sea sediments that are consistent with fuel re-processing sources. Nevertheless, the trace level of these contaminants, and the complex suite of physical and biological factors affecting sediment and water column radionuclide concentrations in near-Alaskan waters will provide a challenge for any monitoring program attempting to unequivocally detect Arctic radionuclide contamination in Alaskan waters that originates from sources in the former Soviet Union.

Although a catastrophic release of contaminants through river flooding or open breaching of containers is one potential outcome of Arctic nuclear waste disposal, it is also possible that subtle detection of newly introduced contaminants will be the only result of a long-term monitoring effort. In order for such monitoring to have the largest chance of significant findings, it should include elements that include detecting seasonal and annual fluctuations in radionuclides that may be linked to transport in ice, or water circulation patterns. Location of the sampling devices at strategic points affected by seasonal ice cover, or in important straits (e.g. Bering Strait) will also be important, at least for monitoring in near-Alaskan waters.

Units of measurement:

The Système International unit for radioactivity is the Becquerel (Bq), equivalent to 1 decay per second.

Thus, 1 m Bq, as used here, is equivalent to 1 decay per 1000 seconds.

To convert to Bq from the older unit of 1 Curie (Ci), equivalent to the radioactivity associated with 1 gram of radium, multiply the number of curies by 3.7×10^{10}. (To convert environmental levels of picocuries [pCi] to mBq, multiply number of pCi by 37.0.)

Background

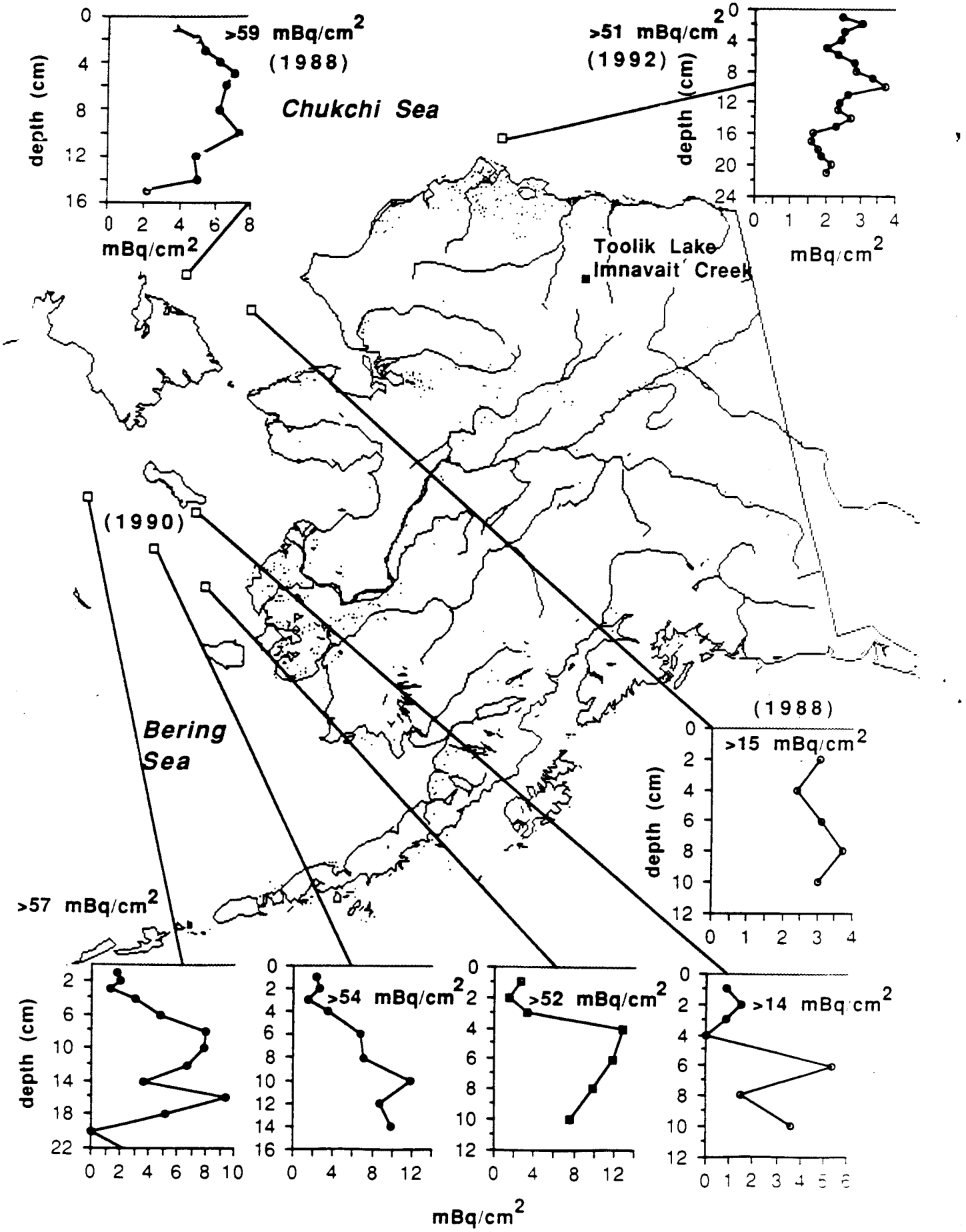
^{137}Cs is an anthropogenic, gamma emitting radionuclide that is a by-product of nuclear fission, weapons production and waste disposal. It has a half-life of 30.2 years.

Because of its strong gamma emission, solubility in water, and incorporation into biological food-chains as an analog for potassium, it is potentially the most significant radionuclide contaminant affecting arctic ecosystems.

The current concentrations and inventories of ^{137}Cs in Alaskan waters and soils are consistent with fallout from nuclear bomb testing in the 1960's; total cumulative ^{137}Cs bomb fallout between the latitudes of 60° and 70° N was ~144 mBq cm^{-2}, as of 1985. Based upon the inventories reported here, as well as other studies, we conclude that there is no evidence at this time for significant contributions of radiocesium to Alaskan inventories as a result of nuclear waste dumping in the former Soviet Union.

Anthropogenic Radioactivity in Selected Marine Invertebrates from Alaskan 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	1988	^{241}Am	2.9
Ampeliscid amphipods	north of St. Lawrence Is.	1986	^{137}Cs	3.3
Macoma calcarea	southeast Chukchi	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


>59 mBq/cm2
(1988)
Chukchi Sea
>51 mBq/cm2
(1992)
depth (cm)
mBq/cm2
Toolik Lake
Imnavait Creek
(1990)
Bering Sea
(1988)
>15 mBq/cm2
>57 mBq/cm2
>54 mBq/cm2
>52 mBq/cm2
>14 mBq/cm2

Inventories of ^{137}Cs (in mBq cm^{-2}) for sediments collected in 1988-1992 in the Bering and Chukchi Seas. Biological mixing by benthic organisms has distributed the radiocesium deeper in the sediments than would otherwise be expected based on sedimentation rates. We have collected longer gravity cores, in continental slope sediments in 1993, and in continental shelf sediments in June 1994, with radioisotope counting still underway, and are finding that radiocesium penetration is limited to about 30 cm in most localities.

Dissolved or water-borne ^{137}Cs can be detected in the water column, and the inventory integrated over the depth of the continental shelf of the Bering and Chukchi Seas ranged from 8.1 to 12.6 mBq cm^{-2} in 1988 (Medinets et al. 1992)*; most of the radiocesium burden on the Bering Sea continental shelf is therefore in the sediments. Although cesium is soluble in seawater, once attached to clay mineral surfaces, it is very tightly bound, so much of the marine burden may have originated on land.

*Medinets, V. I., V. G. Soloviev and B. V. Glebov, Investigation of Cesium-137 Distributions in Seawater, in *Results of the Third Joint US-USSR Bering & Chukchi Seas Expedition (BERPAC), Summer 1988.*, edited by P. A. Nagel, pp 327-329, US Fish and Wildlife Service, Washington D.C., 1992.

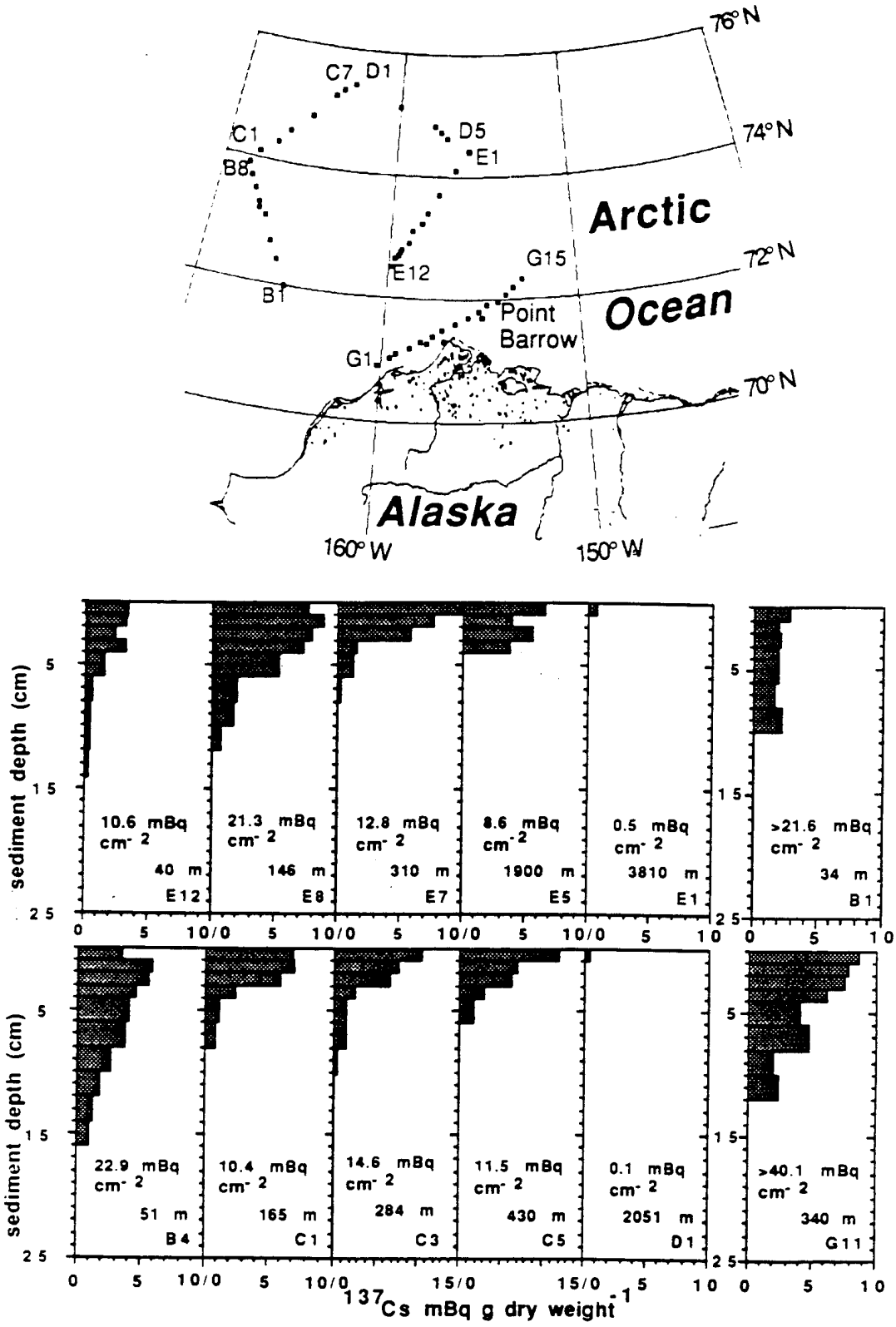
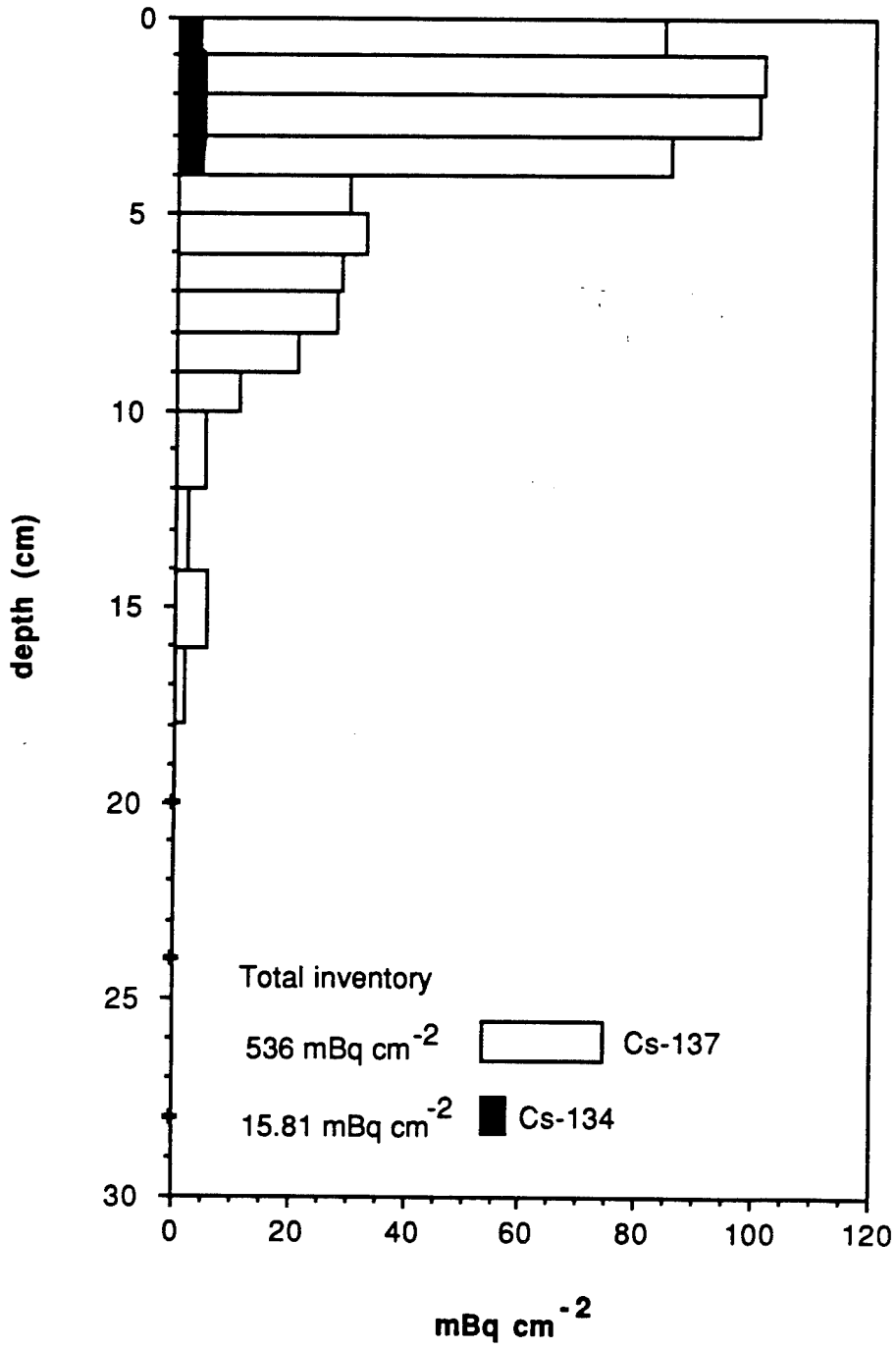


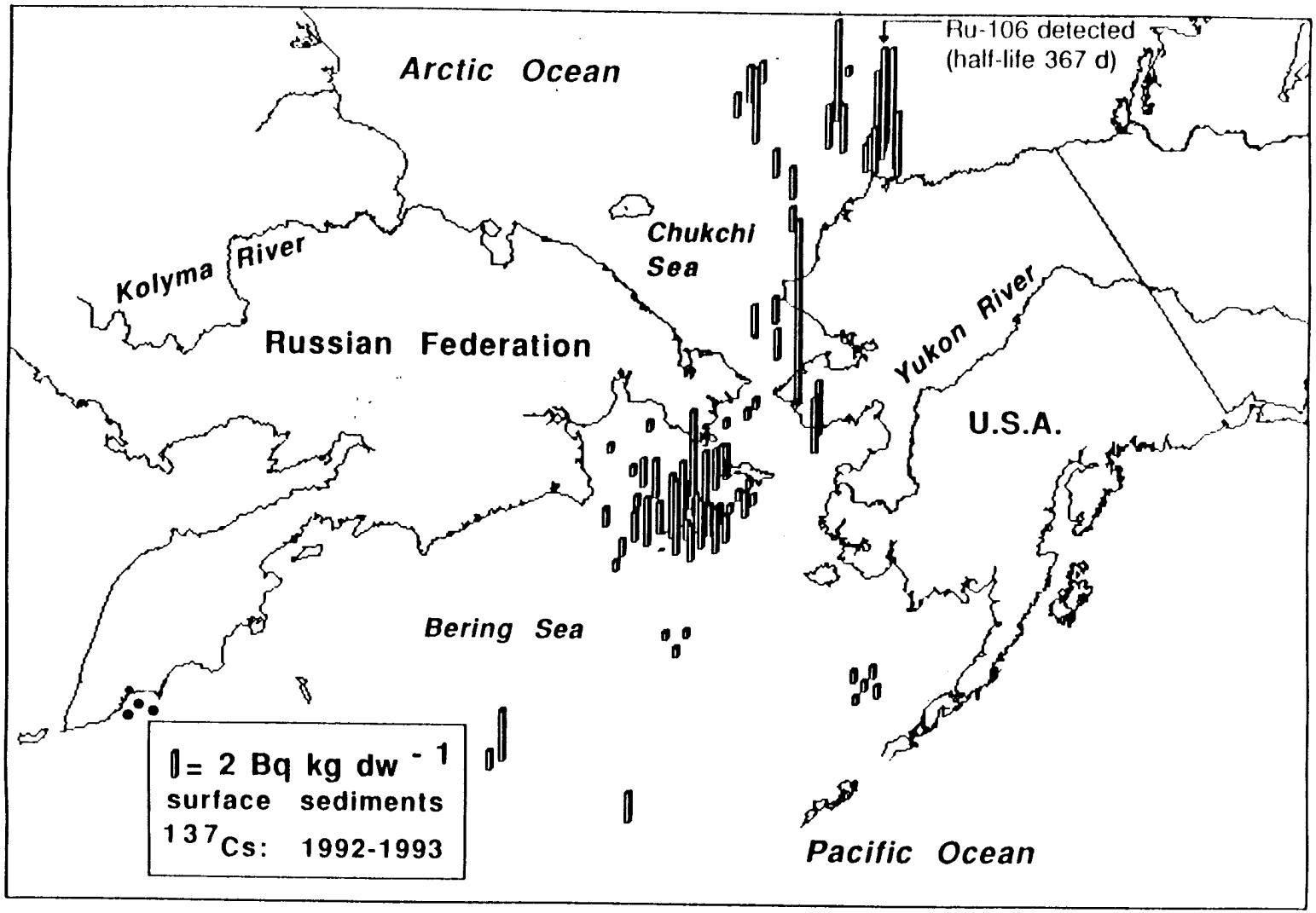
Figure 2. ^{137}Cs inventories for cores collected along a continental shelf-slope-deep sea transect over the Arctic Ocean northwest of Barrow, August, 1993. Low sedimentation rates in the deep Arctic are responsible for the very low inventories and shallow penetration into the sediments observed at 3800 m depth. Deeper penetration in continental shelf sediments is due to a combination of biological disturbance by marine organisms and higher sedimentation rates.



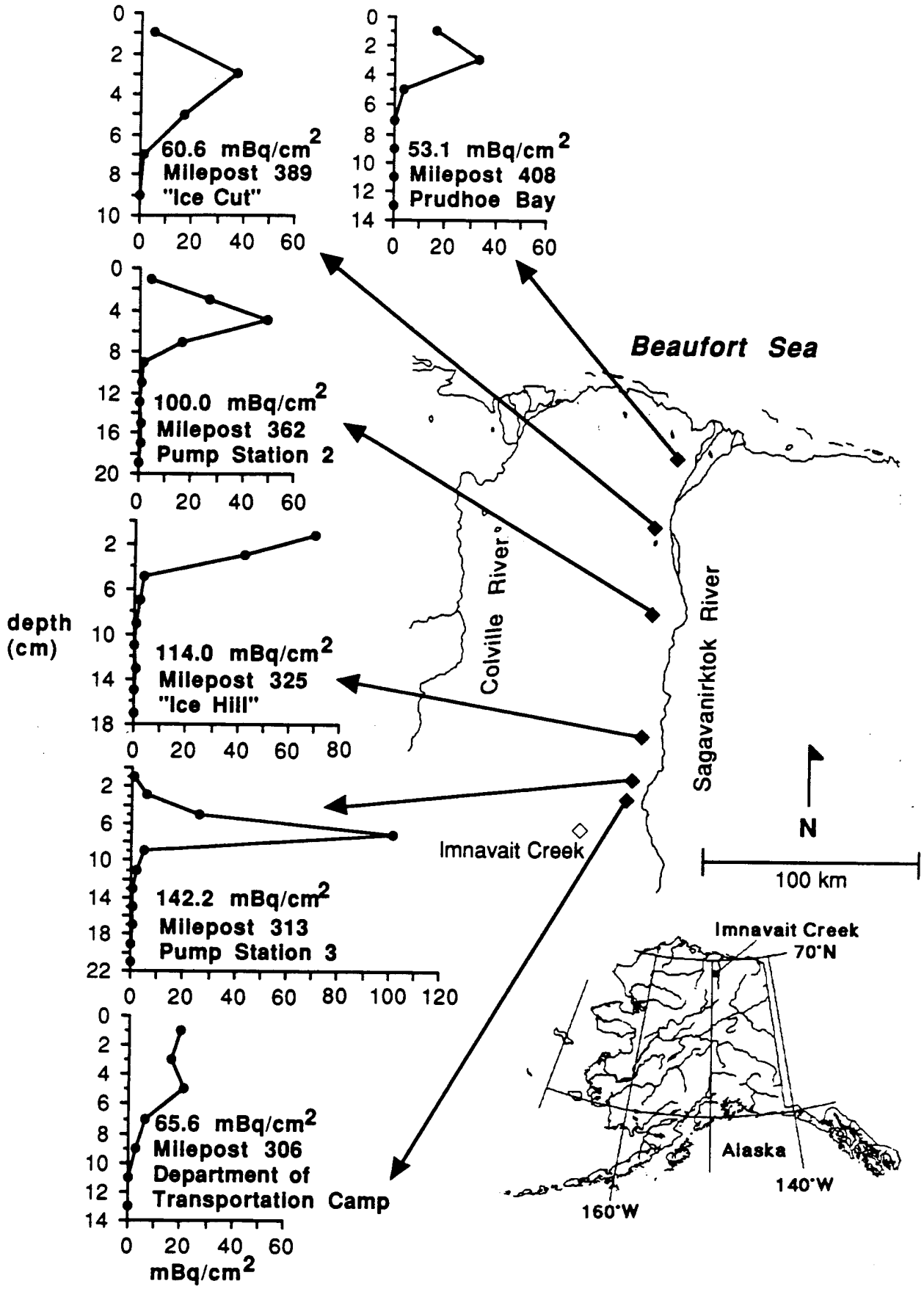
Shallow sediments, Black Sea, March 1993

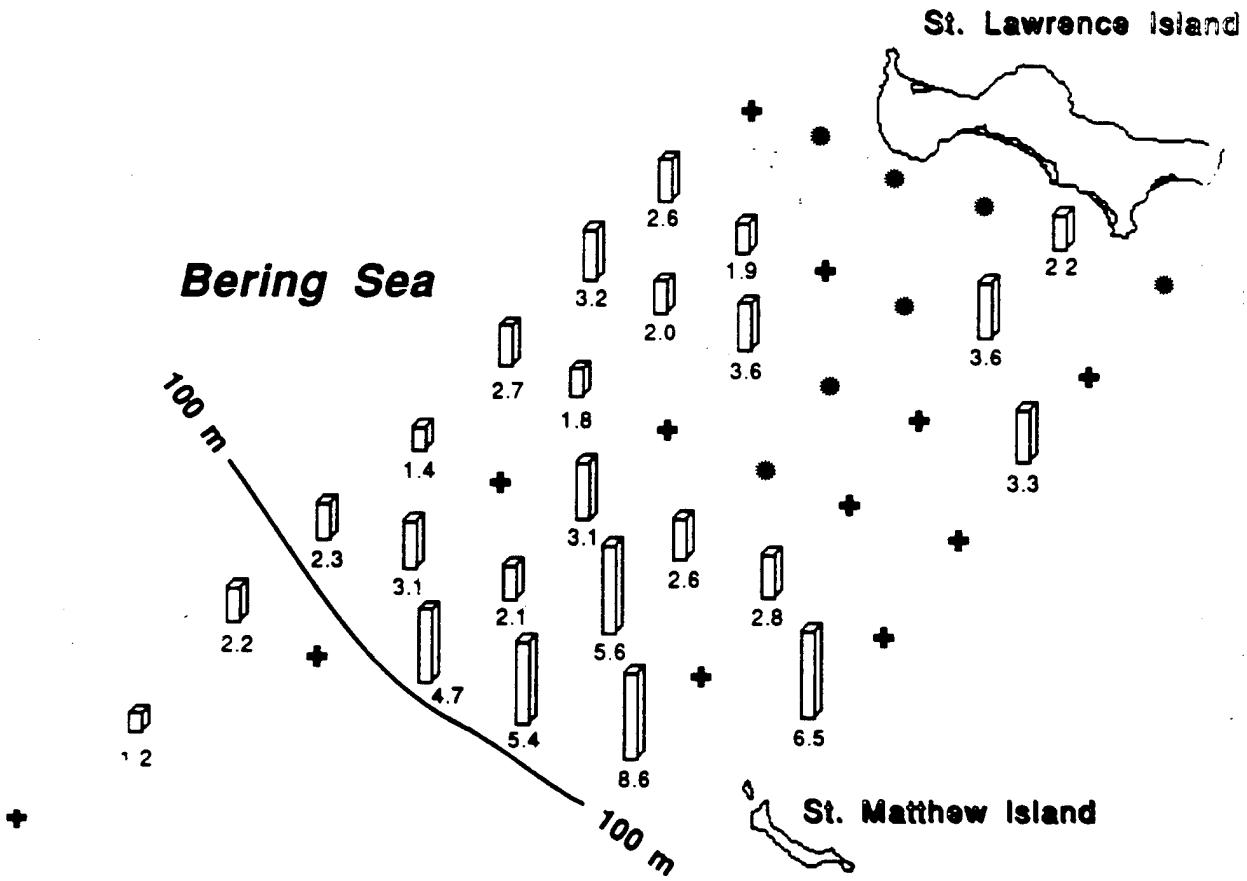
For comparison, →
Cesium-137 inventories for tundra cores, collected on Alaskan North Slope, 1992

←Surface Cesium-137 concentrations, 0-4 cm, for cores collected in the Bering and Chukchi Seas, 1992-1993. Note the similarity between Be-7 and Cs-137 distributions (detail below), also the lower concentrations in regions of high current flow (e.g shoreline areas of Gulf of Anadyr, Anadyr Strait, approaching Bering Strait). The highest radiocesium concentration (12.9 Bq kg dw^{-1}) was observed in Port Clarence, near Teller, a sheltered harbor subject to significant freshwater runoff, which would provide a source of terrestrially deposited Cs-137, irreversibly bound to clay minerals. For comparison with marine sediments more heavily impacted by anthropogenic contamination, we have measured a combined surface sediment concentration of 17.3 Bq kg dw^{-1} of both Cs-137 and Cs-134 in Russian waters of the Black Sea in March, 1993. Total inventories were 536 mBq cm^{-2} (Cs-137) and 16 mBq cm^{-2} (Cs--134), so typical radiocesium concentrations and inventories in Alaska appear to be an order of magnitude less than in Black Sea sediments.



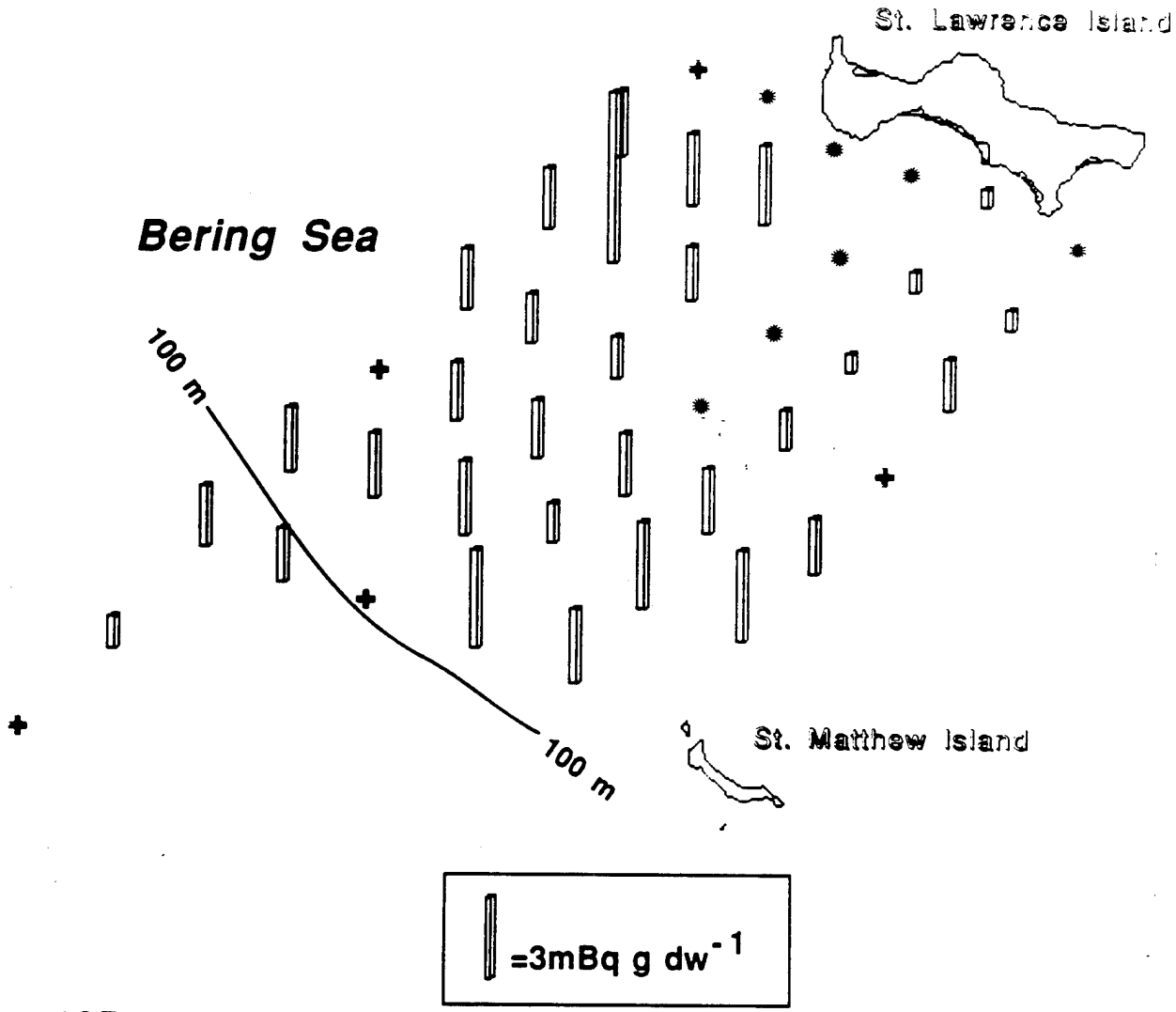
Surface sediment cesium-137 distributions during 1992 and 1993 (Cooper et al., in press). The black dots indicate radioactive dump sites (Yablokov et al., 1993).


60.6 mBq/cm2
Milepost 389
"Ice Cut"
53.1 mBq/cm2
Milepost 408
Prudhoe Bay
100.0 mBq/cm2
Milepost 362
Pump Station 2
114.0 mBq/cm2
Milepost 325
"Ice Hill"
142.2 mBq/cm2
Milepost 313
Pump Station 3
65.6 mBq/cm2
Milepost 306
Department of
Transportation Camp
depth
(cm)
mBq/cm2
Beaufort Sea
Colville River
Sagavanirktok River
Imnavait Creek
N
100 km
Imnavait Creek
70°N
Alaska
140°W
160°W

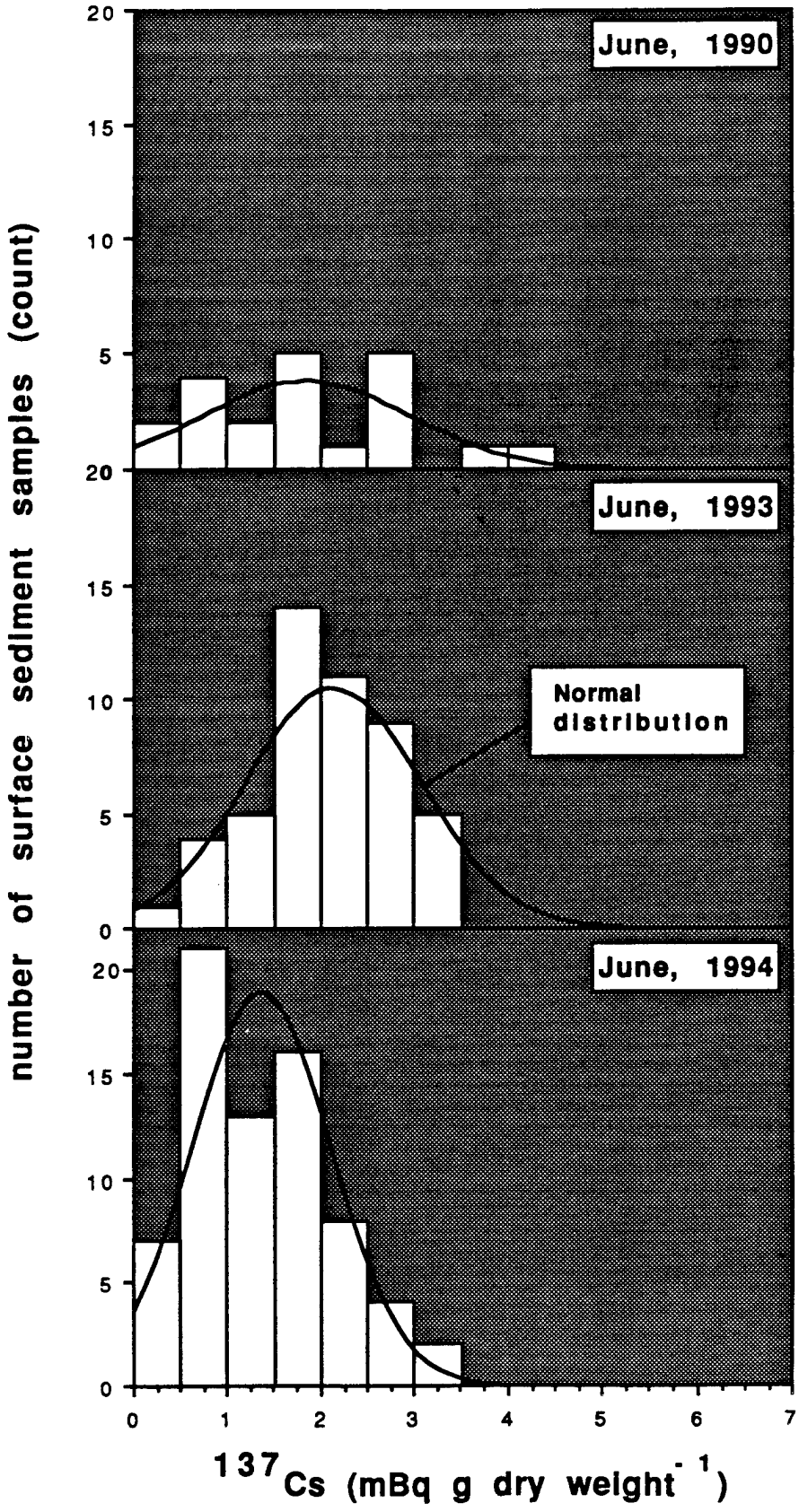


^{7}Be inventories in surface sediments, Bering Sea, June 1993 (mBq cm^{-2}) + = not detected. ● = sandy or rocky bottom, unable to core

Distribution of the natural radionuclide ^{7}Be in 1990, 1993, 1994 south of St. Lawrence Island. This particle-reactive radionuclide (half-life 53 d), can be expected to accumulate under regions with enhanced pelagic productivity and deposition. Beryllium-7 is produced by cosmic ray spallation of N_2 gas in the atmosphere, where it is scavenged and concentrated by precipitation. Once deposited in terrestrial or marine systems, it strongly adsorbs to particulate matter. Thus, its presence in bottom sediments corresponds to areas of recent (days to weeks) particle deposition and focusing. ^{7}Be deposition patterns appear to be influenced by sea ice melt in the ice edge fringing the St. Lawrence Island polynya at the end of the sea ice season. Most ^{7}Be activity in early summer in the region south of St. Lawrence Island has been detected in an arc in the offshore regions to the west and south of St. Lawrence Island, possibly marking the late season boundary of the polynya edge, immediately prior to ice melt. Patterns of radiocesium concentrations appear to follow the short-term trend in ^{7}Be observed each year, so sea ice melt may be another factor influencing distribution of particle reactive radionuclides.



