Nuclear Wastes in the Arctic: An Analysis of Arctic and Other Regional Impacts From Soviet Nuclear Contamination

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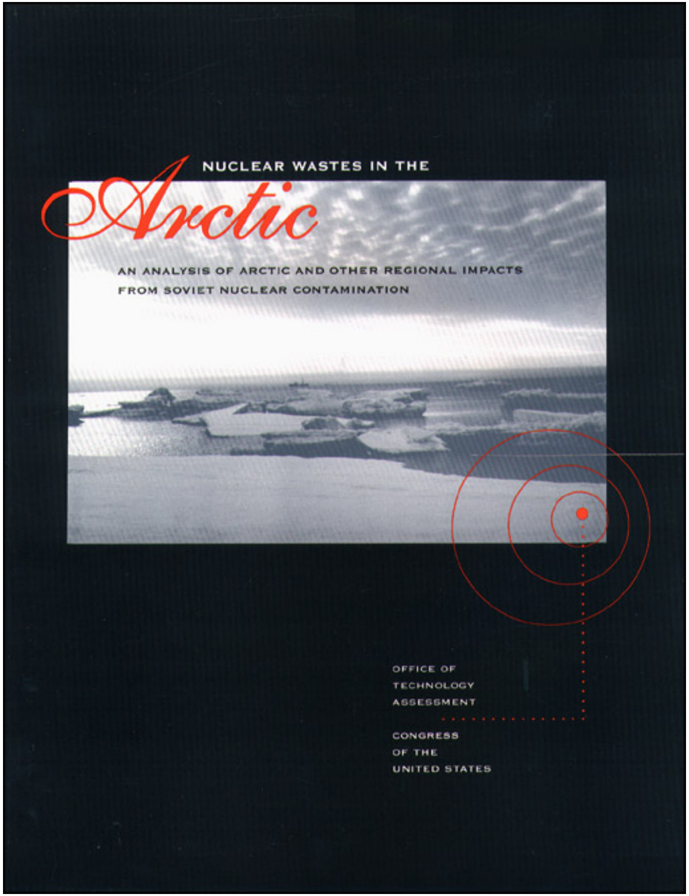

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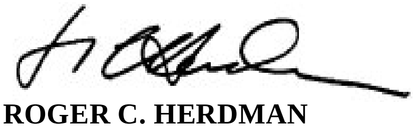
Foreword

One of the lasting legacies of the Cold War, and the buildup in nuclear weaponry and military over the past 50 years, is nuclear waste and its threat to human health and the environment. Notable examples of waste dumped into the open environment have caused people and nations to demand information about what was done and what health risks may result. In 1993, disclosures about Russian dumping of submarine reactors, nuclear fuel, and other wastes into the Arctic and North Pacific Oceans brought this region and its problems into the world spotlight. People in the United States want to know about this dumping and other discharges of radionuclides into the oceans. They want to understand the risks from Russian nuclear activities, both past and future, and the potential threat to their health and that of the Arctic ecosystem.

Because of these concerns, Senator Ted Stevens, Chairman of the Defense Subcommittee of the Senate Appropriations Committee, and Senators William V. Roth and John Glenn, Chairman and Ranking Minority Member of the Senate Committee on Governmental Affairs, asked the Office of Technology Assessment (OTA) to prepare this assessment of Nuclear Waste in the Arctic.

This report examines the environmental and human health impacts from wastes dumped into the Arctic and North Pacific regions, from nuclear contaminants discharged into these environments, and from radioactive releases from both past and future nuclear activities in the region. The report presents what is known and unknown about this waste and contamination and how it may affect public health. Because so many factors are involved and science cannot provide absolute answers to many questions, this study emphasizes the need for care, caution, awareness, and prudence. It also stresses the need for a stable and enduring institutional framework and international cooperation for long-term observation and monitoring.

OTA received considerable assistance during this study from many organizations and individuals. We sincerely appreciate the guidance received from our Advisory Panel, workshop participants, numerous reviewers, contributors, consultants, and contractors. We also received help from several U.S. federal agencies, research institutions, international organizations, the Russian Government and private institutions, the Norwegian Government and private organizations, and others. Without this cooperation and expert advice, OTA would not have been able to accomplish this study.



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Contents

1 Summary, Findings, and Policy Options 1
Key Findings of Study 14
Policy Issues and Options 18
References 25

2 Contamination from Nuclear Wastes in the Arctic and North Pacific 27
Background and Overview 27
Arctic Contamination from Non-dumping Sources 33
Radioactive Contamination from Soviet Nuclear Waste Dumping 45
Research and Monitoring of Radioactive Contamination in the Arctic, the North Pacific, and Alaska 50
Research and Monitoring: Data Gaps and Future Needs 60
Remediation Options 63
Conclusions 71
References 72

3 Environmental and Health Effects of Nuclear Waste Dumping in the Arctic 79
Human Health Effects from Radiation 80
Sources of Ionizing Radiation 85
Potential Health Effects from Nuclear Contamination in the Arctic and North Pacific 86
Ecological Effects of Radiation in the Arctic and North Pacific Regions 106
Conclusions 108
References 110

4 Sources and Risks of Potential Future Contamination 115
The Russian Nuclear Fleet 117
Managing Spent Fuel from the Russian Fleet: Issues and Opportunities for Cooperation 133

Russian Nuclear Power Plants—Safety Concerns and Risk Reduction Efforts **149**
Conclusions **163**
References **166**

5 Institutional Framework and Policies 171
U.S. Initiatives and Programs Supporting Research on Radioactive Contamination in the Arctic **173**
Monitoring and Early Warning Initiatives Designed to Address Radioactive Contamination in the Arctic **194**
Institutional Initiatives and Programs Designed to Prevent Future Arctic Radioactive Contamination **202**
Current Russian Institutional Structure **215**
References **221**

Appendix A: Reviewers 231

Appendix B: Acronyms and Glossary 233

Appendix C: Excerpts from DoD Appropriations Acts for FY1993, 1994 & 1995 Providing Funding and Authority for the Arctic Nuclear Waste Assessment Program (ANWAP) 237

Summary, Findings, and Policy Options 1

All major nuclear nations face nuclear waste problems. Many also share a common history of radioactive contamination incidents stemming from inadequate attention to environmental protection. The United States and Russia, in particular, have some similar nuclear waste management and contamination problems within their respective nuclear weapons complexes. Current work on these problems is enhanced by recently increased cooperation and improved public awareness of the benefits of environmental protection. However, radioactive contamination has endangered public health in some cases and still engenders serious public reaction worldwide for a number of reasons. Among these are the fear resulting from vivid portrayals of atomic bomb victims; concerns about chronic and long-term health impacts from radiation exposure; distrust of governments who kept most nuclear information secret for decades; and the presence of an environmental hazard that is difficult to detect and even more difficult for most people to understand. Any attempt to address solutions to environmental and human health threats from nuclear contamination must consider both the scientific and the social realities.

Protection of the environment and public health requires careful and responsible management and long-term control of nuclear waste. In recent years, as the Cold War and the nuclear arms race have abated, many nations, institutions, and individuals have become increasingly concerned about the environmental legacy of the nuclear age. Reports about nuclear waste dumping, radioactive discharges and accidents, and their potential human health effects have galvanized public attention and forced nations to seek solutions to these problems.

Nuclear waste in the Arctic is a subject that has been brought to the forefront by recent revelations about the dumping of Soviet submarine reactors and waste products in the sea over the past several decades when the region off the northwestern coast of Russia was a hub of nuclear fleet and nuclear testing activities. The Arctic elicits images of vast frozen expanses with little human habitation or industry and a relatively pristine environment. But these images are not always accurate, and contamination from both military and industrial activities has brought questions about its impact not only locally but in the wider Arctic region. Box 1-1 and figure 1-1 describe the geographic focus of this Office of Technology Assessment (OTA) study.

BOX 1-1: Geographic Focus of This Study

The Arctic region is frequently defined as all areas north of the Arctic circle (66.5°N latitude), which means it includes the Arctic Ocean, Greenland, and northern parts of the European, Asian, and North American continents. It has distinguishing characteristics in both political and ecological terms. There are eight Arctic circumpolar nations: the United States, Canada, Russia, Norway, Sweden, Iceland, Finland, and Denmark. All are signatories to the Declaration on Arctic Environmental Protection.

Alaska's northern coast borders the Arctic. Half of the Arctic coastline, however, lies within Russia. That country has historically used these waters as an important transportation route, linking its western and eastern northernmost regions, as well as providing access to the Atlantic and Pacific Oceans. The Arctic region is also home to two-thirds of Russia's fleet of nuclear submarines and icebreakers. To ensure access to harbors all year round, Russia maintains a nuclear-powered fleet of icebreakers, as well as a large number of radioisotope-powered lighthouses.

The central core of the Arctic region—its ocean—is "a sea bordered by prominent countries, all of which have concerns regarding security, resource exploitation, environmental protection, etc." (11). Covering about 390,000 square miles, the Arctic Ocean is the world's smallest. It is almost completely covered by six to 10 feet of ice in winter. In summer it becomes substantially open (ice free) only at its peripheries. There are two international outlets: the Bering Strait, which lies between Alaska and Russia, and the Fram Strait situated between Greenland and Norway's Spitsbergen Islands. These two straits are not only shipping lanes but also the principal routes for exchange of surface waters.

The Arctic Ocean is ringed by seas. Principal among them are the Beaufort (shared by Canada and Alaska); Chukchi (between Alaska and Russia); the East Siberian, Laptev, and Kara Seas of Russia; and the Barents, bordered by both Russia and Norway. The liquid and solid nuclear wastes dumped by the Soviet Navy are located in the Barents and Kara Seas, in the Pacific Ocean along the east coast of Kamchatka, and in the Sea of Japan. In addition, an island group called Novaya Zemlya which separates the Barents and Kara Seas was the site of most of the atmospheric and underground nuclear testing by the former Soviet Union.

Other than Canada's Mackenzie River, all the major rivers that flow into the Arctic's adjacent seas are Russian, and more than 40 percent of that flow is to the Kara Sea. Russia's Pechora, Ob, and Yenisey Rivers empty into the Kara Sea; its Kotuy and Lena Rivers, into the Laptev Sea; and the Indigirka and Kolyma, into the East Siberian Sea. The Pechora River, already severely polluted in some areas, has been under additional ecological threat from leaking oil pipelines, such as the Koma oil spill, which occurred early this year. Nuclear contamination created by facilities thousands of miles south in the Urals could possibly migrate to the Kara Sea and the mouths of the Ob and Yenisey Rivers.

The waters of the Arctic, its sea ice, and sediments are sinks for pollutants. The water, ice, and air currents serve as mechanisms for the transborder migration of pollutants (nuclear and otherwise) originating in all rim nations. Special characteristics of the Arctic region, such as low temperature, short and intensive growing seasons, a widely varying photocycle, permafrost, sea ice, and small number of species, make it very sensitive to environmental insult (6). Pollutants have long residence times, and because Arctic ecosystems are already under stress as a result of the harsh living conditions, they are highly sensitive. Food chains tend to be formed from very few species: therefore, they have large natural fluctuations and are more weakly balanced than those observed in temperate and tropical ecosystems (1).

This report examines the environmental and human health impacts from nuclear wastes dumped in the Arctic (and, to a lesser extent, the North Pacific), nuclear contaminants discharged into these marine environments, and radioactive releases from both past and future nuclear activities in these regions. Questions about the environmental and health impacts of these practices cannot have clear and certain answers. Although some information about waste and contamination is available, it does not follow that we know how, when, or where they may affect people and their health. Because so many factors are involved and science cannot provide absolute answers to many questions, this study emphasizes the need for care, awareness, and prudence. It also stresses the need for a stable and enduring institutional framework for long-term observation or monitoring.

Arctic Nuclear Contamination

Despite popular perceptions of the Arctic as an unscathed area, it has become increasingly clear that this important ecosystem has not avoided the effects of industrialization and development. Evidence of contamination by persistent organic pollutants, heavy metals, and radioactivity has been gathered since the 1950s but did not attract much public interest. However, in the last three years a tremendous amount of attention has been directed to environmental contamination in the Arctic from Russian nuclear sources. Although the activities of several countries have released radionuclides into the Arctic environment for decades, the news of ocean dumping of submarine reactors and nuclear wastes by the former Soviet Union has generated particular interest and concern because it revealed previously secret activities and enhanced the long-standing public fear of radioactivity.

Past dumping of nuclear submarine reactors and fuel assemblies, as well as significant amounts of other radioactive wastes, into waters adjacent to the Arctic and North Pacific Oceans was disclosed in some detail by the Russian Federation in a 1993 white paper that is generally referred to as the "Yablokov report" (3). The ultimate fate and effects of this dumping are unknown, but possible impacts on regional environments and public health have brought concerns not only to Russia but to other countries in the Arctic and North Pacific regions. People in the United States—in particular, Alaska and the Pacific Northwest—want to know about this dumping and other discharges of radionuclides into the oceans. They also want to know about risks to these regions from other Russian nuclear activities, both past and future, and the potential threat to the environment and population beyond Russian borders.

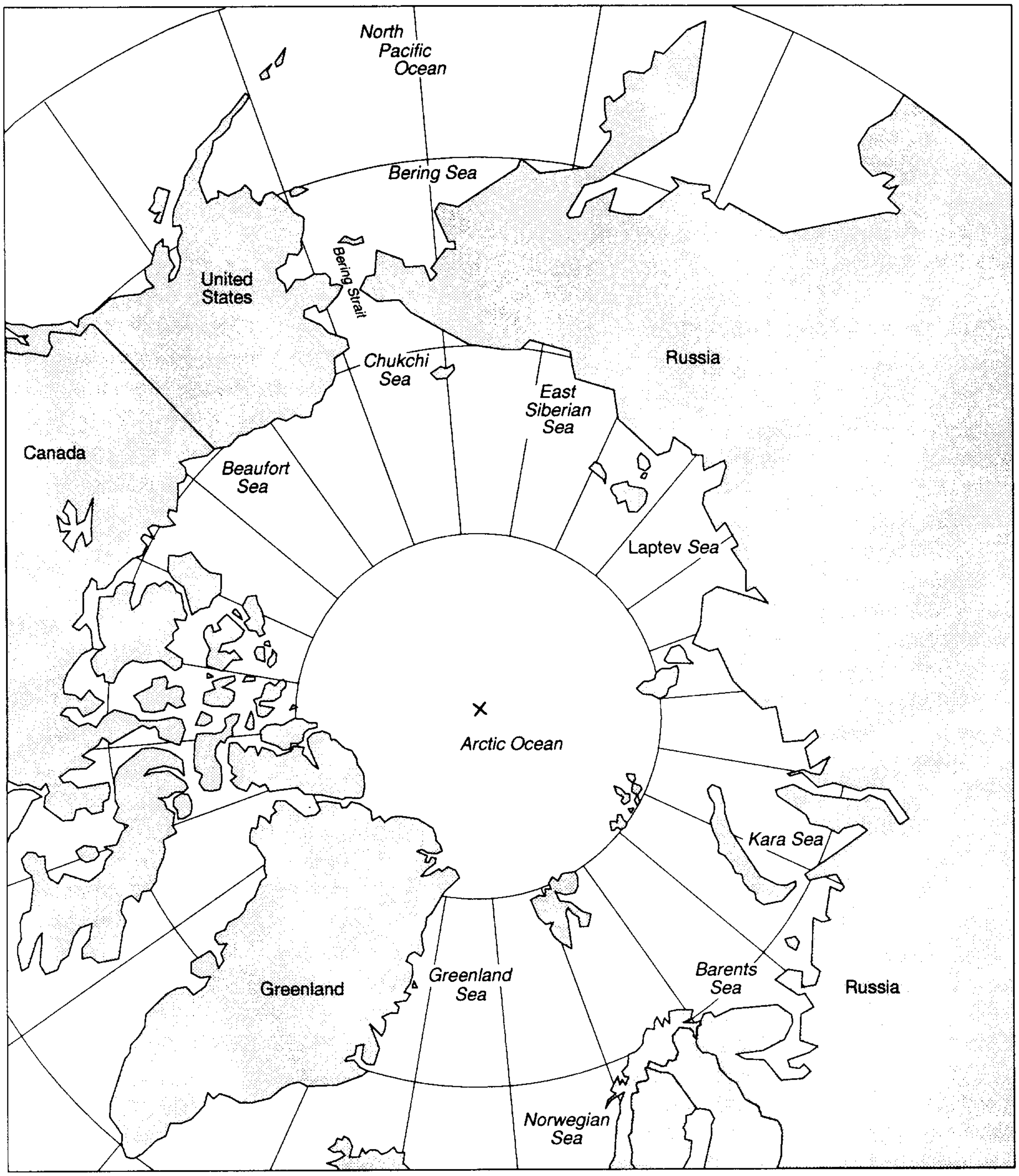
In the United States, a particular concern is the possible threat to Alaskan Native communities, their traditional food supplies, and other Alaskan fisheries resources. The impact of dumping radioactive wastes in Arctic waters is also a key concern of other nations, in particular Norway, which depends on a major fishery in the Barents Sea and is therefore very active in supporting research into such contamination in nearby waters.

Disclosures of Russian Nuclear Dumping

Rumors started to circulate in Russia in 1990 that dumping of nuclear waste had taken place in the Barents and Kara Seas. A conference organized by Greenpeace International in September 1991 brought international interest and concern. At the press conference, Andrei Zolotkov, a People's Deputy from Murmansk, presented a map showing purported dump sites used for radioactive wastes from 1964 to 1986 (13). Local papers published the maps with listings of the sites and numbers of dumped objects (2). When the Soviet Union made no official denial of these allegations at the subsequent 14th Consultative Meeting of the London Convention in November 1991, delegates demanded that it furnish information on past dumping (3).

Meanwhile, news of the Soviet dumping in the Arctic was causing some concern in the United States. In August 1992, Senator Murkowski chaired a hearing of the U.S. Senate Select Committee on Intelligence that focused attention on U.S. and Alaskan perspectives on the problem and the many questions remaining to be addressed. Government officials, scientists, and representatives of Native organizations stressed the need for more information and for cooperation with the Russian Federation to obtain it (9).

FIGURE 1-1: The Arctic Region



SOURCE: Office of Technology Assessment, 1995.

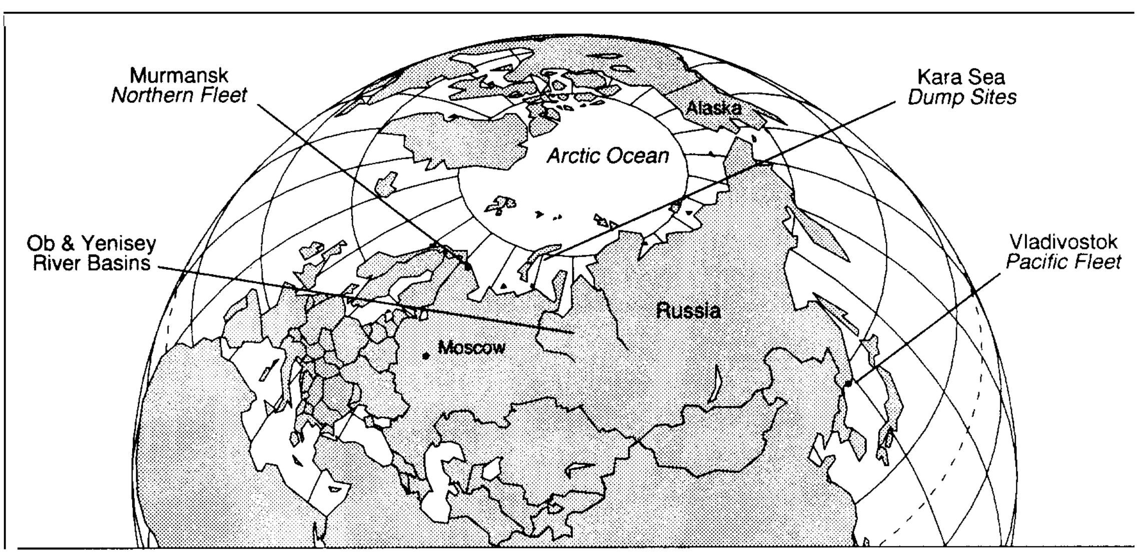
At the November 1992 meeting of the London Convention, the government of the new Russian Federation announced the formation (in October 1992) of a Presidential Commission under the direction of Alexei Yablokov, special environmental adviser to the president, to gather information and "ensure Russia's compliance with obligations under international treaties which it signed as successor to the Soviet Union" (13).

The report of the commission (the Yablokov report), submitted to the president of the Russian Federation in early 1993, was a frank document presenting inventories of both liquid and solid radioactive waste dumping that occurred between 1959 and 1992. It was largely consistent with unofficial accounts (4) and detailed the dumping of damaged submarine reactors, spent fuel from the nuclear fleet, and other radioactive waste into the Kara Sea off the archipelago of Novaya Zemlya (as indicated in figure 1-2), into the Sea of Japan, and in other locations. Other than the estimated inventory of the activity of the items dumped, which has been refined since the release of the report by an expert group working with the International Atomic Energy Association (IAEA), and the precise locations of some of the dumped objects, most of the information presented in the Yablokov report remains a key source of data about the Russians' radioactive waste dumping in the Arctic.

The Yablokov report was a remarkable document to emerge from the new government of the Russian Federation. It represented the results of a tremendous effort to gather information, some of it decades old, from a multitude of Soviet ministries and agencies; to declassify that information; and to report it frankly to the international community and to the Russian people. It spelled out and acknowledged violations not only of international conventions such as the London Convention, but of normative documents that the former Soviet Union had approved, which required coordination with environmental bodies, as well as monitoring and supervision of nuclear safety in handling radioactive waste (3).

The report listed dumping that had taken place in the Arctic and North Pacific since 1959. Wastes listed as dumped in the Kara Sea and in fjords along the coast of Novaya Zemlya included containers, barges, ships, and submarines containing nuclear reactors both with and without spent reactor fuel. Figure 1-3 indicates

FIGURE 1-2: Arctic and North Pacific Fleet Headquarters and Kara Sea Dump Site



SOURCE: Office of Technology Assessment, 1995

TABLE 1-1: Objects Dumped by Northern Submarine and Icebreaker Fleets

Location	Objects	Depth (m)	Estimated activity in 1994 (kCi)
Ambrosimov Inlet	8 submarine reactors (3 with SNF)	20	37.9
Novaya Zemlya Depression	1 submarine reactor (1 with SNF)	300	7.8
Stepovoy Inlet	2 submarine reactors (2 with SNF)	50	22.7
Techeniye Inlet	2 submarine reactors	35-40	0.1
Tsivolka Inlet	3 reactors from icebreaker *Lenin* and shielding assembly from *Lenin* reactor assembly with SNF	50	59.4
Total	16 reactors (6 with SNF) 1 shielding assembly from icebreaker *Lenin* with SNF		127.9

KEY: kCi = kilocuries; SNF = spent nuclear fuel.

SOURCES: Government Commission on Matters Related to Radioactive Waste Disposal at Sea ("Yablokov Commission"), created by Decree No. 613 of the Russian Federation President, Oct. 24, 1992, *Facts and Problems Related to Radioactive Waste Disposal in Seas Adjacent to the Territory of the Russian Federation* (Moscow: 1993); translated by Paul Gallager and Elena Bloomstein (Albuquerque, NM: Small World Publishers, Inc., 1993); N. Lynn, et al., "Radionuclide Release from Submarine Reactors Dumped in the Kara Sea," presented at *Arctic Nuclear Waste Assessment Program Workshop*, Woods Hole Oceanographic Institution, Woods Hole, MA, May 1-4, 1995; Y. Sivintsev, "Study of Nuclide Composition and Characteristics of Fuel in Dumped Submarine Reactors and Atomic Icebreaker Lenin," Part I—Atomic Icebreaker (Moscow: Kurchatov Institute, December 1993); and M. Mount, Lawrence Livermore National Laboratory, personal communication, June 14, 1995.

the reported locations of the dumped wastes. A total of 16 reactors was dumped at five different sites. Six of the reactors and an additional container held spent reactor fuel. The total activity of these materials at the time of disposal was estimated in the Yablokov report to be more than 2 million curies.[1] U.S. and Russian scientists have concluded that, today, only about 5 percent of this activity[2] remains at these Kara Sea dump sites (see table 1-1).

In the Russian Far East, the Yablokov report listed similar dumping (but smaller quantities and lower levels of radioactivity) in the Sea of Japan and near the Kamchatka Peninsula (figure 1-4). It also described nuclear accidents; solid, low-level radioactive waste dumping; extensive low-level liquid waste discharges; the sinking of a nuclear submarine in the Norwegian Sea; and serious problems with the operation of current nuclear refueling vessels in both the Russian north and Far East.

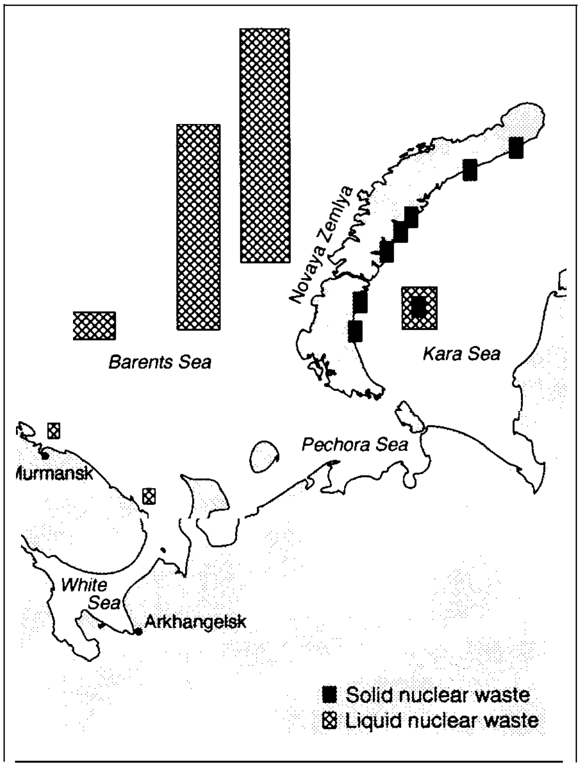
International Response to the Yablokov Report

The activities discussed in the Yablokov report generated tremendous international concern, both about the current status of the dumped waste and its contribution to radioactivity in the nearby Arctic Ocean and about the potential long-term effects of this waste. Since radionuclides can affect human health only if and when humans are exposed to them, the key question is whether and how they may migrate toward populations and other ecosystems (e.g., food supplies) in the future. Over the past two years since the Yablokov report, a number of data collection efforts and investigations to address this question have been undertaken by U.S. investigators, Norwegians, Russians, other nations close to the

[1] Radioactive decay rates ("activity") have two common units of measure, curies and becquerels, both named after scientists who were active late in the last century. The curie (Ci) represents the activity of 1 gram of radium, namely 3.7×10^{10} nuclear disintegrations per second. The becquerel (Bq) is a more modern unit and corresponds to 1 disintegration per second.