^{137}Cs concentrations in surface sediments, Bering Sea, June 1993 (mBq g dw^{-1}) ✚ = not detected. ✸=sandy or rocky bottom,unable to core


June, 1990
June, 1993
June, 1994
Normal distribution
number of surface sediment samples (count)
137Cs (mBq g dry weight-1)
0
5
10
15
20
0
1
2
3
4
5
6
7

One-way Analysis of Variance (ANOVA)

^{137}Cs concentrations in surface sediments of the Bering Sea continental shelf, south of St. Lawrence Island, 1990-1994

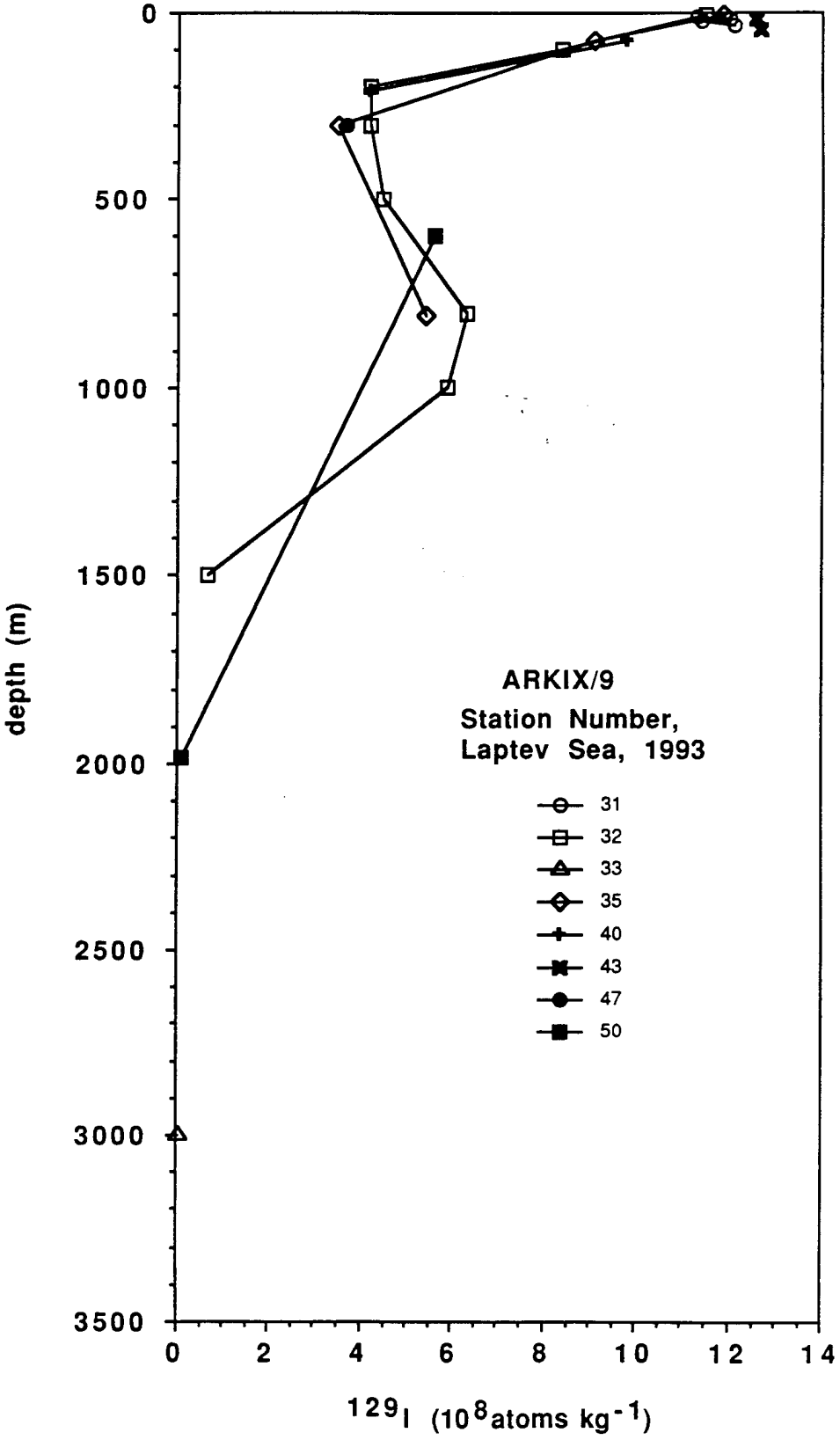
	Degree of Freedom	Sum of Squares	Mean square	F-value	P-value
Cruise No.	2	17.873	8.973	11.593	<0.0001
Residual	139	107.152	0.771		

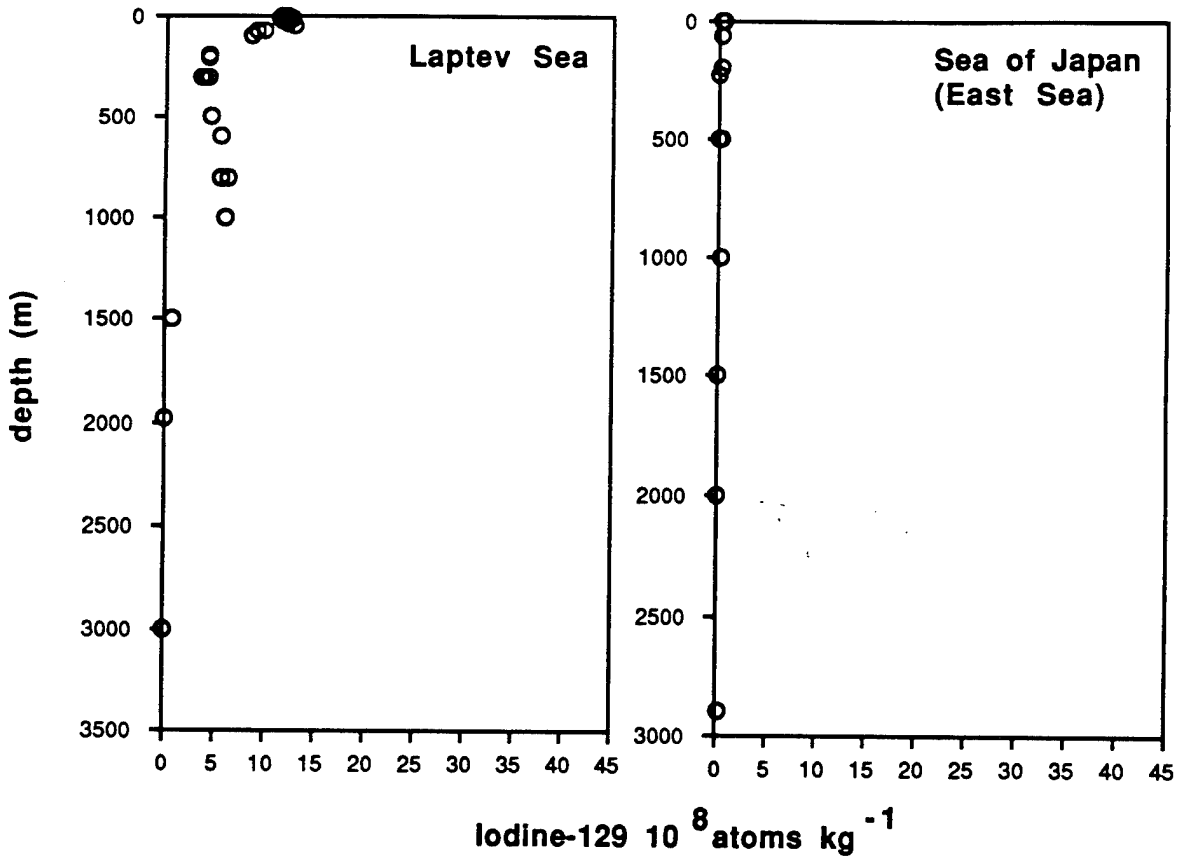
Model II estimate of between component variance: 0.19

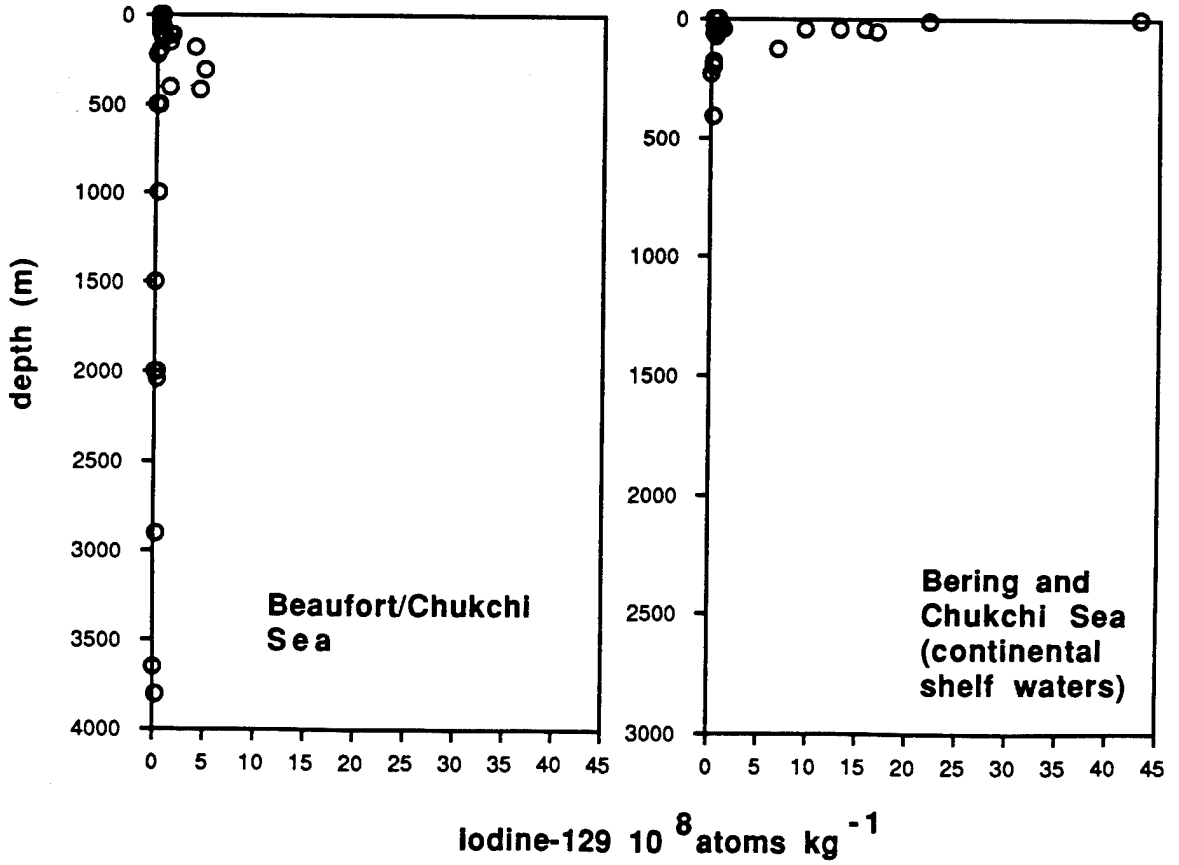
Scheffé Test, Significance level 5%

Cruise Interaction	Mean difference	Critical difference	P-value
1990-1993	-0.293	0.565	0.4400
1990-1994	0.477	0.540	0.0951
1993-1994	0.771	0.441	<0.0001

Conclusion: Significant decline in ^{137}Cs between 1993 and 1994. Declines since 1990 may not be significant due to smaller sample sizes.


0
500
1000
1500
2000
2500
3000
3500
depth (m)
0
2
4
6
8
10
12
14
129I (10^8atoms kg^-1)
ARKIX/9
Station Number,
Laptev Sea, 1993
31
32
33
35
40
43
47
50


Laptev Sea
Sea of Japan
(East Sea)
depth (m)
0
500
1000
1500
2000
2500
3000
3500
0 5 10 15 20 25 30 35 40 45
Iodine-129 10 8 atoms kg -1


Beaufort/Chukchi
Sea
Bering and
Chukchi Sea
(continental
shelf waters)
depth (m)
0
500
1000
1500
2000
2500
3000
3500
4000
0 5 10 15 20 25 30 35 40 45
Iodine-129 10 8 atoms kg -1

Iodine-129 concentrations in seawater, showing a sub-surface increase in Laptev Sea, which is correlated with hydrographic chemistry in the Barents Sea, suggesting a Sellafield origin for the subsurface I-129. This same peak may also be present in the Atlantic layer (>200 m) in the Beaufort and Chukchi Seas. By comparison, I-129 levels in the Sea of Japan (East Sea) are universally low, including a water sample collected in Vladivostok Harbor (0.58 x 10^8 atoms kg^{-1}). High concentrations were often observed in continental shelf samples from the Bering and Chukchi Seas, often in areas of high biological productivity, including Anadyr Strait (9.6 to 13.1 x 10^8 atoms kg^{-1}), Cape Navarin (6.69 x 10^8 atoms kg^{-1}), and the high benthic productivity area north of Bering Strait (16.7 x 10^8 atoms kg^{-1}). The highest concentration measured to date (43.1 x 10^8 atoms kg^{-1}) was at Sweepers Cove, Adak Island, a U.S. Navy base. High populations of benthic marine algae at this location may be responsible for concentration of the radioiodine out of the water column.

These data were collected and analyzed in cooperation with Tom Beasley, U.S. Dept. of Energy, Environmental Measurements Laboratory, New York.

CONCLUSIONS

Although there has been increasing concern over Arctic radioactive contamination, these relatively low inventories do not, by themselves, provide direct evidence for major contamination of the Bering and Chukchi Seas.

Cross-Arctic profiles of ^{129}I, detection of low $^{240}Pu/^{239}Pu$ ratios in deep Arctic sediments, and detection of higher levels of ^{137}Cs in sea ice indicate potential contributions from nuclear fuel re-processing, and waste disposal, possibly in some cases from former Soviet Union sources, or even more distant locations such as Sellafield on the Irish Sea. Despite these indications of the need for monitoring in the Arctic marine environment, it is likely to remain difficult to unequivocally demonstrate nuclear contamination in waters of the U.S.A. Exclusive Economic Zone resulting from activities of the former Soviet Union.

Comparisons over the past five years suggest that ^{137}Cs concentrations in Alaskan marine sediments are continuing to decline, which is consistent with the hypothesis that almost all radiocesium present in the marine ecosystem of the Bering and Chukchi Seas originated from nuclear weapons testing in the 1960's, and that no new significant sources are being contributed.

Spatial variability in ^{137}Cs distributions appears to be dominated by bioturbation in areas of high biological activity, particle settling and current patterns, and locally by the presence of freshwater inflows.

Sorption of Radioactive Contaminants by Sediment from the Kara Sea

By

Mark Fuhrmann[1], Huan Zhou[2], James Neiheisel[3] and Robert Dyer[3]

1. Brookhaven National Laboratory, Building 830, Upton, NY 11973-5000
2. Visiting Scientist, Brookhaven National Laboratory
3. U.S. Environmental Protection Agency, Washington D.C.

The purpose of this study is to quantify some of the parameters needed to perform near-field modeling of sites in the Kara Sea that were impacted by the disposal of radioactive waste. The parameters of interest are: the distribution coefficients (K_d) of major contaminant radionuclides, the mineralogy of the sediment, and the relationship of K_d to liquid to solid ratio. The distribution coefficient, K_d is the ratio, at steady-state, of the concentration on the sediment to the concentration in the water. It is a critical parameter that describes the degree to which a sediment will retain or immobilize a contaminant.

Sediment from the Kara Sea (location: 73° 00' N, 58° 00' E) was sampled from a depth of 287 meters on August 23/24, 1992 and was provided by the Norwegian Radiation Protection Authority. The sediment was a suboxic mud with an average grain size of 17 μm (71.5% silt and 21% clay) and Total Organic Carbon of 93 mg/g. The clay fraction is composed primarily of mixed layer smectite (34%), illite (18%), chlorite (17%) and kaolinite (14%). Uptake kinetics were determined for ^{85}Sr, ^{137}Cs, ^{241}Am, ^{99}Tc, ^{125}I, ^{232}U and ^{210}Pb. Slow kinetics were observed for U and Tc implying that the rate limiting process was probably not adsorption but a reaction prior to uptake. Distribution coefficients were determined for these radionuclides using batch type experiments. In addition the K_d values for ^{137}Cs, ^{85}Sr and ^{99}Tc were also determined using isotherms, allowing an evaluation of the relationship between sorption at differing concentrations of contaminant. If the relationship is linear at the relatively high tracer concentrations in the laboratory experiments, then it is appropriate to use that K_d for the much lower concentrations typically found in the environment. The isotherms for Cs, Sr and Tc were linear. For the batch tests and the isotherms the K_d values were:

Uranium	Slow Kinetics, K_d = 23 mL/g
Lead	Rapid Kinetics, All Pb Removed From Solution
Cesium	Rapid Kinetics, K_d varies with Solid:Liquid, K_d = 230 (batch), K_d = 360 (isotherm)
Strontium	Rapid Kinetics, K_d = 5.3 (batch), K_d = 3.2 (isotherm)
Iodine	Slow Kinetics, K_d = 56 (batch)
Technetium	Slow Kinetics, K_d = 43 (batch), K_d = 3.9 (isotherm)
Americium	K_d = 5600 or greater (batch)

The K_d values of ^{99}Tc and ^{137}Cs are influenced by the solid to liquid ratio. While in a clean laboratory experiment with simple materials there should be no effect; in a natural system (or at least using natural materials) we observed that the K_d for ^{137}Cs varied nonlinearly from 40 to 3600 mL/g as the liquid to solid ratio varied from 3.4 to 6400. The sediment was separated into four size fractions and uptake was determined for each fraction for ^{137}Cs, ^{85}Sr and ^{99}Tc. In addition the sediment was analyzed to determine if it contains observable quantities of anthropogenic radionuclides.

SORPTION OF LONG-LIVED RADIONUCLIDES ON SEDIMENT FROM THE KARA SEA

By

M. Fuhrmann[1]
H. Zhou[1]
R. Dyer[2]
J. Neiheisel[2]

1. Brookhaven National Laboratory, Upton, N.Y., USA
2. United States Environmental Protection Agency, Washington, DC, USA

DATA NEEDS FOR NEAR-FIELD MODELING

- Inventory of Contaminants
- Container Types and Materials
- Container Corrosion Rates
- Waste Form Release Rates
- Bottom Water Parameters
  - Temperature
  - Salinity
  - Suspended Solids
  - Velocities
- Sediment Geochemistry
  - Distribution Coefficients (K_D)
  - Diffusion Coefficients
  - Redox Potential

EXPERIMENTAL METHODS FOR ADSORPTION EXPERIMENTS

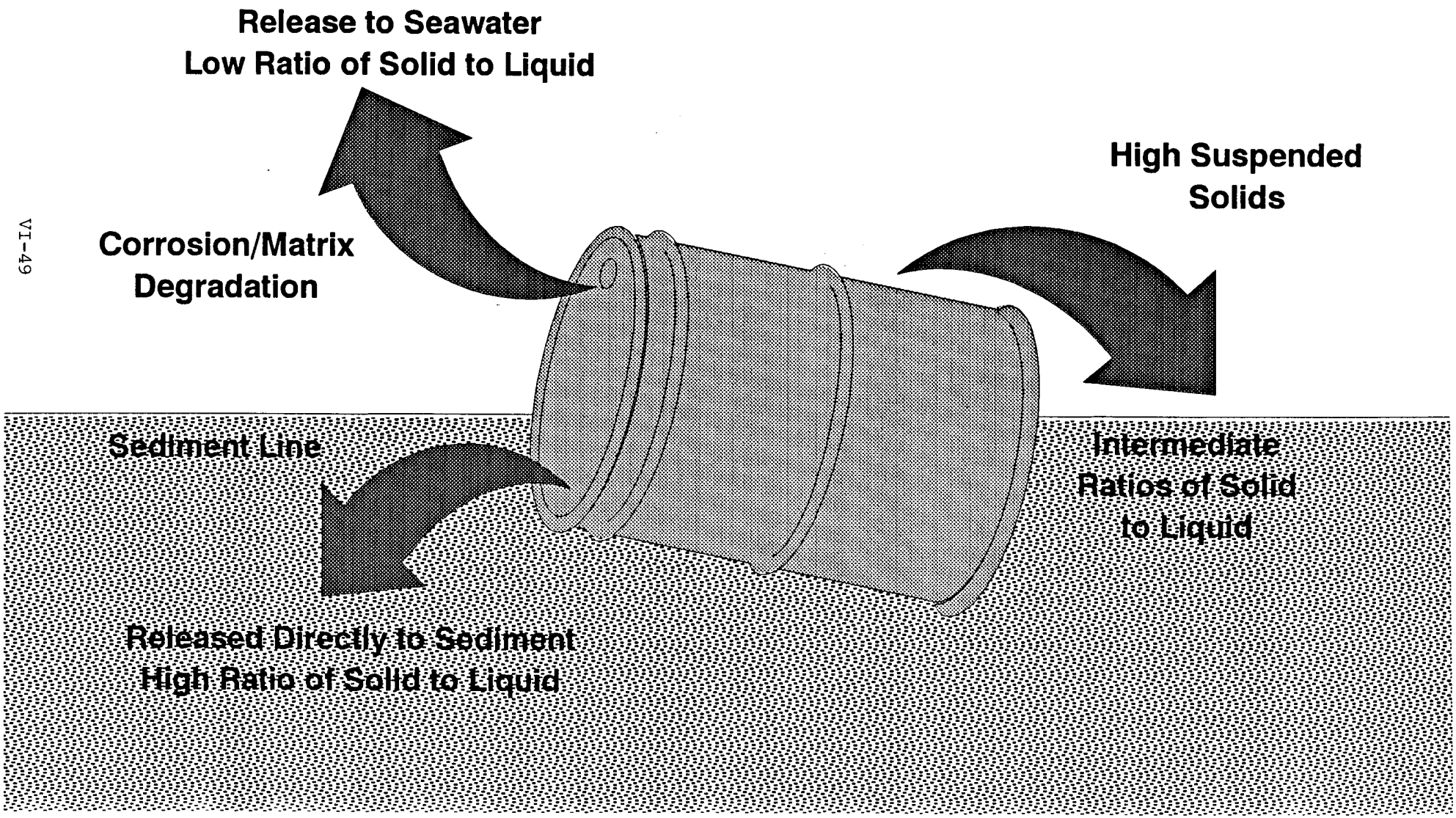
- All work was conducted under an argon atmosphere to preserve redox conditions and authigenic sulfide minerals.

- Contact solutions were sea water (Salinity = 34.67 ppt) with tracer added.

- Kinetics Experiments:
  - * Ratio of dry sediment to water was 0.06.
  - * Samples filtered through 0.45 μM syringe filters before counting.

- Distribution Coefficient, K_d = $\dfrac{\text{Concentration on Solid}}{\text{Concentration in Liquid}}$

Three Scenarios for Radionuclide Release from Waste Forms

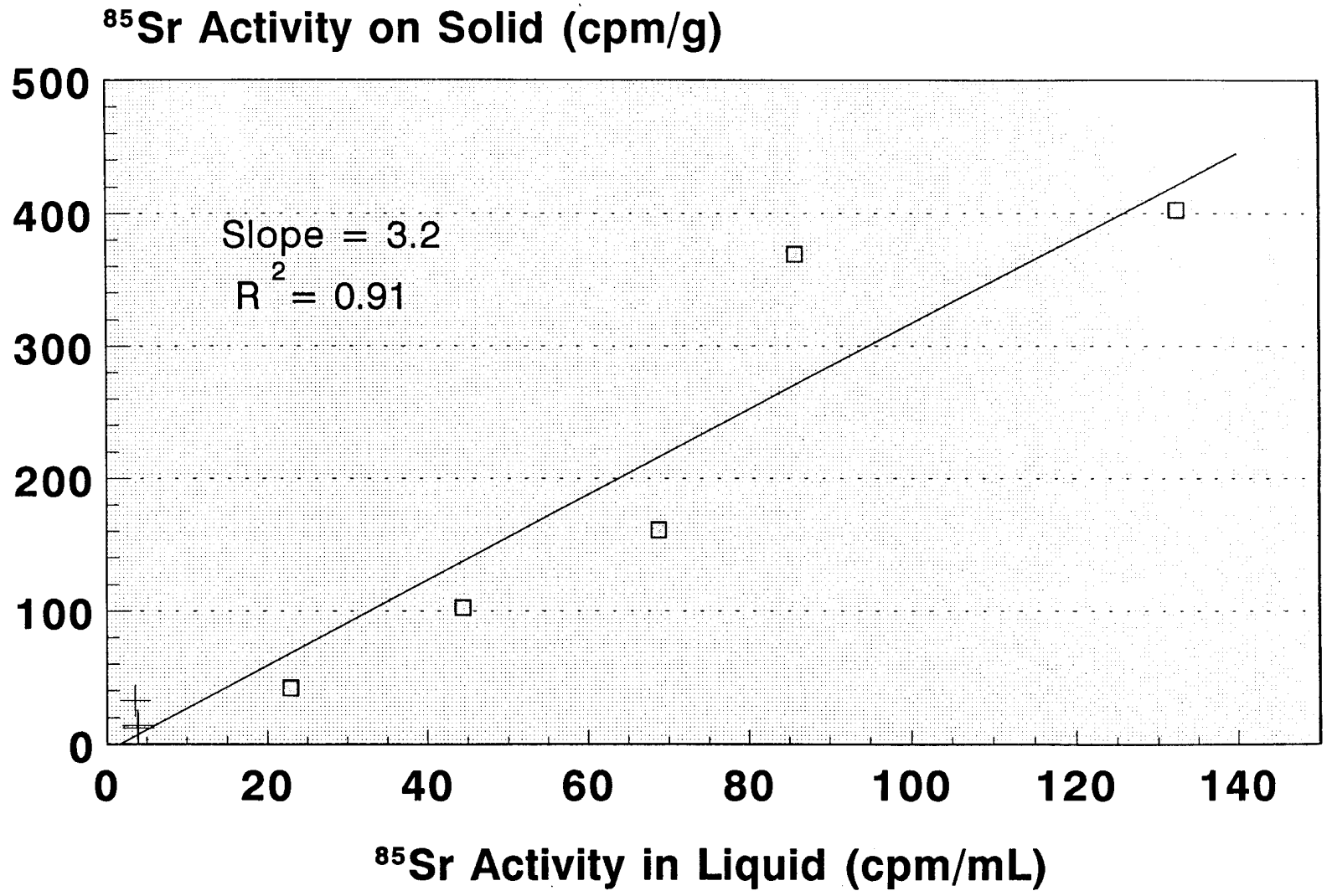


RADIONUCLIDE INTERACTIONS WITH SEDIMENT FROM THE KARA SEA

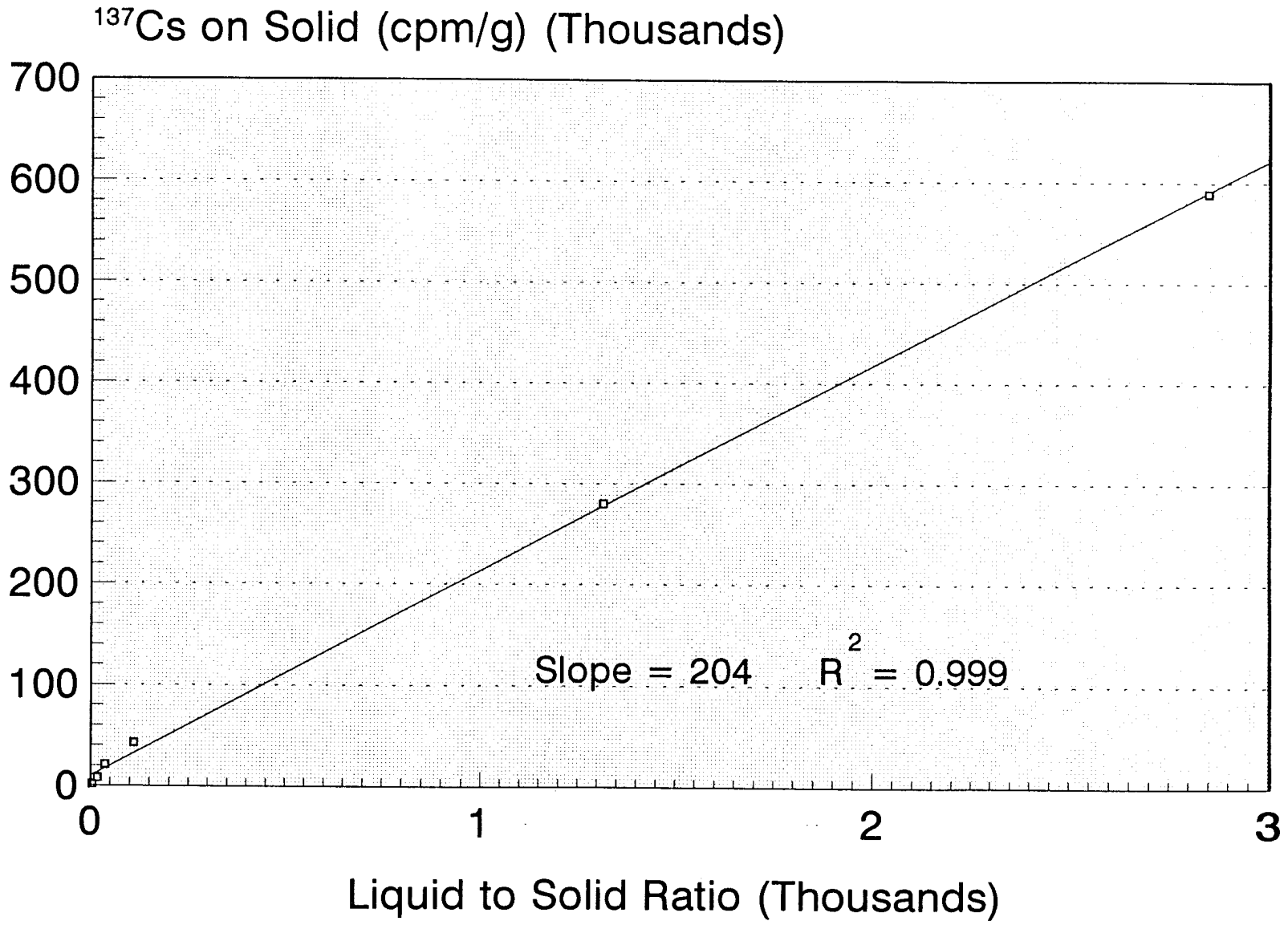
BASED ON LABORATORY EXPERIMENTS

URANIUM	Slow Kinetics, K_d = 23 mL/g
LEAD	Rapid Kinetics, All Pb Removed From Solution
CESIUM	Rapid Kinetics, K_d varies with Solid:Liquid, K_d = 230 (batch), K_d = 360 (isotherm)
STRONTIUM	K_d = 5.3 (batch), K_d = 3.2 (isotherm)
IODINE	Slow, K_d = 56 (batch)
TECHNETIUM	Slow Kinetics, K_d = 43 (batch), K_d = 3.9 (isotherm) which is probably controlled by the distribution between TcO_4^- and Tc_2O_3 or a Tc sulfide
AMERICIUM	K_d = 5600 or greater (batch)

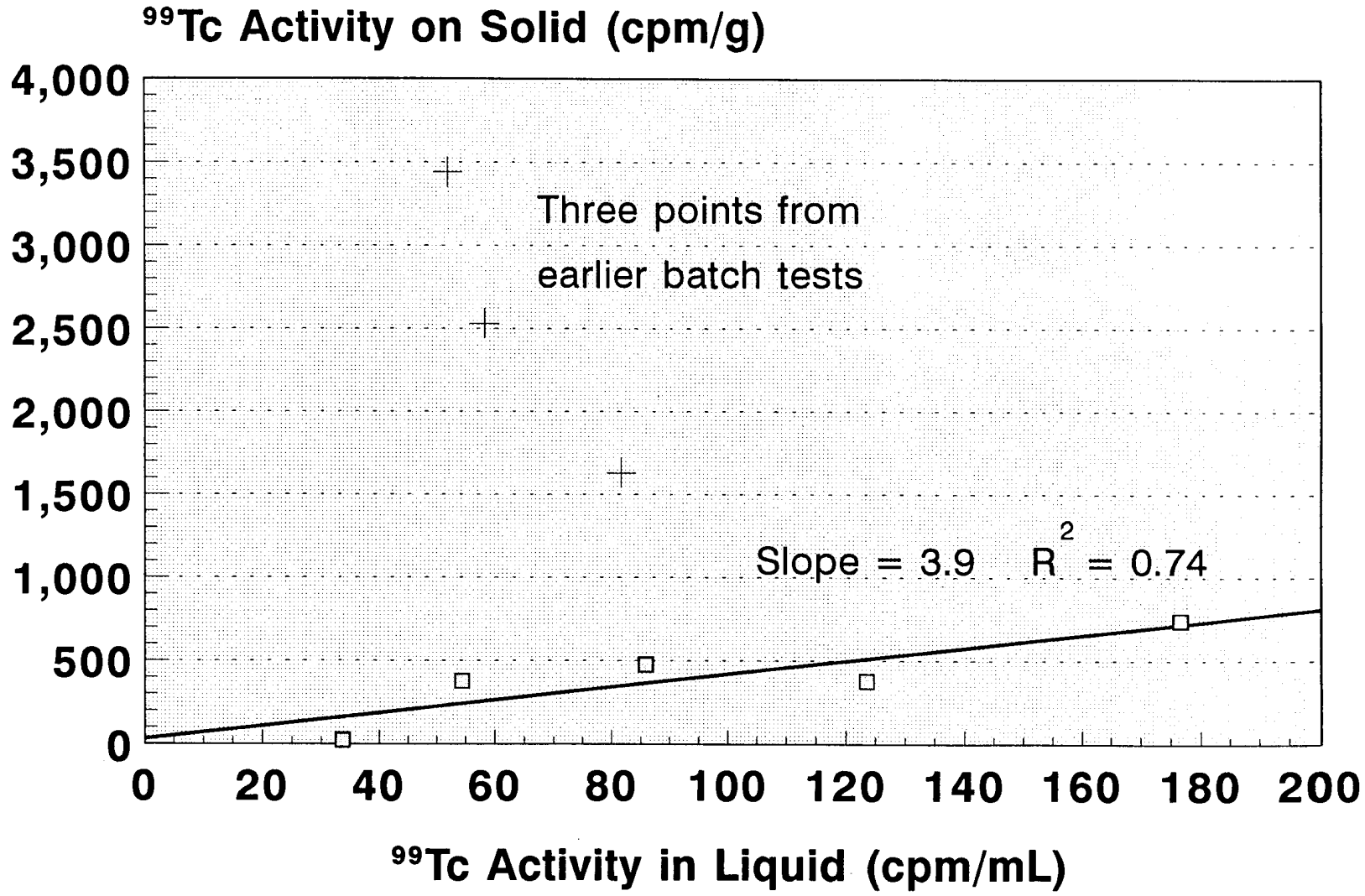
Isotherm for ^{85}Sr on Kara Sea Sediment



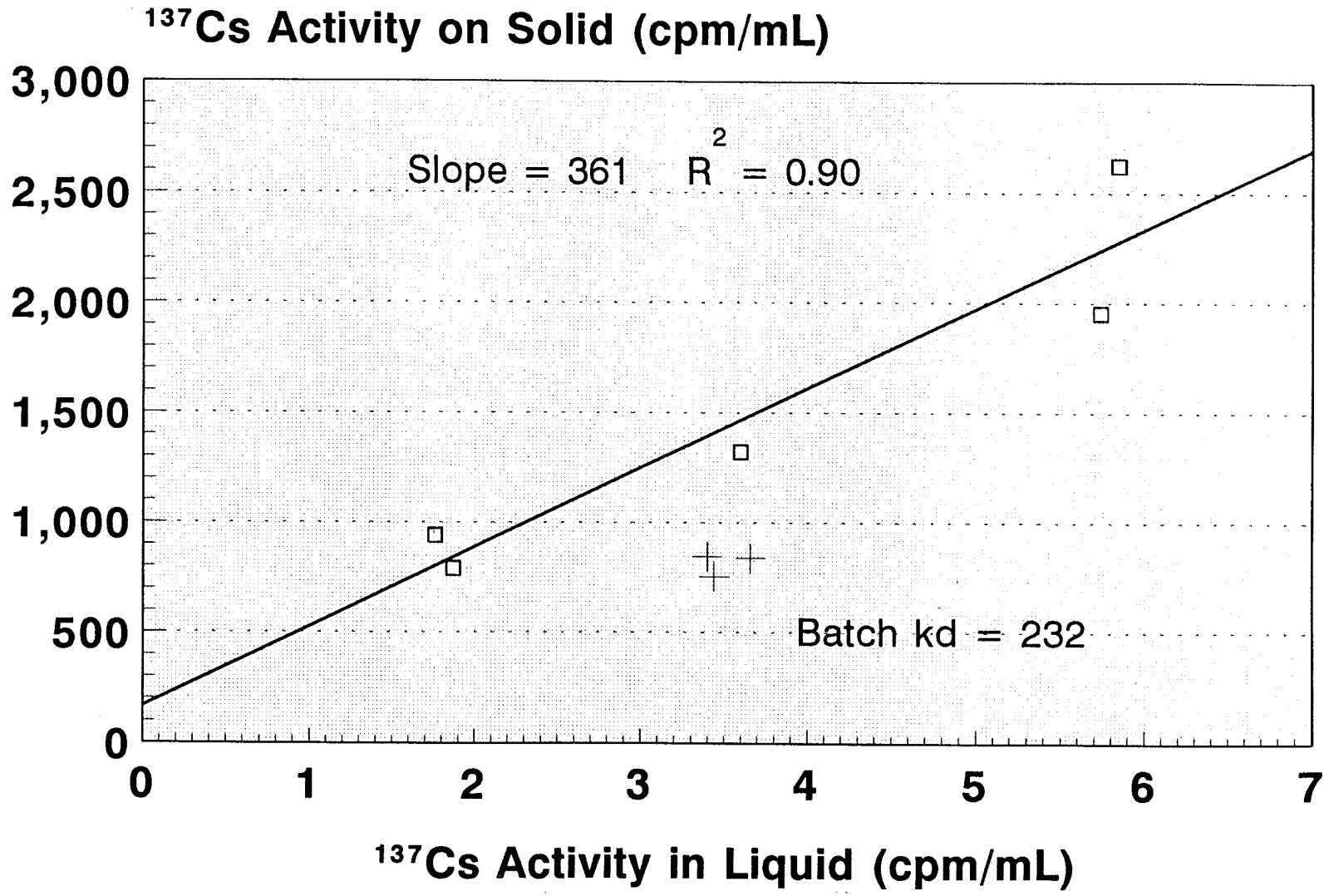
Effect of Liquid to Solid Ratio on Sorption of ^{137}Cs on Sediment from the Kara Sea



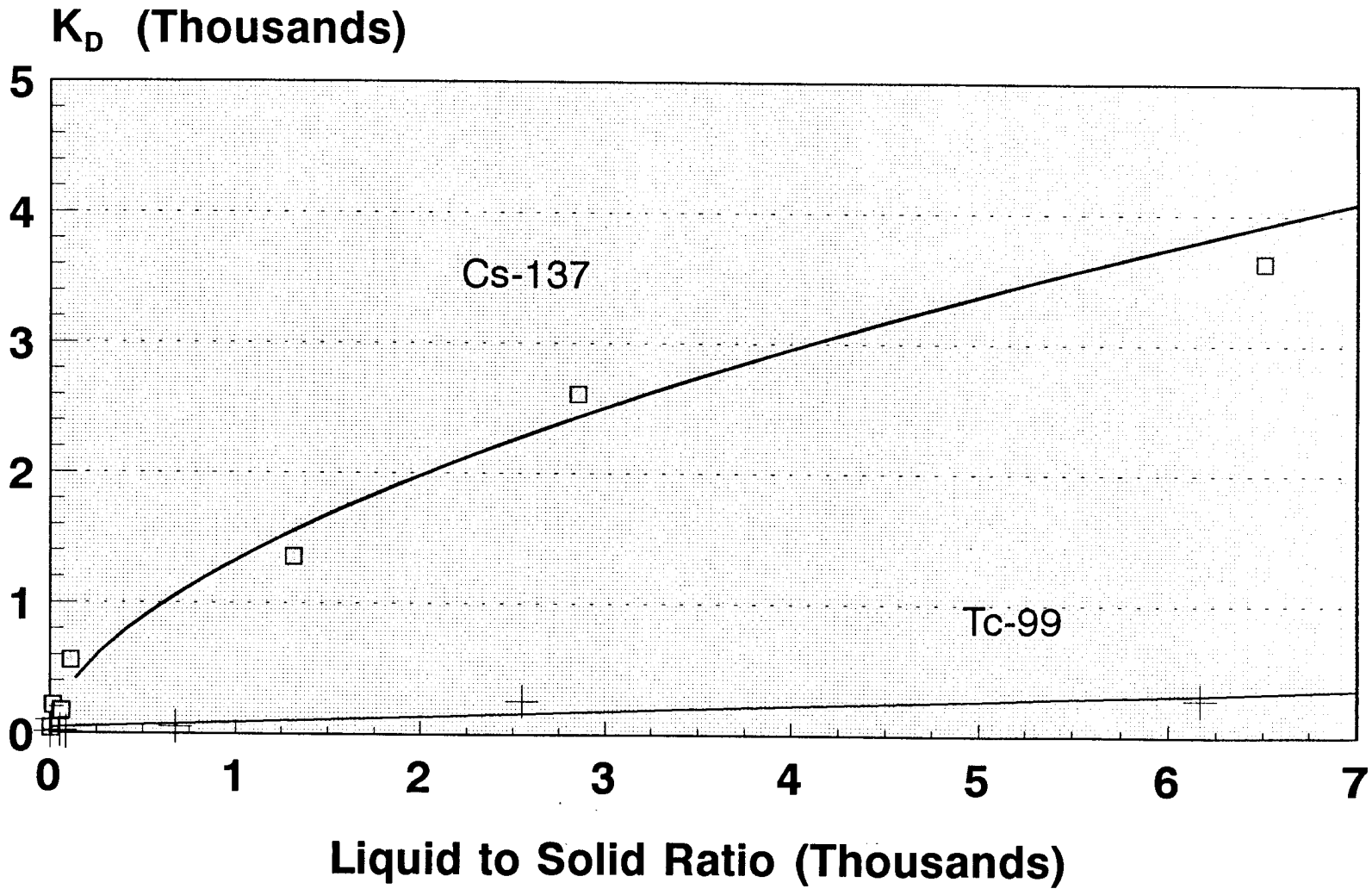
Isotherm for ^{99}Tc on Kara Sea Sediment



Isotherm for ^{137}Cs on Kara Sea Sediment

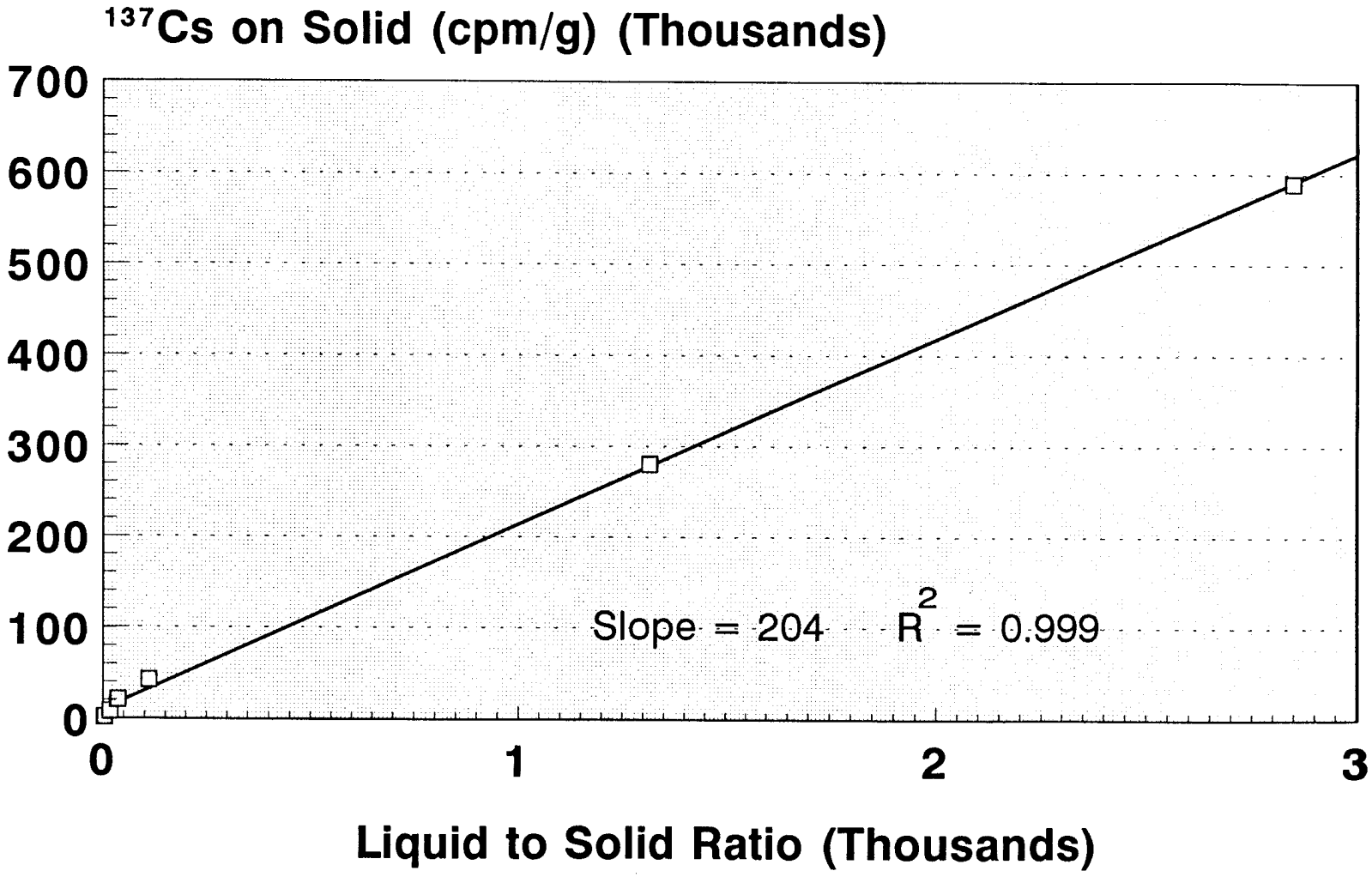


Relationship of K_D to Ratio of Liquid to Solid
^{137}Cs and ^{99}Tc on Sediment from the Kara Sea



Cs-137 Power Regression: Ln y = 3.19 + 0.58 Ln x
Tc-99 Linear Regression: y = 0.044 x + 43.9

Effect of Liquid to Solid Ratio on Sorption of ^{137}Cs on Sediment from the Kara Sea



RADIONUCLIDE ANALYSIS OF SEDIMENT FROM THE KARA SEA

RADIONUCLIDE	OBSERVATION (Bq/Kg)	MINIMUM DETECTABLE ACTIVITY*
MANGANESE-54	BDL	3.1
COBALT-60	BDL	3.4
RUTHENIUM-106	BDL	33.2
CESIUM-134	BDL	6.3
CESIUM-137	BDL	4.0
STRONTIUM-90	BDL	8.9
AMERICIUM-241	0.031 to 0.038	0.008 (Method Blank = 0.030)
PLUTONIUM-238	BDL	0.036
PLUTONIUM-239/240	0.420 to 0.196	0.007 (Method Blank = 0.061)

* Bq/Kg for the first 3 downcore sections.
Analysis performed by Lockheed Environmental Systems and Technologies Co.

PLUTONIUM - 239/240

SAMPLE DEPTH (CM)	WEIGHT DRY (g)	ACTIVITY (Bq/Kg)	ERROR* (Bq/Kg)	MDA** (Bq/Kg)
0 - 3	12.43	0.420	0.080	0.009
3 - 6	12.14	0.395	0.076	0.009
6 - 9	20.12	0.196	0.040	0.005
9 - 12	20.04	0.222	0.043	0.005
MBB***	20.0	0.061	0.023	0.020
LCS****	20.0	4.413	0.368	0.024

* 2 Sigma Total Propagated Error

** MINIMUM DETECTABLE ACTIVITY, by method of L.A. Currie.

*** Method Blank

**** Lab Control Sample, true value = 4.285 Bq/Kg (recovery = 103%)

FUTURE WORK

Two cores and two grab samples were recently obtained from the 1992/3 Norwegian/Russian Expeditions to the Kara Sea, from areas of waste disposal.

Plans:

- Measure K_D values for radionuclides
- Measure radioactivity in the sediment
- Determine mineralogy
- Determine why Liquid/Solid Ratio influences sorption
- Determine effects of oxidation on sorption and remobilization

In addition: arrangements have been completed to obtain a set of cores from the 1994 cruise of the Geolog Fersman to the Kara Sea.

RADIONUCLIDES IN THE ARCTIC ENVIRONMENT AND BIOTA:
Isotopic Fingerprinting to Determine Source Terms

M.J. Hameedi, A. Robertson, and S. Dolvin
National Oceanic and Atmospheric Administration, Silver Spring, MD
&
D.W. Efurd, G.G. Miller, and D.J. Rokop
Los Alamos National Laboratory, Los Alamos, NM

OBJECTIVES

Our primary objective is to establish a quality-controlled data set on spatial distribution and scales of contamination from radionuclides in the environment and selected biota of the Arctic in order to:

- describe the current extent of environmental contamination;
- establish a baseline to determine temporal trends; and
- develop a strategy for establishing a long-term monitoring program.

Secondarily, and contingent upon the results of detailed radiochemical analyses, our objective is also to characterize the type, chemical form, and source(s) of the radionuclides analyzed, and to describe their probable transport and exposure pathways in the Arctic marine environment and biota.

APPROACH

Our principal approach for accomplishing the study objectives is to utilize NOAA's in-house expertise and to establish cooperative efforts with other agencies and institutions in the collection of samples, radiochemical analyses, and interpretation of results. As such, we are augmenting existing studies of environmental contamination and biological effects of toxic chemicals that are being carried out in a number of resource management agencies in Alaska and elsewhere.

For radiochemical analyses, we have opted to have the samples analyzed in detail: gamma counting by Ge(Li) detector on whole sample, plutonium determination by alpha spectrometry and thermal ionization mass spectrometry, americium-241 by alpha spectrometry, strontium-90 by beta counting, cesium isotopes by beta and gamma counting, etc. Such detailed analyses are warranted, at least on a subset of samples, to alleviate a deeply rooted public concern about radionuclides [and other contaminants] in the Arctic environments and food chains as well as to establish a credible baseline for any future environmental monitoring of radionuclides in the region.

General Properties and Examples of Factors That Are Important in Assessing the Impact of Artificial Radionuclides on Biota

Radionuclide	*Principal Form of Emission*	*Half-Life*	*Biological Half-Life*	*Target Organs*	*Biological Retention*	*Chemical Analog*
Cesium-137	Gamma	30 years	11 days	Whole body	Weeks	Potassium
Strontium-90	Beta	28 years		Bone	Years	Calcium
Cobalt-60	Gamma	5.2 years	67 days	GI, Lung	Weeks	Cobalt
Zinc-65	Gamma	245 days	67 days	Liver, lung	Months	Zinc
Iodine-131	Beta	8 days	10 days	Thyroid	Weeks	Iodine
Plutonium-239	Alpha	24K years		Bone, Lung	Years	None

Notes. Most of these data are for higher vertebrate species, e.g., birds. Biological half-life data reported in the literature are highly variable; they may be very different for the same species depending on the mode of introduction of radionuclides, i.e., intramuscular injection versus oral dose.

NOAA's COOPERATIVE ARRANGEMENTS

Los Alamos National Laboratory
Albuquerque -- Radiochemical analyses

National Biological Survey
Anchorage -- Anadromous and marine fish (Alaska; Russian Far East)
Anchorage -- Sediment and bivalves (Talons Is.)
Madison -- Sediment (Wrangel Is.)

Fish and Wildlife Service
Anchorage -- Walrus (St. Lawrence Is.)
Fairbanks -- King eider (Barrow)

National Marine Fisheries Service
Silver Spring -- Bowhead whale, bearded seal (Barrow)
Anchorage -- Beluga whale, ringed seal (Pt. Lay)

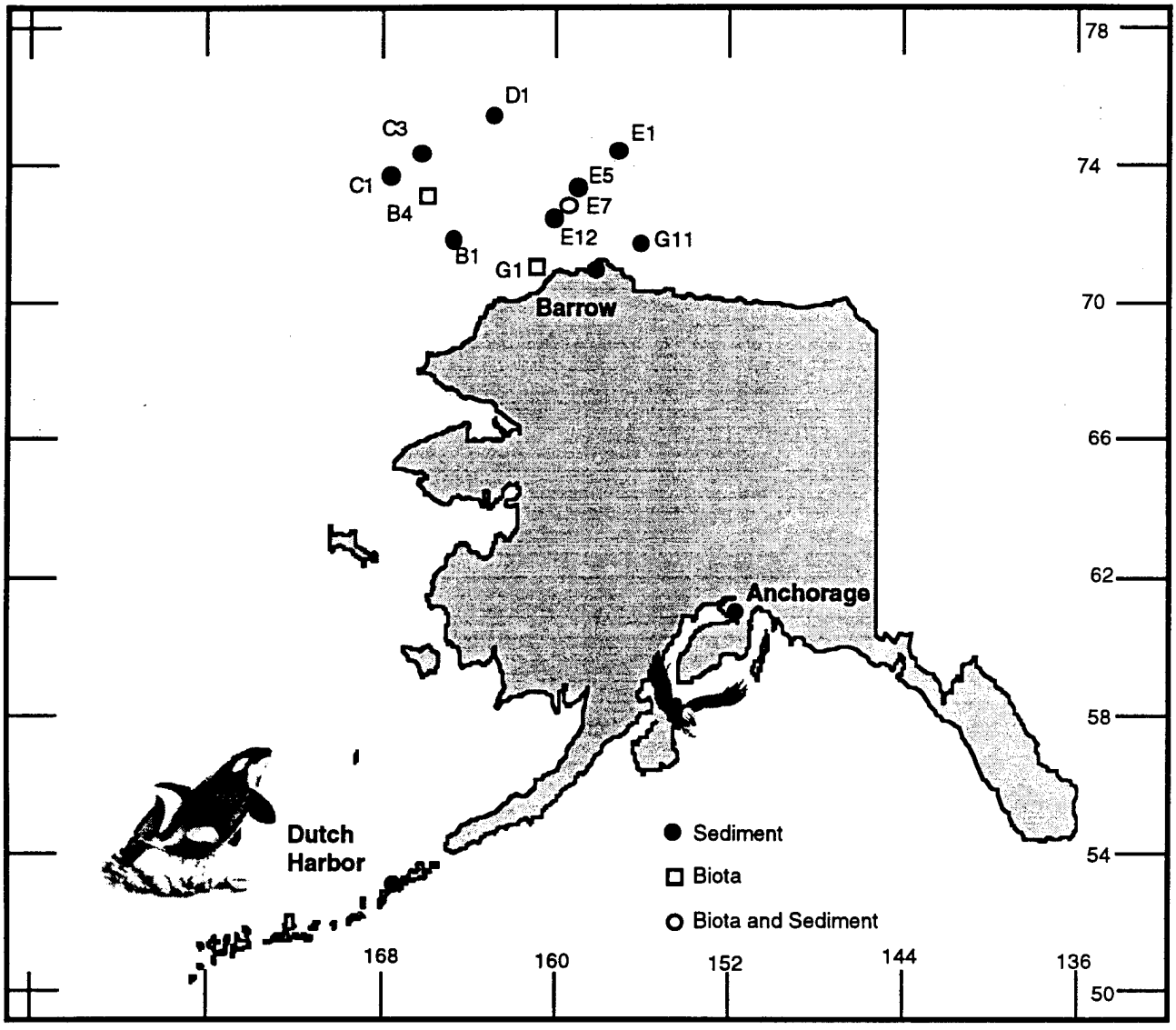
University of Alaska
Fairbanks (IMS) -- Partitioning and mobilization of metals in Chukchi Sea sediments
Fairbanks (GI) -- Field sampling at Barrow

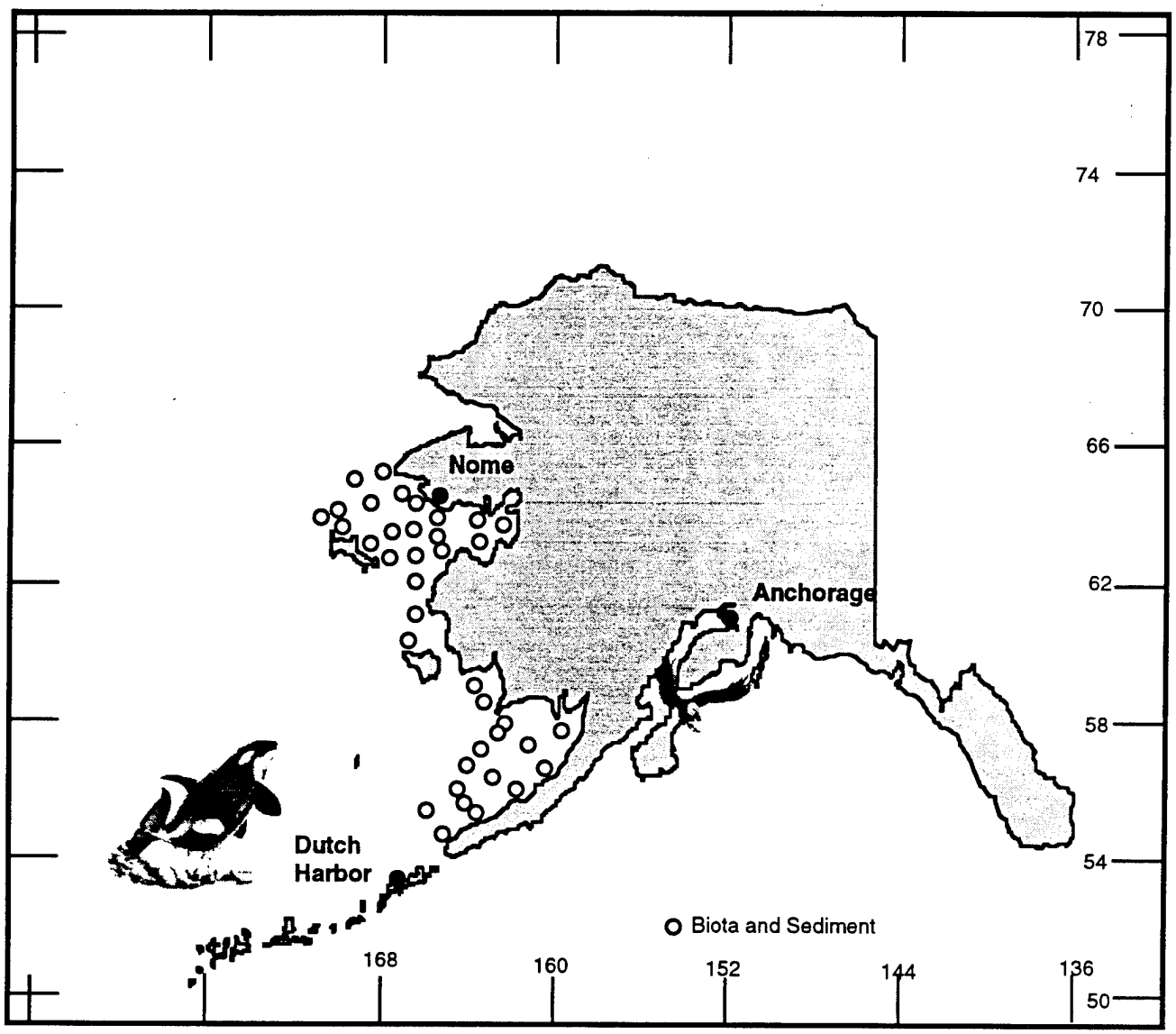
North Slope Borough
Barrow -- Field operational support (1995)
Barrow -- Sediment and biological collections (1995)

State of Alaska, ADF&G
Fairbanks -- Anadromous and marine fish (Alaska; Russian Far East)

NOAA U.S. ARCTIC (ARCRAD '93) PROJECT

Southern Arctic / Chukchi Sea




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66
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54
50
168
160
152
144
136
Nome
Anchorage
Dutch
Harbor
Biota and Sediment

Sediment Radionuclides

Preliminary Data
Do Not Quote or Reproduce

ARCRAD Station	NOAA 93 Station	Wet Weight (g) Whole sample as recvd at LANL	Dry Weight (g) 110° to constant 48 - 96 hrs	Ash Weight (g) 550° org destr 12 - 48 hrs	High Resolution Gamma Ray Spectroscopy				
					Co60	Cs137	K40	Pb212	Pb214
C1	SR7	274.17	99.67	89.92	-	≤2	671	41.0	-
E7	SR2A	154.80	43.59	39.78	-	11.4	585	43.9	-
E12	SR1C	402.86	153.21	143.09	-	5.5	582	33.6	-
E1	SR4	217.06	71.45	67.86	-	≤3	888	62.0	-
E5	SR3B	311.31	101.32	90.57	-	8.2	698	41.3	-
C3	SR6	107.22	103.14	95.41	-	≤4	699	57.0	-
B1	SR9	539.80	281.98	271.76	-	≤3	452	22.3	-
E12	SR1B	476.81	183.72	170.85	-	6.1	590	33.8	-
E12	SR1A	406.23	160.89	151.22	-	≤4	593	28.6	-
G11	SR10	432.14	173.29	158.72	-	7.7	500	43.0	-
D1	SR5A	446.36	207.06	133.25	-	3.1	524	44.1	-
B4	SR8	468.44	123.76	100.19	-	5.3	567	44.7	-
SRM 4354 det					114	39.2	-	-	-
SRM 4350B det					-	21.3	473	37.8	-
SRM 4355 det					-	≤5.9	642	44.0	-
SRM 4354 act					118	49.9	-		-
SRM 4350B act					-	21.7	554	33.0	-
SRM 4355 act					-	0.3	585	43.0	-
Lab Blank 1									
Lab Blank 2									

"-" = data forthcoming
"0" = not detected
All radionuclide data in Bq/kg dry wt.

Sediment Radionuclides

Preliminary Data
Do Not Quote or Reproduce

ARCRAD Station	NOAA 93 Station	Wet Weight (g) Whole sample as recvd at LANL	Dry Weight (g) 110° to constant 48 - 96 hrs	Ash Weight (g) 550° org destr 12 - 48 hrs	Gamma Ray Spectroscopy Beta Counting			Mineral Acids Leached TIMS	
					Cs137	Cs135	Sr90	Pu240/Pu239	Pu239+240
C1	SR7	274.17	99.67	89.92	-	-	-	0.2	
E7	SR2A	154.80	43.59	39.78	-	-	-	-	
E12	SR1C	402.86	153.21	143.09	4.0	-	-	0.23	
E1	SR4	217.06	71.45	67.86	-	-	-	0.18	
E5	SR3B	311.31	101.32	90.57	-	-	-	0.22	
C3	SR6	107.22	103.14	95.41	-	-	-	0.31	
B1	SR9	539.80	281.98	271.76	2.7	-	-	0.21	
E12	SR1B	476.81	183.72	170.85	4.6	-	-	0.21	
E12	SR1A	406.23	160.89	151.22	-	-	-	0.22	
G11	SR10	432.14	173.29	158.72	-	-	-	0.22	
D1	SR5A	446.36	207.06	133.25	3.6	-	-	0.14	
B4	SR8	468.44	123.76	100.19	-	-	-	0.21	
SRM 4354 det					-	-	-	-	-
SRM 4350B det					-	-	-	-	-
SRM 4355 det					-	-	-	-	-
SRM 4354 act					-	-	-	-	-
SRM 4350B act					-	-	-	-	-
SRM 4355 act					-	-	-	-	-
Lab Blank 1								0	≤0.0008
Lab Blank 2								0	≤0.0005

"-" = data forthcoming
"0" = not detected
All radionuclide data in Bq/kg dry wt.

Sediment Radionuclides

Preliminary Data
Do Not Quote or Reproduce

ARCRAD Station	NOAA 93 Station	Wet Weight (g) Whole sample as recvd at LANL	Dry Weight (g) 110° to constant 48 - 96 hrs	Ash Weight (g) 550° org destr 12 - 48 hrs	Mineral Acids Dissolved				
					Alpha Spectroscopy			TIMS	
					Pu238	Pu239+240	Am241	Pu240/Pu239	Pu239+240
C1	SR7	274.17	99.67	89.92	≤0.02	0.05			
E7	SR2A	154.80	43.59	39.78	≤0.03	0.56			
E12	SR1C	402.86	153.21	143.09	≤0.01	0.08	0.02	0.24	
E1	SR4	217.06	71.45	67.86	≤0.02	≤0.02			
E5	SR3B	311.31	101.32	90.57	≤0.09	≤0.12			
C3	SR6	107.22	103.14	95.41	≤0.01	0.07		0.19	
B1	SR9	539.80	281.98	271.76	≤0.02	0.14	0.03	0.17	
E12	SR1B	476.81	183.72	170.85	≤0.06	0.26	0.07	0.20	
E12	SR1A	406.23	160.89	151.22					
G11	SR10	432.14	173.29	158.72	≤0.09	≤0.16			
D1	SR5A	446.36	207.06	133.25	≤0.03	0.06	0.02	0.19	
B4	SR8	468.44	123.76	100.19	≤0.02	0.33	0.10	0.18	
SRM 4354 det					-	-	-	-	-
SRM 4350B det					-	-	-	-	-
SRM 4355 det					-	-	-	-	-
SRM 4354 act					-	-	-	-	-
SRM 4350B act					-	-	-	-	-
SRM 4355 act					-	-	-	-	-
Lab Blank 1									
Lab Blank 2									

"-" = data forthcoming
"0" = not detected
All radionuclide data in Bq/kg dry wt.

Biota Radionuclides

Preliminary Data
Do Not Quote or Reproduce

ARCRAD Station	NOAA 93 Station	Wet Weight (g) Whole sample as recvd at LANL	Dry Weight (g) 110° to constant 48 - 96 hrs	Ash Weight (g) 550° org destr 12 - 48 hrs	High Resolution Gamma Ray Spectroscopy				
					Co60	Cs137	K40	Pb212	Pb214
B4	Sipunculids	190.31	27.98	8.24	-	≤1.0	309	10.4	≤2.5
E7	Crinoids	119.46	31.17	10.67	-	≤0.5	201	≤0.6	≤0.9
G1	Sea Urchins	1575.60	602.30	507.65	-	≤2.2	182	5.6	≤2.4
G1	Spider Crab	711.39	259.69	133.31	-	≤0.8	-	-	≤0.6
G1	Pacific Star	409.24	146.46	94.35	-	≤1.2	265	9.9	≤0.9
G1	Soft Star	94.58	32.69	12.40	-	≤0.8	243	3.9	≤0.9
G1	Nudibranchs	1453.13	439.57	271.84	-	≤2.0	272	≤2.5	≤0.9
Whale Fat		826.02							
Whale Lung		952.29	295.78	8.72					
Whale Liver		1577.21	441.62	15.09					
K. Elder muscle		688.08	225.55	20.23					
Lab Blank 1									
Lab Blank 2									

"-" = data forthcoming
"0" = not detected
All radionuclide data in Bq/kg dry wt.

Biota Radionuclides

Preliminary Data
Do Not Quote or Reproduce

ARCRAD Station	NOAA 93 Station	Wet Weight (g) Whole sample as recvd at LANL	Dry Weight (g) 110° to constant 48 - 96 hrs	Ash Weight (g) 550° org destr 12 - 48 hrs	Gamma Ray Spectroscopy Beta Counting			Mineral Acids Leached TIMS (Bq/Kg)	
					Cs137	Cs135	Sr90	Pu240/Pu239	Pu239+240 Calc
B4	Sipunculids	190.31	27.98	8.24	-	-	-		
E7	Crinoids	119.46	31.17	10.67	-	-	-		
G1	Sea Urchins	1575.60	602.30	507.65	-	-	-		
G1	Spider Crab	711.39	259.69	133.31	-	-	-		
G1	Pacific Star	409.24	146.46	94.35	-	-	-		
G1	Soft Star	94.58	32.69	12.40	-	-	-		
G1	Nudibranchs	1453.13	439.57	271.84	-	-	-		
Whale Fat		826.02			-	-	-		
Whale Lung		952.29	295.78	8.72					
Whale Liver		1577.21	441.62	15.09					
K. Elder muscle		688.08	225.55	20.23	-	-	-		
Lab Blank 1								0	≤0.0008
Lab Blank 2								0	≤0.0005

"-" = data forthcoming
"0" = not detected
All radionuclide data in Bq/kg dry wt.

Biota Radionuclides

Preliminary Data
Do Not Quote or Reproduce

ARCRAD Station	NOAA 93 Station	Wet Weight (g) Whole sample as recvd at LANL	Dry Weight (g) 110° to constant 48 - 96 hrs	Ash Weight (g) 550° org destr 12 - 48 hrs	Mineral Acids Dissolved				
					Alpha Spectroscopy			TIMS (Bq/Kg)	
					Pu238	Pu239+240	Am241	Pu240/Pu239	Pu239+240 Calc
B4	Sipunculids	190.31	27.98	8.24					
E7	Crinoids	119.46	31.17	10.67					
G1	Sea Urchins	1575.60	602.30	507.65	≤0.02	≤0.02			
G1	Spider Crab	711.39	259.69	133.31					
G1	Pacific Star	409.24	146.46	94.35					
G1	Soft Star	94.58	32.69	12.40					
G1	Nudibranchs	1453.13	439.57	271.84	≤0.01	≤0.01			
Whale Fat		826.02							
Whale Lung		952.29	295.78	8.72					
Whale Liver		1577.21	441.62	15.09					
K. Elder muscle		688.08	225.55	20.23					
Lab Blank 1									
Lab Blank 2									

"-" = data forthcoming
"0" = not detected
All radionuclide data in Bq/kg dry wt.