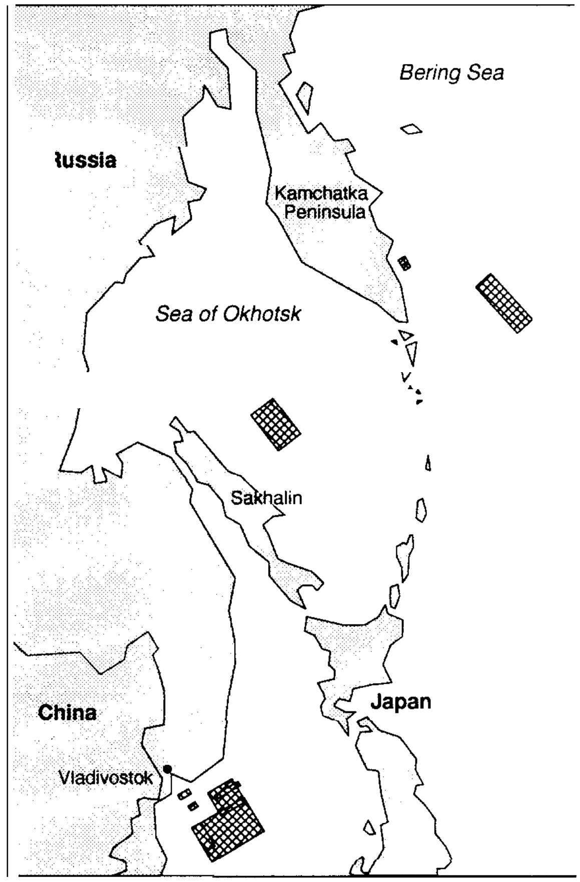
[2] This reduction in estimates is due both to corrections in original inventories and to radioactive decay over time.

FIGURE 1-3: Locations of Nuclear Waste Dumping in Russian Northern Seas



SOURCE: Office of Technology Assessment, compiled from data from Government Commission on Matters Related to Radioactive Waste Disposal at Sea ("Yablokov commission"), created by Decree No. 613 of the Russian Federation President, October 24, 1992, *Facts and Problems Related to Radioactive Waste Disposal in Seas Adjacent to the Territory of the Russian Federation (Moscow,* Russia: 1993).

FIGURE 1-4: Locations of Nuclear Waste Dumping in Russian Far Eastern Seas



SOURCE: Office of Technology Assessment. 1995, compiled from data from Government Commission on Matters Related to Radioactive Waste Disposal at Sea ("Yablokov commission"), created by Decree No. 613 of the Russian Federation President, October *24, 1992, Facts and Problems Related to Radioactive Waste Disposal in Seas Adjacent to the Territory of the Russian Federation (Moscow,* Russia: 1993).

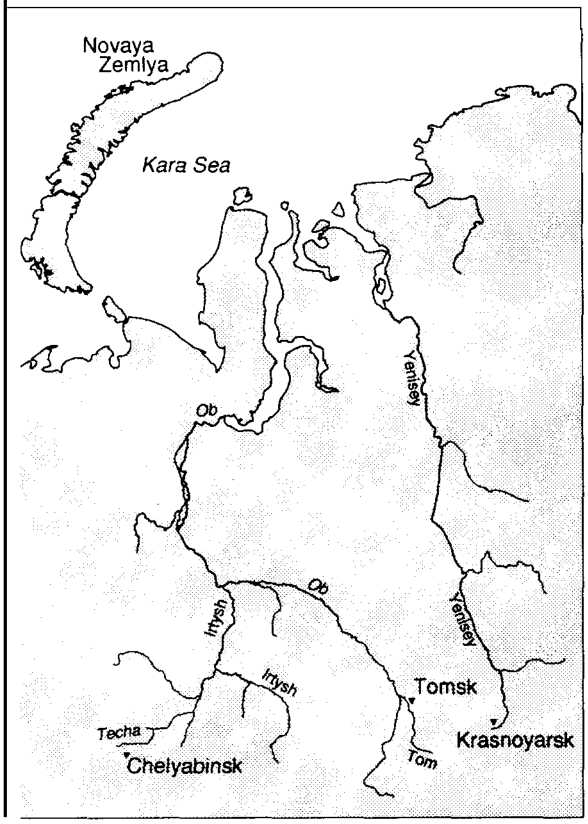
Russian sites, and international agencies such as the IAEA.

The United States has cooperated in a number of international efforts and has established some bilateral agreements with Russia (such as those concluded by the Gore-Chernomyrdin commission) relevant to nuclear dumping issues. The United States is also a party to the Declaration in Arctic Environmental Protection approved by the eight circumpolar nations[3] in June 1991. The Arctic Environmental Protection Strategy (AEPS), a part of the declaration, is a nonbinding statement of cooperation on the development and implementation of programs to protect the Arctic environment. Radioactivity is one of several pollutants identified under the strategy for priority action. The eight circumpolar nations are now planning to establish a new council that would provide the enforcement mechanism lacking in current multilateral agreements on protection of the Arctic.

The most significant U.S. efforts to investigate Arctic nuclear contamination have been the result of money set aside from "Nunn-Lugar"

[3] The United States, Canada, Norway, Russia, Finland, Iceland, Sweden, and Denmark.

FIGURE 1-5: The Ob and Yenisey Rivers



SOURCE Office of Technology Assessment, 1995.

funds appropriated by Congress for the Department of Defense (DOD) in FY 1993-95. During each of the past three years, $10 million has been assigned to DOD's Office of Naval Research (ONR) for the Arctic Nuclear Waste Assessment Program to address the nature and extent of nuclear contamination by the former Soviet Union in the Arctic region. With these finds, ONR has sponsored extensive research activities including nearly 70 different field, laboratory, modeling, and data analysis projects; three major workshops on nuclear contamination of the Arctic Ocean; and extensive collaboration with researchers from Russia, Norway, Germany, Canada, Japan, Korea, the International Atomic Energy Agency, and the Arctic Environmental Protection Strategy. The initial results from ONR's Arctic Nuclear Waste Assessment Program-in the view of many, a significant first step toward understanding the Arctic contamination problem—are expected to be published in scientific journals in 1997.

In the meantime, some tentative conclusions have been reached, but the data collected by these efforts are not yet sufficient to accurately predict the impacts of this dumping. Researchers have not found evidence of significant migration beyond the immediate vicinity of dumped radionuclides that might affect human health in the short run. However, some key unknowns have yet to be addressed, for example: 1) there has been no detailed inspection of many of the dump sites within the past two decades; 2) we have limited knowledge of the possible release rates and the long-term viability of materials used to encase the waste; and 3) some of the critical pathways by which radionuclides can affect humans, such as the biological food chain or transport on moving Arctic ice, are in the early stages of investigation. Several other possible "sources of contaminants that could affect the Arctic environment are also only beginning to be investigated.

In the Kara Sea region, for example, one potential source of contamination is from the large, northward-flowing Siberian rivers, at whose headwaters (more than 1,000 miles upstream) are located the major Russian nuclear weapons production facilities (see figure 1-5). At several of these sites, such as Chelyabinsk, Tomsk, and Krasnoyarsk, the largest releases of radioactive wastes in the world have been recorded over the last few decades. Wastes totaling more than 100 million curies were discharged into lakes and rivers at one site, and billions of curies have been injected directly underground. This contamination has clearly resulted in serious health problems among local populations and is now being studied. Research on whether the contamination may migrate down rivers such as the Ob or Yenisey into the Kara Sea and the Arctic Ocean in the future is now underway.

Overall State of the Environment in the Russian Federation

Although this OTA report focuses on nuclear contamination of the Arctic and North Pacific regions, this problem is part of severe and pervasive environmental degradation of all kinds throughout the former Soviet Union. Thus, while people in close proximity to past and continuing nuclear releases are at increased health risk from exposure to radionuclides, people all over the former Soviet Union are exposed to a host of other environmental contaminants. Extensive air and water contamination caused by nonnuclear industrial and other sources and wastes can also have health impacts. Therefore, the risks from radionuclide releases should be considered not in isolation, but in the context of the broader picture of environmental contamination that follows.

Annual environmental reports now published by Russia contain comprehensive data and information on other types of pollutant generation, releases, and impacts.[4] However, using these data to more fully understand environmental conditions in Russia is problematic. Of major concern are the accuracy and coverage of the data. A World Bank report says, for instance, that ". . .Bank missions have found that the [environmental] data provided was in considerable error (i.e., by factors of 2 to 5 times)" (12). International organizations providing assistance to Russia have recognized this deficiency and the problems it causes for analysis and policy decisionmaking. Both the World Bank, under its Russian Federation Environmental Management Project, and the European Environmental Action Programme for Central and Eastern Europe are helping to set up improved environmental information systems.

To some extent, however, data are not necessary to document the poor quality of environmental protection in Russia today. The problems resulting from chemical pollutants and waste are simply too visible. Descriptions abound of industrial cities with dark skies during the day, rivers that catch fire, and "dead" lakes. These images are reminiscent of conditions in heavily industrialized areas of the United States (and other Western countries) in the 1950s and 1960s, which sparked the enactment and implementation of environmental protection laws addressing air, water, and waste.

All sectors of the Russian economy are responsible for contributing to the country's state of the environment. In most cases, it is difficult to separate military and civilian sources, since under the Soviet system they were often one and the same. Today, massive industrial complexes, which may have been built primarily for military purposes, still emit a full range of air pollutants, release large quantities of untreated conventional and toxic pollutants into waterways, and dispose of hazardous wastes on land, generally in unlined lagoons and landfills (12). For instance, only 9 percent of the toxic waste generated by the ferrous and nonferrous metals industry in 1990 was reported recovered or safely disposed. Complexes built to produce nuclear weapons have released radioactive wastes directly into lakes and rivers and have injected them underground. Urban areas are faced with overcoming all major environmental problems. Situated as they often are amidst industrial zones, cities are subjected to the highest air pollution levels.

As a consequence of these policies and practices, the Russian Federation now faces major costs to clean up and prevent future degradation from all types of pollutants. Its 1992 State of the Environment report concluded that, consistent with economic decline, pollution emissions had decreased. However, the decrease was not as great as expected because enterprises cut back on expenditures for environmental protection. A year later, the State of the Environment report noted that "no appreciable changes" in these trends had occurred. In a recent speech, the Russian Minister for Environmental Protection stated that in 1994, a quarter of national enterprises had actually increased their discharges of harmful air emissions (7).

[4] These reports are called "Report on the State of the Environments of the Russian Federation."

So, while there may be some diminution of pollutant releases in the short-term, as Russia's market economy grows, future discharges into the environment will also grow. To prevent this, cleaner technologies must be incorporated into its industrial base, and proper environmental controls must be installed and maintained for residual wastes. These needed actions apply across the board to all pollution-generating sources, whether nuclear or not.

On the nuclear side, many waste generation and handling practices continue as before. Liquid wastes are still being discharged underground at weapons complex reprocessing facilities. And although the dumping of nuclear wastes into Arctic seas has been discontinued for now,[5] a growing volume of this waste is being generated due to the downsizing and dismantlement of the submarine fleets. Reprocessing of spent fuel from nuclear reactors continues—a practice that has been associated in Russia with increased waste and residue. Although efforts are underway to mitigate some of the contamination from nuclear reactor operations in the Urals, huge amounts of waste will remain uncontrolled in the environment for many decades, with the continuing risk of further migration.

Even as information about severe environmental contamination in the former Soviet Union has emerged from many sources, it is the nuclear contamination of the Arctic and North Pacific that has attracted most attention in the United States. The north coast of the State of Alaska sits adjacent to the Arctic Ocean. The Bering Strait, along Alaska's western coast, is a principal route for the exchange of surface waters between the Arctic and the North Pacific.

Potential Future Contamination

In addition to past radioactive contamination and releases in the Arctic, important questions remain about future releases, dumping, or accidents that could add significantly to the problem. Whereas past dumping has received considerable attention recently from scientists and analysts, the risk of future releases has not been subject to the same scrutiny or careful study. OTA has reviewed the nature and general magnitude of this future risk and the knowledge—or lack of it—about what actions have been, could be, or should be taken. Even though the potential for significant future releases may be difficult to assess from existing data, the proverbial ounce of prevention could well be worth pounds of cure.

Based on the limited information currently available, there are certain key areas that pose future contamination risks from Russian nuclear activities in the Arctic and the North Pacific regions. OTA has selected three of these areas for focus and analysis in this study because they appear to be most significant at this time: 1) the Russian Northern and Pacific nuclear fleets, and their vulnerabilities to accidents during the downsizing and dismantlement now under way; 2) the management of spent nuclear fuel and waste from these fleets, and concerns about effective containment, safety, security, and future releases; and 3) the possibility of accidents or releases from Russian civilian nuclear power plants, particularly those located in the Arctic.

It appears important to evaluate appropriate measures to prevent future releases, dumping, or accidents such as those that have occurred in the past. The management of spent fuel and other radioactive waste from the Russian nuclear fleet presents a special concern. Serious problems exist with the removal of spent nuclear fuel from submarine reactors; the storage of spent fuel aboard service ships that are used in submarine defueling; spent fuel handling and storage at naval bases in the Russian north and Far East;[6] the lack of capacity at land-based storage facilities; the management of damaged and nonstandard fuels for which no reprocessing system

[5] Russia is still not a signatory to the London Convention ban on dumping of all radioactive wastes but has announced informally its intention to refrain from dumping if possible.

[6] The northern naval bases are located mainly on the Kola Peninsula, near the Norwegian border and adjacent to the Barents Sea; the Far Eastern bases are generally near Vladivostok on the Sea of Japan and on the Kamchatka Peninsula.

exists; and the transportation and reprocessing of spent fuel at distant sites such as Mayak. Figure 1-2 shows the general location of the Russian Navy's Northern and Pacific Fleets.

During the past three decades, the Soviet Union built the largest fleet of nuclear submarines and the only fleet of nuclear-powered icebreakers in the world. The Russian Navy has been retiring and decommissioning older nuclear submarines at an increasing rate over the past several years. More than 120 Russian nuclear submarines have been taken out of service, and many are in various stages of dismantlement. Only about 40 of these have had their spent nuclear fuel removed. Some submarines have been out of service with nuclear fuel aboard for more than 15 years. The most serious factors contributing to this condition are the following: 1) Almost all spent fuel storage facilities at the nuclear fleet bases are full, and very little spent fuel is currently being transported to reprocessing sites to make room for fuel removed from nuclear submarines scheduled for decommissioning. 2) There is a lack of fuel reloading and storage equipment (including service ships, transfer bases, and land-based storage), and what does exist is poorly maintained. 3) There are shortages of safe transportation containers, limited facilities for loading and moving them, organizational problems at fuel transfer bases, and lack of upgrades of certain railways. The situation is deteriorating further, with many vessels and facilities lacking adequate maintenance, particularly at a time when the number of decommissioned submarines is expected to grow.[7]

Nonstandard and damaged fuel rods[8] from submarine and icebreaker reactors present another set of problems. Such fuel includes zirconium-uranium alloy fuel, fuel from liquid metal reactors, damaged and failed fuel assemblies, and fuel in damaged reactor cores. Removing this fuel from reactors for temporary storage and selecting or developing appropriate future treatment or storage technologies are challenging and costly and will require some technology not now available in Russia. This process is also moving at a very slow rate because of a lack of resources. Additional evaluation of specific situations and some focused research or development are probably needed to ensure safe management in the future. The question of risks from current or future operations to dismantle nuclear submarines and manage spent fuel has been addressed recently in several studies and is a priority concern.

Potential Health Effects from Nuclear Contamination

People are worried about how extensively the dumped wastes in the Arctic might contaminate the environment and whether they pose current or future hazards to human health or ecosystems. Understanding both current and future risks to human health requires information about the nature and amount of radionuclides released in the environment, and about their transport through the environment and through food chains to reach human beings. Understanding the risks to ecosystems requires additional information about the effects of radiation on the variety of organisms that make up the ecosystems.

Since the release of the Yablokov report describing dumping in the Arctic, more has been learned about some of the wastes, but their condition and likely radionuclide release rates remain largely unknown. Current levels of radionuclides in the seawater and sediment in Arctic marginal seas do not suggest that significant releases have already occurred. Even though current risks would not appear to be increased as a result of the dumping, future release rates and pathways to people remain to be evaluated. Investigations of these transport mechanisms are now under way.

[7] Although the rate of decommissioning will decline in the latter half of this decade, by that time there will be a large backlog of submarine reactor cores (300-350) with spent reactor fuel.

[8] Some reactor fuel is of unique design containing special materials that cannot be processed in current facilities. Other fuel has been damaged due to corrosion or handling and cannot be safely moved with existing equipment.

Scientists have developed models to approximate the behavior of pollutants such as radionuclides in the environment. These require a tremendous amount of site-specific information, much of which is not yet known either for the Arctic environment or for particular dump sites. Several efforts are now under way to model the transport of radionuclides dumped in the Arctic, as well as those released at sites within Russia along rivers that drain into the Arctic.

The most likely route of human exposure to radionuclides in the seas is through the food chain. Thus, in addition to information about radionuclide movement through the physical environment, specific data are needed for the Arctic about biological pathways to human beings. The marine food web is complex, and most available data were collected in temperate climates, rather than Arctic settings. Therefore, information about how radionuclides are transferred and sometimes concentrated through the food chain under special local and regional conditions is required.

People of the world are not equally at risk from radionuclides dumped in Arctic seas or in the Russian Far East. Current and future investigations need to focus on gathering relevant information about the dietary habits and other characteristics of the populations who are most likely to be exposed, such as Native northern populations and others who rely on Arctic marine resources. This information will be important for a thorough risk assessment to estimate the most likely effects on human health. Concerns about contaminants in food and the environment can lead to stress and a disruption of lifestyles that have a negative impact on peoples' lives. As data are gathered, it is critical that the public be involved in the process. Genuine efforts are necessary to ensure that the potentially affected communities participate in decisions, provide input, and have access to the information collected. Meaningful and understandable data are often unavailable to people affected by environmental contaminants; thus, their concerns go unanswered. Citizen participation in the decisionmaking process not only will help with data availability but will improve the credibility of the data and lead to more effective long-term solutions.

If the released radionuclides come in contact with people in amounts sufficient to cause health effects, these effects are most likely to be cancers. Radiation is a known cause of cancer and other health effects at high doses, but at the low doses that might occur from environmental contamination its effects are less certain. International and U.S. radiological agencies have developed radiation exposure limits for the protection of public health from nuclear-related practices. These can be used as reference points to calculate potential radiation exposures and the degree of hazard that radioactive discharges and dumped nuclear waste might pose. Research thus far shows that radionuclide concentrations measured in the Arctic Ocean near the United States are extremely low; thus, any existing exposures would be orders of magnitude below currently established limits.

However, certain contaminated sites within Russia contain very high levels of radionuclides that have exposed people to radiation doses exceeding those normally considered acceptable by the United States and international bodies. There is substantial evidence that radioactive wastes from certain Russian nuclear weapons plants and other facilities have had serious health impacts on local populations. Populations that have been exposed due to certain nuclear accidents are particularly at risk. Both Russian and U.S. experts are now collecting data from these experiences that will be valuable in future health effects studies.

Although Russian people have suffered health impacts from nearby radioactive releases, the situation is drastically different when large regions such as the Arctic are considered, given the uncertainties about very low-level exposures. There is not yet a clear answer to questions of what the future health impacts on the wider region may be from nuclear wastes dumped in the Arctic and North Pacific. Estimates and approximations of future impacts based on the information available do not suggest a noticeable effect on human health or on plant and animal populations. However, many unknowns remain, from the status of the dumped wastes, to the likely movement of radionuclides through the environment, to the dietary intakes of those most likely to be exposed. Native populations in the Arctic depend on fish and marine mammals for a large portion of their diet; thus, special considerations are necessary when evaluating their potential for exposure to contaminants that may be present in the marine environment.

Institutional Framework and Policies

Many national and international institutions are involved in initiatives to address solutions to the problems of nuclear waste dumping and discharges into the sea. Some are addressing the threat of radioactive contamination to regional environments and human health. Others are working to ensure careful and safe future management of nuclear activities, materials, and wastes. An open question is whether these institutions are effective and whether their initiatives can bring about improvements. The improvements needed, and thus the goals of many programs, are not clearly defined and sometimes represent compromises among conflicting objectives. Because the problems are international, it is difficult to harmonize the policies and goals of each nation affected. In addition, many unilateral, bilateral, and multilateral organizations have developed over the years, each with missions that evolve and change to meet the challenges of the day and to reflect unique conflicts or cooperative moods of the time.

Against this complex backdrop, the United States and the international community are directing attention and resources to the problem of nuclear contamination in the Arctic and North Pacific Oceans. The current focus is principally on research and data collection. Although this focus can lead to better knowledge and understanding, it cannot provide all the answers to reasonable concerns about future impacts on human health and the environment any time soon. Therefore research initiatives should be supplemented to some degree by actions to monitor conditions; to provide early warnings should they be necessary; and to prevent future accidents or releases.

For decades, national security and strategic implications largely determined U.S. and international interest in the Arctic. After the dissolution of the former Soviet Union, and in response to various reports documenting that country's radioactive waste dumping practices, the United States and members of the international community began to support domestic and cooperative approaches to assess the potential impacts of these activities. The State of Alaska also plays an important role in these efforts.

The United States has focused most organized efforts on and made the greatest advances in its research initiatives. There are some gaps in the research program relating to regions covered (not much effort in the Far East and North Pacific, for example), pathways investigated (biological pathways), and other factors, but the program is evolving as a reasonably comprehensive investigation of key problems. Much work can still be performed by the United States, but more cooperation with Russia is needed, especially in the area of increased access to specific dump sites and dumped material.

The United States and other nations are now developing plans for possible future monitoring and warning initiatives. International cooperation in this area is imperative if an effective assessment and response program is to follow. International institutions may be the most appropriate organizations to carry out such initiatives. However, long-term consistent support and the adoption of rigorous scientific implementation programs must be ensured for these efforts to be effective.

Some attempts are under way to fund prevention initiatives, but because most of the key decisions must be made by Russia, it is difficult to engender support for long-term substantial assistance from the United States and other countries. OTA has identified some possible joint projects that could benefit both the United States and Russia and could be mutually supported. Other countries such as Norway are proposing support for joint prevention projects. However, the United States Navy has not aggressively pursued cooperation with Russia in the prevention area because of its belief that the Russian military does not need U.S. assistance.

One of the more significant prevention programs relating to radioactive contamination, which has been in effect in Russia for the past several years, involves nuclear power plant safety. The United States and other countries have been funding programs to improve reactor safety in Russia as part of its overall efforts to prevent another Chernobyl. Improvements have been mainly in the areas of added auxiliary equipment, training, monitoring, and warning systems, and regulatory oversight for existing reactors. Efforts by the State of Alaska have also been successful in improving regional cooperation and information exchange. These efforts are particularly important at some sites in the far north where funding is limited and operations are of marginal quality. Here, again, more substantial improvements such as replacing old designs and equipment with safer systems require additional resources and major policy choices that Russia itself must make.

Crucial to U.S. and other international assistance efforts is the need for Russia to strengthen its institutional and legislative systems that are responsible for environmental protection and for the establishment of a nuclear safety culture. Prior to the dissolution of the Soviet Union, most government agencies and institutes responsible for managing nuclear materials operated behind a wall of secrecy with little or no external regulatory oversight. Today, Russia is only slowly beginning to develop the legal framework necessary to effectively enforce basic environmental protection laws, regulate the use of nuclear energy, and manage radioactive materials and wastes.

In sum, all three areas—research, monitoring, and prevention—are critical to protect human health and the environment from widespread and indiscriminate radioactive contamination in the Arctic and North Pacific. Poor waste management practices have alerted the international community. Kara Sea dumping activities by the former Soviet Union have yet to show a direct connection to human health impacts but have nonetheless raised concerns and questions that will require years to answer even partially. Long-term dedication and planning, as well as comprehensive programs within both U.S. and international institutions, will be necessary to adequately protect the Arctic environment and the health of Arctic populations in the future.

KEY FINDINGS OF STUDY

The following description of key findings from OTA's study is presented in summary form and reflects conclusions from our review of an enormous amount of work discussed and referenced in the other chapters of this report. It is also based on meetings, interviews, workshops, site visits, reviewer comments, and feedback from our Advisory Panel.

The first question that OTA addressed in this study was: What kinds of environmental and public health risks are posed by the Russian Arctic nuclear waste dumping disclosed in the Yablokov report, and how do they affect U.S. territory? This question must be answered with some caution. Research and data collection efforts regarding nuclear contamination in the Arctic marine environment are incomplete. Some major gaps exist in our understanding of Arctic systems and processes.

Even so, OTA's analyses suggest that adequate data have been assembled by expert scientists to reach conclusions about immediate risks. *In particular, the research and data collected to date indicate that no significant amounts of radioactive materials have migrated from the marine radioactive dumping in the Russian Arctic and Far East.* This dumping refers to the sites in the Kara Sea, the Barents Sea, and the Sea of Japan that were covered in the Yablokov report. Research to assess contamination from these sites was summarized most recently in May 1995 at a workshop of the principal investigators with the ONR Arctic Nuclear Waste Assessment Program, held in Woods Hole, Massachusetts, and included other work sponsored by key international institutions.

Although only a few of the dump sites in the Kara Sea have been inspected recently by means of international survey cruises, and measurements were not exhaustive, no substantial leakage appears to have occurred, and only very local samples show elevated radionuclide levels. In similar measurements from U.S. and Russian expeditions near the mouths of Russian rivers, no large migration of radionuclides down the rivers has been detected.[9] It is well known that by far the largest amount of radioactivity released into the environment in Russia is found in regions around the major nuclear weapons plants located along the large Siberian rivers that flow into the Arctic. *Only minor releases and transport of these radionuclides into the Arctic Ocean have been suggested by recent research, but future migration and impacts beyond Russian borders constitute a plausible scenario and deserve investigation.*

Research and data collection expeditions in the general Arctic Ocean region indicate that certain activities other than Russian Arctic dumping and river discharges are greater sources of the radionuclides measured to date. *Radioactive contamination from European reprocessing plants and atmospheric weapons testing in the 1960s is identified as contributing to current low-level Arctic contamination, whereas leakage from the nuclear dump sites in the Kara Sea or discharges from the Ob and Yenisey Rivers have not been confirmed in the wider Arctic basin.* European reprocessing sources have been studied and tracked for a long time and thus are well documented. Recent work on the European reprocessing discharge plume has provided good indications of how Arctic Ocean circulation has transported these radionuclides over long periods of time.