ARCTIC OCEAN SECTION 1994 (AOS '94)

UNITED STATES–CANADIAN TRANSPOLAR ICEBREAKER SCIENCE CRUISE

Larry Jendro

Chief, Science Branch

Ice Operations Division, USCG

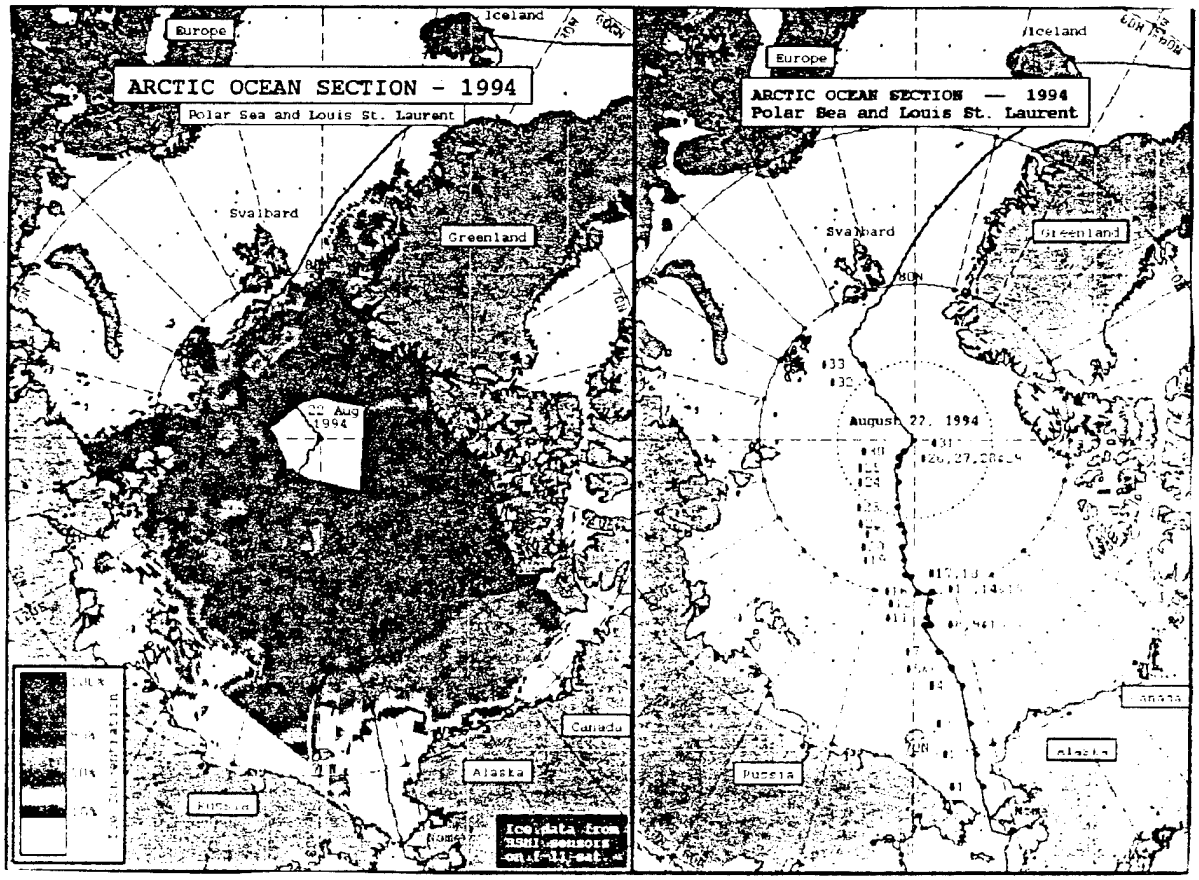
INFORMATION EXTRACTED FROM THE CRUISE REPORT BY APL, UNIVERSITY OF WASHINGTON, 28 SEPT. 1994

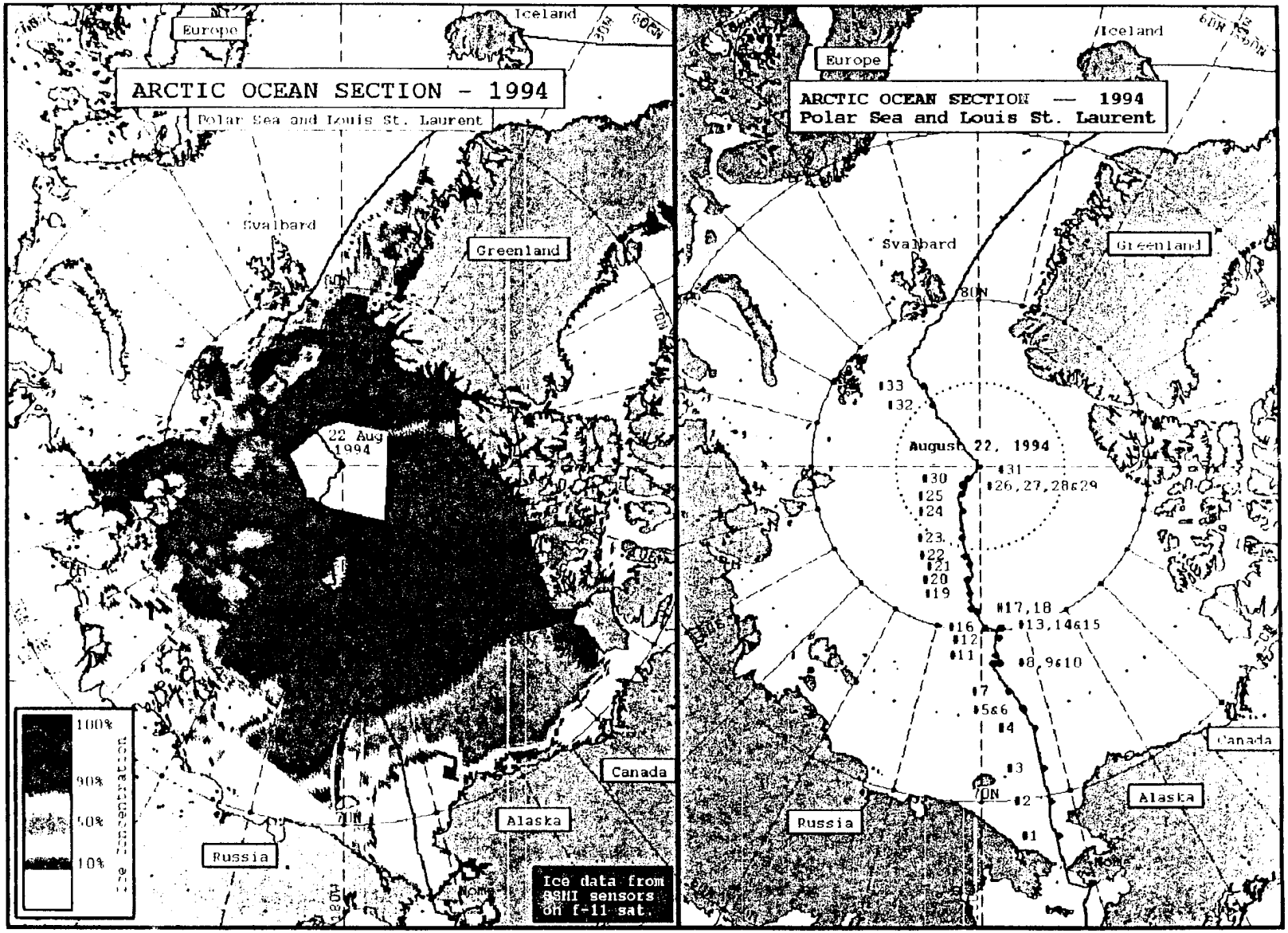
Arctic Ocean Section 1994, (AOS 94)

The United States Coast Guard (USCG) Polar Icebreaker *Polar Sea* joined the Canadian ice breaker *Louis St. Laurent* to support a historic, international, multi-disciplinary Arctic science expedition. Seventy scientists from twenty institutions participated. This was the first cruise to collect oceanographic data on a transect from west to east through the North Pole and in fact, these were the first U.S. and Canadian surface ships to ever visit the North Pole.

Early results indicate: the discovery of an uncharted sea mount, better definition of the structure of the Lomonosov Ridge and that **sea ice is important in the transport of radioactive contamination in the Arctic.**

This cruise demonstrated the capability of USCG Polar Icebreakers to support science expeditions in the most extreme polar conditions. The Coast Guard's polar icebreakers are national science assets. The support of polar science is their first priority mission.




ARCTIC OCEAN SECTION - 1994
Polar Sea and Louis St. Laurent
Europe
Iceland
Svalbard
Greenland
Canada
Alaska
Russia
22 Aug 1994
100%
90%
50%
10%
ice concentration
Ice data from SSMI sensors on f-11 sat.
ARCTIC OCEAN SECTION — 1994
Polar Sea and Louis St. Laurent
August 22, 1994
#33
#32
#31
#30
#26,27,28&29
#25
#24
#23
#22
#21
#20
#19
#17,18
#16
#13,14&15
#12
#11
#8,9&10
#7
#5&6
#4
#3
#2
#1
80N

AOS 94 SCIENTIFIC OBJECTIVES

The Arctic Ocean is perhaps the least well observed and understood of the world's oceans. At the same time, there are increasingly reasons to suspect that the Arctic plays a key role in processes associated with climate maintenance or change, e.g., the thermohaline circulation of the ocean and the global heat balance. There is also growing international, concern that the Arctic has been polluted by a variety of contaminants, including organochlorines and radionuclides. We know neither the regional, nor the global, consequences of a changing or a polluted Arctic, the major reason being the dearth of measurements upon which analyses and models can be based. **The goal of the Canada/U.S. 1994 Arctic Ocean Section was therefore to substantially increase the observational base necessary for understanding the role of the Arctic in global change.**

Specific objectives have been discussed in the Science Implementation Plan dated 26 April, 1994. They concern those measurements which best promote the analysis and modeling of the biological, chemical and physical systems related to the Arctic and global change, and the controlling processes in these systems, viz..

Ocean properties pertinent to understanding circulation and ice cover;

Biological parameters essential to defining the Arctic carbon cycle;

Geological observations necessary to understanding past climates;

Concentration and distribution of contaminants which impact the food chain and the environment;

Physical properties and variability of the ice cover;

Atmospheric and upper ocean chemistry and physics relevant to climate.

In addition, because of contaminant and climate change concerns, **a marine mammals study** was incorporated into the program. Finally, **a ship technology program sponsored by the Canadian and U.S. Coast Guards** interacted closely with many of the science programs, e.g., those related to sea ice.

The AOS 94 Ships

The CCGS *Louis S. St-Laurent* is a 392' ice breaker of 15,500 tons displacement based in Dartmouth, Nova Scotia and is the largest ice breaker in Canada. The ship has three fixed pitch propellers. Five diesel engines supply three propulsion motors that can deliver a total of 27,000 SHP to the three shafts. The ship carried two BO 105-BS4 helicopters for ice reconnaissance and science support. Her total crewing for this mission was 61 including the helicopter pilots and mechanic.

The CTD/rosette, equipped with 36 10 l bottles, was deployed from the boat deck, starboard side, using standard 0.322" conductor wire. The rosette lab, a joined 16' x 20' container, was immediately forward of the deployment point, and the CTD lab an 8' x 12' container, immediately aft. Ice work, including access to the ice, was from the foredeck, which was serviced by two cranes. Net hauls, pump deployments, and box cores were done from the foredeck, starboard side. One winch, with 5/32" wire, serviced the net hauls and pumps, while two winches equipped with 5/1 6" Kevlar line (working in tandem on deep casts) serviced the box core. Sample processing on the foredeck was done in a 8' x 12' container. All other laboratories were interior to the ship.

The USCGC *Polar Sea* is a 399' ice breaker of 13,200 tons displacement based in Seattle, Washington and is one of two Polar class ice breakers in the U.S. The ship has three variable pitch propellers. Each shaft can be powered by one or two diesels of 3,000 HP each (18,000 SHP total in a full diesel mode), or by a turbine which can supply 20,000 HP in a sustained mode (60,000 SHP total, in an all-turbine configuration). Only the diesels were used the first half of the voyage but a mixed turbine-diesel, mode was employed the second half, after a propeller casualty forced the starboard shaft to be secured. The ship carried two HH-65A helicopters for ice reconnaissance and science support. Her total crewing for this mission was 142, including the aviation detachment.

The CTD/rosette, equipped with 24 10 l , bottles, was deployed from the main deck, port side, as were the plankton nets. The CTD wire was 5/1 6" 3–conductor. The rosette lab was an enclosed fixed shipboard installation 16' x 14', located immediately forward of the deployment area. Ice work, including diving, was done from the starboard side aft, either using a platform swung from the flight deck (01 level) by crane, or from the main deck using the gangway. All coring was done from the fantail, where a coring track and J–frame supported the piston coring work. The coring wire was 1/2" 3–strand. A total of seven containers housed the science not accommodated in internal spaces, two on the maindeck, port side, for seismic work, two on the main deck, starboard side, for biology, including radioisotope work, one on the 02 deck, starboard side, for ice core processing, and two on the 02 deck, port side for radiation measurements and air and upper ocean chemistry. The latter container was adjoined by a liquid nitrogen generating plant producing 30–40 l/day in support of a number of science programs. In addition, the port bridge wing housed a portion of the air sampling equipment. The biologic, productivity incubators were sited on the 01 deck, starboard side.

AOS 94 Cruise Narrative

The *Louis S. St-Laurent* and the *Polar Sea* departed Victoria, B.C. together the evening of 17 July, 1994 and boarded the majority of its scientific party of 70 persons by helicopter in Nome, Alaska on 24 July, a few had sailed with the ships from Victoria to set up equipment and make preliminary measurements. We passed through Bering Strait on 25 July and entered the ice in the -northern Chukchi Sea early afternoon of the following day.

During the first few days, the ships worked some distance apart, as the ice was not severe. However, from the 30th of July onward ice coverage was typically ten-tenths and the ships moved close together in tandem for the most efficient ice breaking, taking turns leading. Visibility was generally poor throughout the time spent in the ice, with fog and overcast the rule, 31 July being the only fully clear day.

Beginning in the central Chukchi Sea, the station line ran northward east of the Russia - U.S. Convention line but once past 200 nm from Wrangell Island, our track turned northwestward across the Chukchi Abyssal Plain and onto the Arlis Plateau which we reached on 3 August at 78 N. Heavy ice limited our eastward penetration down the flank of the plateau to longitude 174 18' W. We therefore resumed the station line northward, with the intent of covering the region to the east along 78 N on the return voyage. Near 80 N we again attempted a section to the northeast, but difficult ice conditions limited our penetration in that direction to 80 13' N, 172 46'W. We therefore continued working northwestward across the Mendeleev Ridge and into the Makarov Basin.

On Monday the 8th we had an overflight and data transfer by a Canadian ice reconnaissance flight carrying side-looking radar, which mapped the ice in a swath 200 km wide and extending 1100 km along our intended track northward. From this imagery it was clear that difficult ice conditions lay to the east. Detailed helicopter ice reconnaissance the next few days confirmed this, and on Sunday the 14th, near 85 N 170 E we decided to continue onto the Lomonosov Ridge near 15O E before turning east and running the final northward leg of the outbound voyage along 15O-155 E.

On the 15th of August the helicopter-borne CTD party found a new undersea mountain when the wire stopped paying out and they brought up mud from 850 m where the chart showed 3700 m. Three @miles away on either side they found no bottom at 1450 m.

The next three days brought a northeast gale, snow and poor visibility, and progress was slow through heavy ice. **On the 19th we reached our station on the crest of the Lomonosov Ridge at 88 47'N, 143 E where we planned to turn eastward. There we found the water at intermediate depth to be about 12C warmer than we had seen at the base of the ridge, suggesting that the large gap in the ridge shown in the charts does not exist.** Meanwhile, on the 17th, we had an ice reconnaissance by a long-range Canadian aircraft, and on the 19th, while the ships remained on station on the ridge, we flew a 215 nm helicopter reconnaissance over the intended track. These showed very heavy ice at the location of our intended crossing point of the Lomonosov Ridge to the east, and we therefore decided to continue the section we were on northward and then return along an alternative route which would re-cross the ridge -farther south. From there we would then attempt to get onto the eastern end of the Alpha Ridge to do seismic work and additional, piston coring before continuing both these and our many other planned programs on the long voyage back to Alaska.

However, this was not to be, for shortly after starting northward down the steep ridge flank, **early Sunday morning the 21st of August and about 5O nm from the Pole, the Polar Sea lost a blade on the starboard propeller.** There was also damage to the centerline and port shafts, and these casualties required that the expedition take the shortest route out of the ice, in the vicinity of Spitsbergen. Our intended section northward took us in that direction, and since we had already surveyed that route by helicopter and knew it to be feasible, we decided to continue on our course. **That same afternoon a U.S. Coast Guard C-130 from Kodiak dropped spare parts for our satellite receiver.**

At 0230 Monday morning, Alaska standard time, we reached our next science station at 90 N, the first North American surface ships to do so, and the first ever to do it over the long, unexplored route from the Pacific side of the Arctic Ocean. Our station at the Pole took 28 hours, as we fully deployed every sampling program. Not only could we thereby compare conditions with those found three years earlier by Swedish and German investigators, but we could add a great many new

measurements, for example the concentration and distribution of a great variety of contaminants.

The last few hours before we arrived at the Pole we had seen a large ship on the horizon, which proved to be the Russian nuclear ice breaker *Yamal* hove to in the ice about 20 nm from the Pole to produce a children's television program. The *Yamal* planned to go south along our intended track the next day, coincident with the shortest route out of the ice and the one which we needed to take because of the damage to the Polar Sea. At 0800 on the 23rd we therefore started the twenty miles to the *Yamal*, where **an extraordinary meeting of the three ice breakers took place.** That evening all three ships sailed southward together toward Svalbard and made good progress, reaching south of 86 N by Thursday morning the 25th.

At that point the ice conditions had improved, and we parted company with the Yamal to resume our scientific work, consonant with expeditiously exiting the Polar Basin. The pattern of southerly progress in somewhat lighter ice continued and we occupied several high-quality science stations in the Eurasian Basin. On the 27th we had an airdrop of helicopter parts. The same day we received word from the U.S. Department of State that we were not permitted to continue the work southward within 200 nm of Svalbard. We therefore terminated our section with a station at 83 51' N, 35 41'E. On Tuesday the 30th of August we exited the ice northwest of Spitsbergen, making course for Iceland. On the 31st we stopped the St-Laurent for a contaminant and oceanographic station in the Greenland Sea at 75 N, 6 W. This proved to provide an excellent end point for the Arctic Ocean section, since it showed the prominent role of the Arctic Ocean outflow in changing the convective region of the Greenland Sea in recent years to a warmer more saline state.

The Polar Sea disembarked its scientific party in Keflavik, Iceland on 3 September and then proceeded to Nova Scotia in company with the St. Laurent, the ships being slowed enroute by a storm with winds exceeding 60 knots. The St. Laurent disembarked its scientific party in Dartmouth on 9 September, bringing to a close a remarkable and productive voyage.

Science Summary
(major activities)

- 17 combined biological productivity and biomass stations (PS)
- 5 biomass stations (PS)
- 39 oceanographic stations (LS-L)
- 35 contaminant stations (LS-L)
- 59 ice stations (PS and LS-L)
- 37 box cores (PS)
- 8 box cores (LS-L)
- 17 piston cores (PS)
- 1300 n mi of video and still photography ice morphology survey lines flown (PS)
- 72 CTD stations by helicopter (LS-L)
- continuous and flask/pump sampling for atmospheric volatile organics, dimethyl sulfide, ozone, carbon monoxide and dioxide, organohalides, sulfur dioxide and acid gases, major ions and stable isoptopes, aerosols, and condensation nuclei; halomethanes in water, snow, and ice while on station (PS)
- 2 48-hr contaminant moorings (LS-L)
- radiation using Fourier transform IR spectro-radiometer (mid-IR), near-IR detector, total IR pyrgeometer, solar pyranometer, near-IR pyranometer, and UV radiometer (PS)
- 7 polar bear studies (LS-L and PS)

AOS-94 STUDIES CONCERNED WITH ARCTIC CONTAMINANTS:

Sea Ice Physics and Chemistry:
Terry Tucker, Dr. Tony Gow and Bill Bosworth, U.S. Army Cold Regions Research and Engineering Laboratory.

Arctic-94 Transect: Contaminant Measurements:
R.W. Macdonald & T. Bidleman, Institute of Ocean Sciences, Sydney B.C. **604-363-6409**

Canada/U.S. 1994 Arctic Ocean Section: Arctic Contaminants:
E.C. Carmack, R.W. Macdonald, J. Smith, L. Barrie, T. Bidleman, and M. Ramsey, Institute of Ocean Sciences, Sydney B.C. 604-363-6409

Radionuclide Contaminants:
J. N. Smith, K. Ellis, L. Cooper, Bedford Institute of Oceanography (902) 426-3865

Sources, Fate and Transport of Radionuclides in the Arctic Ocean:
S. B. Moran and J. N. Smith, Graduate School of Oceanography, University of Rhode Island (401) 792-6160

The Character and Quantity of Sediments Transported and Deposited by Arctic Sea Ice:
E. Reimnitz, USGS, Menlo Park, CA (415) 354-3049

Natural and Artificial Radionuclides as Tracers of Particle Cycling and Circulation Time Scales in the Arctic Ocean:
S. B. Moran URI, (401) 792-6530

The Geochemistry of Trace Elements in Arctic Shelf Waters:
C. Measures, Department of Oceanography, University of Hawaii, (808) 956-5924

Marine Mammals:
M. Ramsay, S.D. Farley, G. Garner, R. Norstrom, and D Schell Department of Biology, University of Saskatchewan (306) 966-4412

Cesium-137 Contamination in Sea Ice

Debra Meese*, Lee Cooper+§, I.L. Larsen+, Walter Tucker*, Erk Reimnitz‡ and Jacqueline Grebmeier+§

*USA Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755

+Environmental Sciences Division P.O. Box 2008, MS 6038, Oak Ridge National Laboratory, Oak Ridge, TN 37831

‡US Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025

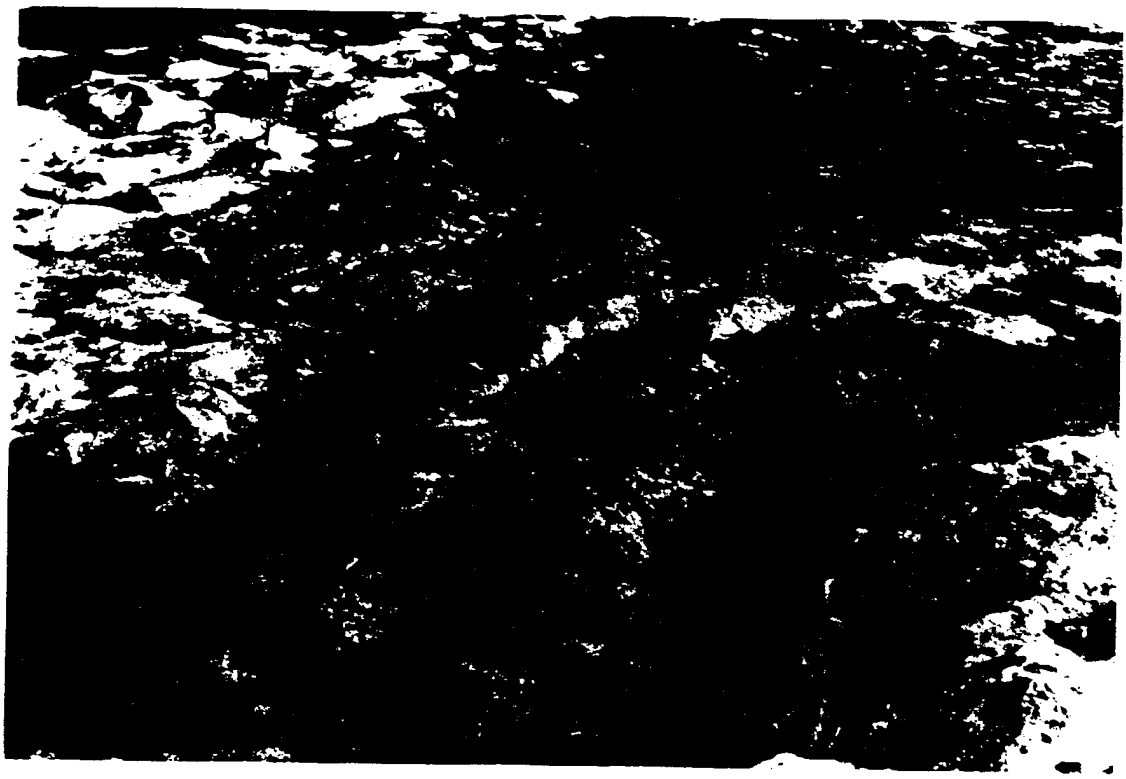
§Graduate Program in Ecology, University of Tennessee, Knoxville, TN 37996

ABSTRACT

Sea ice and ice-borne sediment samples were collected across the western Arctic basin on the joint U.S./Canada Arctic Ocean Section during August, 1994. Samples were processed on board and returned at the completion of the cruise to Oak Ridge National Laboratory for analysis. Sediment was observed on the surface and in the ice from the southern ice limit in the Chukchi Sea to the North Pole. Preliminary results on the ice-borne sediment samples shows widespread elevated concentrations of 137Cs ranging from 4.9 to 73 Bq•kg dry weight-1. The lowest concentrations measured (4.9 to 5.6 Bq•kg dry weight-1) were found in samples on the Chukchi Sea continental shelf, and these concentrations correspond to activities reported for Chukchi Sea bottom sediments. The highest value (73 Bq•kg dry weight-1) found north of the Chukchi Sea, is comparable to elevated levels present in the shelf sediments of the Yenesey River estuary. By comparison, 137Cs concentrations within the ice itself (exclusive of sediment) were less than 1 mBq l-1, indicating that the ice was formed from seawater with substantially lower concentrations than sediments, or that contaminants are rejected in a manner similar to brine.

These results indicate that sea ice is a primary transport mechanism by which contaminated sediments are redistributed throughout the Arctic Ocean and possibly exported into the Greenland Sea and North Atlantic through Fram Strait. The wide variability in the ice-borne sediment concentrations of 137Cs measured along the transect argues that contaminants incorporated on the Siberian shelves can follow much more variable trajectories than is suggested by mean ice drift calculations.

Our findings strongly support future investigations of processes of radionuclide and sediment incorporation into ice. Likewise, modeling of ice transport from the Siberian shelves, as well probability studies of ice trajectories derived from historical and current buoy drift fields are warranted to determine the fate of ice transported radionuclides. Monitoring on the Beaufort Sea shelf of Alaska is suggested.



Sediment laden first year sea ice.



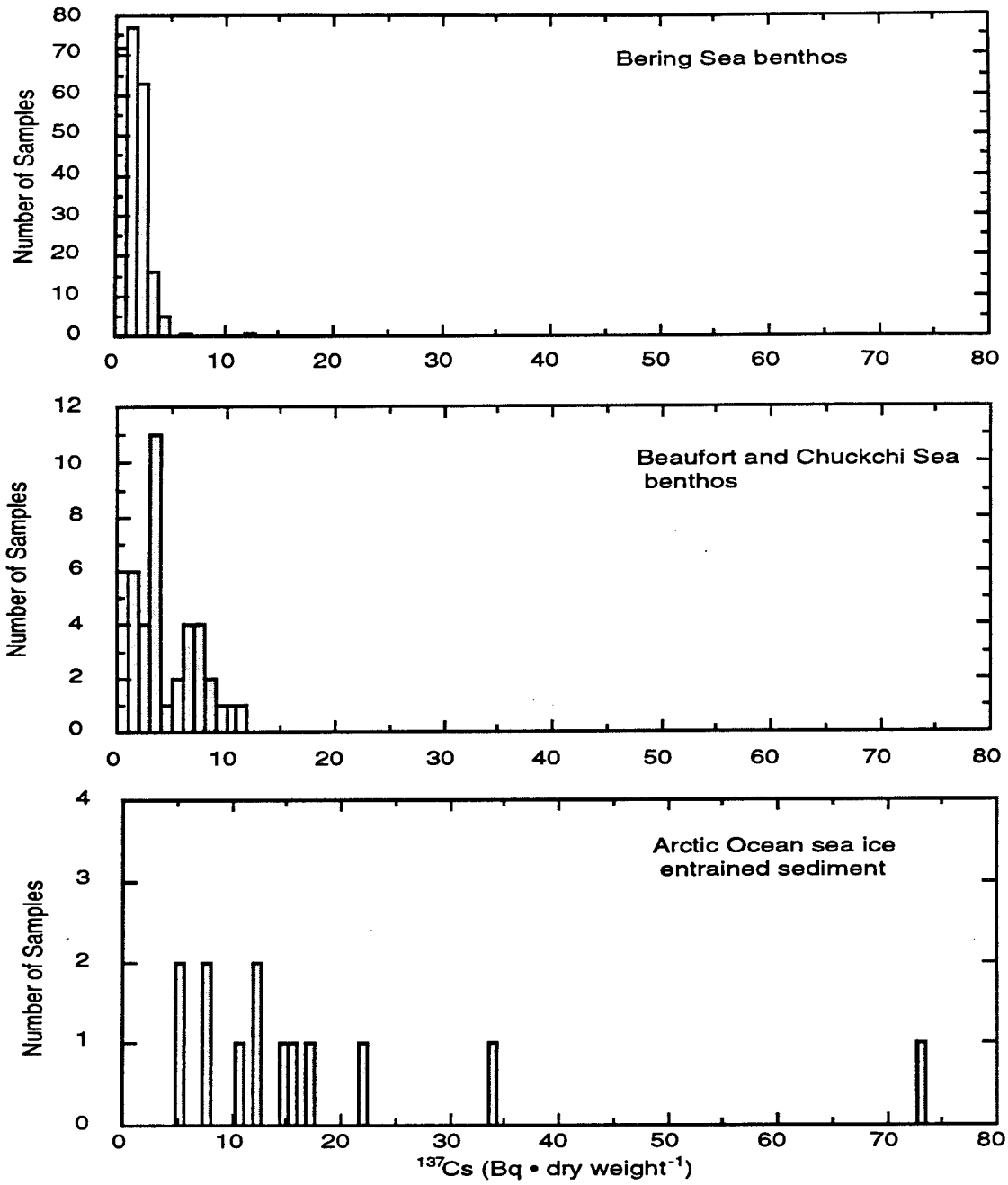
Sediment covered multiyear ice.



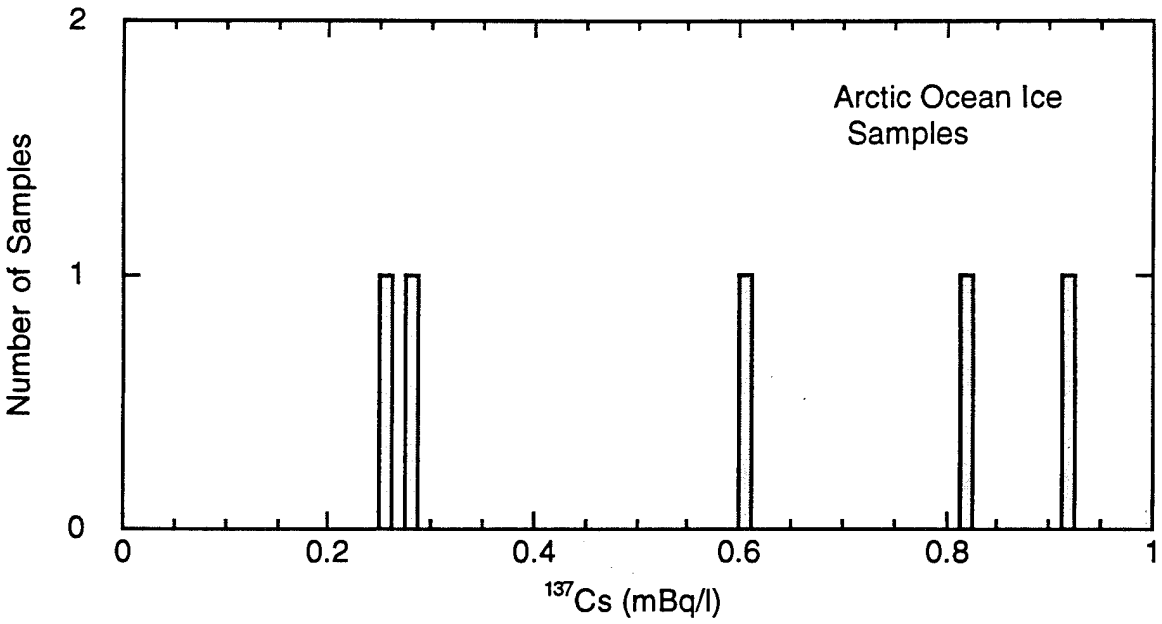
Investigator scraping sediment from the surface of multiyear sea ice for radionuclide and mineralogic analysis.



Multiyear ice cores near the pole. Note the sediment entrained in the ice. With ablation the sediment will eventually reach the ice surface.



Distributions of sediment activities of 137Cs (Bq • kg dry weight-1) detected in surface (0-4 cm) sediments collected in the Bering Sea (top panel), Beaufort and Chukchi Seas (middle panel) and in sediments entrained in Arctic Ocean sea ice (bottom panel). Radioactivity ranges reported correspond to the date of collection. Bering Sea samples were collected in 1990, 1992, 1993, and 1994. Samples north of Bering Strait were collected in 1991, 1992, and 1993. Sediments entrained in sea ice were all collected in August, 1994 except for one sample collected in August, 1993.



Distributions of ice activities of 137Cs (mBq/l) detected in sea ice samples collected in August, 1994 during AOS-94. 4" cores extending through the entire thickness of the ice were obtained. In order to obtain an adequate volume of sample for analysis, approximately 25 meters of ice were collected, melted and processed on board ship.

Sediment Processing Procedure

Wet sediments concentrated from sea ice were separated and radioassayed. Benthic sediments were collected predominately with a HAPS core (133 cm2 surface area) and a Veen grab (0.1 m2 area) in which top sediments were removed before the grab was opened. Sediments collected using the HAPS core were packed wet in 90 ml aluminum cans, as were the sediments from sea ice; sediments from the van Veen grab were packed wet in 500 ml Marinelli beakers. Comparison of sediment 137Cs radioactivities for collections at the same stations using both methods of benthic sediment collection indicate that there is no significant difference in data generated using the two collection methods. Radioisotope counting was accomplished at Oak Ridge National Laboratory using multiple low-background, high resolution germanium detectors linked to a Nuclear Data 9900 (Genie) microprocessing system, recording gamma-spectra in 4096 channels.

Ice Processing Procedure

Processing consisted of adding HCl to adjust the pH, and Cs, Co, Be and Pb tracers were added. Cesium was precipitated out using ammonium molybdophosphate (AMP). NaOH was added to raise the pH to 10, followed by addition of $FeCl_3$ and $FeSO_4$. The $Fe(OH)_3$ precipitate was returned to Oak Ridge National Laboratory for analysis as was some of the remaining water. Radioisotope counting was accomplished at Oak Ridge National Laboratory using multiple low-background, high resolution germanium detectors linked to a Nuclear Data 9900 (Genie) microprocessing system, recording gamma-spectra in 4096 channels.



Russian icebreaker Yamal, USCGC Polar Sea and CCGS Louis S. St. Laurent at the North Pole.

Sediment Incorporation in Sea Ice

(see figure on following page)

1. Fall storms stir up bottom sediments on shallow continental shelves.

2. Frazil and anchor ice is nucleated in the supercooled water containing suspended sediment.

3. Frazil scavenges sediment from the water column and consolidates on the surface.

4. The ice sheet thickens through normal congelation growth below the consolidated dirty frazil ice.

5. The consolidated ice sheet may ridge.

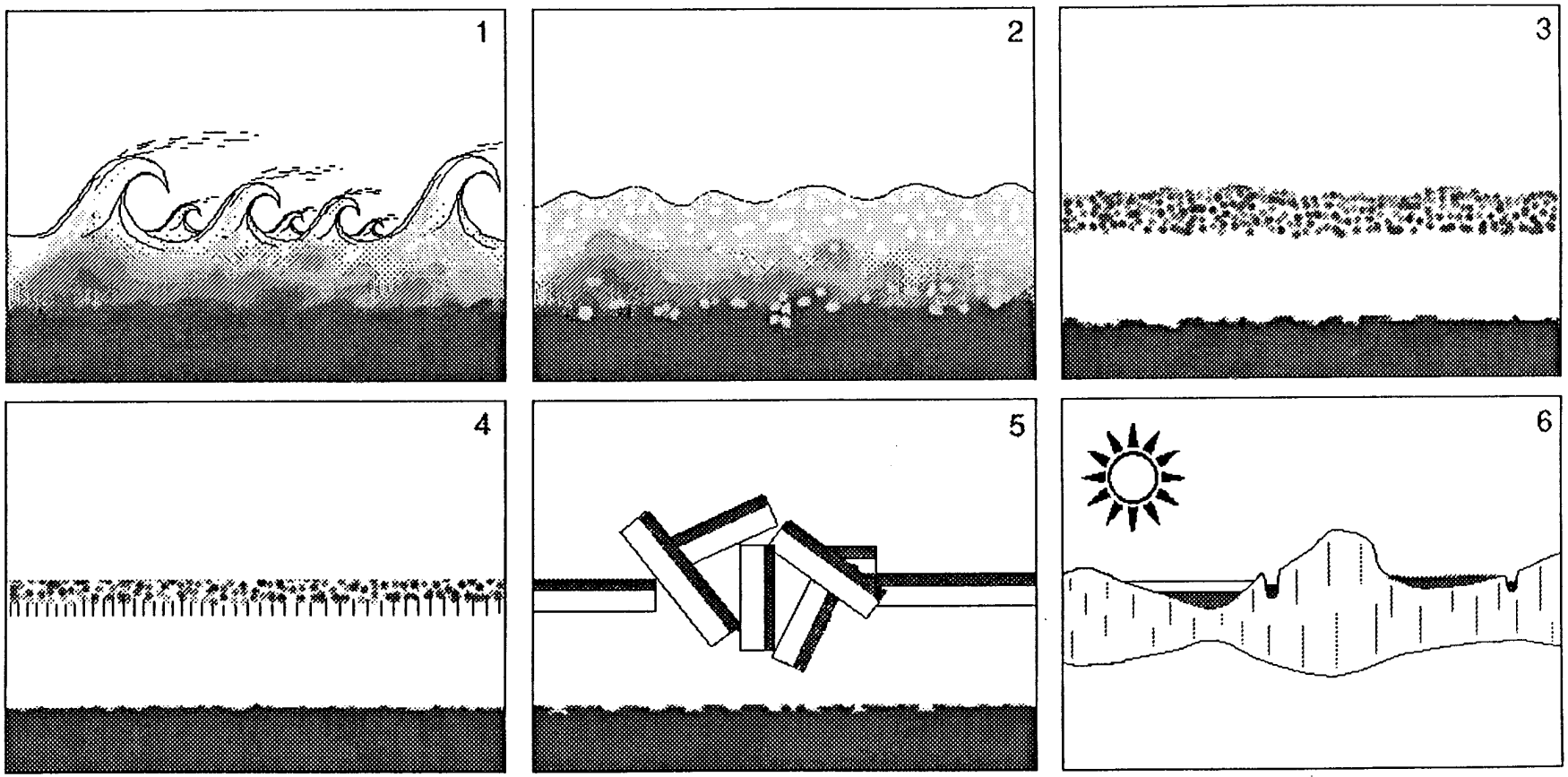
6. During summer ablation, sediment migrates to the ice surface and accumulates in low spots, melt ponds and cryoconite holes.

Major Questions

To what degree are radionuclide contaminants incorporated directly into the ice? The sediment? How do they evolve as the ice ages?

What are the sediment scavenging mechanisms? Vertical scavenging, horizontal scavenging, Langmuir circulations, wave pumping?

How much sediment is released from the ablating floe during summer?



Terry-14

CONCLUSIONS

• Sediment laden sea ice was observed across the western Arctic Basin during AOS-94 from the Chukchi Sea to the North Pole.

• In the ice entrained sediment, 137Cs activities ranged from 4.9 - 73 Bq • kg dry weight-1.

•The highest value (73 Bq•kg dry weight-1) found north of the Chukchi Sea, is comparable to elevated levels present in the shelf sediments of the Yenesey River estuary.

• In the sea ice, 137Cs activities ranged from 0.260 - .925 mBq/l.

• The values in the ice indicate that the ice was formed from seawater with substantially lower concentrations than sediments, and/or contaminants are rejected in a manner similar to brine.

• Our findings show that Arctic sea ice can transport relatively high burdens of sediment-borne radionuclides large distances from their likely point sources on the Siberian continental shelves.

• Transport by sea ice will result in the widespread re-distribution of radionuclides bound to sediments throughout much of the Arctic Ocean, the Greenland Sea and the North Atlantic.

ACKNOWLEDGEMENTS

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DEVELOPMENT OF SOURCE TERM AND RELEASE RATE MODELS FOR THE FORMER SOVIET UNION NAVAL REACTORS DUMPED IN THE KARA SEA

Mark E. Mount

Fission Energy and Systems Safety Program
Lawrence Livermore National Laboratory
Germantown, MD

Abstract

In progressing its work for the International Arctic Seas Assessment Project, under the auspices of the Intentional Atomic Energy Agency, the Source Term Working Group is developing simple spread sheet models to predict the radiation release profile into the Kara Sea from spent nuclear fuel and activated components dumped within the naval reactors and reactor compartments from seven former Soviet Union submarines and the icebreaker *Lenin*. In addition to radioactive decay, the models also account for the degradation of containment materials through corrosion and other mechanisms and predict annual release rates to thousands of years into the future.

Preliminary results from the *Lenin* source term release rate models are described as well as the development status of the source term and release rate models for the nuclear submarine reactors and reactor compartments.

Work performed under the auspices of the US Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-ENG-48 and the US Navy, Office of Naval Research.

DEVELOPMENT OF SOURCE TERM AND RELEASE RATE MODELS FOR THE FORMER SOVIET UNION NAVAL REACTORS DUMPED IN THE KARA SEA

WORKSHOP ON MONITORING OF NUCLEAR CONTAMINATION IN THE ARCTIC SEAS

January 18-19, 1995
Washington, DC

Mark E. Mount
Fission Energy and Systems Safety Program



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NRL/WASH/VG-2

International Arctic Seas Assessment Project (IASAP), International Atomic Energy Agency (IAEA)



- IASAP began in Oslo, Norway on February 1, 1993. Objectives are to:
  - Assess risks to human health and to environment associated with radioactive wastes dumped in Kara and Barents Seas.
  - Examine possible remedial actions related to dumped wastes and to advise on whether they are necessary and justified.
- Four working groups established:
  - Source Term.
  - Existing Environmental Concentrations.
  - Transfer Mechanisms and Models.
  - Impact Assessment and Remedial Measures.

Yablokov Commission Report

- "Facts and Problems Related to Radioactive Waste Disposal in Seas Adjacent to the Territory of the Russian Federation," hereafter called White Book, released in Spring of 1993.
  - Between 1965 and 1988, 16 naval reactors from seven former Soviet Union submarines and icebreaker *Lenin* dumped at five sites in Kara Sea at depths of 20 to 300 m.
    - Six of 16 naval reactors contained their spent nuclear fuel (SNF).
    - Approximately 60% of SNF from one of three *Lenin* naval reactors discarded in reinforced concrete and stainless steel shell container.
    - Estimates of total radioactivity at time of disposal were 2,300 kCi of fission products in SNF and 100 kCi of ^{60}Co in reactor components.

Yablokov Commission Report (continued)

Disposal Site	Disposal Date	Naval Reactors Discarded[a]	Reactors Containing SNF	Activity (kCi)[b]
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[c]	150[d]
Novaya Zemlya Depression	1972	1 (No. 421)	1	800
Stepovoy Inlet	1891	2 (No. 601)	2	200
Techeniye Inlet	1988	2 (No. 538)	-	14
Total		16	6.6	2,400

[a] Entries in parenthesis represent associated factory identification number.
[b] 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.
[c] SNF not contained in naval reactor, but in reinforced concrete and stainless steel shell container.
[d] 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.

NRL/WASH/VG-5

Interagency Arctic Research Policy Committee (IARPC) Workshop on Arctic Contamination



- Held in Anchorage, Alaska on May 2-7, 1993.
- "Estimated Inventory of Radionuclides in Former Soviet Union Naval Reactors Dumped in the Kara Sea" presented by Mark Mount, Lawrence Livermore National Laboratory (LLNL).
  - Time-dependent inventories of fission products and actinides in SNF calculated with ORIGEN2, personal computer code.
    - Input data for *Lenin* derived from Russian literature sources.
    - Input data for submarines derived from Western estimates of operating characteristics based upon NATO classification.
  - Time-dependent inventories of activation products in reactor components and primary system corrosion products based upon generic British calculation for nuclear powered submarine.
  - Variability in ^{235}U enrichment and pre-disposal decay time included.

International Conference on Environmental Radioactivity in the Arctic and Antarctic

- Held at Svanhovd Environmental Center, Kirkenes, Norway on August 23-27, 1993.

- "The Seabed Sources of Radionuclides in the Dumped Reactor Compartment of the Atomic Icebreaker *Lenin*" presented by Yuri Sivintsev, Russian Research Center, Kurchatov Institute, Moscow.

  - Provided information on reactor cores, fuel elements, fuel loads, and operating histories; reactor accident in February 1965; disposal operations in August 1967, including use of furfurol; and selected radionuclide inventories.

    - Activation product activities at reactor shutdown of 24 kCi of ^{60}Co and 8.9 kCi of ^{63}Ni in reactor pressure vessels (RPVs) - about 50 kCi of ^{60}Co in White Book.

    - Fission product activities at end of 1966 of 20 kCi of ^{90}Sr and 23 kCi of ^{137}Cs - about 50 kCi of each in White Book.

    - Total actinide activity at end of 1966 of 3 kCi.

International Conference on Environmental Radioactivity in the Arctic and Antarctic (continued)

- "Estimated Inventory of Radionuclides in Former Soviet Union Naval Reactors Dumped in the Kara Sea" presented by Mark Mount, LLNL.
  - Comparable selected radionuclide inventory estimates for *Lenin* at disposal are:
    - Activation product activities of 34 to 38 kCi of ^{60}Co and 15 to 16 kCi of ^{63}Ni in the RPVs.
    - Fission product activities of 34 to 44 kCi of ^{90}Sr and 40 to 49 kCi of ^{137}Cs.
    - Total actinide activity of 16 to 28 kCi.

First IASAP Source Term Working Group Meeting



- First Consultants Meeting held at IAEA on January 10-14, 1994.
- "Study of Nuclides Composition and Characteristics of Fuel in Dumped Submarine Reactors and Atomic Icebreaker *Lenin*: Part 1 - Atomic Icebreaker" presented by Yuri Sivintsev, Russian Research Center, Kurchatov Institute, Moscow.
  - Provided more information on reactor compartment, cores, fuel elements, fuel loads, and operating histories; disposal operations and configuration of reactor compartment; and detailed radionuclide inventories.
    - Total activation product activity in three RPVs of 37 kCi at disposal and 4.6 kCi in 1993.
    - Total fission product activity in reinforced concrete and stainless steel shell container of 470 kCi at disposal and 50.9 kCi in 1993.

First IASAP Source Term Working Group Meeting (continued)



- Total actinide activity in reinforced concrete and stainless steel shell container of 7.3 kCi at disposal and 2.3 kCi in 1993.

- Total activation product activity in reinforced concrete and stainless steel shell container of 13.7 kCi at disposal and 1.7 kCi in 1993.

- Simple spread sheet models developed to predict radiation release profile into Kara Sea from *Lenin*. Five scenarios considered:

  - Case I: Fuel rods and RPVs in direct contact with sea water.

  - Case II: Fuel rods and RPVs sealed within reactor compartment and in direct contact with contained sea water.

  - Case III: Fuel rods surrounded by furfurol, RPVs filled with furfurol, and both sealed within reactor compartment and in direct contact with contained sea water.

First IASAP Source Term Working Group Meeting (continued)



- Case IV: Fuel rods surrounded by furfurol and within reinforced concrete and stainless steel shell container, RPVs filled with furfurol, and both sealed within reactor compartment and in direct contact with contained sea water.

- Case V: Initial conditions same as in Case IV. Supporting deck and hull structure collapse causing lid of reinforced concrete and stainless steel shell container to be lost through displacement.

45th Arctic Science Conference

- Held in Vladivostok, Russia on August 27-September 2, 1994.
- "Modeling the Release to the Environment in the Kara Sea from Radioactive Waste in the Dumped Reactor Compartment of the Icebreaker *Lenin*" presented by Stephen Timms, Royal Naval College, Greenwich, London and Mark Mount, LLNL.
  - Summary of model and radiation release profile from SNF and activated components.
    - Maximum release rates vary between 37 kCi/yr (Case I) and 1 Ci/yr (Case IV).
    - By 2000, release rates vary between 56 and <0.1 Ci/yr.
    - By 2050, release rates on order of 0.6 Ci/yr.
    - By 2500, release rates on order of 0.2 Ci/yr.
    - By 4000, release rates on order of 0.02 Ci/yr.

Second IASAP Source Term Working Group Meeting

- Second Consultants Meeting held at IAEA on November 14-18, 1994.
- "Study of Nuclides Composition and Characteristics of Fuel in Dumped Submarine Reactors and Atomic Icebreaker Lenin: Part 2 - Nuclear Submarines" presented by Yuri Sivintsev, Russian Research Center, Kurchatov Institute, Moscow.
  - Provided information on reactor fuel elements, fuel loads, and operating histories; disposal operations, including use of furfurol; and detailed radionuclide inventories for pressurized water reactors (PWRs) from nuclear submarines No. 254, No. 260, No.285, No. 421, No. 538, and No. 901.
  - Radionuclide inventories derived from comparison to *Lenin*.
  - Discarded reactors in one of three configurations:
    - RPV with thermal shields, hardware, SNF, and furfurol.

Second IASAP Source Term Working Group Meeting (continued)



- RPV with thermal shields, hardware, and SNF.
- RPV with thermal shields and hardware.

- Simple spread sheet models to be developed to predict radiation release profile into Kara Sea from PWR submarines. Major release paths to be considered are:
  - Hull, RPV, and fuel corrosion for reactor compartments with SNF.
  - Hull and RPV corrosion for reactor compartments without SNF.
  - Special metal container, RPV, and fuel corrosion for reactor from submarine No. 421.
- "Radionuclides Composition, Characteristics of Shielding Barriers, and Analyses of Weak Points of the Dumped Reactors of Submarine N 601" presented by Eugeny Yefimov, State Scientific Center of Russian Federation, Institute of Physics and Power Engineering, Obninsk.

NRL/WASH/VG-15

Interagency Arctic Research Policy Committee (IARPC) Workshop on Arctic Contamination (cont'd)

Disposal Site	Disposal Date	Naval Reactors Discarded[a]	White Book Activity (kCi)[b]	LLNL Total Activity (kCi)[c]
Abrosimov Inlet	1965	2 (No. 285)	807	341 - 845
		2 (No. 901)	400	511 - 1,795
		2 (No. 254)	14	158
	1966	2 (No. 260)	14	158
Tsivolka Inlet	1967	3(OK-150)	150[d]	840 - 1,745
Novaya Zemlya Depression	1972	1 (No. 421)	800	256 - 899
Stepovoy Inlet	1891	2 (No. 601)	200	208 - 219
Techeniye Inlet	1988	2 (No. 538)	14	158
Total		16	2,400	2,630 - 5,977

[a] Entries in parenthesis represent associated factory identification number.
[b] 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.
[c] SNF not contained in naval reactor, but in reinforced concrete and stainless steel shell container.
[d] 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.

NRL/WASH/VG-7

Second IASAP Source Term Working Group Meeting (continued)

- Provided information on reactor compartment, fuel elements, fuel loads, and operating histories; reactor accident in May 1968; disposal operations and configuration of the reactor compartment in September 1981, including use of furfurol and bitumen; and detailed radionuclide inventories for two liquid metal reactors (LMRs) in nuclear submarine No. 601.

- SNF radioactivity assumed to be spatially distributed as follows:

  - 100% of right reactor SNF in right RPV.

  - 80% of left reactor SNF in left RPV and 20% of left reactor SNF within Pb-Bi at top of left steam generator.

- Simple spread sheet models to be developed to predict radiation release profile into Kara Sea from LMR submarine. Major release paths to be considered are:

  - Hull corrosion.

Second IASAP Source Term Working Group Meeting (continued)



- Through top of reactor.
- In horizontal plane of reactor core.
- Corrosion through bottom of reactor.
- Through control rod guide tubes.
- Corrosion of SNF in steam generator of damaged reactor.

Second IASAP Source Term Working Group Meeting (continued)

Disposal Site	Disposal Date	Naval Reactors Discarded[a]	White Book Activity (kCi)[b]	Revised Total Activity (kCi)[c]
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[d]	528
Novaya Zemlya Depression	1972	1 (No. 421)	800	28.3
Stepovoy Inlet	1891	2 (No. 601)	200	37
Techeniye Inlet	1988	2 (No. 538)	14	0.2
Total		16	2,400	990.8

[a] Entries in parenthesis represent associated factory identification number.
[b] 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.
[c] SNF not contained in naval reactor, but in reinforced concrete and stainless steel shell container.
[d] 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.

NRL/WASH/VG-18

Software for Underwater Gamma-Ray Spectrometry

CDNSWC 682, Silver Spring, MD 20903-5640
Dr. Gordon Riel (301) 394-2474, FAX 394-5135, Verify 394-2267

ABSTRACT - We wrote computer programs for an in situ spectrometer to measure the concentration of isotopes at a few percent of background. Analysis of underwater spectra is difficult because scattering in the water reduces the energy of most photons. Our stripping program SPEC finds peaks in the data spectrum from the few gamma-rays that retain their characteristic energy. It fits standard spectra to these peaks. We can calculate standards as needed, using our MONTE CARLO code which was verified by measurements of seventeen (17) isotopes in a 100,000 liter tank. We measured the ocean's background from the surface to 10,000 feet. We shielded our detector with a ton of fresh water and lowered it into the ocean to measure its internal and cosmic ray backgrounds. Our transport code MREMS produces isodose contours throughout a large volume from hundreds of sources. We have validated source models for many nuclear weapons.

Software for Underwater Gamma-Ray Spectrometry

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SUMMARY - We wrote computer programs for an in situ spectrometer to measure the concentration of isotopes at a few percent of background. We calculate standard spectra with a code that was verified by measurements in a near infinite volume. Our transport code produces isodose contours throughout a large volume from hundreds of sources. We have validated source models for many nuclear weapons.

DIFFICULTIES IN ANALYSIS OF UNDERWATER SPECTRA

SHAPE - Scattering in the water reduces the energy of most photons. Backscatter photons from higher energy sources dominate the spectrum in the 100 to 200 keV region.

STANDARDS - To measure standard spectra, one dissolves radioisotopes in a large volume of water, and its disposal will be expensive.

BACKGROUND - The major ocean background is from Potassium-40. Scattering of its 1.46 MeV photons produces counts throughout the energy range of most fission product gamma-rays. The cosmic ray background is difficult to remove, because it varies with depth.

SOLUTIONS

SHAPE - Our stripping program SPEC finds peaks in the data spectrum from the few gamma-rays that retain their characteristic energy. It fits standard spectra to these peaks.

STANDARDS - We can calculate standards as needed, using our MONTE CARLO code which was verified by measurements of seventeen (17) isotopes in a 100,000 liter tank.

BACKGROUND - We measured the ocean's background from the surface to 10,000 feet. We shielded our detector with a ton of fresh water and lowered it into the ocean to measure its internal and cosmic ray backgrounds.

Software for Underwater Gamma-Ray Spectrometry

ANALYSIS OF SPECTRA REQUIRES:

Standard spectra measured with the same detector as the data.

A regression to determine the concentration of each isotope.

We wrote four programs, two to make the standards, and two to analyze the data. They are:

NAME	PURPOSE
MONTE CARLO	Calculate the spectrum observed by a detector exposed to monoenergetic gamma-rays in an infinite water medium.
MERGE	Create a standard spectrum for an isotope by combining monoenergetic spectra in proportion to the relative gamma-ray intensities of the isotope.
GAMMA	Normalize a data spectrum to the energy scale and resolution of the standard spectra. Use the natural Potassium-40 1.46 MeV peak for normalization.
SPEC	Find the concentration of isotopes by finding the amount of each standard spectrum in the data spectrum.
MREMS	Calculate the intensity of radiation fields from discrete sources. Determine isodose contours from hundreds of sources throughout a large volume.

UNIQUE FEATURES OF THE STRIPPING PROGRAM "SPEC"

SPEC was written because programs that analyze relatively clean spectra measured in the laboratory cannot analyze underwater spectra properly.

SPEC finds the photopeaks produced by the small fraction of the gamma-rays that reach the detector with their characteristic energy. It begins with the highest energy peak, finds a matching standard, and subtracts the proper amount of the standard from the data. The amount subtracted is proportional to the concentration of the isotope in the water. SPEC then analyzes the second highest energy peak, and proceeds in order through all the peaks.

Peaks that were not resolved may appear after some standard spectra are subtracted. SPEC will repeat the entire analysis a few times, so that low concentrations of isotopes may be measured.

Random noise produces many false peaks. SPEC smooths the data and tests the peaks before it analyzes them. SPEC tests the peaks after standards are subtracted, because subtractions amplify the effect of the noise. SPEC will smooth the spectrum again, if it finds too many peaks.

Unexpected isotopes cause a some programs to report a false positive. Programs which attempt to set the residual spectrum to zero will take some of the available standard(s) and make them fit the isotope for which they have no standard. SPEC makes no attempt to reduce the residual to zero. It ignores peaks for which it has no standard, and reports the residual spectrum.

ISOTOPES HAVING MORE THAN ONE CHARACTERISTIC GAMMA-RAY

Each standard spectrum includes a list of its major and minor gamma rays. The distinction is based not only on intensity, but also on energy, as higher energy gamma-rays are detected more easily than lower energy gamma-rays.

Thorium and radium daughters have many gamma-rays which could be confused with fission products. For example, peaks at 0.51 and 1.14 MeV look like zinc-65. The confusion is eliminated by testing the thorium and radium peaks at 2.62 and 1.76 MeV first.

The concentration of isotopes having more than one major gamma-ray is based on the gamma-ray which gives the lower concentration. Identifying more gamma-rays as major makes the test more rigorous. Isotopes with several peaks may be missed on the first pass through the standards. Subtraction of other isotopes reveals the missing peaks, and the isotope with several major peaks is measured on a subsequent pass.

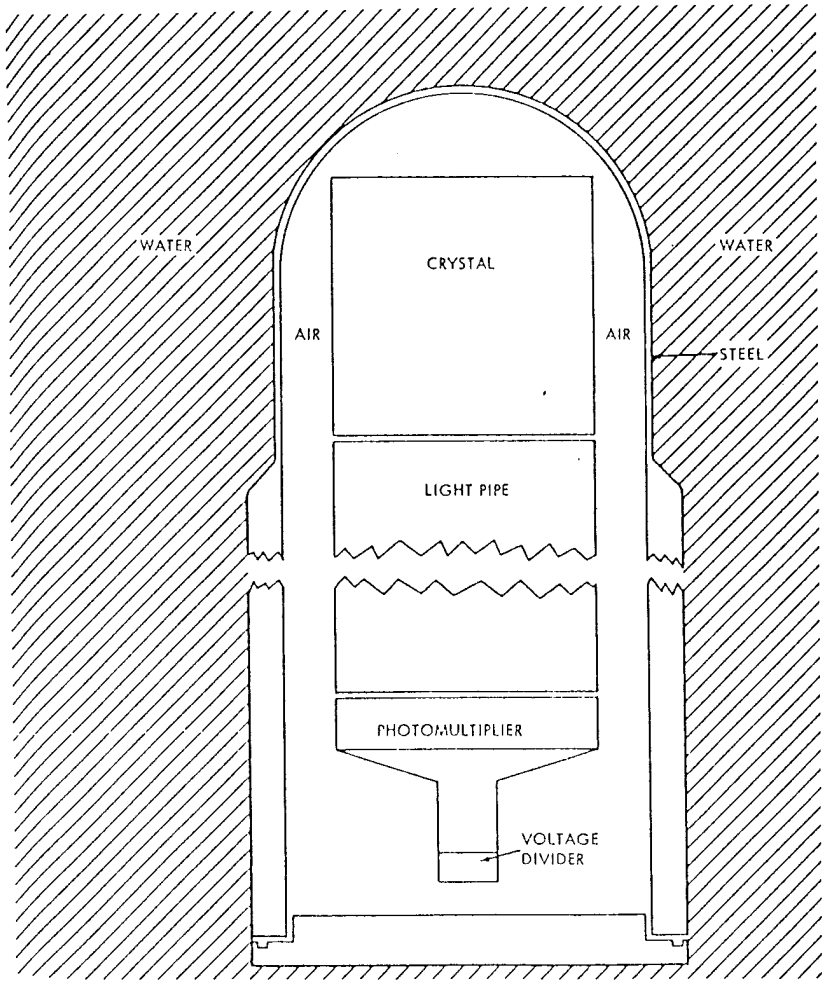
This rule is relaxed for minor peaks which may be present but not observed. If the least concentration is based on a minor peak, it is averaged with the least concentration calculated from a major peak.

Isotopes having more than one gamma-ray are analyzed before those having a single gamma-ray with the same maximum energy. Then, the isotope having a single gamma-ray is analyzed. For example: Both Iodine-131 and Cesium-137 have a photon of about 0.65 MeV. Iodine also has a photon of 0.36 MeV. It's spectrum is subtracted first. Any remaining peak at 0.66 MeV will be assigned to cesium.

Combinations of isotopes can look like an isotope with several gamma-rays. For example: a mixture of barium-133 and cesium-137 has peaks near 0.36 and 0.65 MeV, as dose iodine-131. SPEC would assign the lower concentration to iodine-131 and the remaining activity to either barium or cesium. One may avoid this error by knowing which isotopes may be present. The concentration of other isotopes is a clue to the age and thus the composition of the fission products.

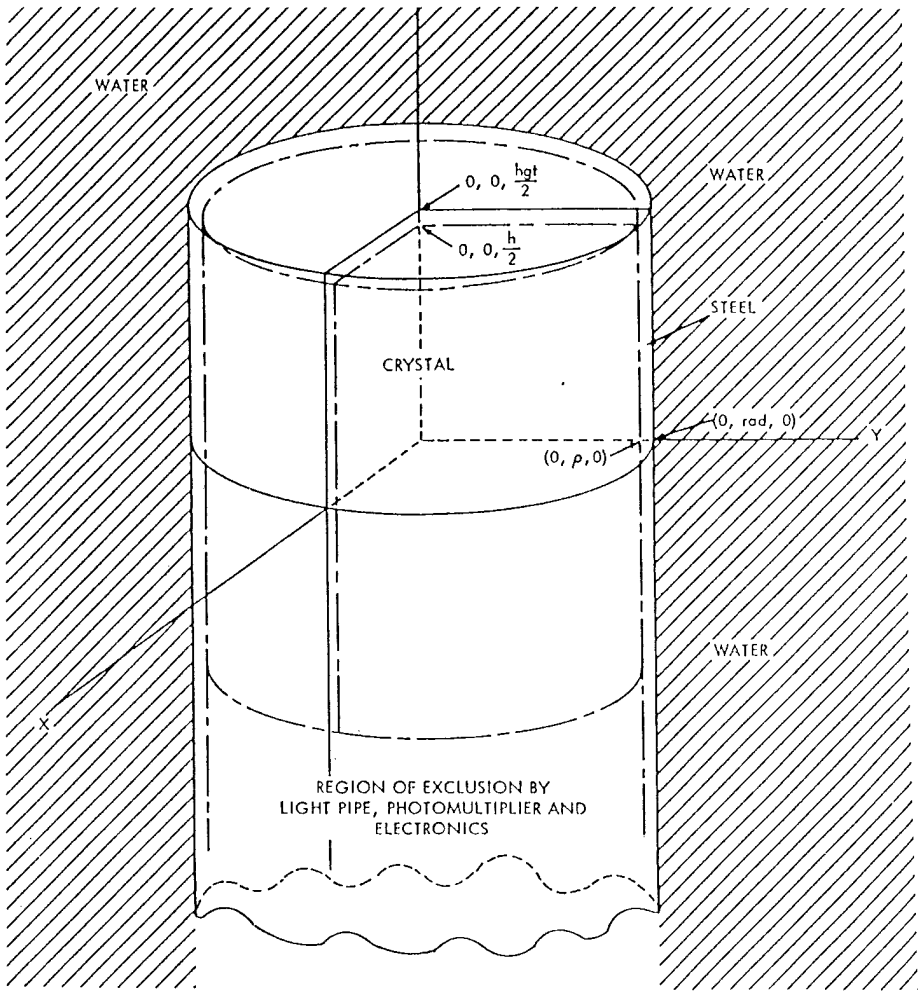
Software for Underwater Gamma-Ray Spectrometry

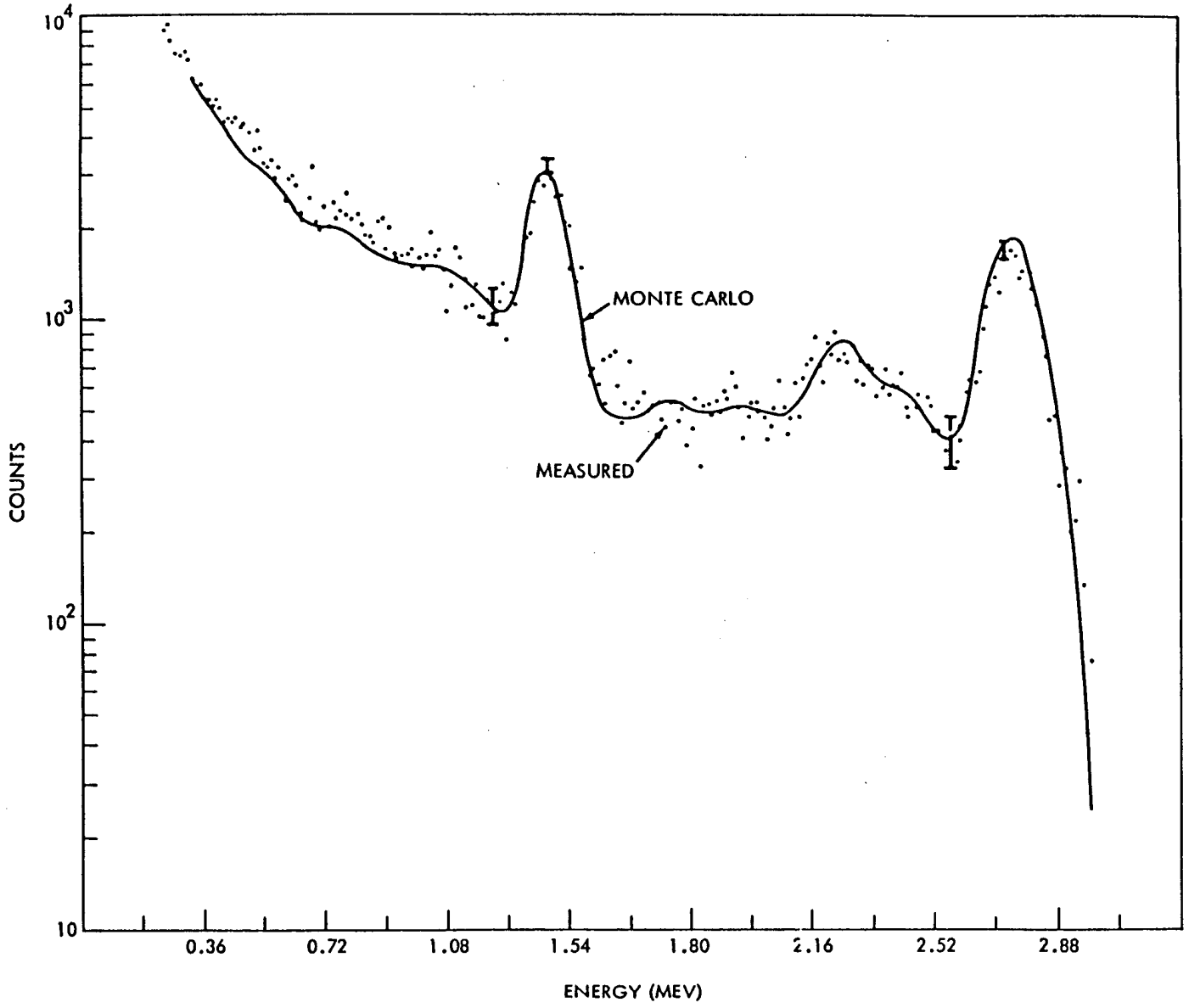
DETECTOR GEOMETRY



Software for Underwater Gamma-Ray Spectrometry

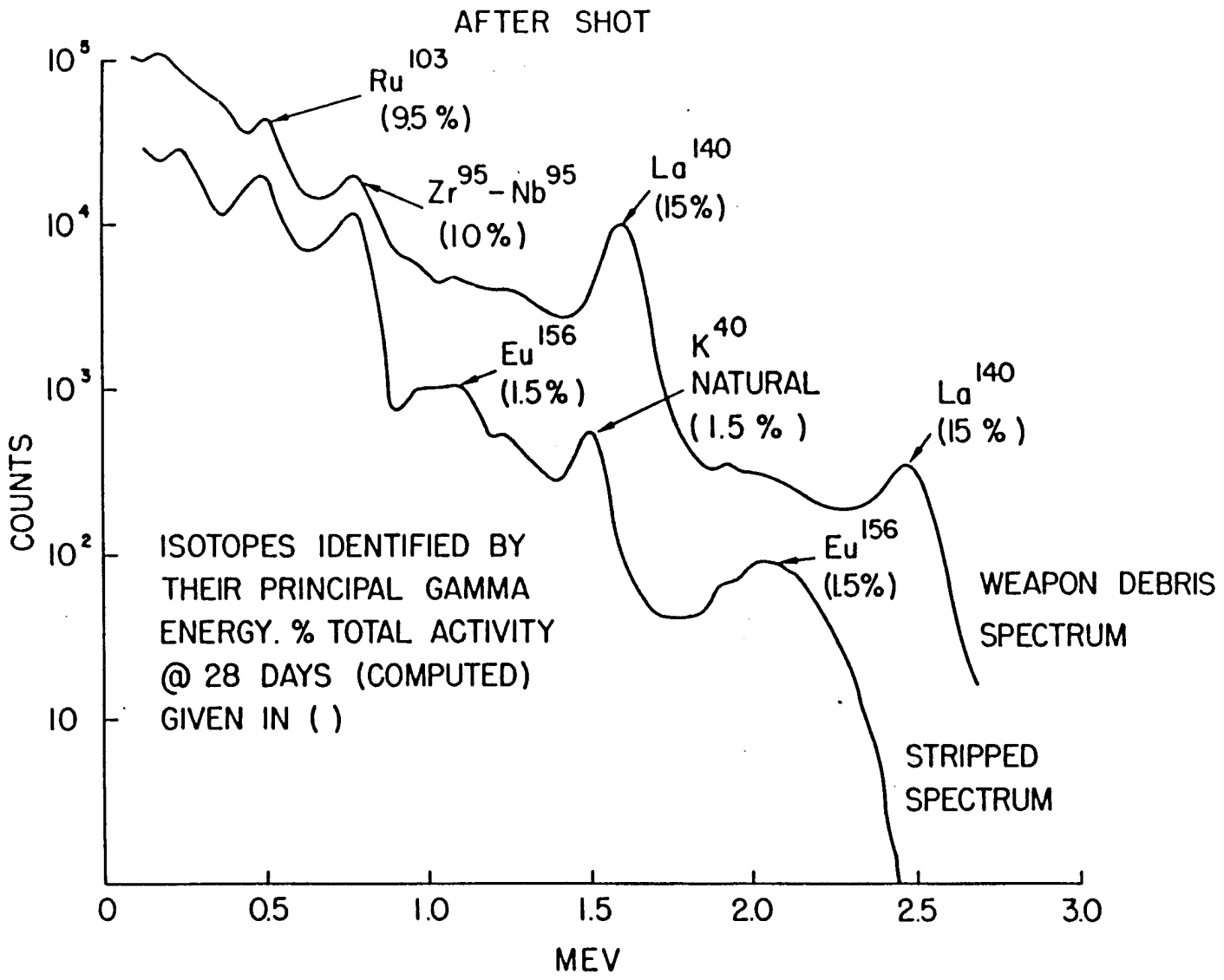
DETECTOR MODEL FOR CALCULATION





Software for Underwater Gamma-Ray Spectrometry

CALCULATED AND MEASURED SPECTRUM OF SODIUM-24



Software for Underwater Gamma-Ray Spectrometry

SUBTRACTION REVEALS ISOTOPE AT LOW CONCENTRATION

Distribution of Natural and Anthropogenic Trace Substances: Implications for Spreading of Contaminants in the Arctic Ocean

P. Schlosser, B. Ekwurzel, and G. Bönisch

[1] Lamont-Doherty Earth Observatory of Columbia University
Palisades, NY, 10964-8000, USA

Recent reports of dumping of radioactive waste in the Barents and Kara Seas (Yablokov, 1993) and the potential for industrial waste releases into the major rivers draining a significant area of the Eurasian continent has engendered a need to assess the impact on the Arctic. Rivers are a source of possible contaminants originating from the hinterland of continents. Therefore, tracing the major circulation pattern of river-runoff from the shelves into the central Arctic Ocean is an important indicator for potential contaminant pathways. Salinity, $\delta^{18}O$, and mass balances allow separation of the river-runoff and the sea-ice meltwater fraction contained in the Arctic halocline. A general understanding of water mass circulation is important for following contaminants entrained in water masses on the shelves that move into the deeper basins of the Arctic Ocean. Spreading patterns and transit times are essential for pollutant transport analysis. The tracers tritium and ^{3}He are useful for determining mean residence times of shallow waters and ^{14}C can determine residence times for the deep waters.