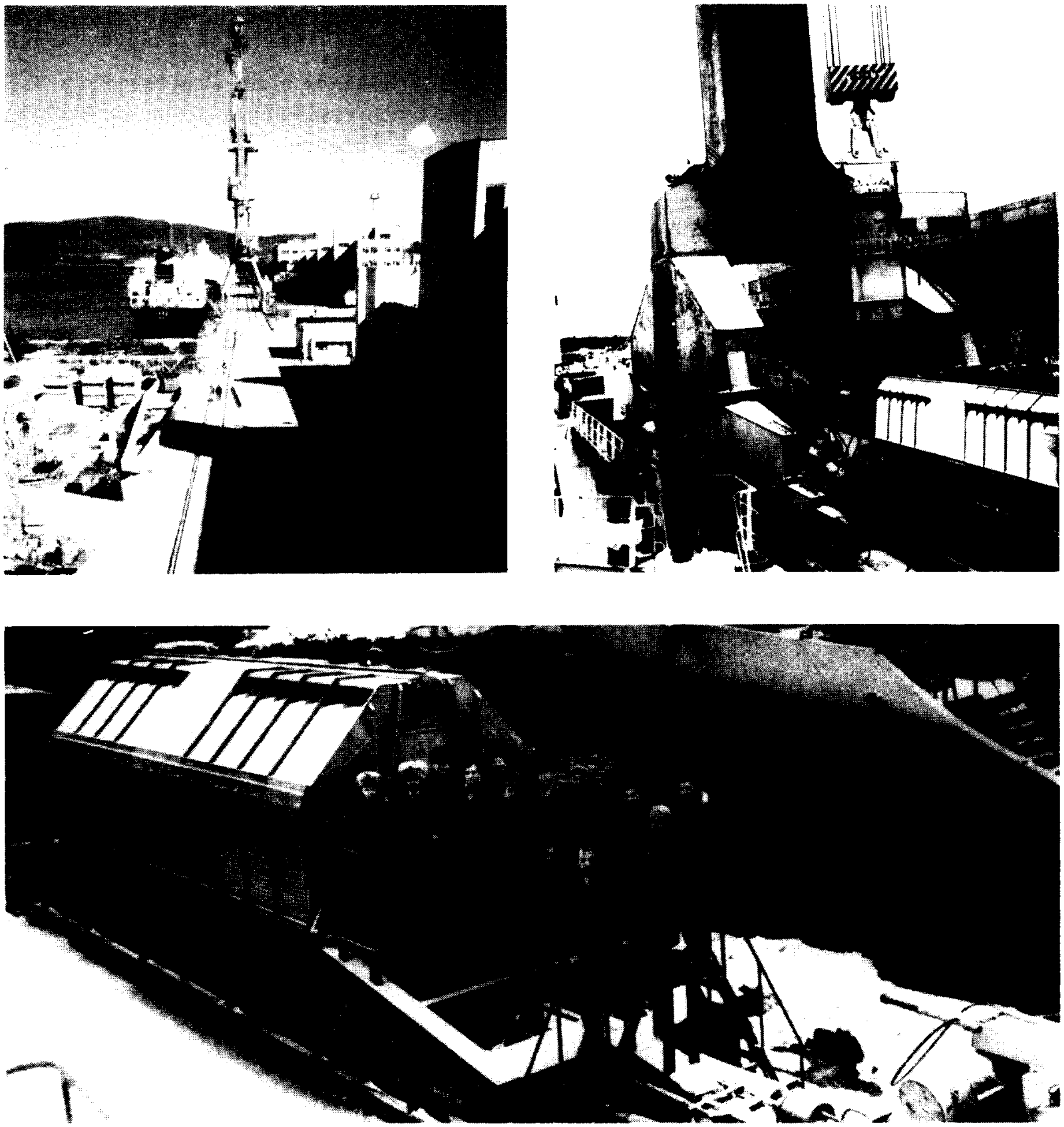
Many researchers are also concerned about Arctic contamination from nonnuclear hazardous materials. Although OTA has not investigated nonnuclear contamination, it is clear that industrial discharges and toxic wastes have entered the Arctic and could present problems. Thus, we have concluded that *contaminants other than radionuclides could have a significant impact on the Arctic environment. The relative magnitudes of risks from other sources such as heavy metals or persistent organics are currently unknown, but expanded risk assessments could help evaluate these factors*. While the ONR research program has been limited thus far to radioactive contamination, other contaminants could also be considered in the future.

OTA has carefully investigated the programs within various federal agencies that have devoted attention to this nuclear contamination question and found no substantive long-term program with specific goals. We have concluded that *the Arctic Nuclear Waste Assessment Program administered by the Office of Naval Research is the only U.S. program specifically evaluating the Arctic radioactive contamination problem. It has accomplished significant data collection and evaluation work over the past three years. To fill some remaining data gaps, additional research is needed in areas such as ice transport, biological pathways, and human exposure assessments.* Many of the scientists engaged in the ONR program recognize the current data gaps and the need for continuing and augmenting the program to fill them. However, the ONR program is not a long-range effort with specific goals for the future.

[9] Sufficient data exist documenting the migration, at least at low levels, of radionuclides down the Yenisey River, probably originating from pass-through reactors and cooling waters. See Figure 1-5.

PETER JOHNSON

MURMANSK SHIPPING CO.



The Murmansk Shipping Company's Atomflot facility showing the dock and service ship Lotta *where spent nuclear fuel is stored (top left); a railroad car used for transporting spent nuclear fuel from Atomflot to the reprocessing plant at Mayak (top right); the dockside crane transferring a spent tie/ shipping cask from (he service ship* Lotta *to the railroad car (bottom).*

OTA's analysis suggests that now is the time to make long-range plans and to structure a more comprehensive program for the future. *Preliminary assessments do not suggest a major, long-term impact on human health for the broad Arctic region from radioactive dumping and discharges that have already occurred. However, identifying the potential for human exposure to radioactivity in the future will require some form of monitoring and a comprehensive, rigorous exposure assessment.* Planning for these has started, and it would be useful for policymakers to define the major goals and key questions so that the risk assessment can be useful and cost-effective.

Because the nuclear material dumped in the Arctic has not been adequately contained for long-term disposal, and because very little specific information exists about the condition of the dump sites, it has been suggested that some form of remediation be considered. Options for remediation range from encasement in place to removal and disposal at a different location. *Although remediation of past dumping is being investigated, it cannot be evaluated fully now because of the lack of data on waste sites and conditions. When such data are obtained, it would be productive to study remediation options further, estimate their risk reduction value and cost, and choose the optimum approaches.*

Most options for the remediation of nuclear wastes dumped into the environment are difficult and costly. *Because it is so difficult to take useful actions after radionuclides have been released into the environment, it is wise to consider prevention efforts now that could minimize future accidents, releases, or discharges. There are several opportunities to enhance safety and prevent future releases from Russian nuclear activities in the Arctic and Far East. Support for cooperative work in reactor safety, submarine dismantlement, spent fuel management, waste disposal, and other related matters deserves careful consideration.*

OTA's investigations of the situation at the local bases of the Russian nuclear fleet in the north and Far East show that severe problems exist in adequate management of nuclear wastes and spent fuel from submarine reactors. These problems include poorly maintained vessels and other equipment for handling spent fuel, overloaded storage and treatment facilities, and a substandard transportation infrastructure. These problems could lead to accidents or pressure to engage in more dumping in the future if they are not addressed soon.

There is, however, some evidence of progress toward improving spent fuel and nuclear waste management practices with regard to the Russian Northern Nuclear Fleet, with the help of international assistance and cooperative efforts. *With continuation and expansion of international efforts to address spent fuel problems in the Russian north (i.e., the Kola Peninsula, Murmansk), some significant improvements are possible in the prevention of future radioactive releases there. The situation in the Russian Far East is more problematic, however, with much less evidence of progress in international cooperation.*

The United States has recently been moving toward more cooperative work with Russia on Arctic nuclear waste issues. U.S.-Russian collaboration in research and reactor safety has grown, and many useful contacts have been made. OTA's analysis concludes that such efforts should continue and expand in the future. These contacts, in particular, could be used to foster and encourage more interaction in areas dealing with the environmental impacts of military activities. *Research on Arctic contamination is enhanced and more politically acceptable when it is conducted cooperatively with Russia and other countries. If monitoring and prevention projects are initiated, they will require further data from Russia and greater access to dump sites. Prevention initiatives will be difficult unless Russia takes the lead and assumes substantial responsibility.*

Even though Russia must be responsible for its own nuclear waste management, the international community must also recognize that the country is limited in its current capabilities and resources. While the Russian government has taken initiatives to identify and describe past nuclear dumping activities, it has not been able to provide many resources for further research or other actions to address the problems. *Russian institutions for environmental protection and nuclear safety have yet to be effective in regulating the military or civilian nuclear complex, but they have been developing better capabilities that could be encouraged over the long term with outside assistance.*

POLICY ISSUES AND OPTIONS

OTA's analyses show that radioactive contamination in the Arctic and North Pacific regions is not an immediate crisis but a long-term, chronic problem requiring a certain level of comprehensive risk assessment, monitoring of conditions, and prevention of future releases. Such approaches would help ensure the greatest possible protection of human health and the environment. Current U.S. policies addressing these issues lack long-term goals or cohesiveness and are not likely to develop such goals without congressional direction and action.

Three possible policy areas that already have a considerable history and institutional framework could be considered by Congress in terms of the direction and support of federal programs to address Arctic nuclear contamination: 1) Arctic research policies; 2) international environmental protection policies; and 3) policies for assistance to or cooperative work with the former Soviet Union. In each case, some programs currently exist and have defined benefits and support. If Congress wished, it could strengthen these programs to help focus future attention and work on the nuclear contamination problem.

Arctic Research Policies

Current Policy Status

Efforts by the United States to assess the Arctic's radioactive contamination began only recently. Traditionally in Arctic research, the U.S. focus was on its strategic and national security importance. However, in 1993, as a response to reports documenting the Soviet Union's ocean waste dumping, the United States adopted the "Policy for the Arctic Region," emphasizing for the first time a commitment to the environmental protection of this important ecosystem and authorizing the State Department as the implementing agency.

Congressional support for research regarding Arctic radioactive contamination began with the passage of the Arctic Research Policy Act (ARPA) in 1984. Congress established the institutional infrastructure (i.e., the Arctic Research Commission and the Interagency Arctic Research Policy Committee, or IARPC) to develop and coordinate U.S. Arctic research programs. In 1992, radioactive contamination from Soviet activities was recognized as a potentially serious problem by ARPA. However, the statute does not provide any specific funds to support activities by the commission or by IARPC agencies[10] regarding research on radioactive contamination in the Arctic.

In 1994, IARPC proposed a $33-million increase in research funds to implement an Arctic Contamination Research and Assessment Program (ARCORA) which would begin in FY 1996. The requested funds, if provided, would support five essential research-related activities in the Arctic: 1) data and information management; 2) data retrieval and synthesis; 3) observation and monitoring; 4) development of models; and 5) analysis of risks. Work in these areas would allow participating U.S. agencies to assess the sources, transport, fate, and environmental

[10] The following federal agencies compose what is officially known as the Interagency Arctic Research Policy Committee (IARPC): Department of State; Defense Nuclear Agency; Naval Sea Systems Command; Central Intelligence Agency; U.S. Coast Guard; Department of Energy; Department of Interior; Environmental Protection Agency; U.S. Geological Survey; National Science Foundation; and National Oceanic and Atmospheric Administration.

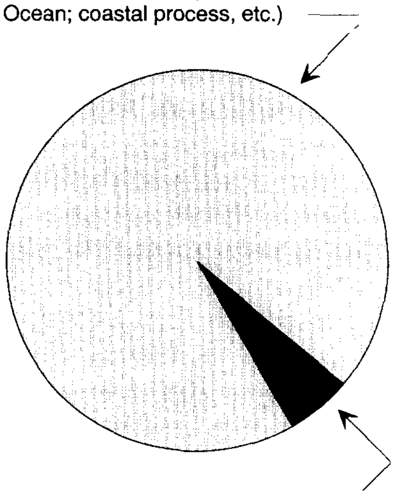
and health effects caused by pollutants discharged directly into the Arctic or accumulated from non-Arctic sources. The NOAA and the Department of Interiorly would be responsible for most of the work. The Environmental Protection Agency, Department of Energy (DOE), and National Science Foundation would also play active roles. Despite interest among proponents, this proposal to fund a federal Arctic contamination research program was not supported by the Administration.

Although the ARPA established the main institutional means for carrying out federal Arctic research, the only relevant program actually being implemented is the congressionally authorized Arctic Nuclear Waste Assessment Program (ANWAP) under the Office of Naval Research of the Department of Defense. For each of the past three years, Congress has mandated through DOD authorizations or Nunn-Lugar legislation that $10 million be allocated to ONR for Arctic research work. Figure 1-6 compares this ONR funding to overall expenditures for Arctic research for FY 1995.

The initial emphasis of the ONR program involved collecting and evaluating existing Arctic environmental data. Subsequent efforts have also included supporting numerous research projects; holding workshops; collaborating with various U.S. and international research organizations; and sponsoring scientific expeditions designed to gather data in the Arctic and evaluate potential transport pathways for radioactive waste. ONR is also expanding its scope of research to include the North Pacific and certain major Russian rivers discharging into the Arctic Ocean.

Support for U.S. research programs, other than ANWAP, depends on the priorities established by individual federal agencies that provide research funds. In the recent past, most federal agencies have not considered Arctic radioactive contamination a priority on their research agendas. At the June 6, 1995, OTA workshop on U.S.

FIGURE 1-6: Expenditures for Arctic Research and Radioactive Contamination Assessment, FY 1995



KEY: ANWAP = Arctic Nuclear Wastes Assessment Program.

SOURCE: C. Myers, National Science Foundation, personal communication, June 7, 1995; Office of Technology Assessment, 1995,

Arctic institutions, officials representing U.S. Arctic research programs stated that their agencies have not provided substantial support to carry out their national and international Arctic research work.

The State of Alaska has played a key role in encouraging cooperation in research with regional governments of the Russian Far East. This cooperation has proven successful in promoting information exchange on past contamination and possible preventive measures. Despite the progress made to date, long-term support for state research efforts remains limited.

During the next phase of its research program, ONR will make the information gathered available to the scientific community and to the populations most likely to be at risk from, or to have concerns about, Arctic contamination, The State of Alaska actively participates in several cooper-

[11] Namely, the U.S. Geological Survey, the U.S. Fish and Wildlife Service, and the National Biological Survey.

ative efforts to research and monitor Arctic contamination. Most efforts by the state emphasize the identification of existing and potential public health and safety hazards, particularly to its Native residents, and the sharing of environmental data among regional governments. Alaska has also been cooperating successfully with Russian regional governments in improving communications, nuclear safety, and emergency response with the involvement of Native communities.

Future Policy Initiatives

Despite the extensive institutional structure created to conduct research in the Arctic, the only U.S. program involved in research on radioactive contamination is ONR's Arctic Nuclear Waste Assessment Program. There is no current policy to continue this ONR work through the next logical phase or to use its results to plan for a transition to comprehensive risk assessments and monitoring.

Congress could continue its current level of financial support for ONR's Arctic Nuclear Waste Assessment Program through an initial risk assessment phase and until future monitoring or corrective measures are adequately identified. Funding of research efforts would most likely be short-term in nature since the main objective would be to collect the data required for future planning, for establishing monitoring programs, and for carrying out long-term risk assessments, if needed. When plans are completed, *Congress could direct ONR to conduct future monitoring and assessment activities as well.* However, the nature of these activities might require Congress to fund the ONR program on a multiyear basis to incorporate long-term planning.

Congress may, on the other hand, opt not to fund ONR's Arctic Nuclear Waste Assessment Program but instead request IARPC or any of the U.S. agencies with Arctic programs to adopt ONR's preliminary research findings and prepare the long-range plan needed to conduct risk assessments and monitoring. Congress might explicitly identify the level of funding for IARPC, or for the relevant federal agency or agencies. Some funds would be needed to adapt ANWAP results to other agencies' goals and to implement a long-range monitoring program. Any such program should delineate clearly the implementing roles of relevant federal agencies. Congress could also request an annual report covering the successes and failures associated with implementation of the plan.

The ONR program plan currently includes efforts to conduct preliminary risk assessment that would be accomplished with existing funding. If Congress does *not* fund the continuation of this research beyond FY 1995, this preliminary risk assessment as well as the publication of research results to date would probably be accomplished over the next one or two years, but no new work could be expected to fill data gaps, conduct monitoring, or investigate new areas. If Congress continues funding for ONR but not for other agencies, research on key unanswered questions could enhance a more rigorous risk assessment and reduce the uncertainties of environmental and health impacts. However, it would be difficult to establish useful long-term monitoring programs, to effectively engage the affected communities in risk assessments, or to address public health concerns without the more active participation and funding of other federal and state agencies on the IARPC.

International Environmental Protection Policies

Current Policy Status

U.S. support for international environmental protection and Arctic research has been effected mainly through bilateral cooperation agreements with Russia. Prior to the dissolution of the Soviet Union, most U.S. actions toward the former Soviet Union centered on mobilizing the economic and military resources needed to withstand any potential threat. Since the Soviet breakup, U.S. policy has become largely supportive of economic and political reform.

An extensive cooperative framework exists between the United States and Russia, but funding for work on Arctic radioactive contamination is limited. As part of their April 1993 Vancouver summit, the Presidents of Russia and the United States agreed, for the first time, to forge a new cooperative venture in many important economic and technical areas (e.g., energy, space, science, technology, environment). Despite its success in certain fields, progress by the Gore-Chernomyrdin commission—the implementing body for U.S.–Russian cooperation—regarding research monitoring of the Arctic's nuclear contamination problem is generally confined to developing institutional relationships, entering broadly defined agreements of cooperation, and in a few cases, studying the technical feasibility of possible environmental solutions.

Lack of funds and government leadership appears to have hindered progress by the Gore-Chernomyrdin commission in Arctic environmental work. At a January 1995 OTA workshop on Arctic institutions and programs, some experts emphasized that the commission lacks a funding mechanism or a specific budget item to support research on Arctic radioactive contamination. They also pointed to the obligation of federal agencies to conform to the Administration's policies and priorities. The limited resources provided under agreements preclude agencies from implementing fully the programs that the commission appears to support.

Considerable concern exists about the clearly inadequate information available on the extent of environmental contamination, particularly in the Russian Far East. The inadequacy of regional environmental data and of agency resources has also limited the ability to map the state of contamination in Russia. The fragmented nature of the institutional structure responsible for ensuring environmental protection in the Russian Arctic region is another matter of concern.

Several international efforts are under way to assess issues of Arctic contamination and to formulate future monitoring and preventive approaches. These will help provide information about contamination and serve as a vehicle for communication and cooperation in research and monitoring activities. The United States stands to benefit from active participation in these cooperative efforts. The United States has participated in several international initiatives, including the International Arctic Seas Assessment Program under the IAEA; the Arctic Environmental Protection Strategy established by the eight circumpolar nations; and other initiatives with Russia, Norway, and various European Nations. Many international environmental agreements and conventions have traditionally kept nuclear issues separate from those of other hazardous contaminants. This separation has made it difficult to formulate policy that would compare the needs and priorities of nuclear and nonnuclear environmental problems.

With regard to nuclear wastes, the United States has not provided an overall strategy for selecting and participating in the most appropriate international entities. Nor has it determined which federal agency would be responsible for developing relevant research strategies, for formulating and overseeing implementation strategies, and for providing the financial resources required in any joint efforts. Because so many institutions are involved in establishing international programs it would be much more efficient for the United States to concentrate on working with a few selected programs that could produce the most useful work and best advance U.S. policy goals.

Future Policy Initiatives

Congress could direct the Administration to prepare a coordinated plan for taking action on programs that result from international agreements. A coordinated plan should incorporate such multilateral efforts as the Arctic Environmental Protection Strategy, which includes the Arctic Monitoring and Assessment Program. It could incorporate the same level of U.S. leadership and commitment exercised through bilateral cooperative programs (i.e., the Gore-Chernomyrdin commission).

Similarly, *Congress could direct the Administration to maintain entities such as the Gore-Chernomyrdin commission and the State Department as instruments of U.S. cooperation and to* *give specific funding authority to certain federal agencies to implement any cooperative research and monitoring projects developed under a coordinated plan.* One clear benefit of a coordinated international plan is that savings could be achieved if two or more nations have certain elements under their control such as access to sites, data, or key research work. Another benefit is avoidance of duplication and, thus, improved efficiency or cost-effectiveness.

Policies for Assistance to and Cooperation with the Former Soviet Union

Current Policy Status

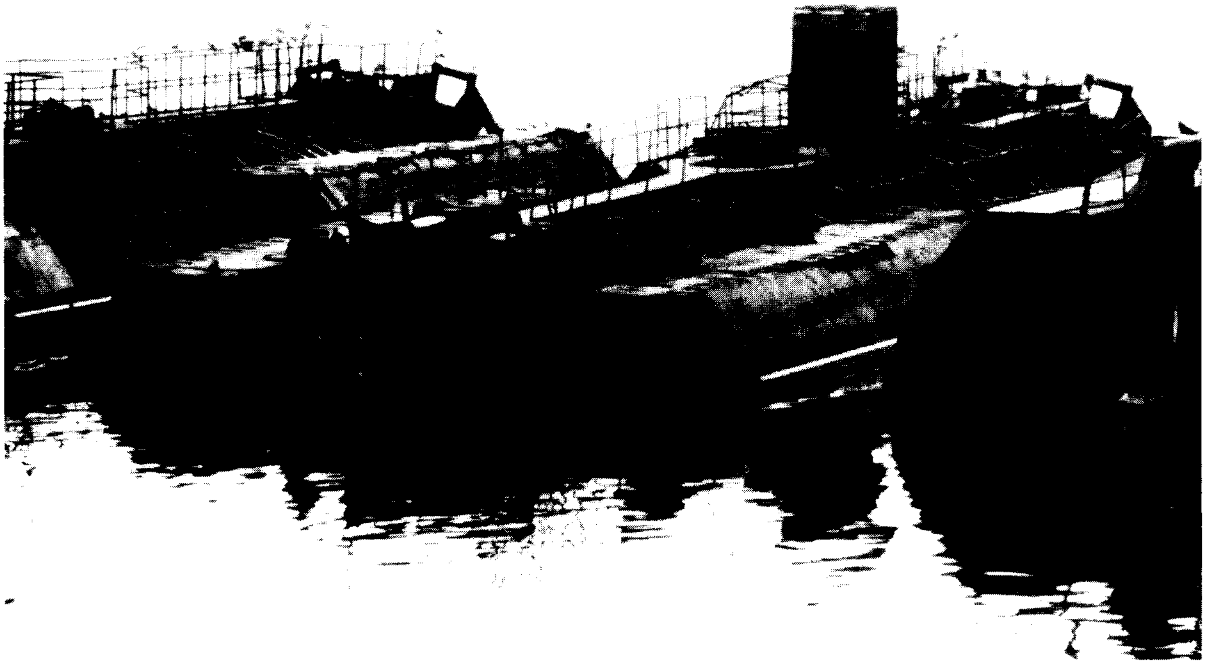
Certain policies for cooperation with the former Soviet Union are designed as initiatives and programs to prevent future Arctic radioactive contamination. Included among the current initiatives are those designed to *improve radioactive waste management practices* and *upgrade Russia's older and most unsafe operating nuclear reactors.* Despite the differences in their nature and in the institutional framework involved, both types have proven useful in improving bilateral and multilateral cooperation with Russia.

One of the existing U.S.-supported initiatives to improve radioactive waste management in the Russian Arctic region is the Murmansk Initiative being implemented under the Gore-Chernomyrdin commission. This is a cooperative effort by Norway, the United States, and Russia to expand the liquid radioactive waste storage and processing capacity at the Murmansk Shipping Company, thereby halting the unsafe management and ocean dumping of these wastes. Currently, Russia continues to accumulate considerable amounts of liquid radioactive waste, particularly at sites where submarine and icebreaker reactors are repaired or refueled. Design work has been funded and construction funds have been identified for facility expansion, but the funding authority for implementing this initiative within the United States has often been unclear or imprecise.

The London Convention is a major international effort designed to prohibit dumping of radioactive waste in the world's oceans. Although its guidelines are voluntary in nature, Russia's failure to sign the convention's 1993 decision to ban ocean radioactive waste dumping is of great concern to many in the international community, particularly the circumpolar nations. One reason for concern is Russia's dumping of low-level liquid radioactive wastes in the Sea of Japan as recently as 1993. Although Russia has agreed to adhere to the principles of the London Convention prohibiting the disposal of all types of radioactive waste in the marine environment, it continues to be the only country that has failed to sign the ban formally. Therefore, the recent signing of the Murmansk Initiative within the framework of the 1994 U.S.-Russia Agreement on Pollution Prevention in the Arctic is significant because it will help Russia meet its commitment to abide by the principles of the London Convention. Russia's voluntary commitment to the convention, in combination with this cooperative agreement, is a good first step, but much more work is necessary to ensure long-term compliance.

In addition to the London Convention, the European Union, Japan, and Norway also support international cooperative initiatives designed to improve Russia's waste management and prevent radioactive contamination in the Arctic. The European Union, for example, is cooperating with Russia to identify and develop waste management technologies for application in the Kola Peninsula. The Government of Japan, on the other hand, is currently financing a project that would provide facilities for treatment of some of the liquid radioactive waste stored by the Russian Navy near the Sea of Japan.

Of the Arctic countries, Norway is the most active in searching for solutions to the Arctic radioactive contamination problem. Of primary concern to Norway are the operational safety of nuclear facilities and the management of nuclear materials and wastes at civilian and military nuclear sites operating near its borders. Recently, the Norwegian government created an interna-



F/eating reactor compartments from decommissioned Russian submarines temporarily stored in Chazhma Bay near Vladivostok.

tional steering committee to cooperate technically and financially with Russia in the removal and cleanup of a Russian nuclear waste service ship in Murmansk (near the Norwegian border) containing damaged spent nuclear fuel from the naval and icebreaker fleets.

Another Norway-led initiative seeks cooperation among Norwegian, U. S., and Russian defense communities in the assessment of military sources of radioactive contamination in the Arctic region. On June 30, 1995, the U.S. Secretary of Defense and his Russian counterpart signed a Memorandum of Agreement to exchange information on the environment, particularly in the areas of environmental protection and cleanup, waste management, and disposal of weapons material. No specific timetable or plan of action was provided. Although this cooperative agreement is broad and lacks a clear plan of action, it constitutes a potentially useful attempt to address key problems relevant to future international Arctic protection efforts.

A second major type of preventive measure addresses commercial reactor safety. U.S. support for a nuclear safety initiative began immediately after the Chernobyl accident in April 1986. Initially, most cooperation consisted of information exchange by the Nuclear Regulatory Commission and the Department of Energy with their Russian counterparts. The commitment of the United States to cooperate with Russia in the field of nuclear reactor safety was expanded at the U.S.-Russian presidential summit in Vancouver, Canada, in 1993. The primary objectives of these initiatives were to help Russia to reduce the likelihood of future nuclear reactor accidents.

U.S. assistance to Russia on nuclear safety issues is multiagency in nature. The State Department and the Gore-Chernomyrdin commission are the principal coordinators; the U.S. Agency for International Development is the agency with overall management responsibilities; and the Department of Energy and Nuclear Regulatory Commission are the executors. Progress has been made under this initiative in the areas of technical training and the provision of some safety equipment.

The State of Alaska has played an important role in cooperating with Russia to achieve nuclear safety, particularly with the government of the region in which the Bilibino nuclear power plant—the nearest to Alaska—is located. Another Alaskan undertaking was the international radiological exercise held in June 1994 on emergency response procedures among Arctic nations. In general, these Alaskan initiatives have helped Arctic national and regional governments to strengthen communications and recognize the need for improved cooperation in the areas of nuclear safety and emergency response.

The United States also participates in the Nuclear Safety Account, a 1992 initiative that finances projects designed to improve the operational and technical safety of nuclear reactors in Russia and other states of the former Soviet Union. In addition to the United States, the European Union has also established a short-term nuclear safety improvement program at the Kola Peninsula Nuclear Power Plant near the Arctic.