The stable isotope results suggest a division of the halocline waters with regard to river derived freshwater component compared to sea-ice component. The southern Nansen Basin has net sea-ice melting, moving north toward the Amundsen basin sea-ice formation and river-runoff fraction increase, and finally the Canadian Basin has a maximum river-runoff fraction. The general results for renewal times are: 1) several years for shelf waters, 2) up to one decade for surface waters, 3) several years to several decades for Atlantic water, 4) several decades for intermediate waters, 5) about 50 to 100 years for deep waters, and 6) up to about 300 years for bottom waters.

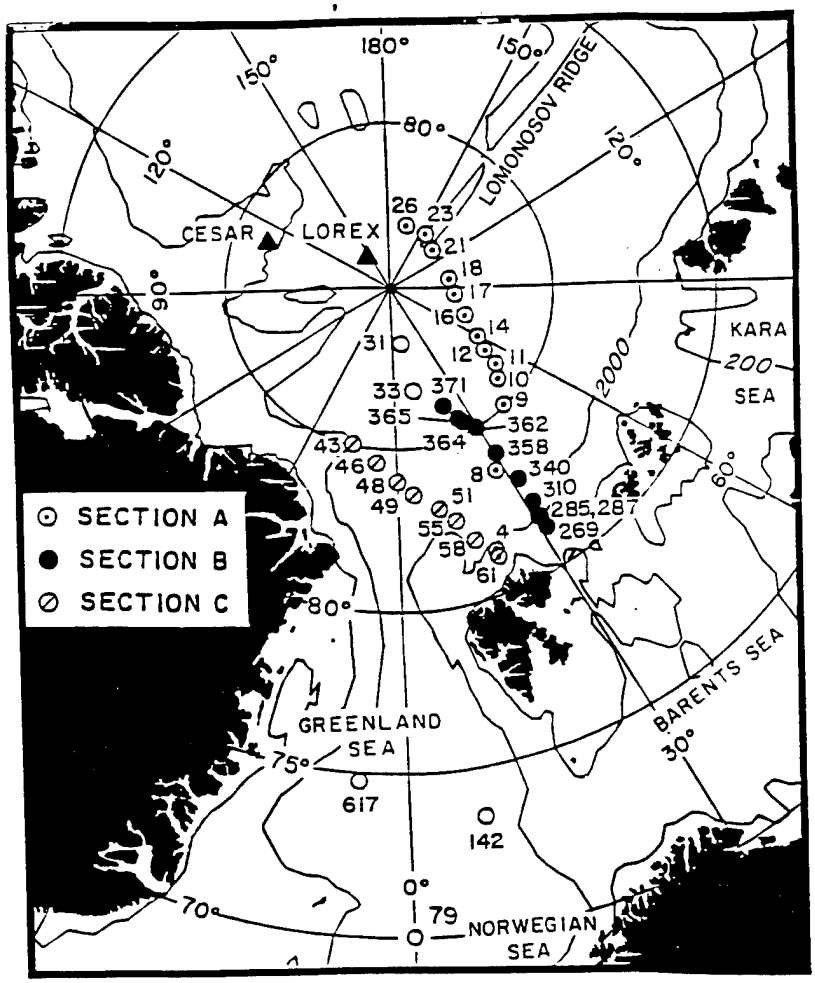


Figure 1. Station locations for the Eurasian Basin of the Arctic Ocean. Sections A and C are from the 1991 International Arctic Ocean Expedition and section B is from the ARK IV/3 cruise in 1987

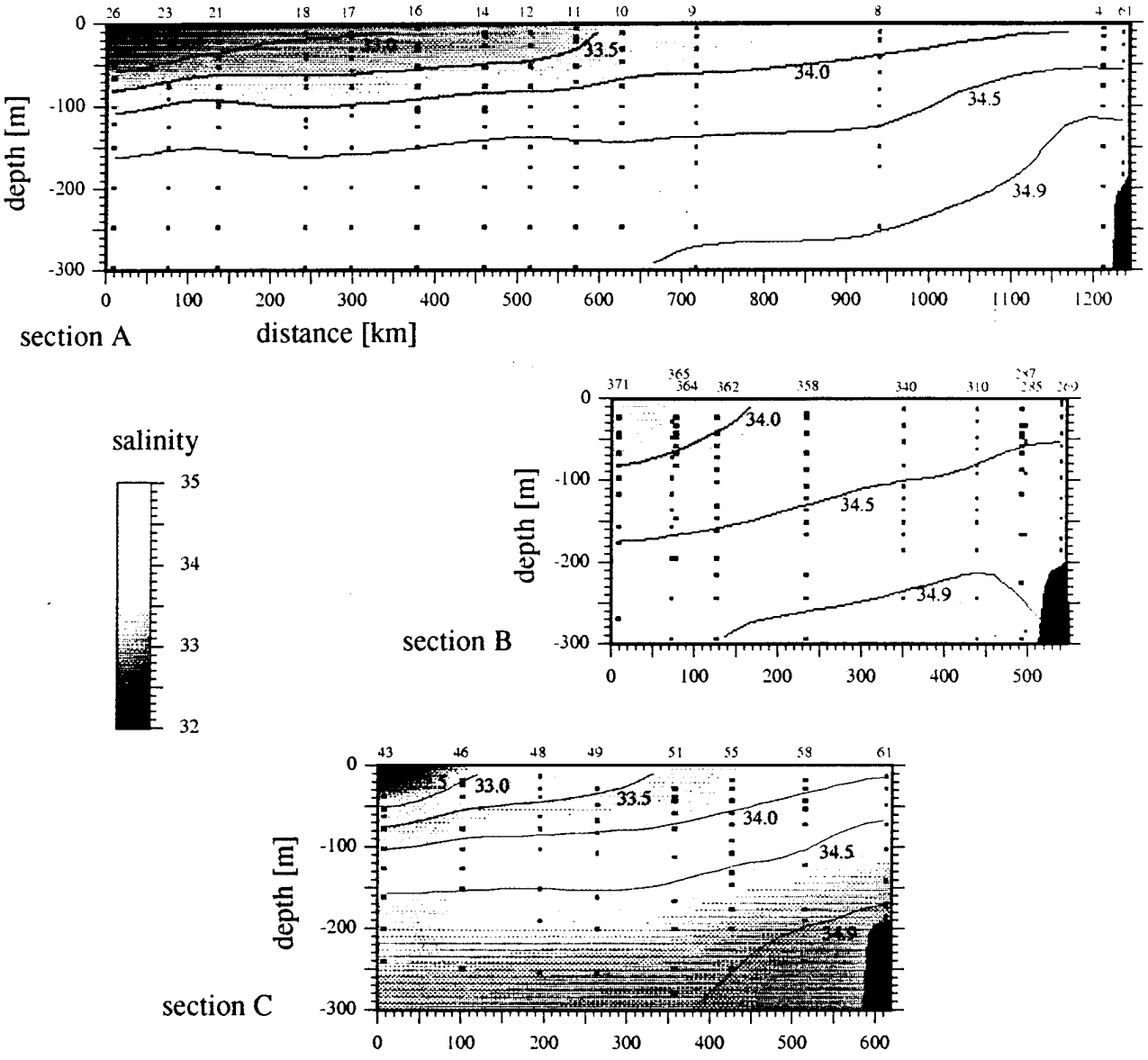


Figure 2A. Salinity for sections shown on Figure 1.
(Bauch et al., 1995; Progress in Oceanography (in Press))

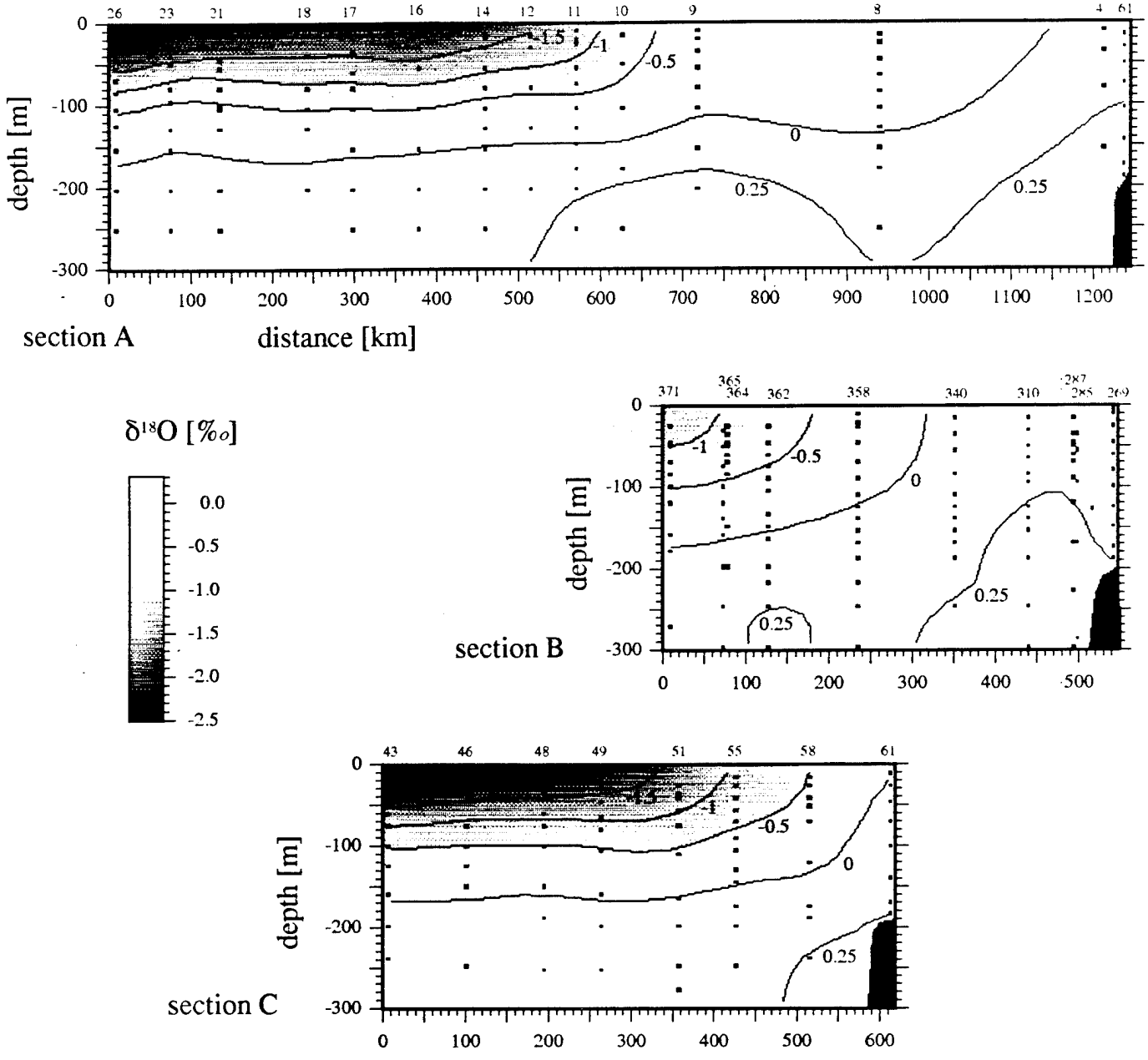


Figure 2B. Delta oxygen-18 results for sections shown on Figure 1. (Bauch et al., 1995; Progress in Oceanography (In Press))

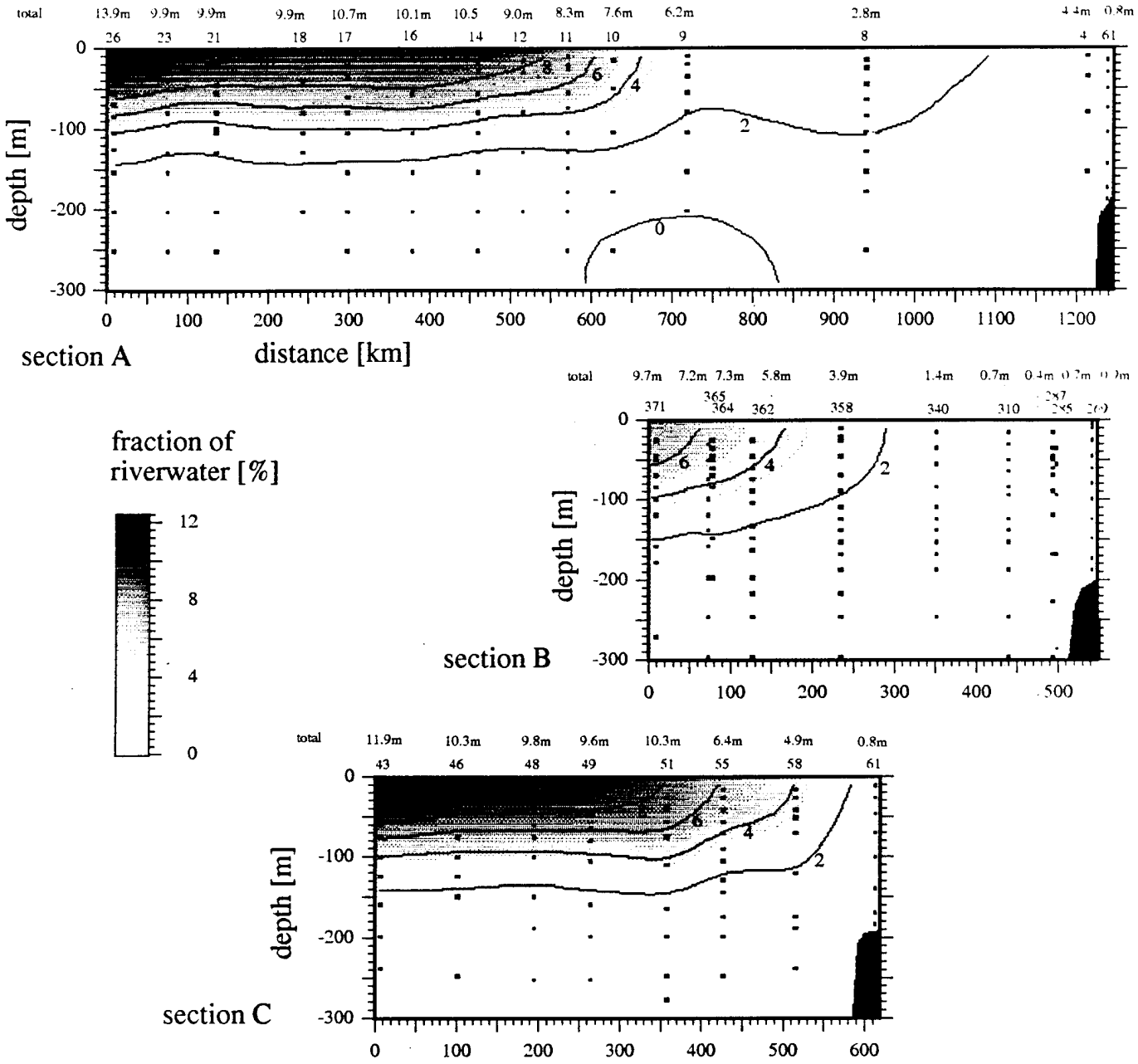


Figure 2C. Fraction of river water for sections shown on Figure 1. (Bauch et al., 1995; Progress in Oceanography (In Press))

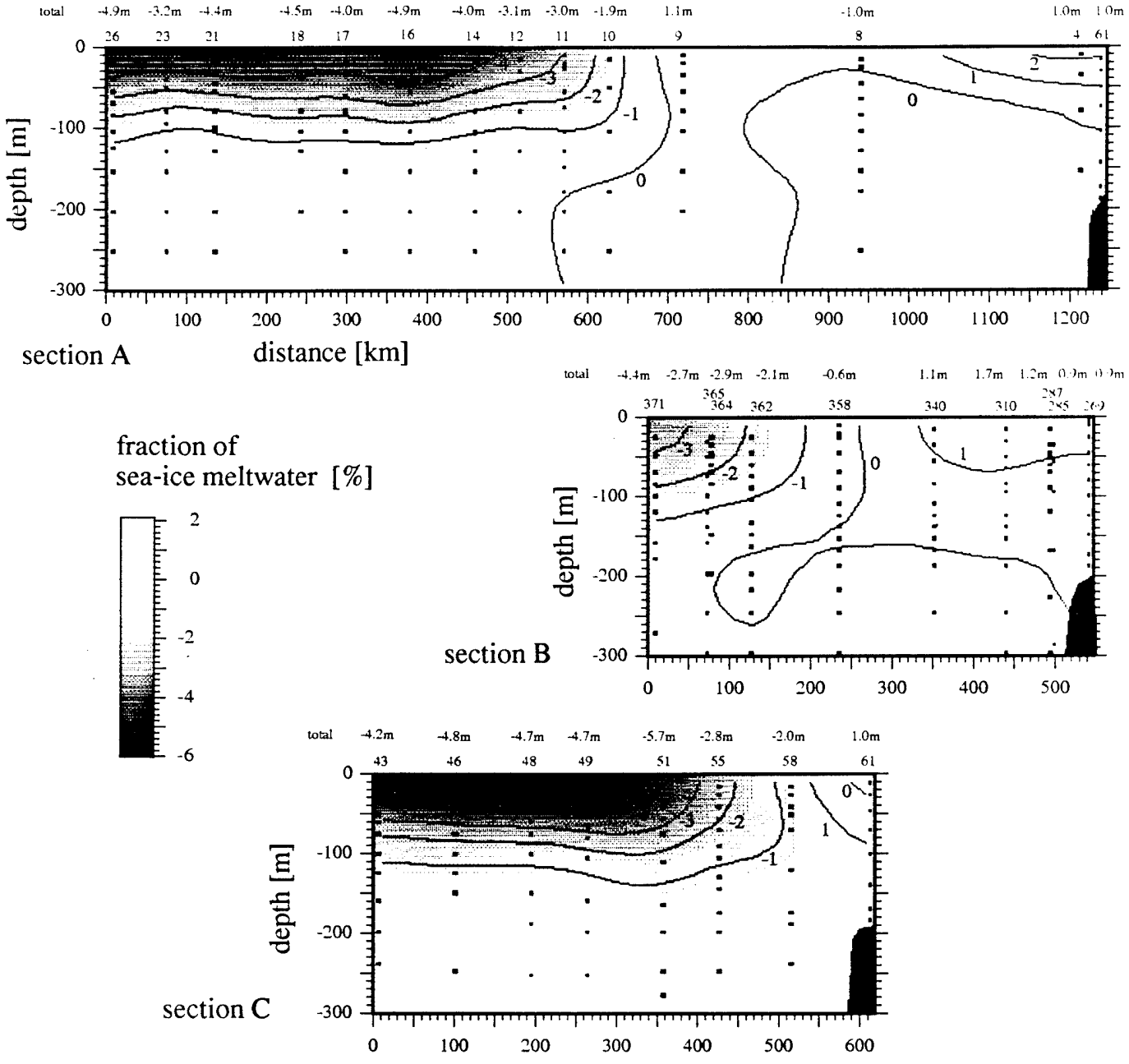
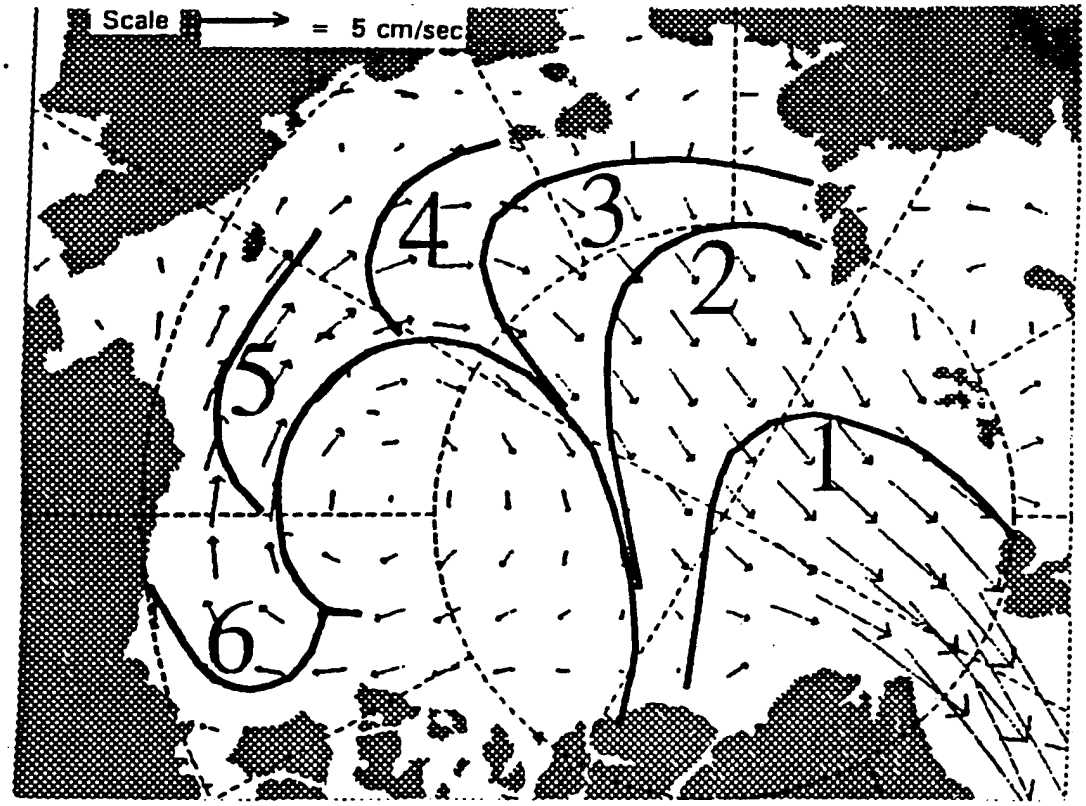


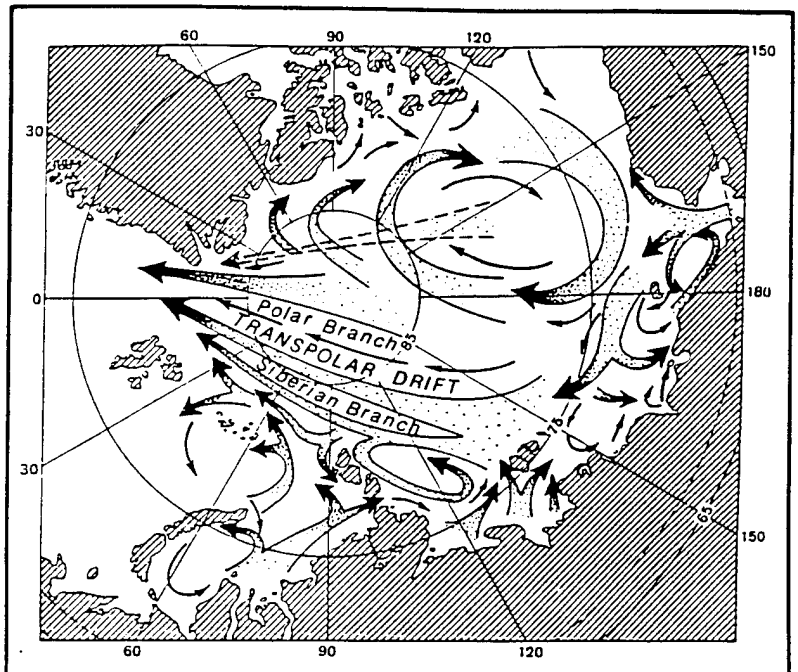
Figure 2D. Fraction of sea-ice meltwater for sections shown on Figure 1. (Bauch et al., 1995; Progress in Oceanography (In Press))

Figure 3.



Annual mean of ice motion in the Arctic Basin based on 1979 through 1990 buoy data. The superimposed lines indicate the number of years the ice resides in the Basin before exiting through Fram Strait.
(International Arctic Buoy Program, 1994)

Figure 4.



Stippled arrows show an early estimate of the average sea ice drift and upper ocean circulation patterns in the Arctic basin [adapted from *Gordienko and Laktionov*, 1969].

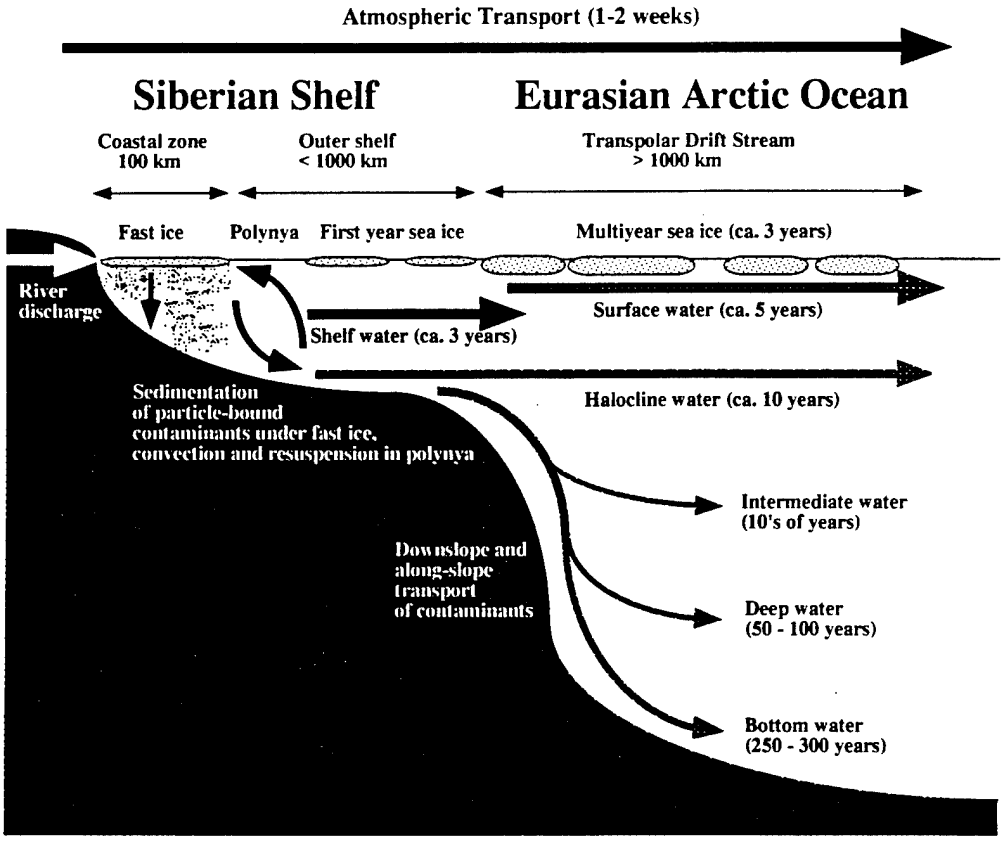


Figure 5. General processes and residence times for shelf and central Arctic ice and water masses.

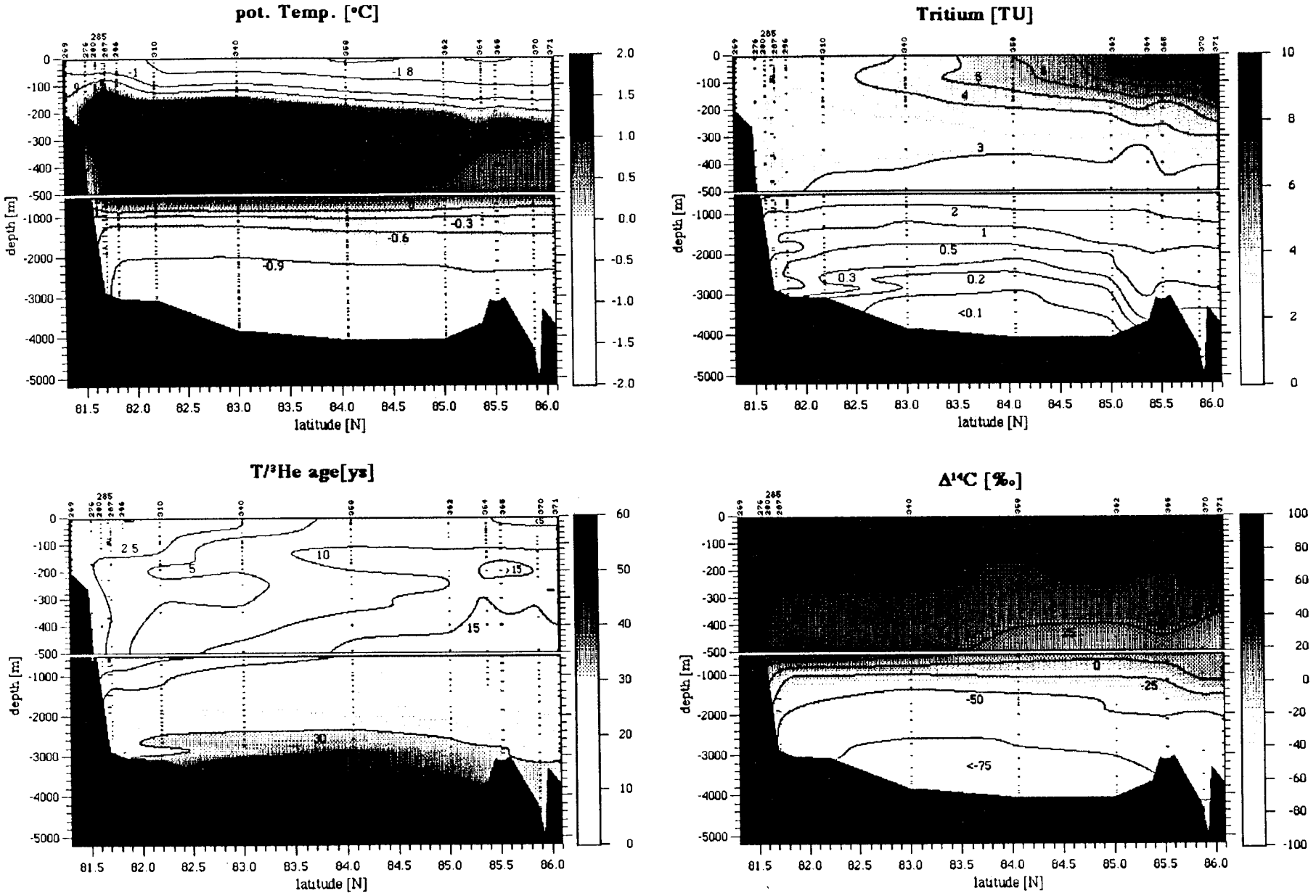


Figure 6. Results from the ARK IV/3 RV Polarstern cruise in 1987 (see section B of Figure 1).

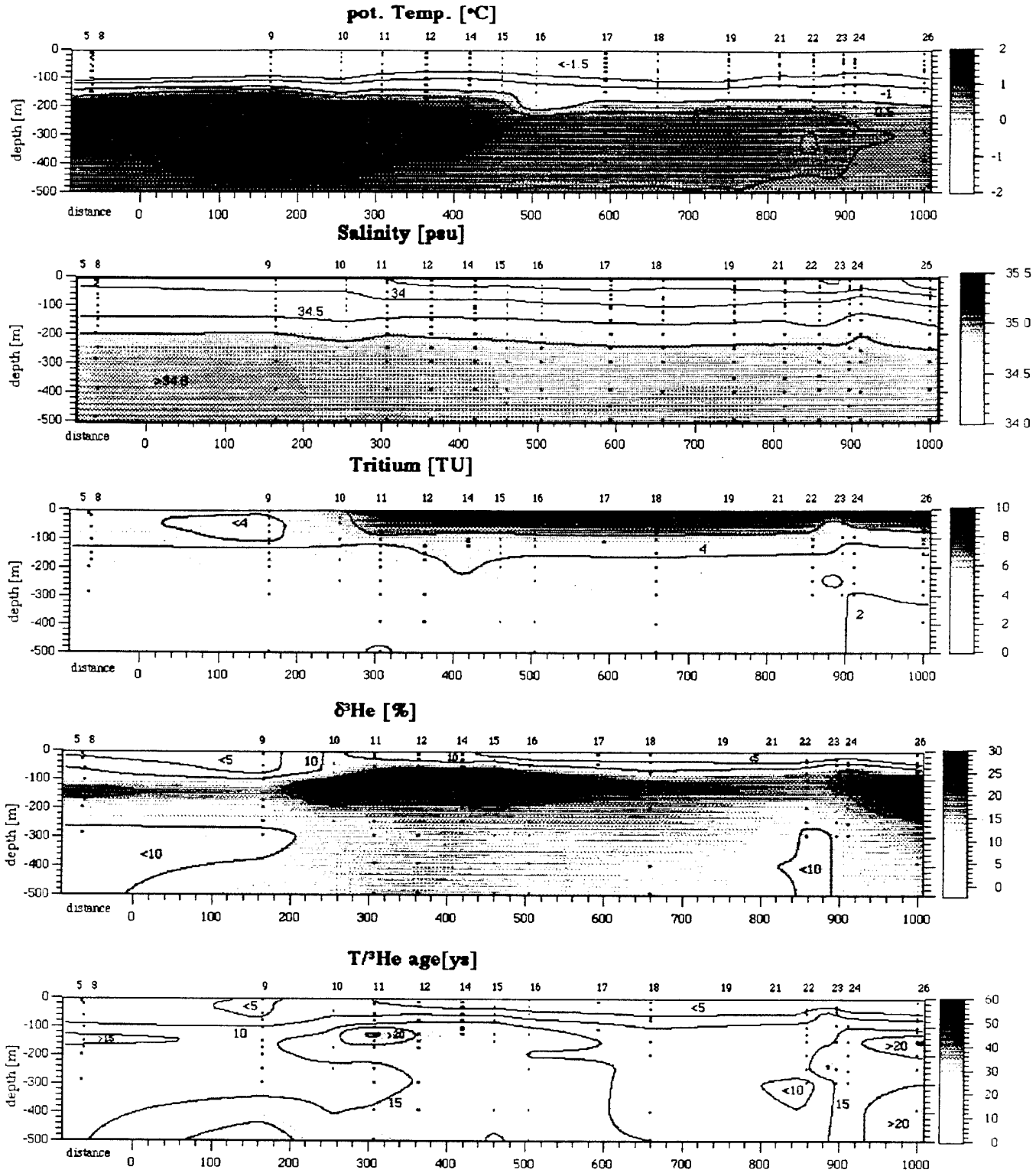


Figure 7. Results from the 1991 International Arctic Ocean Expedition (see section A and C of Figure 1).