OTA has found that a number of national and international programs are in place to improve Russia's nuclear waste management practices and prevent similar recurrence in the future. The varied nature and objectives of the national and international missions supporting these programs make it difficult to evaluate their effectiveness. No attempt has been made by the United States or the international community to evaluate the overall progress made by their cooperative nuclear safety initiatives in the Arctic and determine where improvement is needed.

Russia finds itself in the midst of a difficult transition related to nuclear safety and waste management. Thus far, the creation of new agencies and laws in Russia is just beginning to address the country's radioactive contamination problems and lack of a nuclear safety culture. It is crucial that Russia continue to strengthen these efforts. Equally important is the fact that the severe economic situation affecting this nation now requires creative and flexible approaches by the United States and other countries as a means to ensure long-term cooperation.

A number of U.S.-supported bilateral and multilateral initiatives are under way to collaborate with Russia in the prevention of future radioactive contamination in the Arctic. The major U.S. assistance program has focused on efforts to improve the operational safety of Russia's most dangerous nuclear reactors so as to prevent another Chernobyl-type accident. Continued attention to the goals and coordination of these efforts is needed.

However, the areas of improving spent fuel and nuclear waste management practices and enhancing submarine dismantlement to prevent future radioactive releases have only minimal U.S. support. International cooperative efforts in this area have been evolving, with Norway, the European Union, and Japan taking the lead. Although the United States may not be as threatened by future releases as other countries, it too could benefit from reduced contamination risks in the future, from additional progress in Russian submarine dismantlement, and from new business opportunities for U.S. firms.

Since the disintegration of the Soviet Union, the Russian government has made official its intent to improve environmental protection and nuclear safety. Although considerable progress has been made in the area of environmental regulations, more effective approaches are still needed. It is also crucial that Russia strengthen its agencies responsible for environmental protection and for establishing a nuclear safety culture.

Another benefit to the United States from cooperation with the former Soviet Union is continued, mutual demilitarization in the United States and Russia. The common public notion is that the Cold War is over. However, certain military institutions in both countries continue to distrust each other and are suspicious of the actions and motives of the other side. Existing and new international programs focusing on the environmental legacy of the Cold War could lead to a lowering of these post-Cold War tensions.

Future Policy Initiatives

Congress could continue current support for U.S. participation in bilateral and multilateral cooperative initiatives to improve radioactive waste management and nuclear safety of reactors in Russia. However, Congress could request that U.S. decisions at the bilateral level be coordinated with those involving multilateral approaches to avoid possible conflicts and unnecessary or costly duplication. Adopting a long-term approach is also helpful since establishing a government-supported regulatory and institutional framework and developing the safety culture needed to ensure that Russia's nuclear facilities are properly managed will take some time.

Existing cooperative initiatives, however, do not address issues of spent fuel and radioactive waste management related to Russian nuclear submarines and ships. To include this, *Congress could create a program within an appropriate agency such as DOD or DOE to provide bilateral or multilateral cooperative assistance for improving Russia's management of spent nuclear fuel,* particularly when such efforts would also be in the interest of the United States. To support this program, Congress could establish a new funding authority or make use of existing ones—for example, the Nunn-Lugar program if the initiative involves assistance in nuclear submarine dismantlement or the Nuclear Safety Initiative program if the purpose is mainly to prevent accidents and radioactive releases. Submarine dismantlement per se does not require advanced technology and is clearly within the capabilities of the shipyards that built Russia's submarine fleet. The challenging aspects of dismantlement, however, are the safe removal of spent nuclear fuel and the subsequent management of this and other nuclear wastes. The Russians have had problems in this area, some related to limited resources, and others to poor environmental protection practices; it is here that U.S. cooperation could lead to mutual benefit and advance U.S. interests. If Nunn-Lugar were the vehicle to provide assistance to Russia, it would have to be justified on the basis of an expanded sphere of coverage that, in the long run, could enhance demilitarization and encourage better transfer and safer storage of nuclear materials. Perhaps the greatest benefit to the United States would be a long-range improvement of the nuclear safety culture in Russia and a decrease in Cold War tensions.

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Contamination from Nuclear Wastes in the Arctic and North Pacific 2

Although popular perceptions of the Arctic might characterize it as a pristine area, it has become increasingly clear that this important ecosystem has not avoided the effects of industrialization and development. Evidence of contamination by persistent organic pollutants, heavy metals, and radioactivity has been gathered since the 1950s but has not garnered a great deal of public attention. However, in the last three years a tremendous amount of attention has been directed toward assessing the extent of, and identifying possible remedies to, the environmental contamination problem in the Arctic from Russian nuclear sources. Although the activities of several different countries have released radionuclides into the Arctic environment for decades, news of ocean dumping of submarine reactors and nuclear wastes by the former Soviet Union has generated particular interest and concern because it revealed previously secret activities and enhanced the traditional public fear of radioactivity. This chapter analyzes available information about the wastes dumped in the Arctic and North Pacific, what is known of their contribution to contamination of the marine environment, and the research efforts needed to address unanswered questions. Chapter 3 discusses the information required to understand the health and environmental impacts of this contamination. Chapter 4 addresses other potential sources of contamination of the Arctic and North Pacific environments.

Past dumping of nuclear submarine reactors and fuel assemblies, as well as significant amounts of other radioactive wastes, into waters adjacent to the Arctic and North Pacific Oceans was disclosed in some detail by the Russian Federation in a 1993 government white paper referred to as the "Yablokov report." The ultimate fate and effects of this dumping are currently unknown, but possible impacts on local and regional environments and public health have raised concerns not only in Russia but in other countries of the Arctic and North Pacific regions. People in the United States—in particular, Alaska and the Pacific Northwest—want to know about this dumping and other discharges of radionuclides into the oceans. They also want to know about other risks to these regions from Russian nuclear activities, both past and future, and the potential threat to the wider regional environment and population beyond Russian borders.

As discussed in chapter 3, a particular concern is the possible threat to Alaskan Native commu-

TABLE 2-1: Objects Dumped by the Northern Submarine and Icebreaker Fleets

Location	Objects	Depth (m)	Estimated activity in 1994 (kCi)
Ambrosimov Inlet	8 submarine reactors (3 with SNF)	20	37.9
Novaya Zemlya Depression	1 submarine reactor (1 with SNF)	300	7.8
Stepovoy Inlet	2 submarine reactors (2 with SNF)	50	22.7
Techeniye Inlet	2 submarine reactors	35–40	0.1
Tsivolka Inlet	3 reactors from icebreaker *Lenin* and shielding assembly from *Lenin* reactor assembly with SNF	50	59.4
Total	16 reactors (6 with SNF) 1 shielding assembly from icebreaker *Lenin* with SNF		127.9

KEY: kCi=kilocuries; SNF = spent nuclear fuel

SOURCES: Government Commission on Matters Related to Radioactive Waste Disposal at Sea ("Yablokov commission"), created by Decree No. 613 of the Russian Federation President, October 24, 1992, *Facts and Problems Related to Radioactive Waste Disposal in Seas Adjacent to the Territory of the Russian Federation* (Moscow, Russia: 1993), translated by Paul Gallager and Elena Bloomstein (Albuquerque, NM: Small World Publishers, Inc.); N. Lynn, J. Warden, Y. Sivintsev, E. Yefimov, M. Mount, K. Gussgard, R. Dyer, and K-L Sjoeblom, "Radionuclide Release from Submarine Reactors Dumped in the Kara Sea," presented at *Arctic Nuclear Waste Assessment Program Workshop*, Woods Hole Oceanographic Institution, Woods Hole, MA, May 1–4, 1995; Y. Sivintsev, "Study of Nuclide Composition and Characteristics of Fuel in Dumped Submarine Reactors and Atomic Icebreaker *Lenin*," *Part I—Atomic Icebreaker* (Moscow: Kurchatov Institute, December 1993); M. Mount, Lawrence Livermore National Laboratory, personal communication, June 14, 1995.

nities, their traditional food supplies, and other Alaskan fisheries resources. The impact of radioactive wastes that have been dumped in Arctic waters is also a key concern of other nations, particularly Norway, which depends on a major fishery in the Barents Sea and is therefore very active in supporting research into such contamination in nearby waters.

The 1993 Yablokov report described the extensive past history of Russian dumping of damaged submarine reactors, spent fuel from the nuclear fleet, and other radioactive waste into the Kara Sea off Novaya Zemlya, into the sea of Japan, and in other locations. It was a remarkable document to emerge from the new government of the Russian Federation. The report represented the results of a tremendous effort to gather information, some of it decades old, from a multitude of Soviet ministries and agencies; declassify it; and report it frankly to the international community and to the Russian people. Other than the estimated inventory of the activity of the items dumped, which has been refined since the release of the report by an expert group working with the International Atomic Energy Association (IAEA) and the precise location of some of the dumped wastes, the information presented in the Yablokov report has not been disputed.

As the 1993 Yablokov report described, the Soviet Union dumped a multitude of materials in the Kara Sea and in fjords along the coast of Novaya Zemlya in the 1960s, 1970s, and 1980s, in violation of international as well as domestic laws. The wastes included containers, barges, and ships and submarines containing nuclear reactors both with and without spent reactor fuel. A total of 16 reactors were dumped at five different sites; six of these and an additional container held spent fuel (see table 2-1). The report estimated the maximum total radioactivity of these materials at the time of disposal as more than 2 million curies. Recent studies by Russian and U.S. scientists have reached the preliminary conclusion that about 0.13 million curies are present at these Kara Sea dump sites today.

The Yablokov report also listed similar dumping (of materials with lower radioactivity) in the Russian Far East (the Sea of Japan and near the Kamchatka Peninsula). In addition, the report described some accidents (most notably, the explosion of a naval reactor during refueling in Chazhma Bay near Vladivostok); solid, low-

TABLE 2-2: Solid Intermediate- and Low-Level Radioactive Waste Dumped in Northern and Far Eastern Seas

Location	Depth (m)	Activity in Sr-90 equivalents[a] (Ci)
Kara Sea, Novaya Zemlya Depression	380	3,320
Sedov Inlet, Novaya Zemlya	13–33	3,410
Oga Inlet, Novaya Zemlya	24	2,027
Tsivolka Inlet, Novaya Zemlya	56–135	2,684
Stepovoy Inlet, Novaya Zemlya	25–27	1,280
Abrosimov Inlet, Novaya Zemlya	12–20	661
Blagopoluchiye Inlet, Novaya Zemlya	13–16	235
Techeniye Inlet, Novaya Zemlya	up to 50	1,845
Near Kolguyev Island		40
Chernaya Bay, Novaya Zemlya		300
Barents Sea		>100
North, Total		**~15,900**
Sea of Japan (3 sites)	1,900–3,300	3,820
East coast of Kamchatka Peninsula	2,000–2,570	2,992
Far East, Total		**6,812**

[a]Information from original sources used by the Yablokov commission presented the activity of solid radioactive waste as "activity (strontium-90 equivalent) curies." These units appear to relate to the radiation measured outside the container or object and are not likely to have a consistent relationship to actual activity. The numbers therefore can be used for comparisons only within the low- and intermediate-level solid radioactive waste (SRW) category; more information is needed to understand the radioactivity they might represent today.

SOURCE: Government Commission on Matters Related to Radioactive Waste Disposal at Sea ("Yablokov Commission"), created by Decree No. 613 of the Russian Federation President, October 24, 1992, *Facts and Problems Related to Radioactive Waste Disposal in Seas Adjacent to the Territory of the Russian Federation* (Moscow, Russia: 1993), translated by Paul Gallager and Elena Bloomstein (Albuquerque, NM: Small World Publishers, Inc.).

level radioactive waste dumping; extensive low-level liquid waste discharge; the accident on and sinking of a nuclear submarine in the Norwegian Sea; and serious problems with the operation of current nuclear refueling vessels in both the Russian North and Far East (see tables 2-2 and 2-3).

The dumpings listed in the Yablokov report generated a number of questions about the potential impacts of the discharged radionuclides. Since radionuclides can affect human health and the environment only if and when the radionuclides come in contact with them, the key question is whether and how they may migrate toward populations and other ecosystems in the future. Over the past two years since the Yablokov report, a number of data collection efforts and investigations have been supported to address this question by U.S. investigators, Norwegians, Russians, other nations close to the Russian sites, and international agencies such as the IAEA. Some tentative conclusions have been reached, but the data collected by these efforts are not yet sufficient to accurately predict the impacts of this dumping.

Researchers have not found evidence of migration beyond the immediate vicinity of the dumped radionuclides that might affect human health in the short run. However, some key questions have yet to be addressed, for example: 1) there has been no inspection of many of the dump sites within the past two decades; 2) we have limited knowledge of the possible release rates and the long-term reliability of materials used to encase the waste; and 3) some of the critical pathways for radionuclides to affect humans, such as the biological food chain or ice transport, are only in the early stages of investigation.

TABLE 2-3: Liquid Radioactive Waste Dumped or Accidentally Released in Russian Northern and Far Eastern Seas

Location	Activity at time of dumping (Ci)
Barents Sea—open sea (3 sites)	11,779.0
Barents Sea—coastal (4 sites)	3,389.0
Kara Sea (1 site)	8,500.0
North, Total	**23,668.0**
Sea of Japan (6 sites)	11,984.8[a]
Sea of Okhotsk (1 site)	0.1
East coast of Kamchatka Peninsula (2 sites)	352.2
Far East, Total	**12,337.1**

[a]Includes 0.38 Ci dumped into the Sea of Japan by the Russians in October 1993.

SOURCES: Government Commission on Matters Related to Radioactive Waste Disposal at Sea ("Yablokov commission"), created by Decree No. 613 of the Russian Federation President, Oct. 24, 1992, *Facts and Problems Related to Radioactive Waste Disposal in Seas Adjacent to the Territory of the Russian Federation* (Moscow, Russia: 1993), translated by Paul Gallager and Elena Bloomstein, (Albuquerque, NM: Small World Publishers, Inc.); V.M. Zakharov, "Situation and Course of Action for the Problem of Managing Radioactive Wastes in the Russian Pacific Fleet," *Proceedings of U.S.–Russia-Japan Study Group for Radioactive Wastes in Sea of Japan, Sea of Okhotsk and North Pacific Ocean* (Biloxi, MS: January 1995); V.A. Danilyan, and V.A. Vysotsky, "Nuclear Waste Disposal Practices in Russia's Pacific Ocean Region," *Proceedings of U.S.-Russia-Japan Study Group for Radioactive Wastes in Sea of Japan, Sea of Okhotsk and North Pacific Ocean* (Biloxi, MS: January 1995).

Several other possible sources of contaminants that could affect the Arctic environment are also just beginning to be investigated. In the Kara Sea region, for example, one serious potential source is the large, northward-flowing Siberian rivers, at whose headwaters are located the major Russian nuclear weapons production facilities. Over the last few decades, the largest releases of radioactive wastes in the world have been recorded at several of these sites, such as Chelyabinsk, Tomsk, and Krasnoyarsk. Wastes totaling more than 100 million curies were discharged into lakes and rivers at one site, and over 1 billion curies were injected directly underground at two other sites. Consequences of these releases in the local areas are now under study. Whether high levels of contamination may migrate down rivers such as the Ob or Yenisey into the Kara Sea and the Arctic Ocean is currently under study.

Another related concern is the possibility of radioactive releases from a Russian submarine, the *Komsomolets*, that sank in deep water in the Norwegian Sea in 1989. Although recent surveys have not detected any significant releases and researchers believe that the future threat is minimal, some have advocated actions to continue monitoring and/or provide better barriers to future leakage.

Modeling and Risk Assessment

Research and data collection efforts within the U.S.-supported program under the Office of Naval Research (ONR), as well as research by other nations and international organizations, have provided only preliminary answers to questions about the ultimate fate of the radionuclide releases in the oceans and rivers and their potential impact on public health in the wider region. The traditional scientific approach to providing such answers, known as risk assessment, involves careful definition of the source (e.g., the dumped material, its condition, its potential for leaking and spreading over time, and its hazard); careful modeling of the most likely pathways (transport by ocean currents, by ice movement, through the biota or food chain, etc.); and estimating the risk of human exposure and consequent health impacts based on a number of scenarios. Some work on each of these components is in progress, including modeling of likely pathways through the marine environment. The modeling requires validation where possible, with real measurements and additional data for inputs. An integrated assessment of all of these factors has not yet been done for the radioactive dumping in the Arctic and North Pacific, although planning for such a risk assessment is now under way in the ONR program.

To produce a rigorous risk assessment would require more data and research in areas not yet well investigated (ice transport, biological pathways, human consumption patterns, etc.), as well as the conduct of a multi-year project with substantial investment in resources. Most experts agree that at least four years and several million dollars would be required. However, the size of the effort could be modified substantially, depending on the detailed plan and specific goals. Such goals would have to include (at least): a definition of the population to be studied for health risks; a definition of the region to be considered; a definition of the time frame for investigation; and a definition of the most likely scenarios for pollutant release and migration.

Monitoring

Another aspect of research and data collection that has not yet been undertaken is long-term monitoring of the environment and related indicators that may help provide early warning of potential future health or ecological risks from dumped radionuclides. The OTA review and many experts' conclusions point toward almost no immediate threat to human health beyond Russian borders, based on what is now known about the nuclear waste dumping and discharges under study. That conclusion, however, does not preclude future threats from contamination that has yet to leak and migrate. One possible way to answer the question of future threat is to undertake a rigorous, long-term scientific risk assessment as discussed above. Another way is to devise a monitoring program to facilitate early detection of future releases, anticipate possible migration, and prevent potentially adverse health and environmental impacts.

Many experts have thought about establishing a monitoring program for the nuclear dumping under study, but no specific plan has been put forward. Monitoring could take many forms. It could be tied to some form of leak detection devices at dump sites and possible discharge points (river mouths); it could entail continuous or periodic measuring of ambient concentrations of contaminants; it could involve testing of tissues from animal species important for human consumption (such as sampling Alaskan fish or Arctic mammals); it could involve sampling of some biological indicator. The first step in planning a specific monitoring program has not yet begun; therefore, no specific goals have been set.

If a planning process were initiated, it would be possible to evaluate other past and present monitoring efforts for similar purposes. For example, the Norwegians have initiated a program of measuring radioactive contaminants in fish, other seafood, water, and seaweed in their regions of interest in the Arctic. In the past, the U.S. Navy has conducted surveys at the sites of sunken nuclear submarines in the deep waters of the Atlantic Ocean to measure any discharges to the surrounding environment. Experience with these and other efforts could help develop a program for monitoring nuclear contamination in the Arctic and North Pacific. Information from previous efforts would be useful as a first step toward identifying possible goals and defining approaches needed to establish an effective monitoring program.

Remediation

If a significant risk is posed by radioactive materials dumped or discharged into the environment, it is possible to consider some means of recovery, improved containment, or improved barriers to prevent further releases. The term remediation has been coined in the United States to cover all of these possible measures. In the case of the dumped reactors and solid waste in the Kara Sea or the Russian Far East, much remains unknown about the quality of the containment technology used and its long-term integrity. Therefore, some experts have suggested that the sites be "entombed" in place with a major structure that would encase the material and prevent future leakage. Others have proposed recovering the dumped materials and providing a more secure storage on land. Studies are just beginning to examine the cost and feasibility of some remediation options. However, much more information is required about the condition of the dump sites and the characteristics of the materials themselves before any practical remedial approach could be investigated adequately.

The site that has received the most attention in terms of remediation or possible recovery is the location of the sunken submarine *Komsomolets*. This Russian submarine sank in about 5,000 feet of water in the Norwegian Sea with a nuclear reactor and two nuclear warheads. Expeditions to the site have identified a damaged hull with several holes, some of which were subsequently sealed to minimize water circulation through the vessel's torpedo compartments. Some planning for possible recovery of the submarine has been done, but most experts consider the risk of radionuclide contamination from the *Komsomolets* to be so low as to make its recovery unnecessary.

Remediation at other sites where major amounts of radionuclides have been released (such as the rivers flowing past Russian nuclear production complexes) is possible, and some work at places like Lake Karachai and the Techa River is under way. However, these efforts appear to be more focused on reducing exposure risk to the local population than on preventing future migration into the Arctic Ocean, which is more than a thousand miles downriver.

Some future remediation efforts at the Arctic or North Pacific dump sites may be worthwhile, depending on the findings of the ongoing assessments of potential radionuclide release rates. Norwegian authorities and the IAEA are planning some studies to determine the value of applying containment or recovery techniques to the Kara Sea sites, but no decisions have been made as to the value of any specific technology. Little information exists about implementation costs and funding sources for remediation projects at these sites, and studies to address these questions are just beginning to be considered. The United States has not initiated any such studies and probably could not justify them until much more information about the dump sites themselves is obtained and verified.

The situation described in this chapter provides only a first indication of current conditions and of needs for possible future research. It is evident, however, that when such material is discharged into the open environment, its fate is very difficult to predict in the long term. The only way to obtain answers about future risks is by conducting onsite investigations to identify possible problems. Practical and effective methods of monitoring may assist in observing suggestive trends or providing early warning of releases.

Even though the disclosures of Arctic dumping and other releases caused international reactions and are a serious concern, they are not necessarily the only major concern or the most serious releases or impacts from radionuclides. Other radioactive accidents and discharges of wastes into the Arctic environment (including those of nations other than the former Soviet Union) could be similarly relevant depending on many factors including, most importantly, whether they can lead to human exposure. For example, nuclear weapons testing in the 1960s and the Chernobyl accident in 1986 released large amounts of radionuclides into the atmosphere, and the resulting low-level contamination can be widely measured throughout the Arctic. Also, sea discharges of radioactive wastes from nuclear processing plants in the United Kingdom and France in the 1970s have been detected in Arctic waters thousands of miles away. Researchers have identified and traced specific migration of radionuclides from bomb tests, European reprocessing plants, and the Chernobyl accident, through the atmosphere and the water to various Arctic regions. In fact, since we have little indication of migration from Russian dumping activities, this other contamination, and the methods used to identify it, provide a context in which the impacts of the dumping or discharges from rivers may be investigated.

The following discussion summarizes the current understanding of the extent of radioactive contamination in the Arctic and North Pacific regions resulting from known sources. It evaluates how well the problem has been characterized to date and the uncertainties that remain. It also identifies information and research gaps and suggests important topics for future investigation.

TABLE 2-4: Large Global Releases of Radioactivity

Source	Time period	Amount released (Ci)	Comments
Fallout from atmospheric testing of nuclear devices	1952–1980	25 million, Cs-137 16 million, Sr-90 6.5 billion, H-3	Widely dispersed over the globe
European reprocessing plants	1952–present	5.2 million total to 1986	Discharged into the Irish Sea and English Channel, dispersed through the oceans
Chernobyl	1986	50–80 million total; 6.8 million of long-lived radionuclides	Injected into the atmosphere, with heaviest deposition in Belarus, Ukraine, and western Russia

KEY: Cs-137=cesium-137; H-3=tritium; Sr-90=strontium-90.

SOURCES: A. Aarkrog, "Radioactivity in the Polar Regions—Main Sources," *J. Environ. Radioactivity* 25 (1994); North Atlantic Treaty Organization, Committee on the Challenges of Modern Society, *Cross-Border Environmental Problems Emanating from Defense-Related Installations and Activities*, Final Report. Volume I: *Radioactive Contamination*, Phase I: 1993–1995; U.S. Navy, Office of Naval Research, Radioactive Inventories and Sources of Contamination of the Kara Sea by Riverine Transport, prepared by D.J. Bradley and U.P. Jenquin of Pacific Northwest Laboratory, PNWD-2316 (Richland, WA: Pacific Northwest Laboratory, 1995).

ARCTIC CONTAMINATION FROM NON-DUMPING SOURCES

Global Releases

Three major sources of radioactive contamination released globally have also been sources of radionuclides in the Arctic environment. Listed in table 2-4, these are: 1) global fallout from the testing of nuclear weapons; 2) discharge of nuclear wastes from European reprocessing plants; and 3) the explosion at the Chernobyl nuclear power plant.

The atmospheric testing of nuclear weapons by the Soviet Union, the United States, and other nations has been the single largest source of man-made radionuclides released into the global environment. Millions of curies of radionuclides were released high into the atmosphere and widely dispersed over the globe. As described in box 2-1, all of the largest atmospheric explosions carried out by the Soviet Union took place in the Arctic, on the archipelago of Novaya Zemlya. Underground and underwater tests took place there as well. Radionuclides from global fallout constitute a significant proportion of the radioactivity currently measurable in the Arctic Seas.

European reprocessing plants have also been an important source of radionuclides globally and in the Arctic. Box 2-2 summarizes the amounts of radioactivity that have been discharged over the years, and the movement of radionuclides into the North Sea and then to the Norwegian Sea and beyond into Arctic seas.

The reactor accident at Chernobyl released significant radioactivity into the environment, but the heaviest deposition was not in the Arctic region. Nonetheless, some cesium-137 (Cs-137) has been deposited and transported there, as described in box 2-3.

All three of these sources of released radionuclides have contributed to contamination of the Arctic seas (see table 2-5) and, in addition to the natural radiation sources discussed in chapter 3, provide a context in which further contamination or potential releases can be considered.

Komsomolets

Another cause for concern with regard to possible future Arctic nuclear contamination is the Soviet nuclear-powered submarine *Komsomolets* which sank on April 7, 1989, in the Norwegian Sea approximately 480 km off the Norwegian coast. The *Komsomolets* lies on the ocean floor in international waters at a depth of about 5,000 feet. According to Nikolai A. Nosov from the Rubin design bureau and the deputy chief designer of the *Komsomolets*, the submarine was powered by a single nuclear reactor of the PWR (pressurized water reactor) type and was carrying

BOX 2-1: Nuclear Testing

The first and largest source of radioactive contamination that has been measured throughout the Arctic, and throughout the Northern Hemisphere, was atmospheric testing and use of nuclear weapons. Beginning in the 1940s by the United States and the Soviet Union, and joined in the 1950s and 1960s by Britain, France, and China, more than 2,030 nuclear tests have been carried out worldwide, 511 of them in the oceans or atmosphere (47). In addition, the United States exploded two nuclear bombs over Japan during wartime in August 1945. The total yield of all of these explosions is estimated at 438 megatons, roughly equivalent to 30,000 Hiroshima-sized bombs (48).[a]

The contribution of atmospheric testing to global radioactive contamination has been substantial. It is estimated that 25 million curies of cesium-137 (Cs-137), 16 million curies of strontium-90 (Sr-90), and 6.5 billion curies of tritium (H-3) were released to the atmosphere from these tests (80). Most of the fallout occurred between 1955 and 1966, but the annual amount of fallout from the tests has decreased steadily since the partial test ban treaty in 1963. Atmospheric nuclear explosions have not taken place since a Chinese test at Lop Nor in October 1980 (48).

Many of the tests carried out by the Soviet Union took place at Novaya Zemlya (adjacent to the Arctic Ocean), including all of the very large explosions. At Novaya Zemlya, 132 tests were carried out between September 1955 and October 1990: 87 in the atmosphere, 3 underwater, and 42 underground (71). Despite the fact that about 94 percent of the total yield of all Soviet nuclear tests has been released at Novaya Zemlya (3), there does not appear to have been proportionately greater atmospheric fallout in that region. Available data suggest that the larger explosions took place at more than 1 km in height, so that almost all of the fallout was distributed globally, rather than locally. Indeed, based on data from 1964 to 1969, the Cs-137 accumulation was lower on Novaya Zemlya than in Sweden or Finland (48). In general, nuclear fallout at the two poles is less than at lower latitudes (80), and measurements suggest that fallout near Novaya Zemlya was similar to that in other Arctic areas (see figure 2-1). Similarly, low fallout deposition would be expected throughout the Barents and Kara Seas. However, atmospheric transport was generally toward the east, so it is reasonable that some close-in fallout may have been deposited over the Kara Sea at this time (33).

Carried out in adherence to safety requirements, underground nuclear tests should not lead to the release of radioactive fission products into the atmosphere. However, Russian scientists reviewing the test site at Novaya Zemlya have reported that 25 of the 42 underground tests there released radioactive inert gases and two "were accompanied with dynamic venting to the atmosphere of gaseous and evaporated products (venting of radioactivity)" (71). There have been no investigations about the ultimate fate of these releases in the local or regional environment, but they could contribute to the general problem.

The three underwater nuclear tests conducted at the edge of the Barents Sea on the south side of Novaya Zemlya contributed to contamination of the sediments in this area. Estimates of the inventory expected now in Barents Sea water and sediments from this source, after radioactive decay, are very low. Some recent measurements of sediments in the vicinity of the tests reported higher concentrations over a limited area, thought to stem from the underwater tests (68).

Global fallout on land in the watershed of the Arctic seas constitutes another contribution to the contamination of the Arctic as rivers wash the fallout into the ocean. Rough estimates of the radionuclide contribution to the Arctic from land runoff of global fallout and other sources are shown in table 2-5.

(continued)

BOX 2-1: Nuclear Testing (Cont'd.)

In addition to nuclear tests for weapon development, the former Soviet Union also used nuclear devices for other purposes. The Soviet Peaceful Nuclear Explosion program was active from January 1965 to September 1988, carrying out 116 nuclear explosions. The explosions were used primarily in support of the oil, gas, and mineral industries; to explore geological features at great depths; to create underground storage cavities; and to help extract gas and oil or extinguish burning wells. Eighty-one of the explosions were carried out in Russia (47). It is not known whether or how much these explosions may contribute to nuclear contamination in the Arctic, although they have certainly caused significant contamination of local areas.

[a]One megaton (Mt) is equivalent to the power of 1 million tons of TNT.

SOURCE: Office of Technology Assessment, 1995.

two torpedoes with nuclear warheads as well as conventional torpedoes (18). Much international attention has been drawn to the *Komsomolets* as a potential source of long-term radioactive contamination, especially to the extensive fisheries resources known to exist in this region of the Norwegian and adjacent seas within the Arctic.

As of August 1994, Soviet and Russian authorities had sponsored a total of five expeditions to the *Komsomolets*, with another expedition planned for the summer of 1995. The expeditions served to investigate the extent of the damage to the submarine, study the physical oceanographic characteristics of the area, take samples for measuring the level of contamination, seal holes in the torpedo sections, and determine the future course of action.

Russian authorities have released little information concerning the design and construction of the nuclear reactor aboard the *Komsomolets*. However, they have revealed that the reactor had a capacity of approximately 190 megawatts (MW) and have provided an estimate of the radioactive inventory of the reactor core. According to the Yablokov report, the reactor core contained approximately 42 kilocuries (kCi) of strontium-90 (Sr-90) and 55 kCi of Cs-137 (25). More recently, Russian experts from the Kurchatov Institute have revised the estimated inventory of radionuclides in the reactor of the *Komsomolets* to 76 kCi of Sr-90 and 84 kCi of Cs-137 (48).

Russian officials have reported that the reactor was successfully switched to stable cool-down mode before the submarine was abandoned, the structural integrity of the reactor compartment appears adequate, and water exchange in the region of the reactor compartment is very limited (25). These are all factors that would limit the potential migration of radioactive materials to the outside environment.

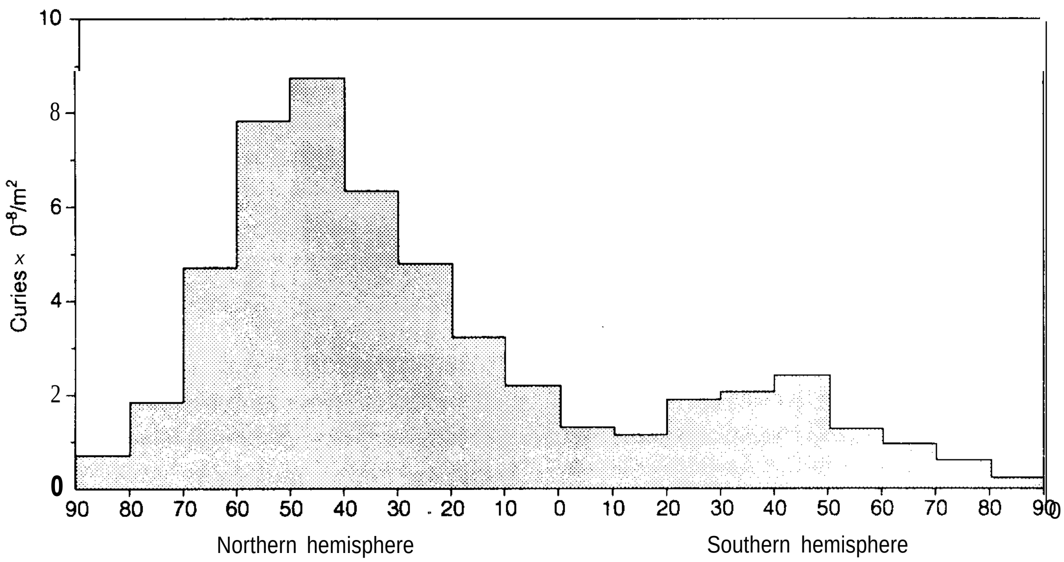
Two nuclear-tipped torpedoes located in the nose section of the *Komsomolets* present another possible concern. Both the Yablokov commission and researchers from the Kurchatov Institute estimate a plutonium (Pu) activity of about 430

TABLE 2-5: Estimated 1993 Inventory of Uncontained Radionuclides in the Arctic Seas

Source	Sr-90 (kCi)	Cs-137 (kCi)
Fallout from atmospheric testing of nuclear devices	70	111
Runoff from fallout on land	41	14
Sellafield Reprocessing Plant	27–54	270–405
Chernobyl		27–135

SOURCE: A. Aarkrog, "Radioactivity in the Polar Regions—Main Sources," *J. Environ. Radioactivity* 25 (1994).

FIGURE 2-1: Latitudinal Distribution of Strontium-90 Deposition from Atmospheric Nuclear Testing



SOURCE: United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), "Sources and Effects of Ionizing Radiation," UNSCEAR 1993 *Report* (New York: 1993).

BOX 2-2: European Reprocessing Facility Discharges

A significant source of contamination that has been documented to have migrated into many areas of the Arctic Ocean is nuclear waste discharged from reprocessing facilities in Europe. Civilian plants at Sellafield and Dounreay in Great Britain, and Cap de la Hague in France, reprocess spent fuel from nuclear reactors, Sellafield began discharging wastes from reprocessing operations into the Irish Sea in 1952, and Dounreay in 1958; Cap de la Hague began discharging into the English Channel in 1966. Between their start-up dates and 1986, when a comprehensive report on radionuclide discharges was released, the three plants discharged a total of 5.2 million curies of radioactivity. The largest contribution by far was from the Sellafield plant (4.3 million curies), followed by the plants at Cap de la Hague (0.6 million curies) and Dounreay (0,3 million curies). The discharges include at least 38 different radionuclides, but the elements of most concern for potential health effects are the beta-emitters cesium-137 (Cs-137), strontium-90 (Sr-90), and plutonium-241 (Pu-241), and the alpha emitters Pu-239 and americium-241 (Am-241) (48), Sellafield, in particular, has bean responsible for "a substantial increase in the inventories of a number of radionuclides (e.g., Sr-90, technetium-99 (Tc-99), Cs-137, Pu-239 and 240) in the North Atlantic as a whole and, in particular, the latitude band into which the discharges were initially dispersed (50-66° N)" (33). Recently the new Thermal Oxide Reprocessing Plant (THORP) at Sellafield began reprocessing spent fuel, so that increases in some radionuclides and decreases in others are projected. The Dounreay facility may increase its output of radionuclides from present levels as it processes fuel from the Prototype Fast Reactor shut down in 1994. Discharges from La Hague continue but have been substantially reduced in recent years (48).

(continued)

BOX 2-2: European Reprocessing Facility Discharges (Cont'd.)

Contributions to contamination in the Arctic from European reprocessing centers have been estimated based on the movement of traceable radionuclides out of the Irish Sea and around the coast of Scotland into the North Sea. From there, the contaminants are carried north through the Norwegian Sea by the Norwegian Coastal Current. The current splits, part traveling east into the Barents Sea, while the remainder travels with the West Spitsbergen Current up through the Fram Strait into the Nansen Basin.

Based on a variety of assumptions (see below), an estimate has been made that about 22 percent of the Cs-137 discharged by Sellafield enters the Barents Sea, en route to the Arctic Basin. At this time, it appears that Atlantic waters entering and mixing with Arctic waters are diluting the Cs-137. Since discharges have been reduced from Sellafield, the Atlantic waters have lower contamination, and older discharges from Sellafield are now flowing out from the Arctic through the Fram Strait (33). Transit time for the movement of Cs-137 from Sellafield appears to be 5 to 6 years to the Barents Sea (33); movement to the Kara Sea takes somewhat longer. Transit time from the plant at Cap La Hague is thought take about two years less.

There are many uncertainties inherent in estimating reprocessing waste contributions to Arctic contamination and the transit times of radioactive contaminants. The inflow into the Barents Sea is subject to strong influences from wind and is therefore highly variable, making estimates of radionuclide transport there difficult. Uncertainty in the contribution from reprocessing also stems from uncertainty in the "background" contribution from global fallout. As pointed out by Kershaw, water masses originating from different latitudes or water depths may have differing amounts of contamination from bomb test fallout. Values of 8-16 x 10^{-11}Ci/m^3 of Cs-137 have been reported for waters of the Arctic region. Higher levels may reflect the movement of waters from the Atlantic, at latitudes where higher levels of fallout occurred. Further uncertainty stems from the sampling itself, which can cover only a limited portion of such a huge volume (33).

In addition to contributions from reprocessing plants of radionuclides such as cesium and strontium, which move with the water, the behavior of particle-reactive compounds such as plutonium could also be of concern. Most of the plutonium released by Sellafield remains bound in the sediments of the eastern Irish Sea (33). However, some fraction of the plutonium, mostly in the higher oxidation state, stays in solution and can be readily detected in the North Sea. Whether it has been transported as far as the Arctic Basin is less clear. Analyses of plutonium isotopes suggest that indeed plutonium from Sellafield has been transported as far as the Barents and Greenland Seas. To date, it has not been possible to quantify the magnitude of this contribution (33,48).

SOURCE: Office of Technology Assessment, 1995.

BOX 2-3: The 1986 Chernobyl Accident

The reactor accident at Chernobyl, Ukraine, in 1986 was another significant contributor to global nuclear contamination, but its specific impact on the Arctic is difficult to estimate. About 2.7 million curies of cesium-137 (Cs-137) were released to the atmosphere and deposited in the northern hemisphere, particularly in Ukraine, Belarus, western Russia, and elsewhere in Europe (2). Based on the deposition of Cs-137 recorded at different sites in Greenland, a total deposition in the Arctic of 27,000 curies of Cs-137 has been estimated by one researcher, with perhaps a total of 135,000 curies including additional contamination transported northward by the West Norwegian Current (2). Others have estimated that Chernobyl contributed 1–2 percent of the 1991 total Cs-137 concentration in the Arctic basin (33).

SOURCE: Office of Technology Assessment, 1995.

curies (approximately 94 percent from Pu-239 and 6 percent from Pu-240) in the two warheads of the *Komsomolets* (6–10 kg of Pu) (48). Russian authorities note that the outer shells of the two nuclear warheads were damaged during the sinking of the *Komsomolets*, and because the hatches of the torpedo tubes are open, nuclear materials in the warheads are now in direct contact with seawater. It is impossible to predict the precise rate of corrosion of the warheads and the rate of release of nuclear materials without specific knowledge of the materials used for the protective coating of the warheads and the titanium hull of the submarine. This information has not yet been made available by Russian authorities. However, according to researchers from the Khlopin Radium Institute in St. Petersburg, analyses of water samples, bottom sediments, surface sediments, and biota taken from 1991 to 1994 indicate that releases of Pu-239 from the nuclear warheads into the environment have thus far been insignificant (37).

Efforts have been made by the Russians to seal the holes in the torpedo section of the *Komsomolets* in order to slow the rate of corrosion of the sections of the warheads that contain nuclear materials. During the expedition to the *Komsomolets* in August 1994 by the Russian research vessel the *Academician Mstislav Keldysh*, nine holes, including two in the torpedo sections containing the nuclear warheads, were sealed with plugs made of rubber and titanium as a means to prevent seawater from contacting the missiles (7,69). Most Norwegian and Russian experts agree that this process should minimize the likelihood of immediate corrosion of the warheads. However, since this type of operation is unprecedented, it is not possible to predict its long-term effectiveness.

Considerations of the potential hazard from the sunken submarine have focused on the eventual release of fission products such as cesium and strontium from the reactor, and plutonium from the nuclear warheads. It is impossible to estimate precisely the fission product release rates without more specific information regarding the reactor, but a recent effort using assumptions about the reactor construction and corrosion rates both for the reactor compartment and for spent fuel, arrived at an upper-bound release rate of Cs-137 of about 13.5 curies per year. Release rates of other radionuclides are likely to be at least an order of magnitude lower (48). As described further in chapter 3, information about the amount of curies released does not by itself provide enough information to indicate what the health and environmental impacts will be, but 13.5 curies per year represents a small source term. Understanding of the movement of the radionuclides and how they could come in contact with humans is required.

Given the estimate of the release rate of fission products such as Cs-137 and Sr-90 from the submarine, the next question is where and how quickly they might be transported through the marine environment. In general, little is known about the ocean currents at various depths. The Yablokov report states that the hydrology of the area in which the submarine sits is extremely complex, and the speed and direction of the currents can change significantly in a short period of time. Bottom currents in this area have been measured at up to 1.5 m/s by Russian scientists (25). Measurements taken by the Norwegian Institute of Marine Research at various depths near the *Komsomolets* site also indicate a strong and variable current, with very limited exchange between the deeper water layers (below 1,000 m) and the surface (5,48).

Norwegian modeling studies suggest movement of the water-soluble fission products up into the Arctic Ocean. Estimates of the potential doses to humans through the food chain from this movement suggest negligible contributions to typical doses. Fishing does not occur at the great depths where the submarine is located, and the radionuclides are diluted tremendously when they reach surface waters.

The model used does not describe the movement of radionuclides such as plutonium, which are not very soluble in water. It is expected that most of the plutonium will adhere to sediment particles in the ocean bottom, as has been observed near the Sellafield reprocessing plant.

Over the last 30 years, discharges into the Irish Sea from this plant have included 200 to 400 kg of plutonium. Ninety percent of this plutonium remains in the sediments close to the discharge point (18). It is expected similarly that almost all of the 6 to 10 kg of plutonium from the *Komsomolets* will also remain localized in the nearby sediments.

Given the present rate of releases and what is known about the condition of the *Komsomolets* and the physical characteristics of the region, most experts agree that the *Komsomolets* does not pose an immediate or long-term threat (15,22,48). In addition, the Russians have taken steps to delay the rate of release of contaminants by sealing up holes near the nuclear warheads. Future expeditions are planned to conduct further research and possibly to seal up more holes, or build a containment shield around the *Komsomolets*, and to continue radiological monitoring to estimate future rates of radioactive releases.

Russia's Nuclear Production Complexes

Like the United States, the Russian Federation has an extensive legacy of environmental contamination at its major weapons production sites. The sites with the largest radioactive releases in Russia are located along rivers that, thousands of miles downstream, ultimately feed into the Kara Sea. The heavy contamination at and around some of these sites could contribute to Arctic contamination if radionuclides are transported by these rivers to the northern seas. Boxes 2-4 through 2-6, covering the weapons production sites of Chelyabinsk, Tomsk, and Krasnoyarsk, describe some of the large releases of radionuclides into the environment that may contribute to contamination of the Arctic as they are washed downstream. They also describe the nuclear wastes still stored or being produced at these sites, which have the potential for release and eventual Arctic impact.

BOX 2-4: Environmental Contamination from Mayak Production Association near Chelyabinsk

The Chelyabinsk region in the southern Urals of Russia is a severely contaminated area, considered to be one of the places most polluted by nuclear waste in the world. Tremendous amounts of radioactive contamination are present at the site from the Mayak production complex, and the cleanup problems posed at the site will be a challenge for many decades to come. Human impacts among the workers and the regional population have been large and efforts are still underway to understand their extent.

The Mayak production association complex, situated about 70 km north of the city of Chelyabinsk in the southern Urals and built in 1948, was the Soviet Union's first plutonium production plant. The last of the five uranium-graphite reactors that produced weapons-grade plutonium was shut down in 1990. The complex now consists of two nuclear reactors including one to produce plutonium-238, a plant for reprocessing nuclear fuel called RT-1, a complex for vitrification of liquid high level wastes and storage of the resulting containers of waste glass, storage facilities for spent nuclear fuel and recycled plutonium and uranium, and several other facilities engaged in defense nuclear activities (52). The Mayak complex is located on mostly flat terrain amidst lakes, marshes, and the floodplains of several rivers, with groundwater in the area at depths from 0.9 to 4.0 m from the surface (74). The complex is located along the Techa River, a tributary of the Ob River system that flows northward into the Kara Sea.

(continued)

BOX 2-4: Environmental Contamination from Mayak Production Association near Chelyabinsk (Cont'd.)

According to Russian sources, approximately 1 billion curies of radioactive wastes has been generated at Mayak over the period of its operation (52). The bulk of this inventory is in the form of high-level liquid radioactive waste and is stored in about 60 special stainless steel tanks reinforced with concrete "shells" (60). In addition, Mayak's solid radioactive waste burial grounds contain 500,000 tons of contaminated materials, with an estimated activity of 12 million curies (50). Moreover, Russian sources acknowledge that at least 130 million curies of radioactivity has been released directly into the environment from Mayak, a sum that is about 2.6 times greater than the amount of radioactivity released from the Chernobyl accident in 1986 (75).

Today, 120 million curies remains in Lake Karachai (50) and continuing release of radioactive products into the lake is a major concern. Though most of the cesium in the waste is apparently bound to the clays at the lake's bottom, the strontium-90 and some nitrates appear to be migrating in a ground water plume which has spread at a rate of up to 80 meters per year and has reached the nearby Mishelyak River (44). Some Russian specialists are concerned that the contaminated water will break into the open hydrologic systems, contaminating the Ob River basin and ultimately flowing out to the Arctic Ocean (75).

In addition to intentional discharges and releases of radioactive wastes and materials, a severe contamination event occurred at Mayak in 1957 when a high level waste storage tank exploded, releasing 20 million curies of radioactivity. Most of the radioactive wastes fell near the tank, but 10 percent of the radioactivity was ejected into the atmosphere and carried great distances eastward. The contaminated area extended northeast from the Mayak complex, covering about 23,000 km^2 (74). Though 10,700 people were ultimately evacuated, more then half of them were not moved for eight months, and the people of the entire region consumed contaminated food from the 1957 harvest (12). The present activity of the radioactive materials released to the environment is now estimated at about 44,000 curies, of which strontium-90 is the primary contaminant (50).

Another contamination event occurred at Mayak in 1967 when a severe drought exposed a dry shoreline on Lake Karachai that had been used since 1951 for storage of radioactive waste. Winds carried about 600 curies over a 2,700 km^2 area up to 75 km from the site (50).

Some steps have been taken or planned to try to minimize further spread of contaminants into the surrounding atmosphere or groundwater. Since 1967 the Russians have been filling in Lake Karachai to limit further air release of radionuclides (50). A plan for removing the contents of the lake for reprocessing and disposal of high-level wastes was ruled out for financial reasons. Instead, large concrete blocks designed to trap sediments inside them as the lake is filled are being put into the lake. Once the blocks are placed and covered with rock and soil, the Russians may pump contaminated water from nearby wells and treat it to remove radionuclides and try to minimize their migration (50). In the meantime, however, liquid low-level wastes are still being discharged into Lake Karachai (24,58).

(continued)

BOX 2-4: Environmental Contamination from Mayak Production Association near Chelyabinsk (Cont'd.)

In addition to Lake Karachai, there are 7 other contaminated reservoirs present at the Mayak site which are a concern from a contaminant transport perspective. Inventories of reservoir volumes and contaminants were presented at a workshop on the environment in October 1992 (75). Russian experts include among the problems needing immediate attention the water regulation of these reservoirs, including both seepage out of the most downstream reservoir and overflow into the Techa River. For example, the water level in one of the Techa River reservoirs has been rising steadily, necessitating raising the height of the dam as a short term solution. With an increase in dam height, seepage of contaminated water out of the dam increases, releasing more radioactive contamination into the Techa River system (75). The migration of contaminated groundwater mentioned above is another serious issue, raising concerns that it will contaminate the Ob basin which leads to the Arctic Ocean (75). The Asanov Swamps, an area of 30 km^2 in the upper reaches of the Techa, are estimated to contain 6,000 curies of strontium-90 and cesium-137 and pose a contamination source to the river system (12,70). Furthermore, flooding that occurred this past spring substantially widened the area of contamination (58).

The extensive contamination that has occurred at and around the Mayak complex has taken a human health toll. As a result of the handling of weapon materials at Mayak, the large releases into the Techa River system, the 1957 high-level nuclear waste tank explosion, and the resuspension of contaminated wastes in 1967, radiation exposures of workers at the plants and some of the general population around the plant exceed the average doses experienced by atomic bomb survivors. According to a 1991 internal Soviet government report, more than 124,000 people were exposed to elevated levels of radiation from living along the river, and more than 28,000 to doses that "may have caused significant health effects" (52). Several thousand plant workers were also exposed. Studies in these populations have indicated increased rates of chronic radiation sickness, as well as increases in leukemia and other cancers (26,35,36). More studies are planned to better characterize the relationship between long-term, low-level exposure to radiation and disease development in these populations. Meanwhile villagers who have only recently learned of their many years of radiation exposure are under tremendous psychological stress as they struggle to understand how it might have affected them. Many are convinced that they have gotten sick or will get sick as a result of the radioactive contamination (21).

SOURCE: Office of Technology Assessment, 1995.

BOX 2-5: Environmental Contamination from Tomsk-7

The Siberian Chemical Combine (SCC), also known as Tomsk-7 or Seversk, is located near the Tom River approximately 16 km from the city of Tomsk in western Siberia. One of the largest weapons production facilities in the world, the site contains five graphite-uranium plutonium production reactors, a uranium enrichment plant, a reprocessing plant, and other plants engaged in the military nuclear fuel cycle (65). Three of the plutonium-producing reactors have been shut down, and the remaining two are dual-purpose reactors that provide heat and electricity for Tomsk and Seversk, as well as weapons-grade plutonium. Tomsk-7 remains an extremely sensitive military installation and is "surrounded by double, electric security fences, guard towers, and patrolled by armed guards between the fences" (73).

(continued)

BOX 2-5: Environmental Contamination from Tomsk-7 (Cont'd.)

Tomsk-7 came to international attention in April 1993, when a chemical reaction caused an explosion in a tank containing uranium nitrate solution during reprocessing of irradiated fuel. The explosion blew a hole in the roof of the building and sent a shock wave which passed down a 100 m gallery and knocked out a brick wall at the end (23). About 40 curies of radioactivity was released through a 150 m stack contaminating an area of more than 40 km^2 to the northeast of the site (24,76). Localized release in the plant was reported to be 4 curies of beta and gamma emitters (23). According to an international team visiting the site soon after the incident, some decontamination had already been carried out, and it appeared that no further offsite decontamination would be necessary (23).

A recent report from the Russian Federation Security Council presents some information on the contamination situation at Tomsk-7 resulting from the production and reprocessing activities of the last 40 years. The report estimates a total inventory of radioactive wastes stored within the industrial zone of the site at 1.2 billion curies at the time of burial (65). The majority of this inventory is in the form of liquid radioactive waste, part of which was discharged into several reservoirs. From the mid-1960s to 1982, an estimated 127 million curies of long-lived radionuclides was released into these reservoirs (48). Efforts are under way to fill in one of these reservoirs with soil (65). According to reports from workers of Tomsk-7, up to 850 kg of plutonium may have been discharged into reservoirs, and 1.5 to 3 kg per month was discharged into a "special sewer" from metallurgical and machining operations (59). Cooling water from the production reactors (low-level waste) was discharged to the Tom River in amounts up to 42,000 cubic meters per day (11). Discharges of cooling waters continue from the dual use reactors. The Tom River feeds into the Ob, which flows northward to the Kara Sea.

In addition to surface discharges, Tomsk-7 is one of three sites in Russia where underground injection has been used as a means of disposal for large volumes of waste. Information from the Tomsk Oil and Gas Geology Association in 1991 indicates that radioactive waste has been pumped into sandy layers 220-360 m deep, 10 to 13 km from the Tom River (50). Russian specialists estimate that 38 million cubic meters of liquid radioactive waste with an activity of 500 million curies has been injected underground (65). A more recent estimate suggests that the current activity of injected wastes at Tomsk-7 is as high as 1 billion curies (50).

Over the last few years, the Russian Ministry of Atomic Energy and the U.S. Department of Energy have had talks about the injection of the radioactive wastes, and Pacific Northwest Laboratory (PNL) began a study of the hydrology of the West Siberian Basin (which encompasses Chelyabinsk, Tomsk, and Krasnoyarsk). A study circulated in April 1994 acknowledges "massive contamination" as a result of nuclear fuel cycle activities there. It observes that though the basin is geologically stable, it is very wet (8). PNL is continuing its study and modeling efforts to better understand how the contaminants injected underground might be expected to move (77,78). Extensive studies have also been carried out by Russian scientists (62).

At a meeting in May 1994 in which Russian scientists discussed waste injection with U.S. scientists, several papers were presented that provided more details on the practice. In most cases, shallow geological layers were used for low-level wastes, and higher-level wastes were injected more deeply. In some instances, water is pumped out to create low-pressure areas that draw the wastes in desired directions (8).

(continued)

BOX 2-5: Environmental Contamination from Tomsk-7 (Cont'd.)

Although "accepted rules of nuclear waste disposal" require it to be isolated in impermeable containers for thousands of years, Russian scientists say the practice of underground injection is safe because of the impermeability of the shale and clay separating them from the earth's surface (50). It is not clear if or when the injected wastes could make their way into contact with human beings. Ideally, migration will be slow enough to isolate the wastes for thousands of years, allowing many of the radioactive elements to decay to less dangerous elements. However, further study of the hydrology of the region is necessary before conclusions can be made.

SOURCE: Office of Technology Assessment, 1995.