Figure 8. Station locations for the USS Pargo Submarine cruise in 1993

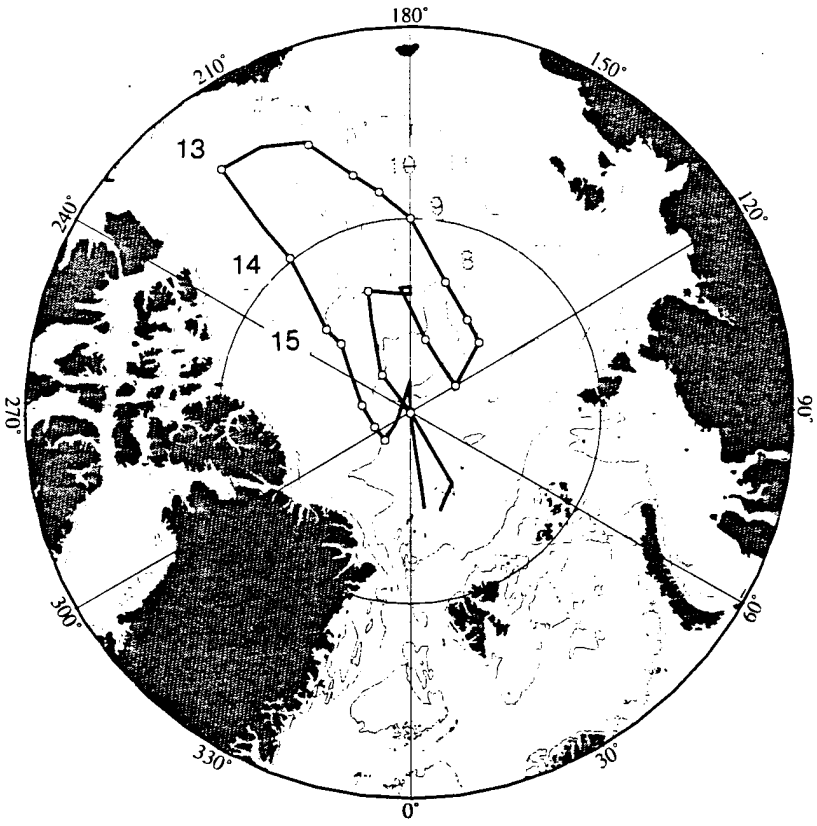


Figure 9. Preliminary results indicate a division of the upper waters in the Canadian Basin into two distinct regimes with different isolation 'ages'.

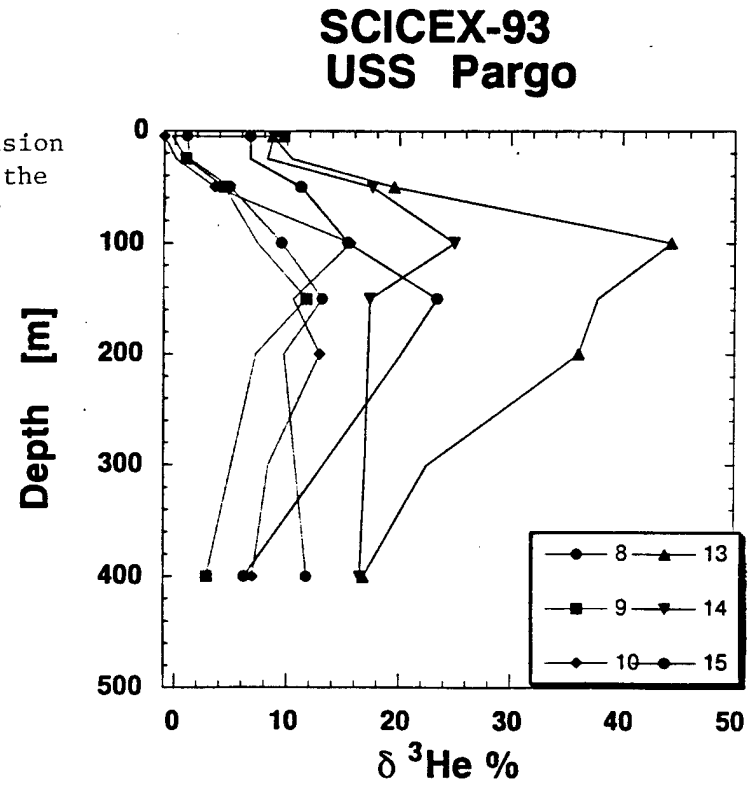
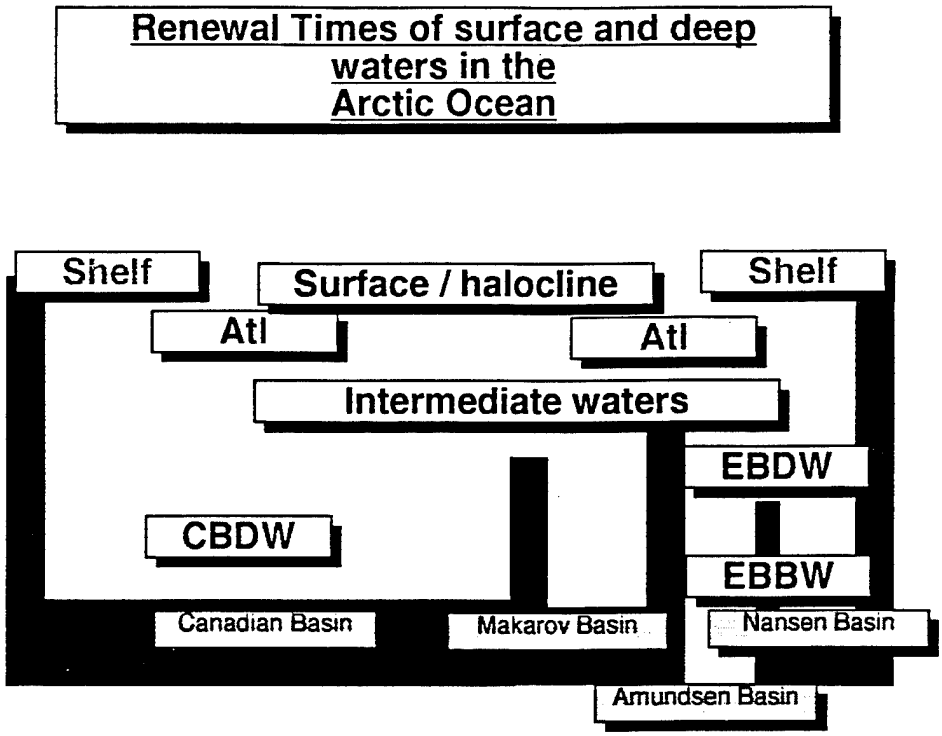
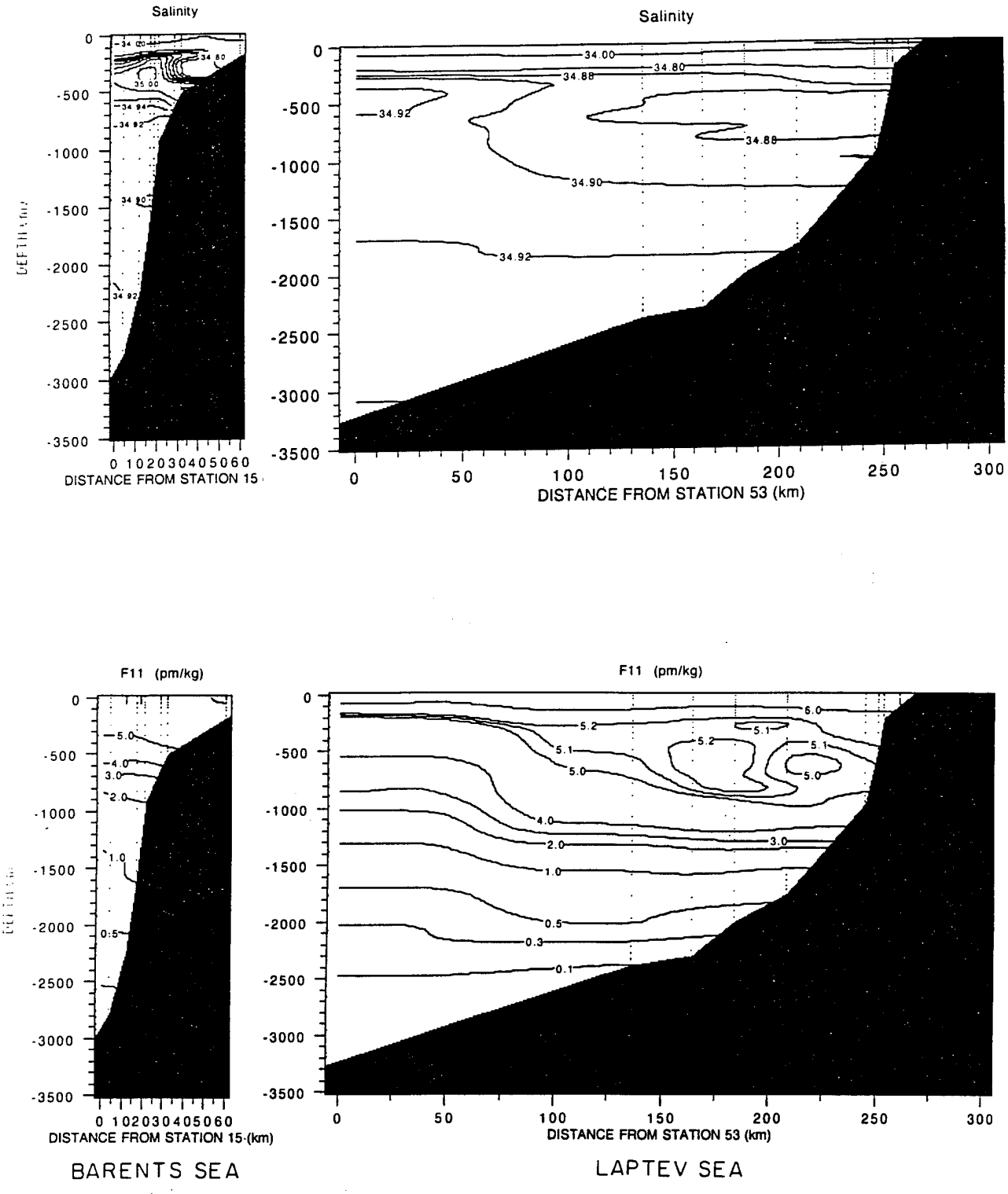


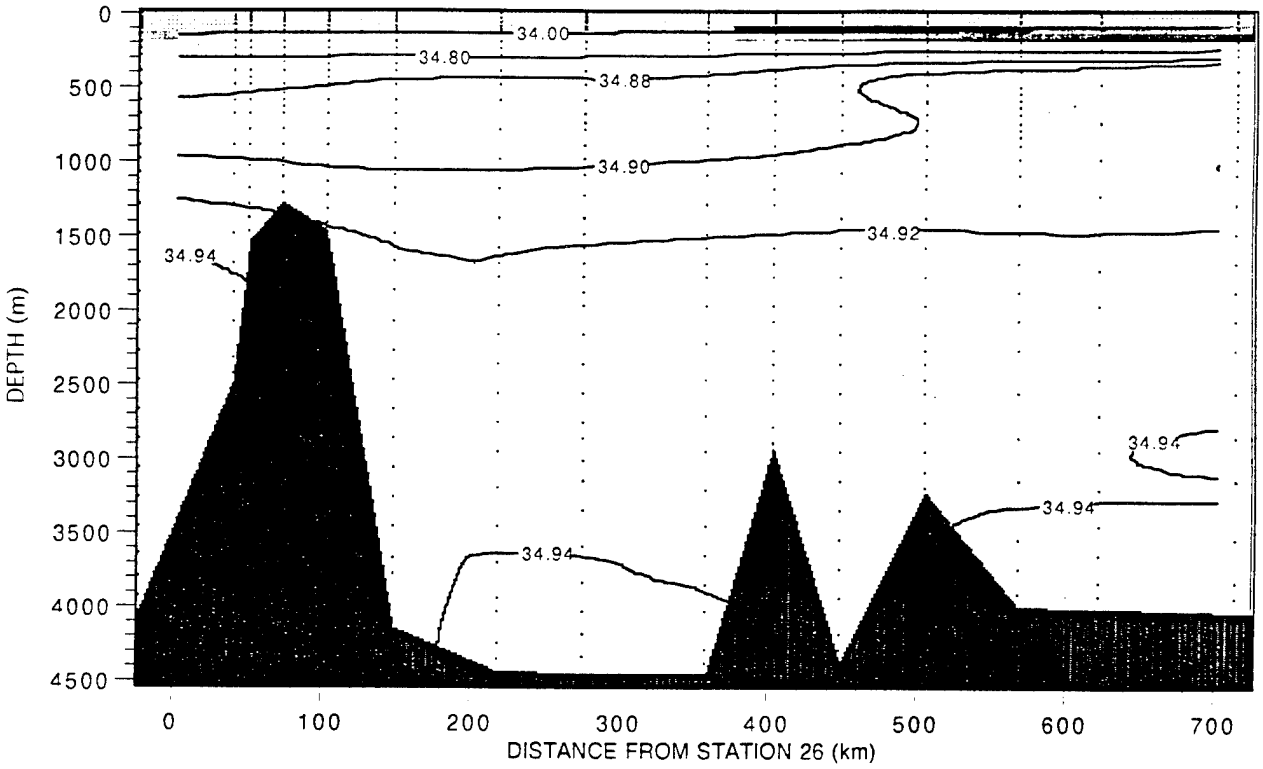
Figure 10.



Shelf	several years
Near-Surface	several years to one decade
Atlantic	several years to several decades
Intermediate	several decades
Deep waters	about 50 to 100 years
Bottom waters	up to about 300 years

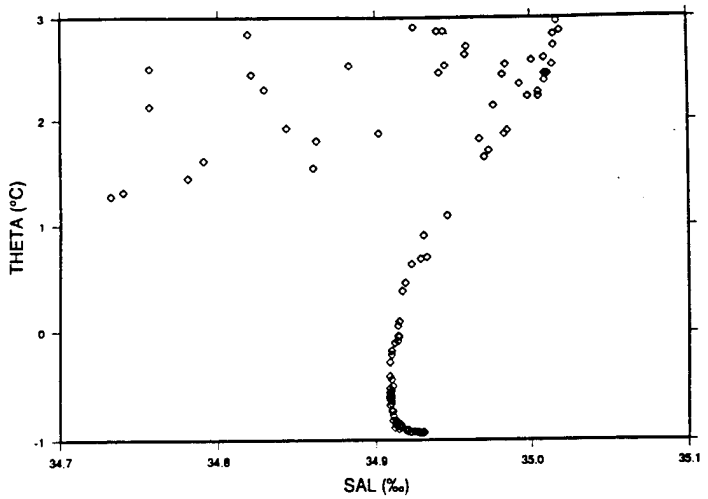


Vertical sections of salinity and F-11 for the Barents Sea slope region (Ark IX/4 stations 6-15) and the Laptev Sea slope region (Ark IX/4 stations 44-53).

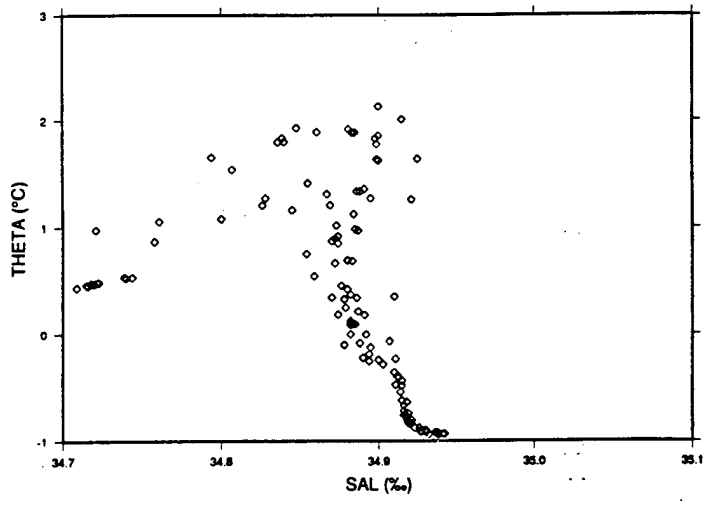


Vertical section of salinity for Oden 91 stations 9-26 (Anderson et al, 1994).

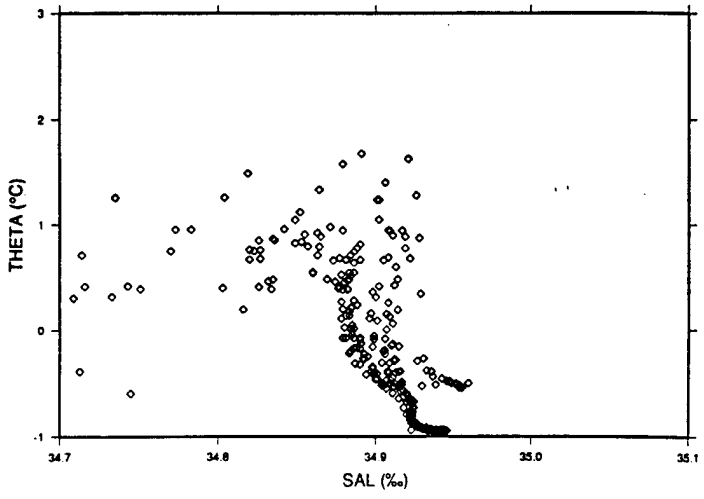
ARK IX/4 STATIONS 6-15



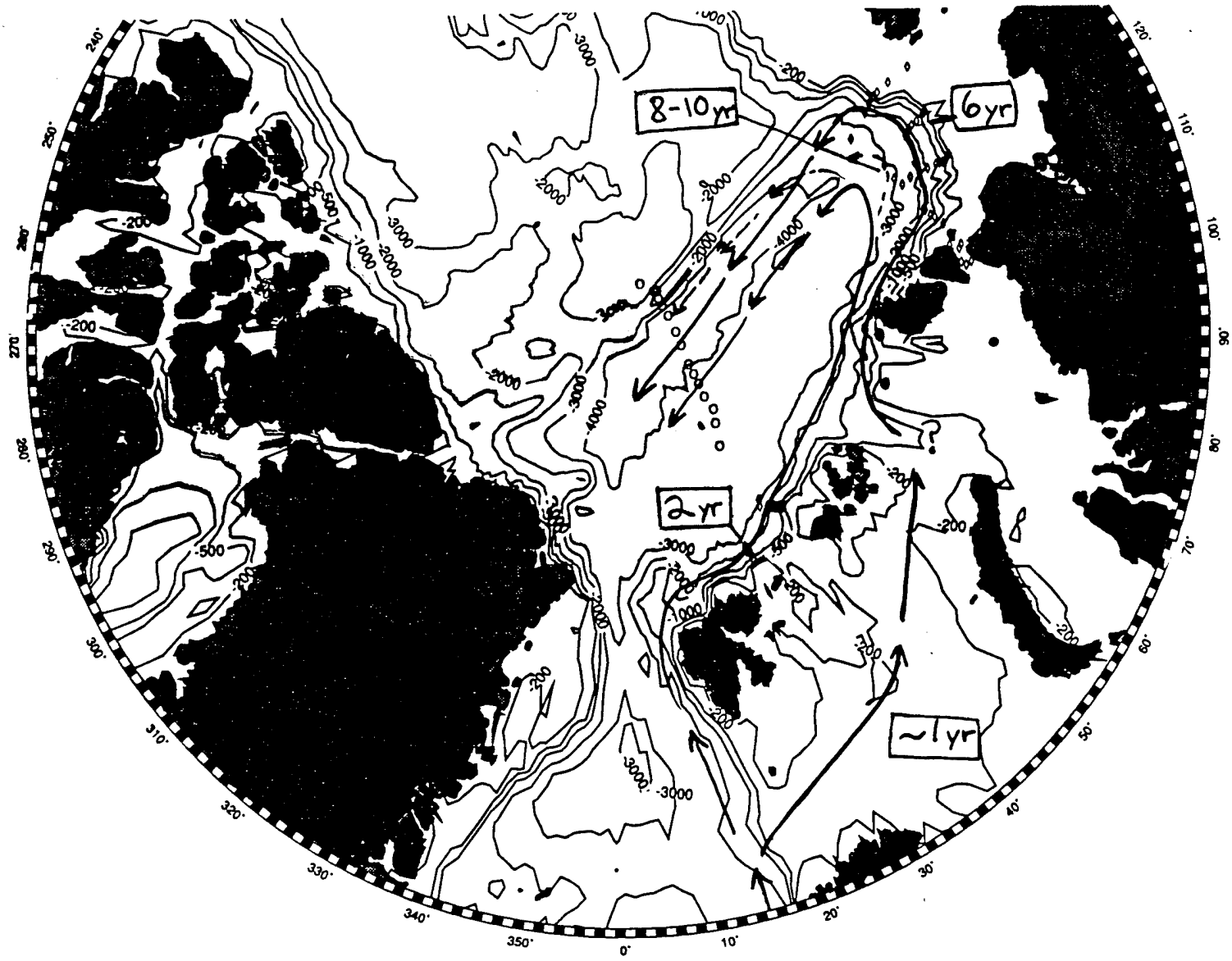
ARK IX/4 STATIONS 44-53



ODEN STATIONS 9-26



Potential temperature vs salinity for the Barents Sea slope region (Ark IX/4 stations 6-15), Laptev Sea slope region (Ark IX/4 stations 44-53), and the central Eurasian Basin (Oden 91 stations 9-26, Anderson et al, 1994).



Tritium/He-3 ages and flow paths for the Fram Strait and Barents Sea branches of Atlantic Water. The tritium/He-3 ages were determined by Markus Frank and Reinhold Bayer of the University of Heidelberg.

The Barents Sea Branch of the Atlantic Layer, a Direct Pathway to Arctic Intermediate Waters for FSU Nuclear Wastes

William M. Smethie, Jr.
Lamont-Doherty Earth Observatory
Palisades, New York 10964

Hydrographic and anthropogenic tracer data collected along the continental slopes of the Barents and Laptev seas during the summer of 1993 on the Polarstern Ark IX/4 cruise provide evidence that Atlantic water enters the Arctic in two branches, one through Fram Strait and the other through the Barents Sea, as suggested by Rudels et al (1994). The Barents Sea branch is modified by cooling and mixing with shelf and river waters and flows off the shelf as a denser water mass between the Barents and Laptev seas. After leaving the shelf, this water sinks to a depth zone of 300 - 1300 m. It has a relative low salinity indicating a shelf origin and this is confirmed by high CFC concentrations associated with the low salinity signal. The F-113/F-11 and tritium/He-3 ages for this water mass over the Laptev continental slope indicate a transport time of about 5 years from the Barents shelf region. This water displaces the Atlantic layer from the Fram Strait branch offshore. The theta/salinity characteristics of this water mass are also observed in the Amundsen Basin extending to the Lomonosov Ridge (Anderson et al, 1994) indicating this water mass is transported in a cyclonic fashion around the Eurasian Basin as proposed by Rudels et al (1994). FSU nuclear waste disposal sites are located in the Barents and Kara seas close to the region where the Barents branch of Atlantic water is transformed into a more dense water mass that then flows into the Eurasian Basin to form intermediate water. These wastes could be incorporated into the Atlantic water during its transformation and thus, injected directly into the intermediate waters of the Arctic Ocean.

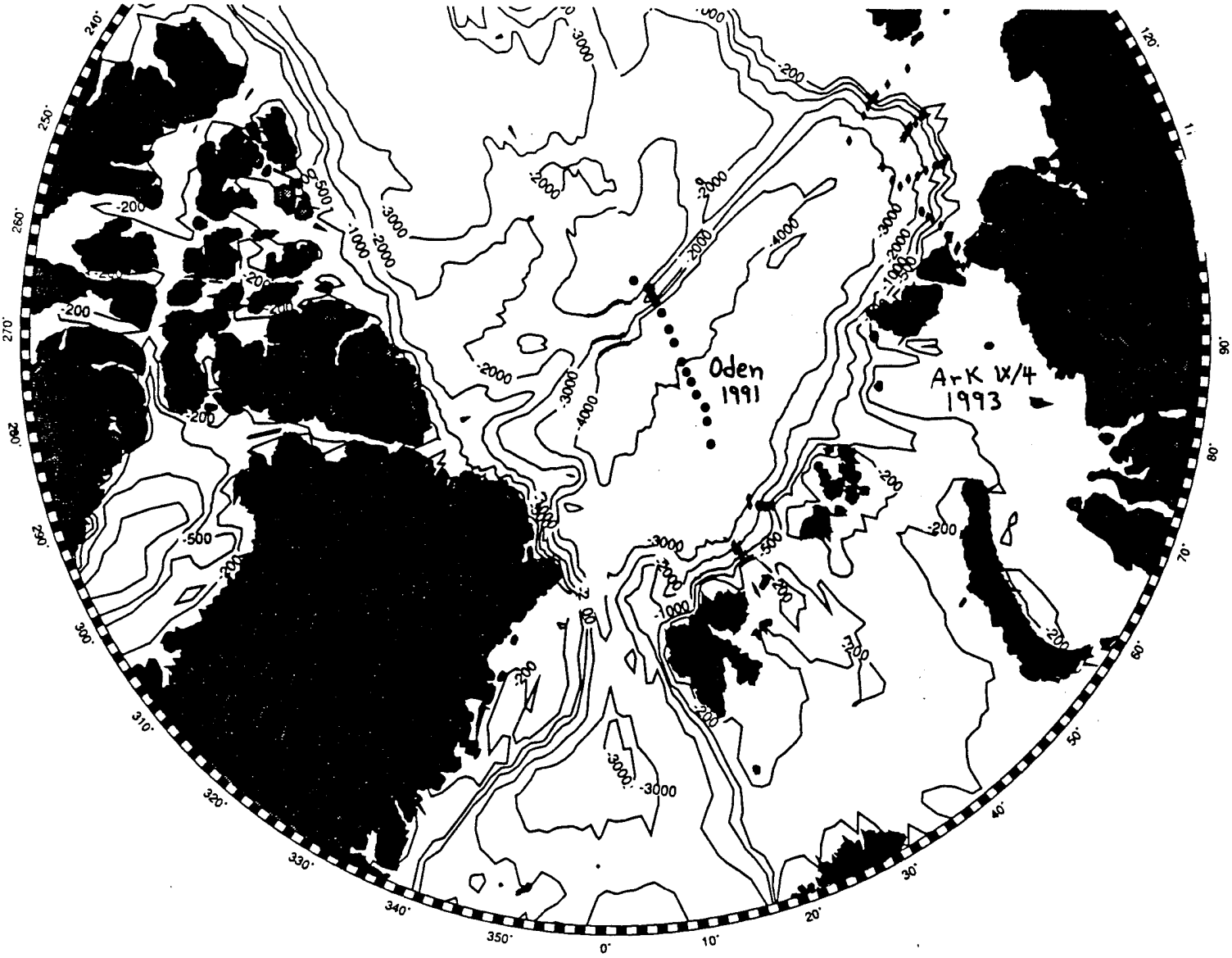
References

Anderson, L.G., G. Bjork, O. Holby, E.P. Jones, G. Kattner, K.P. Koltermann, B. Liljeblab, R. Lindegren, B. Rudels, J. Swift. 1994. Water masses and circulation in the Eurasian Basin: Results from the Oden 91 expedition. J. Geophys. Res. Oceans, 99:3273-3283.

Rudels, B., E.P. Jones, L.G. Anderson, and G. Kattner. 1994. On the intermediate depth waters of the Arctic Ocean. J. Geopys. Res. Oceans, in press.

Acknowledgments

The temperature and salinity data for the Ark IX/4 cruise were taken by U. Schauer of the Alfred Wagner Institute, the tritium and He-3 data by M. Frank and R. Bayer of the University of Heidelberg and the CFC data by G. Mathieu of LDEO. The results presented here are based on discussions with these people and with R. Muench of Science Applications Inc. and B. Rudels of the University of Hamburg who are also principle investigators for the Ark IX/4 cruise.



Station locations for the Ark IX/4 and Oden 91 cruises.

VII. Summary

A. Overview

As stated in the introduction, this workshop was focused on three questions:

- What are the monitoring requirements? What should be measured and to what sensitivity? The answers depend, of course, on the monitoring goals such as risk assessment for human populations, environmental concern in for the impacted regions, data collection for modeling the long range radionuclide transport in the Arctic or scientific investigation of transport mechanisms.

- What sensor technologies are available, either existing or on the horizon, for long term monitoring of radionuclide levels in the Arctic? The technologies considered include nuclear sensors, hydrography and oceanography instruments, support systems and communications.

- Where should in situ instruments be placed and how extensive a monitoring network is needed?

The participants were in near unanimous agreement that the workshop was both timely and necessary to begin to address the above issues. A consensus existed for the need for careful planning of a monitoring network. Monitoring within this program must be directed to target specific scientific and policy objectives. Factors such as cost, reliability, effectiveness, communications and support requirements must all be considered. The evidence gathered to date in the ANWAP program indicates a lack of an immediate radiological threat. Therefore, a monitoring program should be focused primarily on collecting data required for understanding the transport processes and secondarily as a sentinel to provide an early alert of potential future problems. For the risk assessment requirements, passive or electronic dosimetry monitored at key locations could fulfill the objective of monitoring changes that could impact human population dose. Alternatively, monitoring of food sources or other biota from the impacted regions is another means of assessing human risk. However, most participants felt more data was required. Monitoring stations should be designed for data collection to address scientific questions and not just the integrated dosimetry needed for risk assessment to human populations. This data is needed to determine the impact on radionuclide transport of the annual processes of freezing, thawing, the spring influx of fresh water and the movement of ice.

B. Radiation Detector and Related Technologies

Gamma ray spectroscopy was the emphasis of most of the radiation sensor technology papers. This is principally due to the difficulty of measuring any other radiation in situ and

the probability that γ-ray emitters would accompany most nuclear waste released into the marine environment. A few papers did present other technologies notably J.E. Koster in the use of ionization to measure alpha activity. An ionization chamber could be used to look at the alpha emission off of the water surface. An alternative approach to radiation monitoring was presented by N.S. Fisher. Instead of the placement of sensors in situ, the periodic sampling of marine biota such as bivalves or sea stars would serve as bioindicators of radionuclide releases. His laboratory research has demonstrated the retention of radionuclides in the sea star increased dramatically with lower water temperatures.

Both NaI(Tl) and high purity Germanium (HPGe) γ-ray spectrometers have been effectively adapted for underwater use. Both have been demonstrated to be capable of remote underwater measurements. HPGe detectors are not under consideration for monitoring because of the cooling requirements. These detectors must be cooled to 80 - 100 K for operation. This requires either liquid nitrogen cooling or a mechanical cooler, neither of which could be operated at remote monitoring sites for long durations. On the other hand, NaI(Tl) scintillator detectors have operated quite successfully in a variety of underwater scenarios. The problems associated with NaI(Tl) detectors are relatively poor energy resolution, temperature dependent gain changes, the bulky photomultiplier tube (PMT) design, moderately high power requirements for the PMT and fragility of the scintillator/PMT detector. Most of these problems have been surmounted by careful design and data analysis as illustrated in the presentations given by G. Reil and P. Povinec. An example of the type of system needed is the low power, ruggedized detector and electronics package with only a 1 watt power load which has been developed by Oceanor. This power load meets the requirements for long term remote monitoring.

To meet the monitoring needs of improved energy resolution, low power, and compact, rugged design, alternatives to NaI are under consideration. Room temperature semiconducting detectors such as CdZnTe, GaAs, and HgI_2 are possible candidates. Also, hybrid systems such as CsI scintillators with photodiodes replacing the PMTs may yield improved performance. S. King presented data on the performance of several of these detectors purchased from commercial vendors in rugged, waterproof housings. B. Patt also discussed the performance of a CsI/HgI_2 photodiode detector. The goal for using any of these detectors is to provide better resolution that a NaI/PMT detector with less power consumption in a rugged, compact design. Presently, commercially available detectors do not meet the monitoring requirements for sensitivity and ruggedization. The efficiency of these detectors is limited by the size currently available. Significant efforts are underway to improve the performance of semiconducting detectors. Further detector development should continue to be followed for potential use in Arctic monitoring.

C. Other Results of Interest

The following section will highlight some of the information reported during the workshop. J. Goldstein reported on a variety of potential methods for satellite

communication. Many choices will exist in the next few years utilizing the low earth orbit networks capable of high bandwidth data transmission with near continuous coverage. This aspect of communications is well developed. The more difficult issue is the communication from the sea floor or from buoys that are trapped in the ice each year. Two techniques discussed were magneto-inductive (MI) communications and high speed acoustic modems. Both techniques are limited in range. The acoustic transmission may also be limited by the ice cover. An MI concept system included a fiber optic link to a point just below the maximum ice depth. The MI link completed the transmission link to the surface or shore. Alternative schemes to arise from the workshop discussions were hardened buried fiber optics, data retrieval by AUV, a "flying plug" ROV link to a ship or the use of a retractable antenna which would be extended during the "summer" ice-free months and retracted to avoid damage by the ice for the remainder of the year.

P. Schosser reported on field work to separate the components of sea ice melting and river runoff by measuring salinity, $\delta^{18}O$ and mass balance. In the Canadian basin the surface waters were over 10% river runoff. This data should be directly comparable to modeling predictions of river water transport in the Arctic. D. Meese reported on radioassays of sediment trapped in the sea ice in the central Arctic. The ^{137}Cs activity in one sample was comparable to that reported in the Yenisey river estuary. This activity is well above the activity reported for bottom sediments in both the Kara and Chukchi seas. This has strongly suggested the possibility that sediment incorporated into ice is important in the long range transport mechanism, but the extent of the total activity being transported is unknown and should be investigated. Another report of interest was the identification by J. Smith of a Sellafield signature using the ratio of $^{129}I/^{137}Cs$ in the central Arctic.

D. Discussion Session

The Monitoring Workshop concluded with a panel-led discussion of monitoring issues. Drs. Peter Becker, Stephanie Pfirman, Ruth Preller and Pavel Povinec were the panel members, Dr. Gary Phillips reviewed the goals of the workshop and Dr. Steven King moderated the session. A brief synopsis of the major discussion points and opinions follows.

The definition of monitoring and its role within ANWAP generated a great deal of discussion. The consensus definition of monitoring was the periodic or continuous measurement of radioactivity, hydrographic, oceanographic and other related parameters. The opinions were quite varied on the role of monitoring. It was agreed that there were many possible roles for monitoring and that depending on the purpose, monitoring systems could be quite different in size, complexity and cost. Monitoring sites and instrumentation systems must carefully consider the program objectives and be targeted to address specific issues. If properly designed, a monitoring program could yield high quality data at reasonable costs. Some of the roles enumerated were:

- Risk Assessment This is the driving force for many radionuclide monitoring

programs. The discussions of the need for monitoring for risk assessment were wide ranging. This was the most controversial topic. Opinions were expressed that there never was and never will be any problems of radionuclides in the Arctic. Therefore, monitoring is not necessary. Another participant held the opinion that no periodic measurements should be taken until most of the major processes in transport, biological uptake and other scientific issues were understood. On the opposite side, the opinion was expressed that for Norway monitoring was absolutely required in order to counter alarmist reports of hazardous levels of radioactivity. It was generally agreed that based on the present knowledge, what has been dumped and what is presently in the rivers will not pose a global problem. However, regional problems may occur. Modeling for risk assessment by the IAEA demonstrated that a release rate of 1 PBq/yr over 10 years could produce a dose of several tenths of μSv/yr in the region around Dikson for native populations. However, it was also stated that a more probable release rate was two orders of magnitude lower.

- Modeling data requirements and validation Ruth Preller and others associated with modeling made a strong case for the need of measurements on a continuous basis. There is a great need for data during the 9 months in which no cruises take place, particularly during the spring thaw. Verification of model predictions and gathering of data for input to the models were both emphasized. Data is needed to determine the source terms, the present annual release rates, transport pathways and partitioning of the radionuclides. In particular the benthic sediment transport in the Kara, its variability and driving factors are not well understood. Also data on the quantity and seasonal variability of radionuclide transport from the rivers is required.