BOX 2-6: Environmental Contamination from Krasnoyarsk-26

The Krasnoyarsk Mining and Chemical Combine (MCC), also formerly known as Krasnoyarsk-26, Devyatka, Atomgrad, and now renamed as Zheleznogorsk, is situated approximately 60 km from the city of Krasnoyarsk, along the bank of the large Yenisey River, which flows north into the Kara Sea. Constructed in the 1950s, most of the facility is located 250 m to 300 m underground (48). The combine consists of three RBMK-type graphite-moderated, water-cooled reactors for the production of weapons-grade plutonium; a reprocessing plant to separate plutonium, uranium, and other fission products; and storage facilities for radioactive wastes. Two of the three production reactors at the combine have been shut down since 1992, but the third reactor is a dual-use reactor and continues to operate, supplying heat and electricity to the region. The two shut-down reactors had an open primary circuit that used water from the Yenisey River to cool the reactor core and released the water directly into the river after use. The current operating reactor has a closed primary circuit and uses water from the Yenisey River in its secondary cooling circuit (48).

Construction of a new aboveground reprocessing plant (RT-2) began in 1983 but was suspended in 1989 as a result of public opposition and economic problems (39). However, the Russian President has recently issued a decree calling for the continuation of construction of RT-2, which when completed would reprocess both domestic and foreign spent nuclear fuel.[a] Most of the liquid radioactive waste at the site is from reprocessing activities; the completion and operation of RT-2 would greatly increase the amount of radioactive wastes generated there.

Similar to the Mayak and Tomsk-7 nuclear complexes but to a lesser extent, local reservoirs and ponds are used as receptacles for the discharge of liquid radioactive wastes at Krasnoyarsk-26. Four reservoirs there reportedly hold up to 50,000 of curies (50). Efforts are reportedly under way to fill in one of these reservoirs with soil and sorbents for cesium (50).

Liquid radioactive waste generated by the Krasnoyarsk Mining and Chemical Combine has primarily been disposed via underground injection at the Severny site located within the sanitary protection zone of the combine for the past 25 years. Severny is located on a terrace, 100 m above and 750 m from the east bank of the Yenisey River, approximately 20 km north of Krasnoyarsk-26. A large part of the injected waste is transported to Severny through a reportedly leaky pipeline, which has spilled an unknown amount of liquid radioactive waste of all levels along its path to the injection site (10,48). Overall, Russian specialists estimate that more than 4.5 million cubic meters of liquid radioactive waste with more than 0.7–1 billion curies of activity at time of disposal has been injected at Severny at three different levels (84). The current activity of this injected waste is estimated by Russian experts at 450 million curies (17).

(continued)

BOX 2-6: Environmental Contamination from Krasnoyarsk-26 (Cont'd.)

Studies carried out by Russian institutes have determined that the injection site is satisfactory and has not negatively affected the surrounding environment (10), However, local Russian specialists have revealed a number of potentially serious concerns associated with the use of Severny as an injection site, including insufficient understanding of the geology and hydrology of the region. Specialized geomorphological, hydrogeological, and engineering studies have not been conducted there in the past 30 years. It has yet to be determined conclusively that the clay boundaries of the injection strata are continuous and thus able to prevent seepage of the liquid radioactive waste. Furthermore, the injection site is located in a zone of possible seismic activity. Potential earthquakes at the injection site may lead to the migration or discharge of injected radioactive waste into the basin of the Greater Tel and Yenisey Rivers (1 O).

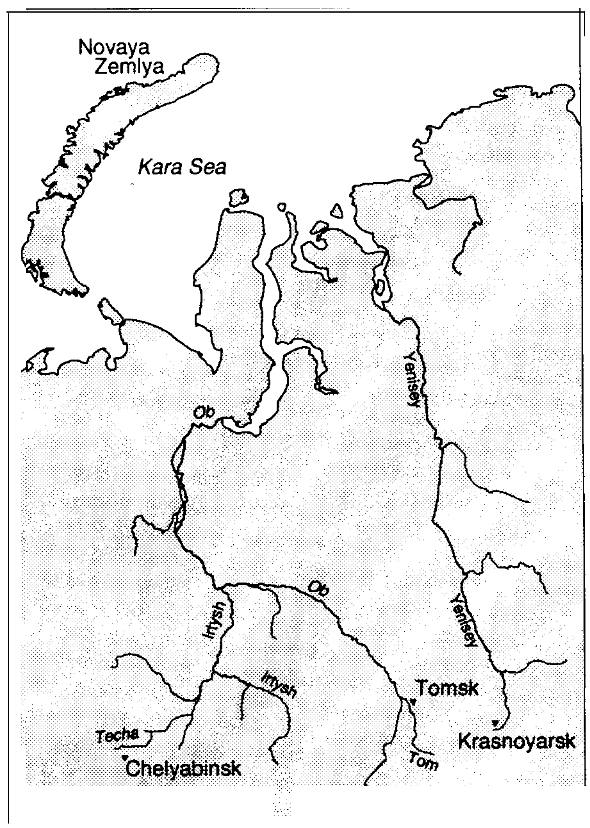
[a] On January 25, 1995, President Yeltsin signed the Edict on Structural Reorganization and Conversion of the Nuclear Industry in the City of Zheleznogorsk in Krasnoyarsk Kray. This document orders continuation of construction of RT-2 after a mandatory study by ecological experts.

SOURCE: Office of Technology Assessment, 1995.

Almost nothing was known about Chelyabinsk, Tomsk, and Krasnoyarsk before the increased openness of the Soviet Union in the late 1980s. These sites were among the secret cities established by Josef Stalin to work on military projects. They were not listed on maps, and few Soviet citizens even knew of their existence. Information about the status of radioactive sources and releases from these sites continues to be, for the most part, very limited. The most information has been forthcoming about the Mayak production facility near the city of Chelyabinsk. The Russians have openly discussed the challenges posed by this site, and these are now being studied jointly by the U.S. Department of Energy and Russia's Ministry of Atomic Energy.

Despite still somewhat limited information on the sites, it is clear that significant contamination of water bodies and soils has taken place at the three nuclear production complexes. A large proportion of the releases has been in the form of underground injection, but the human and environmental effects caused by these disposal practices-how, where, and when the radioactive materials may resurface or make their way into drinking water or the rivers-are still unknown. The three nuclear production sites are located on rivers that ultimately feed into the Kara Sea in the Arctic (see figure 2-2). Because of the great

FIGURE 2-2: The Ob and Yenisey Rivers



SOURCE: Office of Technology Assessment, 1995.

distances between these three sites and the Arctic, no large quantities of radionuclides appear to have reached the mouths of the rivers at this time (41,83). Over the long term, however, the potential contribution of these sites requires further study because several possible scenarios of floods or dam failures could trigger more extensive releases downriver into the Arctic seas. Box 2-7 describes the current findings from sampling in the Ob and Yenisey rivers and the modeling being carried out to better understand future risks.

RADIOACTIVE CONTAMINATION FROM SOVIET NUCLEAR WASTE DUMPING

Revelations in recent years have brought to light two sources of nuclear waste contamination from the former Soviet Union that have the potential to contribute to contamination in the Arctic and North Pacific. The extensive radioactive contamination at the inland nuclear production facilities located along rivers that empty into the Arctic is discussed above and in boxes 2-4 to 2-7. The remainder of the chapter focuses upon the dumped liquid and solid wastes described in the 1993 Yablokov report and what has been learned about contamination they have contributed to the Arctic environment.

BOX 2-7: Siberian Rivers as a Source of Nuclear Contamination of the Arctic

The Ob and Yenisey Rivers are large north-flowing Siberian rivers which empty into the Kara Sea. The Ob is about 3,700 km long, with a catchment area of almost 3 million km^2 and an average flow of almost 400 km^3 per year (81). The Yenisey River has an even larger average annual flow of 630 km^3 (34). The location of both rivers is illustrated in figure 2-2. Because of the extreme temperatures in the Arctic, the rivers and their estuaries are frozen about 10 months of the year, severely reducing water flow. When the snow in the southern parts of the catchment areas melts, tremendous volumes of water rush downstream carrying with them sediment and ice. The ice itself also often contains sediments and particles (57). These rivers are of concern as a source of radioactive and other pollutants to the Arctic Seas.

Potential radionuclide contributions to the Arctic Seas from these rivers come from two sources: global nuclear fallout from atmospheric testing, and releases into the environment at the nuclear production sites. It appears that global fallout onto land from nuclear weapons testing is by far the predominant contributor to radionuclide flow in the Ob and Yenisey rivers to date.

Starting in 1961, measurements of strontium-90 (Sr-90) in the Ob and Yenisey waters as they entered the Kara Sea were taken by the USSR Hydrometeorological Service. These measurements permit the estimate of the contribution of Sr-90 for the years 1961-1989 as totaling about 30,000 curies from the Ob and Yenisey rivers together (66,82). Based on an observed ratio of Cs-137/Sr-90 of 0.1 in the river waters, the output of cesium-137 (Cs-137) into the Kara Sea is estimated at 3,000 curies.

These estimates are consistent with nuclear fallout as the predominant source. Though most are retained in the soil, a certain proportion of radionuclides deposited on land as fallout is ultimately washed into these rivers. Aarkrog has estimated that the runoff of Sr-90 in an area is 10 percent of the deposition inventory, while the runoff of Cs-137 is 2 percent (1). The catchment area of the Ob is roughly 3 million km^2, the largest among all of the rivers feeding into the Arctic. Based upon estimates of fallout deposition at different latitudes in the Northern Hemisphere (80), it is possible to estimate a contribution to the Kara of 13,500 curies of Sr-90 and 4,590 curies of Cs-137 from the Ob River from global fallout (uncorrected for decay). The contribution from the Yenisey River's smaller catchment area would be lower.

(continued)

BOX 2-7: Siberian Rivers as a Source of Nuclear Contamination of the Arctic (Cont'd.)

Discharges and accidents at the nuclear production complexes provide another large potential source of radioactive contaminants to the rivers and ultimately the Arctic. As described in boxes 2-4, 2-5, and 2-6, tremendous inventories of radioactive materials are known to contaminate the areas surrounding three of Russia's largest nuclear production complexes that are located near rivers that ultimately feed into the Ob and Yenisey rivers. The Mayak Production Facility near Chelyabinsk is at the Techa River which ultimately feeds the Ob River via the Iset, Tobol and Irtysh rivers; Tomsk-7 is on the Tom River which also empties into the Ob River; and Krasnoyarsk-26 is situated close to the Yenisey River.

Despite the large releases at the Mayak Production Association and clear evidence of contamination in the Techa and Iset rivers, it does not appear that measurable levels of radionuclides from Mayak or from Tomsk have made their way down the entire length of the Ob River from the weapons complexes to the Arctic. Cesium measurements made in sediment samples from the Ob Estuary in 1993 indicated low levels consistent with fallout as a source (9). These samples were taken in areas where rapid flow regularly disturbs and mixes the sediments. Sediment cores collected further upstream in more sheltered pools and channels of the Ob River were also collected in 1994 (41). Since these cores are from sites where water flow is not as turbulent, they can provide some information about the timing as well as the presence of radionuclides. Analysis of these samples to date suggests no measurable contribution at these sites from the production facilities at Mayak or Tomsk. Instead, the data are consistent with a major signal contributed by nuclear testing fallout, and an additional signal perhaps contributed by venting from underground tests carried out in Novaya Zemlya (41,42).

An additional source of information about the possible nuclear contamination contributions to the Arctic from the Ob River comes from measurements of the radionuclide iodine-129 (I-129). From a limited sample set, I-129 measurements in the Kara Sea and the Ob River suggest that the Ob may contribute slightly to the I-129 inventory in the Kara Sea, though the larger source of I-129 there appears to be from the Sellafield Reprocessing Facility (61). More information is needed to reconcile this information with the lack of reprocessing signals observed to date in the lower Ob sediments.

Measurements of radionuclides in the waters and sediments of the Yenisey Estuary and River have also been taken. Levels of Cs-137 in the Yenisey Estuary area were higher than those seen in the Kara Sea or the Ob Estuary (9). Plutonium concentrations were higher than those observed in the Ob Estuary, but not higher than at some sites in the Kara Sea (9). The higher concentrations may come from more concentrated weapons testing fallout. However, there is also evidence that radionuclides from the direct flow reactors at Krasnoyarsk have migrated down the Yenisey. Short-lived radionuclides characteristic of those created in reactor cooling waters were measured in samples collected as far as 890 km from the discharge point (83). Another Russian investigator also reports measurement of long-lived isotopes in the river water, sediments, and biota that are thought to be from cooling waters of the reactors at Krasnoyarsk-26 (38).

(continued)

BOX 2-7: Siberian Rivers as a Source of Nuclear Contamination of the Arctic (Cont'd.)

All told, however, from data analyzed to date it does not appear that the majority of radionuclides released to the environment through discharges and accidents at the nuclear production sites have made their way down the rivers to the Kara Sea as yet. At Mayak, many of the radionuclides are thought to remain in the Asanov Marshes, while large amounts are also held in reservoirs of the Techa River. Since the inventories are extensive, efforts are being made under the auspices of the Department of Defense's Arctic Nuclear Waste Assessment Program to model the migration of radionuclides down the rivers either in a steady release, or in a sudden pulse that might result from a reservoir dam breaking or a large flood. Using existing data and data currently being gathered and analyzed on the characteristics of the radioactive sources and the rivers and estuaries, the modelers will try to estimate river contributions of Sr-90, Cs-137, and Pu-239 to the Kara Sea. The models will address two different scenarios, a steady continuous release of contaminants and a sudden large release of radionuclides as from dam breakage or a flood.

Sources of radioactivity to be entered into the steady stream model are discharges from reactor cooling, from reprocessing facilities, and effects of nuclear testing at Semipalatinsk. U.S. experts have estimated the radionuclides released to lakes and rivers from operation of the Russian plutionium reactors (50). Sources for modeling a pulse-like release of contaminants include reprocessing plant wastes now in ponds and reservoirs, wastes injected into deep wells, and some other smaller potential sources. The latter sources require additional modeling to estimate movement of contaminants through groundwater to reach the river. The movement of some of these sources is fairly well understood, such as the contaminated groundwater plume under Lake Karachai at Mayak, while movement of other contaminants, such as from the large injection wells at Tomsk and Krasnoyarsk, are more difficult to predict. Efforts to carry out this source modeling involve several different Russian and U.S. organizations, and will probably take several more years to complete (54).

In the meantime, for purposes of understanding potential shorter-term transnational contamination, modelers are focusing on the most reasonably likely and significant sources of radioactive contamination into the river which could lead to a radiation dose many kilometers away in the Kara Sea. These are migration of radioactive contamination from the Asanov Marshes, seepage of radioactive contaminants under the dams holding back radioactive reservoirs, and the possibility of reservoir dams giving way. Emphasis has been heavier on modeling the Ob River, because potential sources are more readily available to the river and represent a more probable risk of catastrophic release (53,55).

Additional models are being used to consider the river transport of the contaminants. Hydrography and radionuclide concentration data collected at various points along the Ob and Yenisey will be used to calibrate and validate the models. The estuaries at the mouths of the Ob and Yenisey are also complex systems which are challenging to model. Information to be incorporated includes behavior of the salt wedge, mixing, tidal versus river flow, and the behavior of the ice in the estuary.

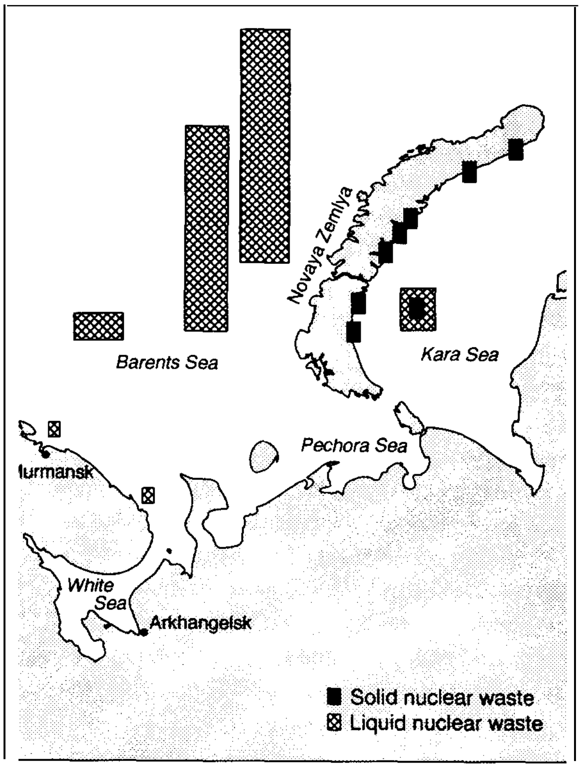
A large amount of data has been collected to incorporate in this series of models, and work is ongoing to refine the models. The data demands of the modeling have lead to the accumulation of a tremendous amount of data, which should be helpful both for addressing the basic science questions and for answering the more immediate question of potential risks from the rivers to the Arctic seas.

SOURCE: Office of Technology Assessment, 1995.

Disclosures About the Dumping at Sea

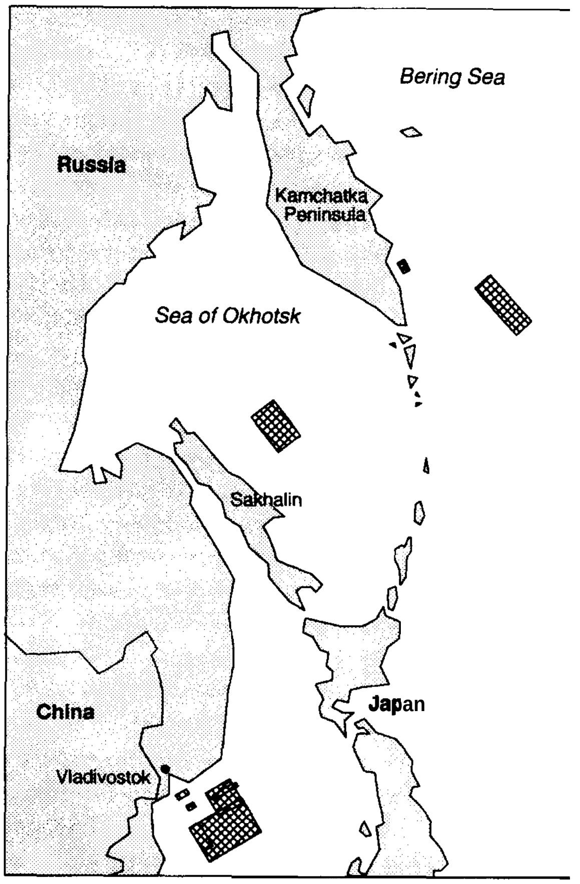
The Yablokov report on radioactive wastes disposed at sea described the dumping of liquid and solid wastes into the Arctic and North Pacific by the Soviet Navy and Murmansk Shipping Company at several different areas in the Barents and Kara Seas and in the Pacific Ocean (east coast of Kamchatka) and Sea of Japan. It also detailed

FIGURE 2-3: Locations of Nuclear Waste Dumping in the Russian Northern Seas



SOURCE: Office of Technology Assessment, compiled from data from Government Commission on "Matters Related to Radioactive Waste Disposal at Sea ("Yablokov commission"), created by Decree No, 613 of the Russian Federation President, October 24, 1992, *Facts and Problems Related to Radioactive Waste Disposal in* Seas *Adjacent to the Territory of the Russian Federation (Moscow,* Russia: 1993),

FIGURE 2-4: Locations of Nuclear Waste Dumping in Russian Far Eastern Seas



SOURCE: Office of Technology Assessment, compiled from data from Government Commission on Matters Related to Radioactive Waste Disposal at Sea ("Yablokov commission"), created by Decree No. 613 of the Russian Federation President, October 24, 1992, ***Facts and*** *Problems Related to Radioactive Waste Disposal* ***in Seas Adjacent to the Territory of the Russian Federation (Moscow,*** Russia: 1993).

releases from leaks and accidents. Figures 2-3 and 2-4 show the locations of the solid and liquid waste dumping in the Russian North and Far East, respectively.

Liquid wastes were reported dumped at five different areas in the Barents Sea (along with six other accidental releases in bays and elsewhere) and nine areas in the Pacific Ocean (east coast of Kamchatka) and the Sea of Japan (table 2-3). In the Russian North, this dumping yielded over 189,634 m^3 of waste with more than 20,653 curies of radioactivity. The report also notes leaks from storage and an accident aboard a nuclear submarine that contributed further contamination. In the Russian Far Eastern seas, the volume of dumped liquid waste reported was more than 123,497 m^3, with 12,337 curies of radioactivity. Little information about the origin and radionuclide composition of this liquid waste is available, but it is likely to have originated from cleaning operations at shipyards and from reactor cooling systems (48).

Solid wastes were in a multitude of forms, including containers, barges, ships, and submarines containing nuclear reactors both with and without spent reactor fuel. According to the

Yablokov report, most of the volume dumped was low- and intermediate-level waste produced during the operation of nuclear submarines, surface vessels, and icebreakers (table 2-2). The report also described dumping of high-level radioactive wastes in the form of spent fuel and reactors from nuclear submarines and an icebreaker (table 2-1). A total of 16 reactors dumped at five different locations in the Kara Sea are listed; spent nuclear fuel remains in six of the reactors and an additional container from the icebreaker *Lenin*. Attempts were made to contain the fuel. For example, the damaged fuel assemblies from the *Lenin* were reported to be encased in a concrete and metal container, stored on land for a period, and then dumped with the *Lenin* reactor section. Nonetheless, the reactors with spent nuclear fuel constitute the greatest amount of radioactivity and thus the potential for the most serious future releases. The Yablokov report included an estimate that at the time of disposal, the upper limit on the activity of all of this spent nuclear fuel was 2.3 million curies. The two largest dump sites are Abrosimov Fjord where 1.2 million curies was deposited, and the East Novaya Zemlya Trough, into which 799,200 curies was dumped.

Since the time of the dumping, natural radioactive decay has reduced the inventory of radioactivity. Radioactive decay calculations performed at the Lawrence Livermore National Laboratory, along with revised estimates of the nuclear reactor working histories developed through the work of the IAEA, suggest that less than 130,000 curies of radioactivity remains in the reactors and spent fuel (43,46).

The Yablokov report states that until 1983, monitoring of the waste disposal areas was carried out by the Northern and Pacific fleets of the Soviet Navy, with surveys to measure levels of "biologically hazardous radionuclides in seawater, bottom sediments, and commercial and marker species of water life in radioactive waste disposal areas" (25). In addition, more extensive radiological studies were carried out at different times between 1960 and 1990 by various research facilities to determine optimal conditions for radioactive waste discharge by the Navy (25). After 1983, responsibility for monitoring radiation conditions in radioactive waste discharge and dumping areas was given to Goskomgidromet, the State Committee for Hydrometeorology. The Yablokov report lists expeditions carried out in 1975 in the Sea of Japan, in 1982 in the Kara Sea, and the Joint Russian–Norwegian expedition in 1992 in the Barents and Kara Seas.

Despite these expeditions, however, the report stresses that none of the surveys carried out after 1967 came closer than 50-100 km to solid radioactive waste disposal sites (25). This is repeated in a recent report by Gosatomnadzor, the Russian nuclear regulatory agency, "For 25 years no surveillance has been conducted at the solid waste dump sites which results in that it is practically impossible to define the condition of solid waste protection barriers, the speed and scale of radionuclide release" (24). This remained the case until joint Russian–Norwegian expeditions visited some of the dump sites in 1993 and 1994. Furthermore, even though monitoring data were collected by the Northern fleet and many related research institutes, these collections did not constitute a coordinated system of monitoring the radioactive objects dumped at sea, according to the Yablokov report (25).

Much of the remainder of this chapter reports research done and questions remaining about these dump sites and the nature of their contribution to Arctic and North Pacific contamination.

TABLE 2-6: Conferences and Congressional Hearings on Arctic and North Pacific Contamination from Dumped Nuclear Waste

Location	Dates	Topic
Washington, DC	Aug. 15, 1992	*Hearing*: Radioactive and Other Environmental Threats to the United States and the Arctic Resulting from Past Soviet Activities
Arkhangelsk, Russia	Oct. 14–18, 1992	Ecological Problems in the Arctic
Oslo, Norway	Feb. 1–5, 1993	Consequences of Dumping of Radioactive Waste in Arctic Seas
Anchorage, AK	May 2–7, 1993	Arctic Contamination
Woods Hole, MA	June 7–9, 1993	Radioactivity and Environmental Security in the Oceans
Kirkenes, Norway	Aug. 23–27, 1993	Environmental Radioactivity in the Arctic and Antarctic
Washington, DC	Sept. 30, 1993	*Hearing*: Nuclear Contamination in the Arctic Ocean
Biloxi, MS	Jan. 12–13, 1995	Japan–Russia–United States Study Group on Dumped Nuclear Waste
Woods Hole, MA	May 1–4, 1995	Arctic Nuclear Waste Assessment Program Workshop
Oslo, Norway	Aug. 21–25, 1995	International Conference on Environmental Radioactivity in the Arctic

SOURCE: Office of Technology Assessment, 1995.

RESEARCH AND MONITORING OF RADIOACTIVE CONTAMINATION IN THE ARCTIC, THE NORTH PACIFIC, AND ALASKA[1]

The response to the information provided in the Yablokov report was international consternation and the birth or adaptation of a host of projects and programs to characterize the situation. The issue is, *does the amount and disposition of this waste pose any large short- or long-term risk to public health or the environment?* Because so few data were available to the international community at the time, major efforts were made to gather more. Interest in and research activity on the topic are reflected in the number of workshops, international conferences, and congressional hearings held over the past few years (table 2-6).

In the United States, Department of Defense (DOD) funds were used to launch the Arctic Nuclear Waste Assessment Program (ANWAP), administered through the Office of Naval Research (ONR).[2] Internationally, the IAEA began the International Arctic Seas Assessment Project (IASAP) (described in chapter 5). The Norwegians, whose large fishing industry is potentially threatened by concerns over radioactivity in the Arctic seas, were also active in addressing the problem through a joint Russian–Norwegian expert group formed in 1992 for this purpose.

Findings from the Joint Russian–Norwegian Expert Group

Expeditions carried out by the Joint Russian–Norwegian Expert Group in the summers of 1992, 1993, and 1994 have made important con-

[1] Much of the information presented in this section was excerpted from a paper prepared for OTA by Drs. Burton Hurdle and David Nagel of the Naval Research Laboratory. Additional information was drawn from a paper prepared for OTA by Dr. Lee Cooper of Oak Ridge National Laboratory.

[2] ANWAP has been funded through DOD at $10 million per year for FY 1993, 1994, and 1995.

tributions to the state of knowledge of the contamination levels in the Kara Sea and some of the dump sites along Novaya Zemlya. Although the research ship *Victor Buinitskiy* did not visit the specific sites of the dumped nuclear wastes in 1992, researchers took water and sediment samples at 13 stations, two in the Barents Sea and the remainder in the Kara Sea. The radiation measurements from these samples, analyzed in five countries, were presented at a meeting in Kirkenes, Norway.