- Scientific investigation of Arctic transport processes One of the primary monitoring roles as understood by most participants is the gathering of long term data to further our understanding of the processes which are responsible for movement of radionuclides and their incorporation into the food chain. As one participant said "It is ludicrous to think that we can develop an understanding of Arctic processes by making annual expeditions at the same time every year to this region." Another point made was that the understanding of the transport of radionuclides could also aid in the understanding of the transport of chemical contaminants.

- Policy Since the original driving force behind the ONR program was public concern over the contamination of the Arctic and its impact on Alaska, the political requirements remain an important consideration. Even if risk assessment in conjunction with modeling could claim that no adverse effects would result from any present or future contamination, there is still a policy driven monitoring requirement to verify the model conclusions. It was strongly felt by several participants that we must demonstrate that these sites are "under control." In addition the US participation in AMAP commits us to perform monitoring in our sector of the Arctic.

Monitoring systems can be of almost any degree of complexity and technological development. Depending on the specific sites and goals, radiation sensors as simple as integrating and/or recording dosimeters could measure the changes in overall radiation levels. However, several participants made the point that spectrometry can provide much more information than integrating dosimeters. Gamma rays are the best candidates for monitoring radiation primarily because of measurement difficulties for alphas and betas in a marine environment. In addition the dominate components of the nuclear waste are fission fragments and activation products so γ-ray emitting radioisotopes are expected to be a component of any release. N. Fisher id point out that the some of most biologically significant isotopes for benthic biota are also the ones that are more difficult to monitor (e.g. Pu isotopes, ^{90}Sr). However, IAEA calculations of local human dose based on the consumption of fish led to the conclusion that 70% of this dose is from ^{137}Cs. Other data of importance to collect are currents, temperature, salinity, and turbidity. Finally, even though the probability of a major release was considered remote, many felt a monitoring system must be capable of responding to a major release of radionuclides by sounding an immediate alert.

A number of sites for monitoring were mentioned including tracking the return flow through the Kara Gate to the Barents Sea, pathways from the Kara into the central Arctic basin, the river estuaries, Abrosimov and Chernaya Bays. Other sites mentioned include Murmansk harbor and the Barents Sea off the Kola peninsula. A Russian, Japanese, Korean, IAEA collaboration already plans to establish a monitoring program in the Sea of Japan.

An additional topic of concern was the disposal of radiothermal generators (RTG's) used in lighthouses. At least one RTG with 30 PBq (800 KCi) of ^{60}Co was lost at sea. Several people expressed the concern that this monitoring effort should be integrated with other Arctic programs to fully utilize available resources. Another interesting suggestion is that the requirements for the Comprehensive Test Ban Treaty for the detection of underwater explosions could utilize a similar monitoring platform.

The discussion period was concluded after an hour and a half. However, the issues addressed could have been discussed for much longer. It was clear that much more discussion, in smaller groups must take place in order to plan the scope and function of future monitoring efforts.

E. Final Thoughts

The primary workshop goals as stated in the introductory talk were:

- to bring people together to address monitoring questions,
- to generate discussion and new thinking, and

- to begin planning for the design, configuration and deployment of a monitoring network.

Based on the enthusiastic response of many of the participants the first two bullets were an overwhelming success. An often heard comment was that participants were not even aware of much of the research being presented at the workshop. The workshop brought together detector R&D scientists, communications and other systems engineers, and Arctic researchers. The third goal was more elusive. Planning for monitoring will require more extensive meetings of smaller, more focused groups. General guidelines that can be derived from the workshop include:

- Keep it simple
- Determine the mission: risk assessment, transport model verification, open scientific questions, or policy requirements.
- Target specific locations such as the Ob and Yenisey rivers, Abrosimov or Chernaya Bays, and/or key outflow points from the Kara Sea such as the Kara Gate.
- Provide time series data of both radioactivity and oceanographic parameters such as current, temperature, salinity and light transmissivity for observation of the dynamic annual changes in the Arctic regions.

VIII. Annoucement of Modeling Workshop

Preliminary workshop announcement. Draft # 8 dated 10. March 1995

MODELING REQUIREMENTS FOR WATER MASS DYNAMICS, ICE AND RIVER TRANSPORTS IN THE KARA SEA

Sponsors: Office of Naval Research (proposal submitted)
Norwegian Ministry of Defence (« to be «)
The company OCEANOR (« «)

Scientific Chairman: Professor Thomas A. McClimans,
Norwegian Hydrotechnical Laboratory (SINTEF NHL)

Workshop Chairman: Oivind Grenness, Norwegian Defence Research Establishment

Host: Norwegian Defence Research Establishment (NDRE)

Time: 26 - 30. June 1995 Place: Trondheim, Norway Classification: Unclassified

The proposed workshop will concentrate on the hydro-meteorological aspects of environmental pollution in arctic waters. The problems are related to military and industrial activities.This new enemy threatens the health, economy and social structure of all circumpolar nations and their neighbors.The arctic region has had, and still has a particular military significance related to its strategic geographic location, to nuclear technology and weapons. This workshop and possible future workshops is an acknowledgement that the cold war has not reduced our ability to share knowledge, experience, resources and concerns, and join forces to defend the environment.

This workshop is intended as one step into a series of proposed workshops for scientists from the national defence research institutes in Russia, The United States and Norway, as part of the initiative taken for a joint trilateral effort to combat environmental pollution of arctic waters. Civilian experts with whom they cooperate and experts from the international community who are engaged in the general problem area of arctic marine environmental pollution should also attend.

The goal of the first workshop is to facilitate, establish and encourage communication and discussion of the present status and future requirements for information related to the understanding of the water mass dynamics, river water structure, ice dynamics and mixing processes for evaluating pollution transport in the Kara Sea, with a view to propose programs to aquire the necessary information for modeling purposes.

For further information contact:

Workshop Chairman	Oivind Grenness NDRE	Tel: + 47 33 03 32 37 Fax: + 47 33 04 78 34 E-mail: OIG@FFI.NO
Workshop Secretary	Natasha Smirnova Svalbard Mineral A/S	Tel: + 47 33 04 88 03 Fax: + 47 33 04 88 03
Scientific Chairman	Thomas A. McClimans SINTEF NHL	Tel: + 47 73 59 24 17 Fax: + 47 73 59 23 76 E-mail:Thomas.McClimans@NHL.SINTEF.NO

Preliminary agenda items:

Draft # 8, dated 10. March 1995

1. Review of available oceanographic & hydrological data:

- CTD data banks
- Current measurements
- Flux and transport assessments
- Drift buoys
- River data
- Remote sensing of the sea surface and of rivers
- Water level & tides

2. Review of available ice information:

- Ice data banks
- Ice thickness observations
- Ice drift and transport assessments
- Seasonal and climatic variations and trends
- River ice characteristics and dynamics
- Remote sensing of ice
- Ice as pollution transport agent

3. Review of available meteorological information:

- Data banks and arctic weather problems
- Arctic air-sea interaction
- Seasonal and climatic variations and trends
- Air as pollution transport agent

4. Mixing and interaction processes:

- Water mass analysis
- Wind mixing, tidal effects, current shear
- Mixing, freezing, transport and melting of resuspended sediments
- Precipitation

5. Modeling:

- Review of existing models
- Modeling requirements for field data programs

6. New technologies:

- Buoys - moored and drifting
- Towed sensor platforms
- Multispectral remote sensing
- Monitoring system communications

7. Logistics : (by russian navy)

- Russian military and territorial issues
- Russian weather and ice forecast support
- Russian harbor support facilities in Dikson

8. Workshop group activities:

- Identify problems
- Specify requirements
- Propose programs

9. Round table discussion items:

- Activities planned for 1995
- Measurement strategy and programs
- Monitoring and winter programs
- Tri-national scientific crews on future research cruises
- Information exchange
- Exchange scientist programs
- Future workshop arrangements

It is considered essential that participants are prepared for off line discussions and consultations, and that, if required, evening sessions may be scheduled. Therefore, the anticipated duration of the workshop is 5 days. Coffee, beverages and light informal canteen lunches will be included in a modest registration fee. Preliminary intent for presentations/titles are invited, as are suggestions for alternative agenda items. Presentations, including overhead viewgraphs, should be timed for 15 to 20 minutes. Question- and discussion periods will be interspersed between the presentations. Presentations must be in russian or english, interpreter assistance will be provided. English will be the working language for written material. Hard copy of presentations and viewgraphs should be submitted. in english, upon arrival to the workshop.

IX. List of Participants

LIST OF PARTICIPANTS

DR KNUT AAGAARD
POLAR SCI CTR/APPL PHYS LAB
UNIVERSITY OF WASHINGTON
SEATTLE WA 98195
Phone: 206-543-8942
Fax: 206-543-3521
E-mail: aagaard@apl.washington.edu

IHMWAR AGGARWAL
NRL, CODE 5603.2
WASHINGTON, DC 20375
Phone: (202) 767-9316

DR CLARK ALEXANDER
SKIDAWAY INST OF OCEANOGRAPHY
10 OCEAN SCIENCE CIRCLE
SAVANNAH, GA 31411
Phone: (912) 598-2329
Fax: (912) 598-2310
E-mail: clark@skio.peachnet.edu

TOM ARMBRUSTER
STATE DEPARTMENT OES/OA
21ST & C STREETS NW
WASHINGTON DC 20520
Phone: (202) 647-9098
Fax (202) 647-1106
E-Mail: None

MOSES ATTREP JR
LOS ALAMOS NATIONAL LABORATORY
MS J514
LOS ALAMOS NM 87544
Phone: (505) 667-0088
Fax (505) 665-4955
E-Mail: mattrep@lanl.gov

ROBERT AUGUST
NAVAL RESEARCH LABORATORY
CODE 6610
WASHINGTON DC 29375-5345
Phone: (202) 767-5468
Fax (202) 404-8076

IVAR BABB
NOAA NATIONAL UNDERSEA RESEARCH CENTER
1084 SHENNECOSSETT ROAD
GROTON CT 06340
Phone: (203) 445-4714
Fax (203) 445-2969
E-Mail: babb@unconnvm.unconn.edu

DR JOHN C BAJUS
OCEANEERING TECHNOLOGIES INC
501 PRINCE GEORGES BLVD
UPPER MARLBORO MD 20772
Phone: (301) 249-3300
Fax (301) 390-4025
E-Mail: JOHNBAJUS <BAJUS@ACCESS.DIGEX.NET>

AMIT BANERJEE
PRINCETON ELECTRONIC SYSTEMS
PO BOX 8627
PRINCETON NJ
Phone: (609) 799-4839
Fax: (609) 799-7743

DR MAHALINGRAM BASKARAN
TEXAS A&M UNIVERSITY AT GALVESTON
PO BOX 1675
GALVESTON TX 77551-1675
Phone: 409-740-4706
Fax: 409-740-5002
E-mail: baskaran_m@tamug2.tamu.edu

DONNA M BEALS
SAVANNAH RIVER TECHNOLOGY CENTER
BLDG 735-A D-104
AIKEN SC 29808
Phone: (803) 725-4137
Fax: (803) 725-4478

PETER BECKER
CENTER FOR COASTAL PHYSICAL OCEANOGRAPHY
ORITTENTON HALL
768 52D ST.
NORFOLK, VA 23529
Phone: (804) 683-5557
Fax: (804) 683-5550
E-Mail: becker@ccpo.odu.edu

JOHN BROZENA
NRL
CODE 7420
BLDG. 65, RM. 135
WASHINGTON, DC 20375
Phone: (202) 767-2024
Fax: (202) 767-0167

FRANK BUCHOLTZ
NRL
CODE 5675
WASHINGTON, DC 20375
Phone: (202) 767-9342
Fax: (202) 404-8645
E-mail: buchortz@nrlfs1.nrl.navy.mil

WILLIAM M. CAREY
ARPA
3701 NORTH FAIRFAX DR
ARLINGTON, VA 22203-1714
Phone: (703) 696-2355
Fax: (703) 696-2204

MICHAEL A. CHAMP
GERG
4601 NORTH FAIFAX DRIVE, SUITE 1130
FALLS CHURCH, VA 22045
Phone: 703-237-0505
Fax: 703-241-1278
E-mail: machamp@aol.com

ROB G CLEMMER
US DEPT OF ENERGY
NN-20
1000 INDEPENDENCE AVENUE SW
WASHINGTON DC 20585
Phone: (202) 586-9721
Fax: (202) 586-0485
E-Mail: rg_clemmer@PNL.gov

DR LOU CODISPOTI
CENTER FOR COASTAL &
PHYSICAL OCEANOGRAPHY
OLD DOMINION UNIVERSITY
NORFOLK VA 23529

DR LEE COOPER
ENVIRONMENTAL SCIENCES DIVISION
PO BOX 2008 MS 6038
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE TN 37831
Phone: (615) 574-5397
Fax: (615) 576-8646
E-Mail: jg9@stc10.ornl.gov

HUGH D COPELAND
NCCOSC RDTE DIV 524
53475 STROTHE ROAD RM 271
SAN DIEGO CA 92152-6320
Phone: (619) 553-2661
Fax: (619) 553-6305
E-Mail: MILnet copelan@NOSC.mil

KATHY CRANE
NAVAL RESEARCH LABORATORY
CODE 7420
CODE 4555 OVERLOOK AVENUE SW
WASHINGTON DC 20375-5345
Phone: (202) 767-2024
Fax: (202) 767-0167

FREDERICK R CRAWFORD
LAWRENCE LIVERMORE NATIONAL LAB
MS L58
P O BOX 808
LIVERMORE CA 94550
Phone: (510) 422-8178
Fax: (510) 422-5102
E-Mail crawford10@llnl.gov

DR THOMAS CURTIN
OFFICE OF NAVAL RESEARCH
CODE 322
800 N QUINCY ST
ARLINGTON VA 22217
Phone: 703-696-4119
Fax: 703-696-2710
E-mail: curtint@onrhq.onr.navy.mil

DR TED DELACA
UNIVERSITY OF ALASKA FAIRBANKS
P O BOX 757560
301 SIGNERS HALL
FAIRBANKS AK 99775-7560
Phone: (907) 474-7314
Fax: (907) 474-7225

JOHN M. DIAMANTE
1614 SHERWOOD ROAD
SILVER SPRING, MD 20902
Phone: (202) 260-4877
Home: (301) 681-7759

LT JAMES DISHAW
AFTAC
1030 S HIGHWAY A1A
PATRICK AFB FL 32925-3002
Phone: (407) 494-7250
Fax: (407) 494-5460
E-Mail: JDISHAW@RAYLEIGH.AFTAC.GOV

MR ROBERT DYER
OFFICE OF RADIATION AND INDOOR AIR
US ENVIRONMENTAL PROTECTION AGENCY
401 M STREET SW (6603J)
WASHINGTON DC 20460
Phone: 202-233-9290
Fax: 202-233-9629

DOUGLAS C ECHERT
NORTHWEST RESEARCH ASSOCIATES
SUITE 220 BUILDING 7
300 120TH AVENUE NE
BELLEVUE WA 98009
Phone: (206) 453-8141
Fax: (206) 646-9123
E-Mail: skip@nwra.com

LEWIS ECHOLS
ARPA/NMRO
3701 N. FAIRFAX DR.
ARLINGTON, VA 22153
Phone: (703) 696-2244
Fax: (703) 696-2203
E-mail: lechols@arpa.mil

LT ROBERT EDSON
OFFICE OF NAVAL RESEARCH
CODE 322
800 N QUINCY ST
ARLINGTON VA 22217
Phone: 703-696-4104
Fax: 703-696-2710
E-mail: edsonr@onrhq.onr.navy.mil

DR DEWARD W EFURD
CHEMICAL SCIENCE AND TECHNOLOGY
MS J514
LOS ALAMOS NATIONAL LABORATORY
LOS ALAMOS NM 87545
Phone: (505) 667-2437
Fax: (505) 665-4955
E-Mail: dwe@lanl.gov

BRENDA EKWURZEL
LAMONT-DOHERTY EARTH OBSERVATORY
PALISADES, NY 10964-8000
Phone: (914) 365-8703
Fax: (914) 365-8155
E-mail: brendae@ldeo.columbia.edu

DR W. T. ELAM
NAVAL RESEARCH LABORATORY
CODE 6685
4555 OVERLOOK AVENUE SW
WASHINGTON DC 20375-5345
Phone: (202) 767-3014
Fax: (202) 767-4868
E-Mail: elam@anvil.nrl.navy.mil

KELLY FALKNER
COLLEGE OF OCEANIC AND ATMOSPHERIC SCIENCES
OREGON STATE UNIVERSITY
CORVALLIS OR 97331
Phone: (503) 737-3625
Fax: (503) 737-2064
E-Mail: KFALKNER@OCE.ORST.EDU

DR NICHOLAS FISHER
MARINE SCIENCE RESEARCH CENTER
STATE UNIVERSITY OF NEW YORK
STONY BROOK NY 11794
Phone: (516) 632-8649
Fax: (516) 632-8820
E-mail: NFISHER@CCMAIL.SUNYSB.EDU

DR DAN R FORTNEY
DSR CORPORATION
CENTER FOR MONITORING RESEARCH
1401 WILSON BLVD SUITE 1100
ARLINGTON VA 22209
Phone: (703) 276-7900
Fax: (703) 243-5379
E-Mail: FORTNEY@BENO.CSS.GOV

MALCOLM FOWLER
LOS ALAMOS NATIONAL LABORATORY
MS J514
GROUP CST-11
LOS ALAMOS NM 87545
Phone: (505) 667-5439
Fax: (505) 665-4955
E-Mail: 083775@INLdp3.lanl.gov

MARK FUHRMANN
BROOKHAVEN NATIONAL LAB
BUILDING 830
UPTON NY 11973-5000
Phone: (516) 282-2224
Fax: (516) 282-4486
E-Mail: FUHRMAN1@BNL.GOV

CAPT CHARLES B. GALLEY
ARMED FORCES RADIOBIOLOGY RESEARCH INST
RADIATION SOURCES DEPT.
8900 WISCONSIN AVE.
BETHESDA, MD 20889-5603
Phone: (301) 295-1048
Fax: (301) 295-0735

CAPT J D GEORGE MSC USN
NAVAL DOSIMETRY CENTER
NATIONAL NAVAL MEDICAL CENTER
BETHESDA MD 20889-5614
Phone: (301) 295-5422
Fax: (301) 295-5981

JOSEPH A GOLDSTEIN
NAVAL RESEARCH LABORATORY
CODE 5554
4555 OVERLOOK AVENUE SW
WASHINGTON DC 20375-5337
Phone: (202) 767-3029
Fax: (202) 767-3377
E-Mail: goldstei@ITD.nrl.navy.mil

OIVIND GRENNESS
NORWEGIAN DEF RES ESTABLISHMENT
PO BOX 115
N-3191 HORTEN
NORWAY
Phone: +47 33 03 32 37
Fax: +47 33 04 78 34
E-Mail OIG@FFI.NO

OIVIND GRENNESS
NORWEGIAN DEF RES ESTABLISHMENT
PO BOX 115
N-3191 HORTEN
NORWAY
Phone: +47 33 03 32 37
Fax: +47 33 04 78 34
E-Mail OIG@FFI.NO

CHRISTOPHER GUAY
OREGON STATE UNIVERSITY
COLLEGE OF OCEANIC & ATMOSPHERIC SCIENCES
OCEAN ADMIN BLDG. 104
CORVALLIS, OR 97331-5503
Phone: (503) 737-3971
Fax: (503) 737-2064
E-Mail: cgway@oce.orst.edu

DR JAWED HAMEEDI
NOAA/NOS/ORCA2
1305 EAST WEST HIGHWAY
SILVER SPRING MD 20910
Phone: (301) 713-3034 (EXT 170)
Fax: (301) 713-4388
E-Mail: JHAMEEDI%R%D@C.DOC.GOC

DAVE HARRIS
LAWRENCE LIVERMORE NATL LAB, L205
P O BOX 808
LIVERMORE CA 94550
Phone: (510) 423-0617
Fax: (510) 423-4077
E-Mail: DBH@S18.ES.LLNL.GOV

RALPH L. HASTINGS
DEPT. OF ENERGY
GA-033/NN-21
PO BOX 45157
WASHINGTON, DC 20026
Phone: (202) 586-0736
Fax: (202) 586-0485

ALAN K HAYASHIDA
NAVAL UNDERSEA WARFARE CENTER DET
ARCTIC SUBMARINE LAB CODE 9062
49250 FLEMING ROAD
SAN DIEGO CA 92152-7210
Phone: (619) 553-7445
Fax: (619) 553-0972
E-Mail: alan@manta.nosc.mil

MICHAEL HIGHTOWER
OCEANEERING TECHNOLOGIES INC
501 PRINCE GEORGES BLVD
UPPER MARLBORO MD 20772
Phone: (301) 249-3300
Fax: (301) 249-4022

KEN HILL
PRINCETON PLASMA PHYSICS LAB
PO BOX 451
PRINCETON NJ 08543
Phone: (609) 243-2088
Fax: (609) 243-2418
E-Mail: HILL@PPPL.GOV

F. ALLAN HILLS
US GEOLOGICAL SURVEY, MS 939
BOX 25046 FEDERAL CENTER
DENVER CO 80225
Phone: (303) 236-5542
Fax: (303) 236-0459
E-Mail: fahills@sedproc.cr.usgs.gov

DR CHARLES HOLLISTER
WOODS HOLE OCEANOGRAPHIC INSTITUTION
WOODS HOLE MA 02543
Phone: (508) 457-2000 (Ext 2501)
Fax: (508) 457-2190
E-mail: chollister@whoi.edu

DR ROBERT W HOLST
NAVAL RESEARCH LABORATORY
CODE 6601
WASHINGTON DC 20375-5345
Phone: (202) 767-2990
Fax: (202) 767-3709

GI HOON HONG
KOREAN OCEAN RES & DEV INSTITUTE
PO BOX 29 ANSAN
SEOUL 425-600
KOREA
Phone: 82-345-400-6180
Fax: 82-345-408-5822
E-Mail: ghhong@sari.kordi.re.kr

BURT HURDLE
NAVAL RESEARCH LABORATORY
CODE 7103
WASHINGTON, DC 20375
Phone: (202) 767-3489
Fax: (202) 767-0167

DAVID HUTCHINS
MARINE SCIENCES RESEARCH CENTER
STATE UNIVERSITY OF NEW YORK
STONY BROOK NY 11794-5000
Phone: (516) 632-8649
Fax: (516) 632-8820
E-Mail: dahutchins@ccmail.sunysb.edu

LAWRENCE M JENDRO
US COAST GUARD, COMMANDANT (G-NIO-3)
2100 SECOND STREET SW
WASHINGTON DC 20593-0001
Phone: (202) 267-1457
Fax: (202) 267-4425
E-Mail: L.JENDRO/G.NIO@CGSSMTP.COMDT.USCG.MIL

DR LEONARD JOHNSON
GERG
4601 NORTH FAIRFAX DRIVE, SUITE 1130
ARLINGTON VA 22203
Phone: (703) 525-7201
Fax (703) 525-7206
E-mail: GLJGERG1@AOL.COM

WARNICK J. KERNAN
EG&E/EM
RSL-21
P O BOX 1912
LAS VEGAS NV 89125
Phone: (702) 794-1044
Fax: (702) 295-8040
E-Mail: KERNAN-WJ@EGG.NV.DOE.GOV

GREG KLUNDER
LAWRENCE LIVERMORE NATIONAL LABORATORY
PO BOX 808, L-371
LIVERMORE CA 94550
Phone: (510) 423-5083
Fax: (510) 424-6617
E-Mail: glklunder@lbl.gov

T. KOOIJ
ARPA
3701 NORTH FAIRFAX DR
ARLINGTON, VA 22203-1714

JAMES E KOSTER
LOS ALAMOS NATIONAL LABORATORY
MS J561
LOS ALAMOS NM 87545
Phone: (505) 667-3346
Fax: (505) 665-9277
E-Mail: JKOSTER@GODIVA.LANL.GOV

DR ROBERT LAMONTANE
NAVAL RESEARCH LAB
CODE 61182
WASHINGTON DC 20375
Phone: 202-767-2312
Fax: 202-767-1716

DAVID LAYTON
LAWRENCE LIVERMORE NATIONAL LABORATORY/U
OF C MS L-453
7000 EAST AVENUE
LIVERMORE CA 94550
Phone: (510) 422-0918
Fax: (510) 423-6785
E-Mail: LAYTON1@LLNL.GOV

ANTHONY LAVIETES
LAWRENCE LIVERMORE NATIONAL LAB
MS L-230
7000 EAST AVENUE
LIVERMORE CA 94550
Phone: (510) 423-6766
Fax: (510) 422-3160
E-Mail: LAVIETES1@LLNL.GOV

HARRY L LOUFT
REMOTE SENSING LAB - DOE
RSL-14
P O BOX 1912
LAS VEGAS NV 89125
Phone: (702) 295-8879
Fax: (702) 295-8745

TERRY A LUALLIN
NAVAL UNDERSEA WARFARE CENTER DET
ARCTIC SUBMARINE LAB - CODE 906B
49250 FLEMING ROAD
SAN DIEGO CA 92152-7210
Phone: (619) 553-7459
Fax: (619) 553-0972

CHRISTOS M MAKRIS
DOE/NN-20
GS-033
1000 INDEPENDENCE AVENUE SW
WASHINGTON DC 20585
Phone: (202) 586-9309
Fax: (202) 586-0485
E-Mail:
CHRISMAKRIS <DOE-EGG@ACCESS.DIGEX.NET>

KEITH MARLOW
SANDIA NATIONAL LABS
DEPT 5914
ALBUQUERQUE NM 87185-0571
Phone: (505) 844-8130
Fax: (505) 844-7593

GARY F MASTNY
NCCOSC RDTE DIV 524
53475 STROTHE ROAD RM 271
SAN DIEGO CA 92152-6320
Phone: (619) 553-2802
Fax: (619) 553-6305
E-Mail: MASTNY@NOSC.MIL

WAYNE MEITZLER
PACIFIC NORTHWEST LABORATORY
K7-22
P.O. BOX 999
RICHLAND, WA 99352
Phone: (509) 375-3718
Fax: (509) 375-3641
E-Mail: wd_meitzler@pnl.gov

MR RON MILES
NEPTUNE SCIENCES
150 CLEVELAND AVENUE
SLIDELL LA 70458
Phone: (504) 649-7252
Fax: (504) 649-9679

DR BRUCE MOLNIA
US GEOLOGICAL SURVEY
917 NATIONAL CENTER
RESTON VA 22092
Phone: (703) 648-4120
Fax: (703) 648-4227
E-mail: BMOLNIA@USGS.GOV

DR ED MYERS
NOAA/OAR/PDC(R/PDC)
1335 EAST-WEST HIGHWAY (SSMC3)
SILVER SPRING MD 20910
Phone: (301) 713-2465
Fax: (301) 713-0666

DR DAVID NAGEL
NAVAL RESEARCH LAB
CODE 6600
4555 OVERLOOK AVE SW
WASHINGTON DC 20375
Phone: 202-767-2931
Fax: 202-767-3709
E-mail: NRL6600@CCF.NRL.NAVY.MIL

DR CHARLES NEWSTEAD
DEPARTMENT OF STATE
WASHINGTON DC
Phone: (202)
Fax: (202) 647-1106

DR MARSHALL ORR
NAVAL RESEARCH LAB
CODE 7120
4555 OVERLOOK AVE SW
WASHINGTON DC 20375
Phone: 202-767-3359
E-mail: ORR@WAVE.NRL.NAVY.MIL

BRADLEY PATT
XSIRIUS INC
1220 AVERIDA ACASO
CAMARILLO CA 93012
Phone: (805) 484-8300
Fax: (805) 383-7185
E-Mail: 73313.1454@COMPUSERVE.COM

DR ROBERT PELLENBARG
NAVAL RESEARCH LAB
CODE 6101
WASHINGTON DC 20375
Phone: 202-767-2479
Fax: 202-404-2312

STEPHANIE L. PFIRMAN
BARNARD COLLEGE/COLUMBIA UNIVERSITY
3009 BROADWAY
NEW YORK NEW YORK 10027
Phone: (212) 854-5120
Fax: (212) 854-5760
E-Mail: SPFIRMAN@BARNARD.COLUMBIA.EDU

GARY W PHILLIPS
NAVAL RESEARCH LABORATORY
CODE 6610
WASHINGTON DC 20375-5345
Phone: (202) 767-5466
Fax: (202) 404-8076
E-Mail: PHILLIPS@RADEF.NRL.NAVY.MIL

PAVEL P POVINEC
INTERNATIONAL ATOMIC ENERGY AGENCY MARINE
ENVIRONMENT LABORATORY
BP NO 800 MC-98012 MONACO
Phone: 33 92 05 22 22
Fax: 33 92 05 77 44
E-Mail: POVINEC@UNICE.FR

KARL REINITZ
DEPARTMENT OF ENERGY NN-20
1000 INDEPENDENCE AVENUE
WASHINGTON DC 20585
Phone: (202) 586-6992
Fax: (202) 586-2612

CARL RESTER
CONSTELLATION TECHNOLOGY CORPORATION
9887 4TH STREET NORTH
SUITE 100
ST. PETERSBURG, FL 33702
Phone: (813) 577-9887
Fax: (813) 577-1217

DR MIKE RICHARDSON
NAVAL RESEARCH LAB
CODE 7431
STENNIS SPACE CENTER, MS 39529-5004
Phone: 601-688-4621
Fax: 601-688-5752
E-mail: MIKER@ZEPHYR.NRLSSC.NAVY.MIL

DR GORDON RIEL
NSWC
WHITE OAK ATTACHMENT CODE 682
10901 NEW HAMPHIRE AVE
SILVER SPRINGS MD 20903
Phone: (301) 394-1083
Fax: (301) 394-5135
E-mail: GRIEL@RELAY.NSWC.NAVY.MIL

J. C. RITTER
NAVAL RESEARCH LABORATORY
CODE 6610
WASHINGTON, DC 20375-5345
Phone: (202) 767-2124
Fax: (202) 404-8076

DR ANDREW ROBERTSON
US DEPARTMENT OF COMMERCE
NOAA/NOS/ORCA2
6001 EXECUTIVE BLVD ROOM 323
ROCKVILLE MD 20852
Phone: (301) 713- 3032 (EXT 162)
Fax: (301) 713-4388
E-mail: AROBERTSON@BANYAN.ROC.NOAA.GOV

CDR RICHARD A ROOTH
US COAST GUARD
COMMANDANT (G-NIO)
2100 SECOND STREET SW
WASHINGTON DC 20593-0001
Phone: (202) 267-1456
Fax: (202) 267-4425
E-Mail: R.ROOTH/G-NIO@CGSMTP.COMDT.USCG.MIL

MR DENNIS ROTHENBERGER
US NAVY
4251 SUITLAND RD
WASHINGTON DC 20395-5720
Phone: (301) 669-3815
Fax: (301) 669-4282

DR PETER SCHLOSSER
LAMONT-DOHERTY EARTH OBSERVATORY OF
COLUMBIA UNIVIVERSITY
PALISADES NY 10964
Phone: (914) 365-8707
Fax: (914) 365-8155
E-mail: PETERS@LDEO.COLUMBIA.EDU

DR MARTHA R SCOTT
TEXAS A&M UNIVERSITY
DEPT OF OCEANOGRAPHY
MS 3146
COLLEGE STATION TX 77843-3146
Phone: (409) 845-5179
Fax: (409) 845-6331
E-Mail: MSCOTT@ASTRA.TAMU.EDU

R. SEESHOLTZ
ARPA
3701 NORTH FAIRFAX DR
ARLINGTON, VA 22203-1714

BUZZ SELTZER
OCEANEERING TECHNOLOGIES, INC.
501 PRINCE GEORGES BLVD.
UPPER MARLBORO, MD 20772
Phone: (301) 249-3300
Fax: (301) 249-4022

DR WILLIAM SMETHIE JR
LAMONT-DOHERTY GEOLOGICAL OBSERVATORY OF
COLUMBIA UNIVERSITY
PALISADES NY 10964
Phone: (914) 365-8566
Fax: (914) 365-8155
E-mail: BSMETH@LDEO.COLUMBIA.EDU

DR JOHN N. SMITH
DEPT OF FISHERIES & OCEANS
BEDFORD INST BOX 1006
DARTSMOUTH NOVA SCOTIA
CANADA B2Y 4A2
Phone: (902) 426-3865
Fax: (902) 426-6695
E-mail: J_N_SMITH@BIONET.B10.DFO.CA

DR JOHN N. SMITH
DEPT OF FISHERIES & OCEANS
BEDFORD INST BOX 1006
DARTSMOUTH NOVA SCOTIA
CANADA B2Y 4A2
Phone: (902) 426-3865
Fax: (902) 426-6695
E-mail: J_N_SMITH@BIONET.B10.DFO.CA

ILYA STEVENS
NCCOSC RDTE DIV 524
53475 STROTHE ROAD RM 271
SAN DIEGO CA 92152-6320
Phone: (619) 553-2826
Fax: (619) 553-6305
E-Mail: STEVENS@NOSC.MIL

DR JAMES H. SWIFT
UNIVERSITY OF CALIFORNIA SAN DIEGO
SCRIPPS INSTITUTION OF OCEANOGRAPHY
9500 GILMAN DRIVE DEPT 0214
LAJOLLA CA 92093-0214
Phone: (619) 534-3387
Fax: (619) 534-7383
E-Mail: JSWIFT@UCSD.EDU

WILLIAM L TEMPLETON
PACIFIC NORTHWEST LABORATORY
BATTELLE MEMORIAL INSTITUTE
PO BOX 999
RICHLAND WA 99352
Phone: (509) 372-6214
Fax: (509) 372-6199
E-Mail: WL_TEMPLETON@PNL.GOV

PROF DR J THIEDE
RESEARCH CENTER FOR MARINE GEOSCIENCES - GEOMAR
WISCHHOFSTRASSE 1-3 24148 KIEL
GERMANY
Phone: 49 431 7202 115
Fax: 49 431 725 5391
E-Mail: JTHIEDE@GEOMAR.DE

FRANCIS TSANG
IDAHO NATIONAL ENGINEERING LAB
P.O. BOX 1625 - MS-2202
IDAHO FALLS, IDAHO 83404
Phone: (208) 526-9803
Fax: (208) 526-1390
E-Mail: drfrancist@aol.com

W B TUCKER
US ARMY COLD REGIONS RESEARCH & ENGINEERING LABORATORY
72 LYME ROAD
HANOVER NH 03755
Phone: (603) 646-4268
Fax: (603) 646-4644
E-Mail: WTUCKER@HANOVER-CRREL.ARMY.MIL

DR PETER VOGT
NAVAL RESEARCH LAB
CODE 7420
WASHINGTON DC 20375
Phone: 202-767-2024
Fax: 202-767-0167

KATHY WALZ
STATE DEPARTMENT
OES/OA/MLP ROOM 5806A
21ST & C STREETS NW
WASHINGTON DC 20520
Phone: (202) 647-9098
Fax: (202) 647-1106

LCDR STEPHEN M WHEELER
US COAST GUARD
COMMANDANT (G-NIO)
2100 SECOND STREET SW
WASHINGTON DC 20593-0001
Phone: (202) 267-1453
Fax: (202) 267-4425
E-Mail: S.WHEELER/G-NIO!@CGSMTP.COMDT.USCG.MIL

DR WILLARD G. WINN
WESTINGHOUSE SAVANNAH RIVER COMPANY
SAVANNAH RIVER TECHNOLOGY CENTER
BLDG. 735-A, D-WING
AIKEN SC 29808
Phone: (803) 725-2057
Fax: (803) 725-4478

PATRICK WINTER
NSWC
WHITE OAK ATTACHMENT CODE 682
10901 NEW HAMPHIRE AVE
SILVER SPRINGS MD 20903
Phone: (301) 394-1710
Fax: (301) 394-4510
E-mail: WINTERS@OASYF.DT.NAVY.MIL

DR TSIH YANG
NAVAL RESEARCH LABORATORY
CODE 7123
WASHINGTON DC 20375-5000
Phone: (202) 767-2579
Fax: (202) 404-7813
E-Mail: YANG@WAVE.NRL.NAVY.MIL