The final report of the 1992 cruise states:

> "At present time, the level of contamination of radionuclides in the southern Barents Sea and the Kara Sea can be attributed to global fallout, releases from [the] Sellafield [U.K.] reprocessing plant, contribution from the rivers Ob and Yenisey, and contribution from the Chernobyl fallout... The possible radiological impact on man and the environment as a result of the observed levels of contamination is extremely low...at present, the influence of the dumped radioactive wastes on the general level of radioactive contamination in the Kara Sea is insignificant. However, local effects in the vicinity of the dumping sites cannot be excluded, as these areas were not adequately investigated."[3]

The 1993 Norwegian–Russian cruise was able to investigate some of the dump sites. The *Victor Buinitskiy* visited dumpsite areas in Tsivolky and Stepovogo Bays in Novaya Zemlya and the Novaya Zemlya Trough in the Kara Sea to provide a general assessment of potential radioactive contamination in the water, sediments, and biota (31). Analyses of the Cs-137, Sr-90, and Pu-239 and 240 in collected samples indicate that the level of radioactive contamination in the investigated areas is low, comparable to that observed in 1992 in the open Kara Sea. In the Tsivolky Bay, where the *Lenin* reactors were reported to be dumped, Cobalt-60 (Co-60), which may have originated from the dumped nuclear waste, was measured in the upper sediments, but components of the *Lenin* were not located. The expedition located one of the submarines dumped with nuclear fuel in the outer part of the Stepovogo Bay, and analysis of sediment samples from near its hull may suggest some leakage of fission products from the submarine reactors. In the inner portion of Stepovogo Bay where the bottom waters are isolated by a "sill," elevated Cs-137 values were found. Cobalt-60 was also present in these samples, which may be a sign of possible leakage from the dumped waste. Only a detailed study of Stepovogo Bay will answer this question. Concentrations of Cs-137 in surface sediments of the Novaya Zemlya Trough, also mentioned in the Yablokov report as a site for nuclear waste dumping, were similar to those in the open Kara Sea in 1992.

The 1994 Norwegian-Russian cruise visited the Abrosimov Bay and returned to the Stepovogo Bay. The expeditions located three of the four nuclear submarine reactor compartments reportedly dumped in the Abrosimov Bay (32). Preliminary data gathered on the cruise indicated elevated Cs-137 gamma-ray levels near two of these reactors, while only Co-60 radiation was observed near the third. Sediment and water contamination levels were low overall, comparable to the open Kara Sea, except for elevated Cs-137 in sediment near the dumped objects.

From the limited information available, it appears that any leakage that may have taken place so far from dumped wastes has at most led to very local contamination. More extensive inspection of the dumped objects (in particular, all of the reactors with spent fuel) and sampling of the environment nearby are necessary.

U.S. Arctic Nuclear Waste Assessment Program (ANWAP)

The research program undertaken by DOD's Office of Naval Research to address the concerns

[3] Joint Russian–Norwegian Expert Group for Investigation of Radioactive Contamination in the Northern Seas, "A Survey of Artificial Radionuclides in the Kara Sea. Results from the Russian–Norwegian 1992 Expedition to the Barents and Kara Seas" (Osteras, Norway: Norwegian Radiation Protection Authority, 1993).

posed by nuclear materials dumped in Arctic seas has been a large and broad research effort. Administered through the ONR, the program has focused on five topics: 1) the environment through which dumped nuclear materials might move; 2) the character and containment of the materials themselves; 3) their potential motion and disposition as determined by physical, chemical, and biological factors; 4) possible risks to people and nature; and 5) future monitoring of the materials. The Office of Naval Research organized its program around these topics while utilizing existing academic, industrial, and government capabilities. The primary objective of the program is to determine whether or not the radioactivity dumped in the Arctic Seas by the former Soviet Union (fSU) presents a threat to the economy or to the health of U.S. citizens. Box 2-8 discusses these five topics, the research questions they engender, and the current knowledge base.

Over the past few years, water, sediment, and biological samples were collected by five ships in the eastern Arctic near the dump sites and major river estuaries, and five ships collected samples in the western Arctic near Alaska. In 1993 and 1994, research cruises to investigate radioactive contamination in the Arctic were conducted by U.S., Canadian, and German icebreakers, the University of Alaska Research vessel *Alpha Helix*, a U.S. submarine, and five Russian vessels. A summary of the ships, cruise regions, stations, and samples obtained in the Arctic and nearby seas in the summer of 1993 is given in table 2-7. The locations sampled from these ships in 1993 and 1994 are illustrated in figure 2-5. More than 11,000 samples were obtained from 600 ocean stations in order to assess background radiation from fallout and other sources, and to search for elevated radiation levels associated with Soviet and Russian nuclear waste.

BOX 2-8: Key Research Topics and Knowledge Base of the Arctic Nuclear Waste Assessment Program (ANWAP)

Topic	Knowledge Base
1. The environment through which the dumped radioactive materials might move: What is the background radioactivity already in the environment due to naturally occurring radioisotopes and the effects of testing and discharge from nuclear reprocessing plants? Further, what are the physical, chemical, and biological environmental factors that will determine the transport and disposition of unconfined radionuclides in the environment?	A great deal was known and has been learned in the first two years of ANWAP regarding radioactivity in the Arctic. The information is either already in the geographic information system database set up for this program or will be incorporated as soon as it is made available. There remain, however, significant gaps in knowledge of the spatial and temporal distributions of radioactive materials in the Arctic.

(continued)

BOX 2-8: Key Research Topics and Knowledge Base of the Arctic Nuclear Waste Assessment Program (ANWAP) (Cont'd.)

2. The dumped materials themselves (the so-called source terms): What radionuclides have been dumped, and in what quantities, chemical states, and containers? When, if at all, will these materials be released, and at what rates?	Three reactor compartments dumped with their nuclear fuel have been located during the past two summers by joint Norwegian-Russian expeditions. However, a reactor with fuel, a container carrying spent fuel from the icebreaker *Lenin,* nine of the ten reactors dumped without their fuel, and virtually all of the thousands of containers dumped with low levels of radioactivity have not been found. Location of all the reactors, assessment of their material condition by optical examination at least, and sampling of reactor materials and the surrounding seafloor remain major unsatisfied program requirements. This is particularly evident for the fueled reactor dumped in the East Novaya Zemlya Trough.
3. The movement and disposition of dumped materials: How will the nuclear materials move under the influence of physical, chemical, and biological factors? When and where will they finally come to rest (e.g., sorption onto particles, precipitation on the seafloor, burial by sediments)?	Major progress has been made in calculating the physical circulation of the radioactive materials, by assuming that they are free and mobile in the environment, with attention to riverine inputs as well. However, benchmarking the ability of the models to predict deep as well as surface circulation, and the inclusion of chemical processes such as particle binding of radionuclides and biological processes such as bioturbation, remain for the future. Further, the potential role of ice in influencing or determining the motion and fate of radioactive materials in the Arctic seas is not known in even the broadest outlines.
4. The risks to and impact on people and nature due to the movement and disposition of the dumped materials: What portion of the ecosystem, if any, will be affected by the radioactive materials carried in the water column, deposited in sediments, and incorporated in living creatures? Will concentrations of radionuclides in the food chain, or any other process, threaten human health or economics?	To date, several calculations have been made by different organizations to estimate risks to humans from the dumped nuclear materials. Although complete in the sense that they yield a numerical prediction of human risk, these calculations are quite superficial. Elaboration of the models used and acquisition of the many major parameters required as input need to be carried out.

(continued)

BOX 2-8: Key Research Topics and Knowledge Base of the Arctic Nuclear Waste Assessment Program (ANWAP) (Cont'd.)

5. Potential monitoring of regions of interest near the sources, along transport paths, or at locations where people or the environment may be at risk: What instrumentation should be in place at which locations? What samples should be taken and measured, and over what time scales, to ensure that transported radionuclide materials do not exceed concentrations of concern from any viewpoint?

Monitoring by sampling when possible, with associated laboratory measurements, is a well-developed practice that has been employed in the first two years of the program. However, open-sea monitoring of radioactivity on demand is in a rudimentary stage in terms of available technologies and strategies. The relative efficacy and costs of monitoring near the source regions, which may or may not be susceptible to potential remediation of any kind, or near a region of interest such as Alaskan fishing grounds, requires study.

SOURCE: B.G. Hurdle and D.J. Nagel, "Nuclear Contamination of the Arctic Seas and Estuaries; Current Status of Research and Future Requirements," paper prepared for the Office of Technology Assessment by the Naval Research Laboratory, Washington, DC, April 1995.

Measurements on samples from these Arctic surveys have just begun. Previously available information, and the limited data obtained so far from materials collected through this program, have not indicated migration of radionuclides from Russian sites to the wider regional environment. Data from localized regions in the Kara Sea do show radionuclide concentrations that suggest an influence of inputs from local nuclear bomb tests, dumping, or discharge from the Ob and Yenisey Rivers. However, limited measurements to date in the Kara Sea show generally lower concentrations than those in the Baltic Sea from Chernobyl and in the Irish Sea where radioactivity has been discharged from the Sellafield reprocessing facility in the United Kingdom.

This research is continuing during 1995, and studies should provide further useful data. Emphasis in FY 1995 is on carrying out a risk assessment, examining strategies for monitoring, communication of results to concerned stakeholders, consideration of all sources of Arctic contamination, increased Russian participation, and increased participation in national and international forums to prevent duplication (16).

Radioactivity in Water, Sediment, and Biota

A major thrust of the Department of Defense program, the Norwegian-Russian collaboration, and other international efforts has been to characterize the present level of radioactivity in the Arctic seas, the Sea of Japan, the Ob and Yenisey River estuaries, and other regions of interest. The results from the DOD Arctic Nuclear Waste Assessment Program for FY 1993–94 are given in the annual report ONR 322-95-5 (51). Some of the major findings are as follows:

1. Radionuclide concentrations in Alaskan waters are low and can be explained mainly by fallout from atmospheric testing of nuclear weapons. There may also be a weak signal from the 1957 accident at Chelyabinsk-65.
2. Investigations by the United States and by collaborating programs from Norway, the fSU, Korea, and Japan suggest that levels of radionuclide activity in the Arctic and Pacific regions are low.
3. To date, measurements and analyses of radionuclide contamination in the Arctic marine environment indicate that they come mainly from:
   a. atmospheric testing of nuclear weapons,

TABLE 2-7: Arctic Research Cruises Sponsored by the Office of Naval Research to Investigate Radioactive Contamination, 1993

Cruise	Location	Stations	Sediment	Water	Biota
Alpha Helix[a]	Bering and Chukchi Seas	196	500	4,700	250
G. Fersman	Kara Sea (dump site)	66	1,000	50	
Mendeleev[b]	Kara Sea and Ob River	30	300	300	100
Okean	Bering and Chukchi Seas	64	1,000	300	500
E. Ovsyn	Ob and Yenisey Rivers, Kara Sea	77	450	400	500
Polar Star	North American Arctic	62	200	200	12 trawls
Polarstern	Laptev Sea		22	24	
USS Pargo	Arctic Ocean	15		150	
D. Zelensky	Barents and Kara Seas	7	100		
H. Larsen	Chukchi Sea	66		100	
Various[c]	Laptev, East Siberian, Chukchi, Beaufont, and Bering Seas		400		

[a]Some samples collected from the *Alpha Helix* in the Chukchi Sea during 1992 will also be analyzed by this program.

[b]Many samples obtained by the Shirshov Institute of Oceanography from the *Mendeleev* will be measured.

[c]Sediment samples collected with U.S. Navy sponsorship in the 1960s and 1970s.

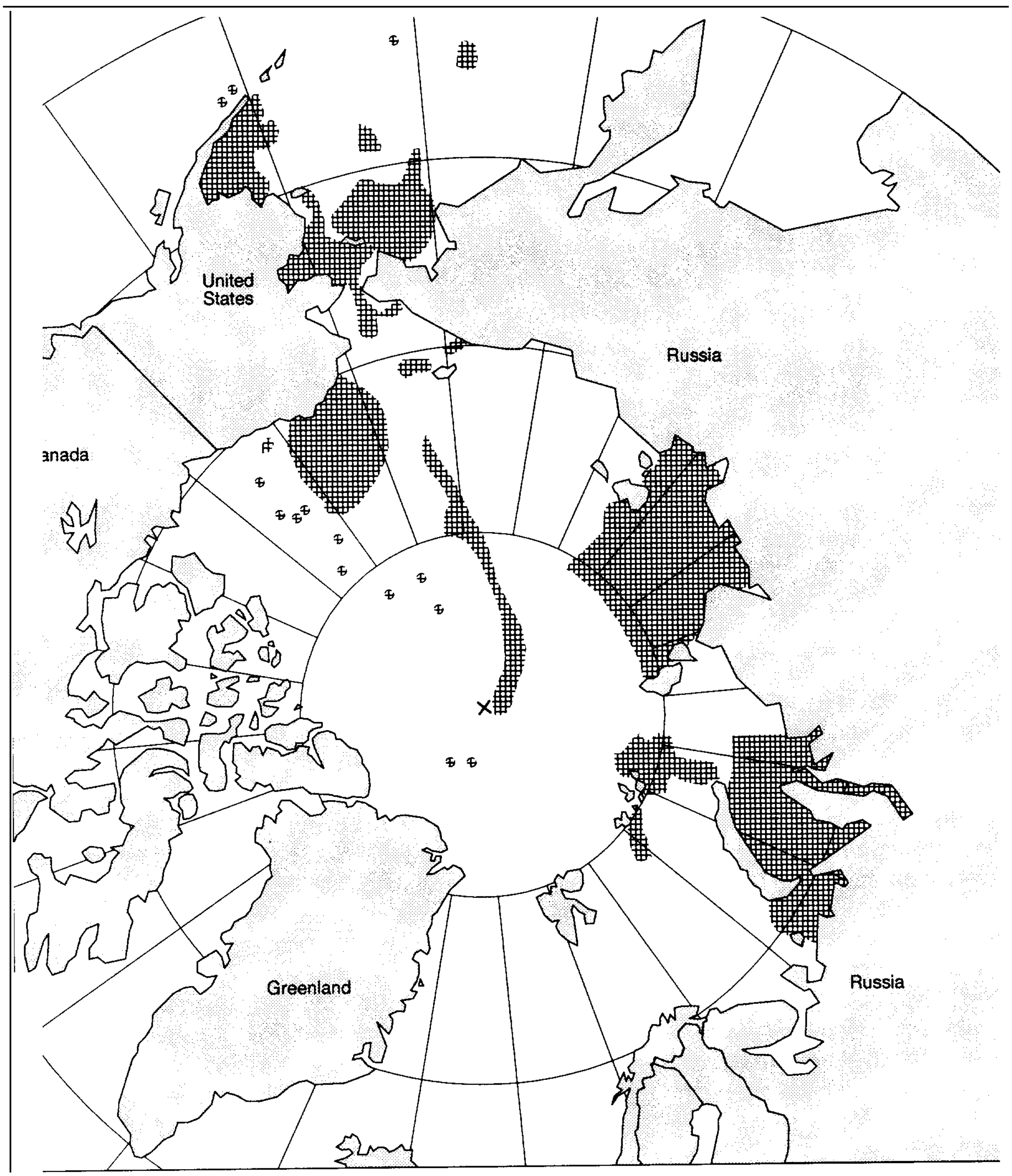
SOURCE: B.G. Hurdle and D.J. Nagel, "Nuclear Contamination of the Arctic Seas and Estuaries; Current Status of Research and Future Requirements," paper prepared for the Office of Technology Assessment by the Naval Research Laboratory, Washington, DC, April 1995.

b. nuclear fuel reprocessing wastes carried into the Arctic from reprocessing facilities in Western Europe,
c. accidents such as Chernobyl and the 1957 explosion at Chelyabinsk-65, and
d. Chernaya Bay weapons tests in southwestern Novaya Zemlya.

Because the signals from sources a and b have decreased with time, region-wide concentrations of radionuclides in the water column and in surface sediments appear also to have decreased from their peak levels.

4. Based on preliminary data analyses, the Yenisey and Ob Rivers appear to have had only a modest impact on radionuclide levels in the Kara Sea and the Arctic Ocean region in general. Small but detectable signals from nuclear facilities on these rivers have been measured over large areas, and there is a zone of enhanced Cs-137 concentration near the mouth of the Yenisey River.
5. Calculations based on Russian data of initial inventories suggest that the total activity of the radioactive waste dumped in the Kara Sea region by the fSU over the last 40 years has decayed to a level of approximately 0.13 million curies today (43). Most of this radioactivity is from the nuclear reactors that still contain fuel, and most of this radioactivity still appears to be contained.
6. Local sites of elevated radionuclide concentration arising from Soviet dumping and weapons testing have been identified in the Kara Sea region. Studies in Chernaya Bay in southwestern Novaya Zemlya where nuclear weapons were tested are similar to those at

FIGURE 2-5: Areas Sampled During ONR-Sponsored Expeditions in 1993 and 1994



SOURCE: Office of Technology Assessment and Office of Naval Research, 1995

Eniwetok Atoll, a U.S. test site. Joint studies by Norway, the fSU, and the IAEA have found elevated concentrations in highly localized regions in Novaya Zemlya bays where the Soviet Union dumped waste containers and nuclear reactor compartments, some still containing fuel. The preliminary results of this trilateral program suggest little leakage from the reactor compartments containing fuel. Zones with elevated concentrations of Cs-137 have been identified in the Novaya Zemlya Trench.

7. Very preliminary large-scale numerical modeling studies of water transport, run for a simulated period of 10 years, suggest that radionuclides released to the Kara Sea region would have their concentrations substantially reduced by the time they reached Alaskan coastal waters. More work is needed to substantiate and enhance this model, however, including incorporation of the role of sediments in sequestering radionuclides.

Recently, Cs-137 activity has been reported for sediment trapped in the sea ice in the central Arctic. This has heightened concern over the potential for the long-range ice transport of radionuclide-bearing sediments. The activity in one sample taken north of the Chukchi Sea was reported comparable to the elevated levels present in the Yenisey River estuary. However, other sources are possible, and the origin of this sea ice contamination has not yet been determined. Another report of interest was the identification of a characteristic ratio of radionuclides in the central Arctic that would most likely come from Sellafield.

Database Development

Adequate data sets for the distribution of manmade radionuclides in the Arctic Ocean and its surroundings do not exist because of the lack of data, particularly in the western Arctic Ocean near North America, in the central Arctic Ocean, and north of Siberia. Recent work related to the current programs has made improvements in the quantity and quality of these data but much more needs to be done.

There are significant Russian data sources, but these still need to be collected, compiled, and integrated into western databases to facilitate assessing the concentrations of radionuclides in the water (marine, lakes, and rivers), sediment, ice, flora, and fauna and determining how these concentrations have varied over space and time. It is also important to gather data collected in the neighboring seas to determine the degree of radionuclide pollution in the Arctic relative to the rest of the world.

As part of the Arctic Nuclear Waste Assessment Program, the Naval Research Laboratory (NRL) is currently setting up a geographical information system (GIS) to computerize, among other items, the extensive body of information collected from the various scientific expeditions sponsored by ANWAP since 1993. Completion of the GIS would enable: 1) creation of a database of existing radionuclide data on the water, sediment, ice, and biota; 2) development of databases of bathymetry, rivers, sedimentation, and biota, as well as physical and chemical oceanographic, riverine, and estuarine processes; and 3) compilation of the information needed to predict the degree of risk posed by these radionuclides to the Arctic environment and its inhabitants and others who utilize Arctic marine resources.

Efforts by NRL to set up its Arctic database have included compiling preexisting radionuclide data, developing connections with Russian colleagues, and developing collection efforts for new data. In addition, some efforts are directed toward developing a system that would enable individuals to query databases to gather statistical information. Attempts have been made to develop a more inexpensive and user-friendly GIS operating system so that individuals can perform their own analyses.

As of December 1994, databases were constructed at the Naval Research Laboratory for: 1) the location of stations and ship tracks; 2) the distribution and concentration of radionuclides in sediments and the water column; 3) the distribution of nuclear tests, accidents, etc.; 4) the location of dump sites; 5) the distribution of various nuclear facilities and sites of interest; and 6) digitized bathymetry, rivers, and marine resources.

The NRL work has been extended by cooperation with international programs. By 1996–97, NRL plans to have a comprehensive radionuclide GIS that should serve as an international platform from which information can be extracted to carry out a risk assessment program. One possible destination of this GIS could be the database of the Arctic Monitoring and Assessment Program (AMAP)[4] in Arendal, Norway. Other major exchanges of data could be carried out with the IAEA as well as with major national and international contributors to the GIS. NRL will also investigate, together with the Norwegian Radiation Protection Agency, the efficacy of installing its data in the United Nations Environmental Program's environmental GIS facility in Arendal, Norway.

The GIS system being developed at NRL has already proved useful in disseminating archived information to investigators from many countries and agencies and in sharing data.[5] Data exchange efforts have led to further cooperative projects, such as the collaboration between the Naval Research Laboratory and the Okeangeologia Russian Scientific Research Institute on the research vessel *Professor Logachev* in a trip to the Svayataya Anna Trough and other areas in the Kara and Barents Sea region during the summer of 1994.

Status of Modeling

Although observations such as those compiled in the Naval Research Laboratory's GIS database can provide useful pictures of past and present levels of radioactivity at certain locations within the Arctic seas, it would be difficult to monitor all or even several regions of the Arctic for long periods of time. For this purpose, tested and validated numerical models can provide information that will both compliment and enhance the existing database. Numerical models can help explain the dynamic transport pathways for the contaminants once they enter the ice or ocean system. In addition, numerical models can "forecast" the dispersion of radioactive materials with either known or estimated sources. Numerical models can illustrate processes that are determined to be the most important for the transport of radioactive materials. Several numerical models are presently being tested by the ANWAP community and the European scientific community. A majority of these models are regional, focusing on one particular oceanographic basin such as the Kara or the Chukchi Sea. In addition, numerical models of the river systems that may serve as major present and future sources of radioactive contamination are also being modeled in ANWAP.

In 1993, the NRL developed a numerical model to include a radioactive tracer component. The model was then tested using sources defined by the Yablokov report; both low-level solid and liquid radioactive waste were used, as well as the high-level solid waste located along the eastern side of Novaya Zemlya. In all cases it was assumed that each source was leaking at a continuous rate based on the total amount of radioactive material dumped at that site and the period of time over which it was dumped. A major conclusion of those studies was that at the end of a simulated 10-year release, the levels of radioactivity in the waters along the north Alaskan coast were approximately five orders of magnitude lower than those found in the Kara Sea. These results were described in the DOD Preliminary Report to Congress entitled "Nuclear Pollution in Arctic Seas" (72). However, research on the circulation of Arctic waters using tracers present in these waters suggests that the model might over-

[4] AMAP is a program carried out by the eight Arctic countries to monitor, assess, and report on the environmental health of the Arctic. It is described more fully in chapter 5.

[5] Data have been exchanged with the Norwegian Radiation Protection Agency; Tokai University in Japan; University of Edinburgh; Norsk Polar Institute; the Netherlands; the IAEA in Vienna; the IAEA Marine Environmental Lab in Monaco; KORDI, the Republic of Korea Institute of Oceanography; the German Hydrographic Service; the VNII Okeangeologia in St. Petersburg; and the Shirshov Institute of Oceanology in Moscow.

estimate the dilution. These studies suggest that the surface waters that flow across the pole and through Fram Strait are diluted by about a factor of 10 (4,63,64). Such findings illustrate the need to use experimental data to calibrate models used to predict or estimate the movement of pollutants. Once the models of the movements of water have been validated with experimental data, the modeling can be further developed by accounting for the important roles of chemistry and sediments, which should be important influences in the movement or sequestration of radionuclides.

With FY 1994 funding, NRL continued the FY 1993 studies by adapting the model to accept river outflow and using data from the Yablokov report to simulate rivers as a source of contaminant release into the Arctic. Levels of radioactivity resulting from these simulations show good agreement with observations from the Kara Sea. Other modeling efforts are currently underway within both ANWAP and IASAP, which will add to current knowledge of the ultimate fate and effects of this radioactive contamination.

Monitoring

Long-term monitoring of the environment and related indicators to help provide early warnings of potential health or ecological risks from dumped radionuclides has not yet been undertaken. Monitoring can serve a variety of purposes, and the type of monitoring to be carried out, if any, must be discussed in conjunction with the goals to be achieved. For example, monitoring can help to fill critical data gaps about radionuclide transport. The sudden release of radioactive waste from reservoirs, storage ponds, underground storage, or marine dump sites into the Arctic environment poses a potentially significant long-term environmental problem. Since measurements of the radioactivity in the Kara Sea and the Ob and Yenisey Rivers are typically conducted during the two- to three-month ice-free summer, the transport and fate of radionuclides during the rest of the year is poorly characterized. Many researchers believe that a monitoring system is needed to provide a better understanding of transport processes during the ice-covered times of the year, as well as annual cyclical events such as the spring thaw. This monitoring capability is not presently available. The difficulty and expense of collecting data on radioactivity using traditional oceanographic cruises limit spatial and temporal coverage. In situ monitoring could improve this situation if the monitoring device could be deployed by air or a convenient ship and were of low enough cost to be considered expendable.

Other types and scales of monitoring are also under discussion for other purposes. One Russian official, who participated in the Woods Hole, Massachusetts, conference on Radioactivity and Environmental Security in the Oceans: New Research and Policy Priorities in the Arctic and North Atlantic, suggested that a global marine radiation monitoring organization be established (49). The organization's mission, as proposed, would be to forecast radiation impacts and to support decisionmaking on actions to be taken regarding radioactive marine objects. The functions of this proposed organization could be conducted in the Russian Arctic, as a case study, to determine how effectively the organization might operate. Nosov (49) recommends that the organization:

- conduct ongoing radiation monitoring of identified objects to predict their structural integrity;
- assess the accuracy of prediction models and update these models accordingly;
- develop an environmental database of this information; and
- provide information to support decisionmaking on protection and associated mitigation options.

As part of any monitoring strategy, scientists need to know what instrumentation to place at which locations, what samples to take and measure, and over what time scales. NRL is investigating various semiconductor and scintillator detectors in sturdy, waterproof housings. It is also developing new gamma-ray detectors (27). Communication channels will have to be established for these continuous, remote, bottom-stationed devices to transmit their finding to scientists for analysis.

However, as in Nosov's proposal, monitoring does not stand on its own but fits within a structured plan of response to a particular need. Since the needs have not yet been fully characterized, there is little agreement among scientists on the proper strategies to use in monitoring these regions or even the necessity of monitoring. No determination has been made as to the level of radioactivity that needs to be monitored. Should the existing level of contamination be monitored, or is it sufficient for a monitoring capability to detect only radioactivity at a level resulting in a biologically significant dose? Many other questions also have to be addressed more fully, such as the capabilities of in situ measurement technologies, suitable sensors, and testing of prototype systems. Most important, the purpose and goals of monitoring require clear definition.

RESEARCH AND MONITORING: DATA GAPS AND FUTURE NEEDS

The conclusions from research to date must be considered as preliminary because of the gaps in data and analysis that remain. This section identifies some significant gaps in knowledge that must be addressed to fully understand the potential impacts of nuclear waste dumping.

Source Terms

Much remains unknown about the source terms for the major nuclear waste dump sites in the Kara Sea. Important work is being carried out on land by the IAEA International Arctic Seas Assessment Project Source Term Working Group to learn more about the design of the reactors, their working histories, and their containment. The information should be available in early 1996 and will be critical for understanding the risks posed. Nonetheless, there remains a need for more information to be gathered at the sites themselves, such as that collected in the 1993 and 1994 expeditions of the Joint Russian–Norwegian Expert Group. Their explorations extended to four of the areas in which reactors with spent fuel were reportedly dumped, but only three out of five of the reactor compartments or containers with spent fuel have been located thus far.

Investigations at these sites should include:

- a comprehensive survey and assessment of conditions around the dumped objects—especially at those sites that have not been visited for long periods (decades);
- location of each of the reactors and assessment of their condition through photographs, video, in situ gamma-ray measurements, and systematic water and sediment sampling for radionuclides; and
- similar assessment of containers and other objects located during the search for the reactors. Russian Navy and Russian scientific and technical participation is needed.

For a better understanding of the potential impacts of nuclear wastes washed into the Arctic from the large, north-flowing Siberian rivers, the extent and condition of riverine contamination from land-based sources, including groundwater hydrology, must be more fully assessed to determine how much and how far contamination has traveled downstream, and what the effects of such contaminants might be to the Arctic.

Container Materials

To understand the potential for future releases, further study of the dumped containers is necessary. The lifespan and integrity of container materials has had only brief consideration whether they are submarines, reactors, or other waste material containers. For example, some of the reactors and containers have been enclosed in furfural, a resinous material designed to prevent contact of the reactors with seawater for several hundred years. However, data to support this estimate are not available. Similar uncertainty exists about the lifespan of other container materials in seawater.

Environmental Factors and General Sampling

A great deal still needs to be learned about the physical oceanography and geophysics that control transport mechanisms within the Kara Sea and northward into the Arctic basin. Surface and bottom circulation in the Kara Sea needs to be comprehensively examined, and the question of ice transport should be investigated.

One need is to develop an understanding of the dynamics of circulation characteristics, including advection, mixing, and dispersion, of Kara Sea waters and their interaction with adjacent seas. Knowledge of the relationships among currents, wind forcing, tidal forcing, density structure, and sediment resuspension is required for this understanding. Other issues to be investigated are the ice motion in the Kara Sea, the impact of the Siberian Coastal Current on the ice, and possible sediment transport via sea ice into the Arctic basin.

Finally, it is important that field operations collect a complete set of water column and sediment measurements of radionuclide levels in the Kara Sea.

Benthic Biota

It is important to improve the database on bottom-dwelling organisms to identify and quantify benthic biological pathways and radionuclide transport relevant to the radiation exposure of man as well as marine organisms. To this end, it is necessary to investigate benthic food webs to help identify potential exposure pathways, to examine the sedimentation rates of particles that scavenge radionuclides from the water column, and to make an assessment of the radionuclide exposure of key bottom-dwelling organisms.

Marine Mammals

Our knowledge of the density of marine mammals such as bears, whales, and seals, of their food chains, and of their use and consumption by indigenous peoples is limited. Available data on stable element concentrations should be used to develop biological concentration factors for these animals.

Marine Geology

The marine geology database should be developed to identify the pathways for transport of water, particles, and sediment-borne radionuclides brought about by variations in seafloor morphology and sediment type, as well as the degree of redistribution of sediment-bound radionuclides caused by local instabilities of the seabed. Detailed information is required on sediment properties, bathymetry, acoustics, and bottom dynamics, among other factors.

Physical Oceanography

The transport and disposition of radionuclides also depend on the physical characteristics of the ocean. Relevant data include compilations of temperature, salinity, density, and oxygen content; seasonal oceanographic and riverine information; and compilations of ice movement and transport.

Pathway Analysis and Modeling Research

There is a lack of information on radionuclide concentration factors for biota, as well as distribution factors between sediment and water, in the Russian Arctic region (28). Although current ANWAP models can predict surface circulation, there is a need to benchmark the ability of the models against experimental data; to develop and evaluate models that predict deep circulation patterns; and to include chemical processes such as radionuclide binding and biological processes such as bioturbation in these models (27).

Substantial gaps exist in our understanding of the potential role of ice in influencing or determining the motion and fate of radioactive materials in the Arctic seas (27). Specifically, data are needed on the transport process during the ice-covered times of the year, as well as during annual cyclical events such as spring thaw. Data on ice gouging are also needed to understand its potential as a means for damaging containers and releasing radionuclides. Data are lacking with which to assess the relative contribution of these ice mechanisms to the redistribution of contaminants in the Arctic region (56,57).

To understand the transport and fate of radionuclides in Russian rivers and in Arctic and Pacific seas, it is necessary to use a combination of numerical models, field observations, and remotely sensed data. This requires building integrated numerical models composed of different modules such as ice; physical oceanographic, biological and chemical processes; and riverine sources. A numerical modeling system is necessary that can be made available to all interested parties for studying this and other possible future waste dumping problems in the Arctic and its marginal seas.

Monitoring Requirements

Ultimately, monitoring requirements will depend on the needs identified in other phases of research, particularly through a systematic risk assessment. The monitoring required to address some specific data gaps has been described. Measurements of the radioactivity in the Kara Sea, and in the Ob and Yenisey Rivers are typically conducted in the two to three ice-free summer months. The transport and fate of radionuclides during the rest of the year is poorly characterized, due mainly to regional inaccessibility. Continuous, remote monitoring of radionuclide concentrations and other environmental data at dump sites or in rivers is necessary to complete the research on radionuclide transport in or to the Arctic seas and as an early warning for any episodic change. A monitoring system could provide a better understanding of transport processes during the ice-covered times of the year, as well as during annual events such as the spring thaw. This monitoring capability is presently not available for the Arctic environment.

Monitoring systems do not exist that could be deployed for a long duration in the Arctic. More efforts are needed to organize and bring together groups of experts in the fields of marine radiochemistry, radiation sensor technology, communications, risk assessment, ocean systems, oceanography, and marine geology to begin to address some of the important issues related to monitoring.

Data Availability

An understanding of the effects and potential implications of radioactive waste dumping in the Arctic depends entirely on the availability of reliable data indicating the extent of current contamination and the likely future disposition of the contaminating radionuclides. A variety of factors combined to make such data fairly scarce, however, at least as the problem first attracted attention and concern (1991–93). First, the Arctic by its nature is an area in which research that might be considered routine in other parts of the world is extremely difficult. Ice, extreme cold, and rough seas limit the times of year that research vessels can safely or productively go out. Relatively few investigators specialize in the distinctive systems of this part of the earth, and the difficulty means that the research is more expensive.

Second, the areas that are the immediate focus of concern (at least in the Russian North) are within the territorial waters of Russia, formerly the Soviet Union, which for more than 40 years during the Cold War did not welcome international investigators into its seas. Indeed, because the dumping was carried out by the military, it was secret even within the U.S.S.R. until declassified by the Yablokov commission in 1992. However, efforts are continuing to make information more available and to improve access.

Since the break-up of the Soviet Union and publication of the Yablokov report, however, information from the Russians about the environmental status of the Arctic and North Pacific Seas has been increasingly available. Russian scientists and technical experts have been active participants in conferences to facilitate data exchange, presenting relevant information to the international community.

A tremendous amount of information has been collected from research under the auspices of

ANWAP, but it has not become rapidly available. Analyses are time-consuming, and many data will first appear through publication in the scientific literature, which is a slow process. Otherwise, abstracts are available from presentations at workshops and meetings, and project descriptions along with a general summary of findings are provided in the FY 1993–94 report of the program (51).

Reliability/Comparability

Since a multiplicity of institutions representing several different nationalities have participated in data collection to contribute to understanding the extent of radionuclide contamination in the Barents and Kara Seas, questions of comparability of data collection methods and analysis are natural.

In the analysis for the 1992 joint Russian–Norwegian cruise, the issue of data comparability was addressed scientifically through intercomparison and intercalibration exercises carried out with the help of the IAEA laboratory in Monaco. These showed the analytical results of the two countries to be in reasonable agreement, with measurements of radionuclides in sediments in better agreement than those in water (31). Similar comparisons were carried out for the 1993 cruise, and again fairly good agreement was found for measurement of Sr-90 and Cs-137.

Data collected through the Arctic Nuclear Waste Assessment Program is consolidated and provided to Congress through annual reports without peer review. Ultimately many of the findings will be reported in the scientific literature after having been subjected to peer review.

The comparability of data may be of most concern for historical data. For example, as data from the past are combined in a GIS database, is there any means of ascertaining the methods used for analysis or otherwise gauging their reliability? In some cases the data were published in the form of contour lines, without the raw numbers to indicate whether they represent the average of many individual samples or simple single data points connected together. In such instances it will be impossible to judge data quality. All information collected in the future should be subjected to quality assurance standards.

REMEDIATION OPTIONS

Background

To reduce or eliminate the risk posed by radioactive material dumped in the Arctic region, decisionmakers must consider what type of remediation, if any, should be adopted to protect public health and safety and the environment. No attempt is made in this section to recommend an option for remediating the dump sites. Instead, the following material describes the information which decisionmakers will need and outlines a framework which could be used in the remediation decision process. Information from the two major efforts currently underway (i.e., IASAP and ANWAP) to gather information about transport models, pathway analyses, and possible exposures and doses that could be received from these dumped materials will be needed to reach these decisions. This analysis also draws on the work by the Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP).

The only official forum in which remediation options are being considered is through the IAEA's International Arctic Seas Assessment Project. This group of experts is asked to make recommendations regarding what response(s), if any, should be taken to the nuclear wastes dumped in the Arctic (67). The scope of their effort does not include consideration of the wastes dumped in the Russian Far East.

In terms of remediation options, IASAP's Remedial Measures Working Group is the most relevant. The first meeting of experts participating in this group was held in Vienna on January 23–27, 1995. Although the group has not yet issued a report from its initial meeting, background materials in support of the meeting (referred to as "Report of Working Party 3") were drawn on to develop the decisionmaking framework presented here (29). The Remedial Measures Working Group plans to wait for the results of IASAP's Source Term and Modeling

Working Group before making any recommendations on specific remedial actions that should be taken (50). IASAP expects to complete its work in 1996 (40).

In the United States, the Office of Naval Research is also involved via ANWAP, in assessing the risk posed by the radioactivity dumped in the Arctic region. ONR's goal is to "determine with high confidence whether the dumped and discharged radioactive material presents a threat to the Alaskan economy or the health of U.S. citizens" (72). ONR's research and monitoring in this region are intended to support the risk assessment and the decisionmaking process to determine what remediation measures, if any, should be employed.

Information Needed to Assess Mitigation Options

The specific information required to begin to assess mitigation or remediation options can be divided into two principal areas:

1. the condition of dump sites (physical, chemical, and biological factors), and
2. the status of dumped material (burial status, structural integrity of containers, waste form, and concentration of radionuclides, etc.).

Condition of Dump Sites

Prior to selecting a particular remedial option, experts must obtain adequate information on the physical and chemical characteristics of the environment surrounding the dump site. Important physical conditions are the depth of the site; the bathymetry of the surrounding areas to identify prominent seafloor features; and the physical stability of the site. For example, researchers want to know whether there are strong turbidity currents in the region that could destabilize the seabed sediment. Ocean currents around the sunken *Komsomolets* submarine, for example, have been measured up to 1.5 m/s (25). Knowledge of sedimentation rates in the region is also important.

The weather is a crucial factor. There are only two months of reasonably good working conditions in the Kara Sea (August–September). Tides may also be important—the tides in the Novaya Zemlya fjords reach 180 cm (6).

Chemical conditions to be measured include distribution coefficients (K_d) which describe the degree to which radionuclides will be retained or bound by sediment particles. Biological factors include determining whether the site serves as an artificial habitat and spawning location for organisms, identifying benthic organisms that are likely to be exposed to radionuclides, and measuring sedimentation rates of biogenic particles that scavenge radionuclides from the water column.

Status of Dumped Material

The burial status of the dumped material is important in assessing possible remediation actions. Is the material uncovered, partially covered, or totally buried? A good understanding of the structural integrity of the objects containing the material (e.g., drums, boxes, submarine hulls) is critical.

It is generally believed that the sunken barrels or containers dumped in the Arctic seas are probably made of mild steel. Knowing the corrosion rates and identifying any breach points in these barrels or containers are critical in estimating release rates of radionuclides. In addition, it is important to be aware of the structural integrity of submarine hulls (particularly the pressure vessels of fueled submarines). There is some indication, for example, that small amounts of radioactivity may be leaking from the NS 601 submarine sunk in the Stepovogo Bay of Novaya Zemlya (32). There is also concern about the spent fuel from the damaged *Lenin* reactor; this was placed in a concrete-steel box, on top of a larger box containing three *Lenin* reactor components without fuel. Both boxes were placed inside another box which was sunk in the Tsivolka Fjord. The box containing the spent fuel might not have been welded to the box on which it was placed and could have shifted in the process of being sunk. This box containing spent fuel constitutes the largest single radioactive source, by a factor of three, that has been sunk in the Kara Sea (6).

Other important factors include knowing the waste form of the dumped material and determining its integrity and estimated time of failure. Furfural is a compound that was used by the Soviets to enclose reactors and containers, and as previously mentioned, its effective lifetime is not known with confidence. It is important to estimate the lifetime of particular radioactive wastes or materials more accurately in order to estimate the release rates of encapsulated materials and to identify possible remediation needs and options.

Researchers also need to know the types of radionuclides contained in the dump sites and their concentration in the environment. This information is collected on expeditions such as those undertaken by the Joint Russian–Norwegian Expert Group in 1993 and 1994. Samples of sediment, water, and biota were collected and analyzed for radionuclides such as Cs-137, Pu-239 and 240, Co-60, and europium-152 and 154 (Eu-152, 154) for indications of whether and what amounts of radionuclides have been released from reactors or containers. In 1993, samples taken close to the hull of a dumped submarine indicated higher concentrations of Cs-137 than in the surrounding area, and the element europium was identified. These results suggested that radioactivity was leaking from the submarine reactor (32). Preliminary results from the 1994 cruise to two bays in which nuclear wastes were dumped suggested some local Cs-137 and Co-60 contamination from dumped containers of nuclear waste, with less contamination currently present near dumped reactors containing spent nuclear fuel. Elevated levels observed in 1993 near the submarine reactor with spent fuel in Stepovogo Bay were not supported by repeated onsite measurements during this expedition (19).

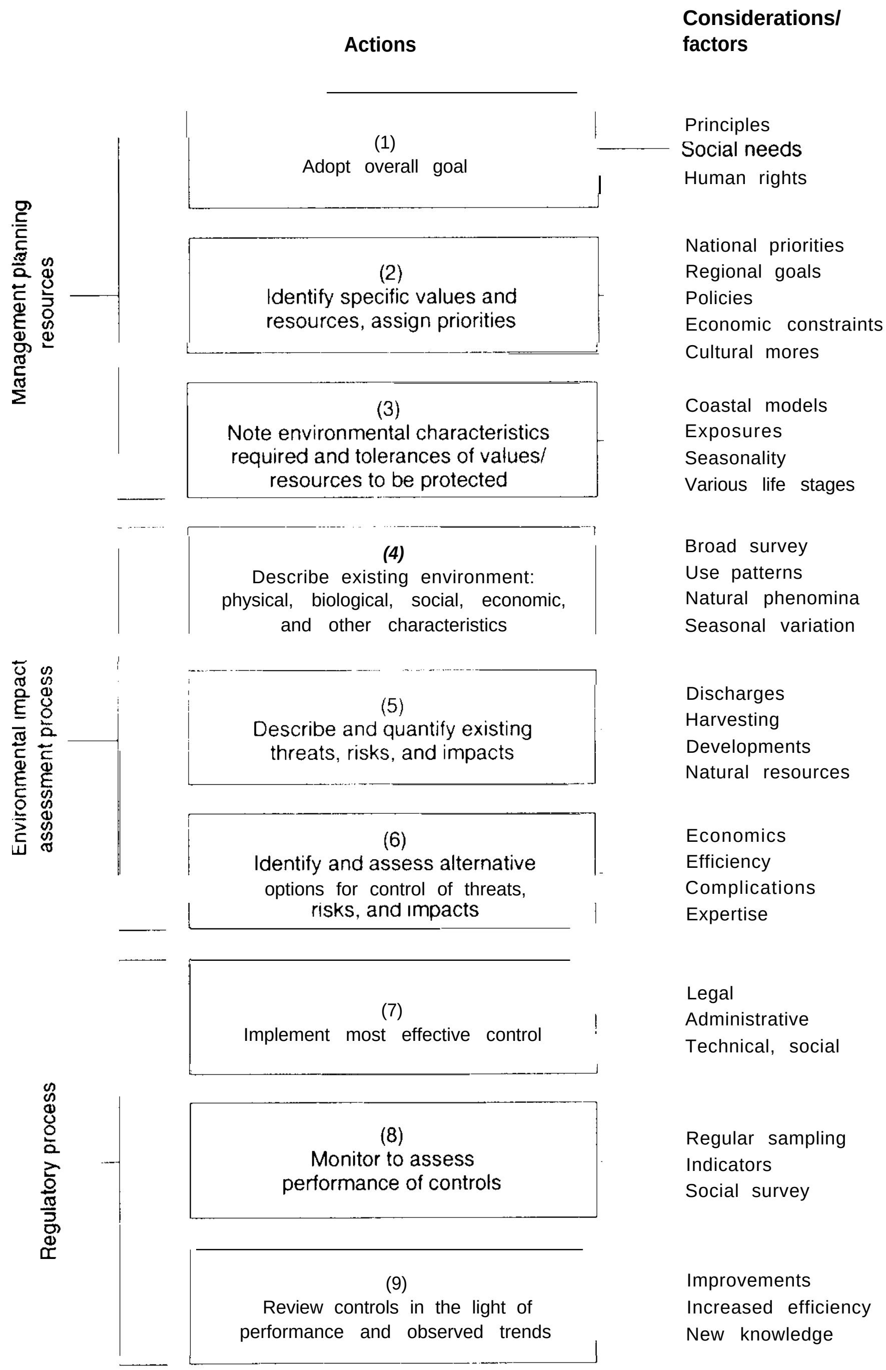
An Integrated Framework for Evaluating Mitigation Options

The Group of Experts on the Scientific Aspects of Marine Pollution issued a report on the possibility of a common framework for managing radioactive and non-radioactive substances to protect the marine environment. This report was written in response to questions posed by the Inter-Governmental Panel of Experts on Radioactive Waste Disposal at Sea (IGPRAD). In its report, GESAMP finds that "a frequent problem in environmental monitoring and with assessments of the quality of the environment is that the information gathered is hard to interpret in a management (i.e., nonscientific) context. Thus, it is difficult to decide whether a particular set of environmental conditions is acceptable unless the aspirations of society are explicitly defined" (30). GESAMP recommends that goals be established for protecting the environment and that tolerances or regulatory standards be established to support these goals. With this framework in hand, environmental impact assessments can be used to provide a basis for designing measures to reduce or prevent damage. The framework can then help to identify where intervention might be used to mitigate adverse effects. The regulatory process, in turn, can be designed by using control measures and performance monitoring to identify the need for any revision of decisions made earlier in the framework (30).

Figure 2-6 depicts the overarching management framework developed by GESAMP for protecting the environment. The framework contains a hierarchical sequence of planning, assessment, and regulatory activities that are critical for environmental protection. Although the framework was designed as a general tool for use in the marine environment, in its modified form it is a relevant tool for decisionmaking concerning the management of radioactive material dumped in the Russian Arctic. Decisionmakers may wish to work their way through the various steps in figure 2-6 to help them decide what remedial action(s), if any, are necessary. Steps 1 through 5 are the basis for making the decision in step 6.

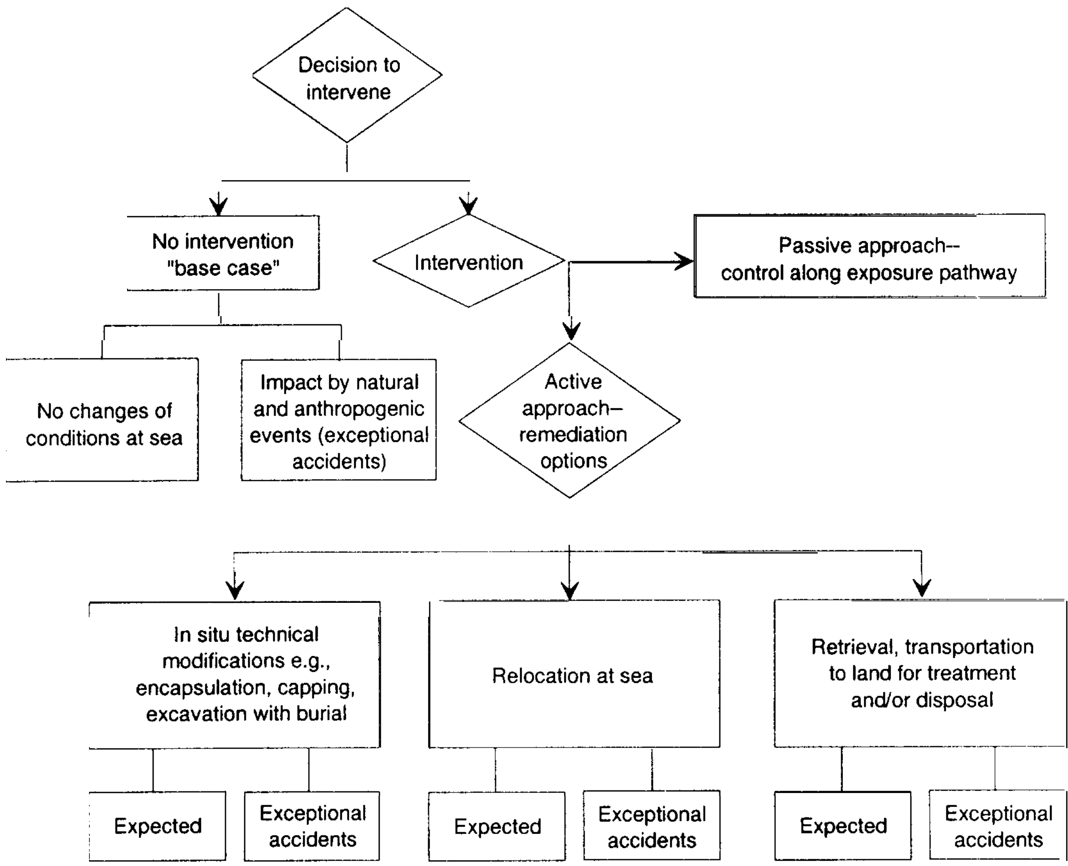
One issue that adds to the difficulty of selecting an appropriate mitigation option is the lack of any internationally agreed-upon mechanisms or values for determining when it is necessary to intervene and remediate a site (29). In other words, steps 2 and 3 of figure 2-6 have not been completed. Nonetheless, one objective of the IASAP project as defined in the Report of Work-

FIGURE 2-6: Management Framework for Protecting Marine and Other Environments



SOURCE: Office of Technology Assessment, adapted from Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP), *Can There Be a Common Framework for Managing Radioactive and Nonradioactive Substances 10 Protect the Marine Environment?* GESAMP Reports and Studies No. 45, Addendum 1 (London, England: 1992).

FIGURE 2-7: Framework for Evaluating Mitigation Options to Remediate Radioactive Dump Sites at Sea



SOURCE: Office of Technology Assessment, adapted from International Atomic Energy Agency (IAEA), "Report of Working Party 3," materials given to members of the International Arctic Seas Assessment Project's Working Group on Remediation Measures in preparation for the initial meeting, Vienna, Austria, January 23-27, 1995

ing Party 3 is to examine possible remedial actions related "to the dumped wastes and to advise on whether they are necessary and justified" (29).

Steps 4 and 5 are accomplished by collecting necessary information on the condition of the dump sites and status of the dumped material. This information is used in step 6 as decisionmakers select an appropriate mitigation option. Figure 2-7, which is adapted from a figure developed by the IAEA (29) for its Remedial Measures Working Group, illustrates a framework for evaluating options that would likely be available to decisionmakers.

Mitigation Options

It is very possible that decisionmakers would choose different options, depending on the conditions present at a particular dump site. For example, one may choose an option (e.g., no intervention) for sites containing low levels of contamination and another option (e. g., a technical measure to contain waste in situ) for those containing higher-activity waste in structurally unsound containers. No attempt is made here to identify or recommend the most appropriate option for particular conditions at a dump site. Instead, this section describes both the series of steps or framework that a decisionmaker would use in selecting mitigation options and the factors that must be considered in assessing each option.

The first choice that a decisionmaker must face is whether or not to intervene. In making this initial decision, it is critical to understand the consequences of taking no action—leaving the dumped material on the sea bottom. IAEA refers to this as the "base case" against which intervention measures can be judged, and efforts to complete this assessment are being actively pursued by the other IASAP working groups (29). Even the no-action option has two possible outcomes—an expected situation, in which forecasted consequences occur and no accidental situations arise, and exceptional situations in which a low-probability event occurs. Such low-probability events can be accidents (e.g., icebergs colliding with dumped material or fishing vessels inadvertently dropping objects on containers and rupturing them) or non-accidental rare events (e.g., people deliberately disturbing dumped material or seismic events rupturing containers). Calculating this base case is a critical first step in defining outcomes against which all other options can be compared.

In analyzing intervention options, there are two broad choices—a passive approach and an active approach. Under the passive approach, options are available that do not cure the root cause (i.e., take some action at the dump site) but that address some exposure pathway emanating from the root cause. Examples of such actions include restricting the local population from using or consuming resources from the region in which the material was dumped. Another action may involve relocating the local population away from a region of radiological concern.

Under the active approach, several remediation options are available, all of which deal with managing the dumped material in some way. These can be divided into three generic options: 1) in situ technical modification of the material (e.g., encapsulating the material, capping over the material, excavating underneath the material and burying it); 2) relocation of the material from all sea sites to a common location; and 3) retrieval of the material and its transportation to land for storage, treatment, and/or disposal.

It should be noted that any of these options would require very specialized equipment to maneuver or deploy heavy loads and otherwise manipulate materials underwater in potentially rough weather. Such equipment exists or could be developed by modifying existing vessels (20), but the procedures would be costly.

In situ technical modification of the material

1. *Encapsulate the material*: Dumped radioactive material can be encapsulated by several methods. It is possible to coat the material or cover it with some type of cement. Various kinds of cement are available. Cement density, setting time, and strength can be altered by adjusting its composition. The dumped material can also be surrounded by a structure of steel that can be filled with cement or some other material. The Kurchatov Institute has studied the durability of another encapsulation material, furfural, in seawater. Furfural is a compound derived from oats that polymerizes to form a solid. It was used by Russians to fill some of their sunken reactor compartments and act as a barrier to radionuclide release. Some Russians have attributed a 500-year lifetime to furfural (25), but this requires confirmation (46).

   In the case of building a structure around the dumped material (which could include a submarine) prior to encapsulating it, a cofferdam could be built, constructed of blocks bolted or welded together above the center well. These blocks may be made from prefabricated pieces of steel to ease storage and handling issues aboard the workship. The internal volume of the blocks could be either open to the sea or filled with heavy drilling mud if greater weight were required. Once the cofferdam is in place, the seawater from within could be displaced by mud or cement pumped from the drill string. Cement may be preferable because it would set in place and be more permanent than mud (20).

2. *Cap the material:* The dumped material can be covered with sedimentary material or capped. This is a common practice used in managing contaminated areas of dumped dredge spoils. It is important to monitor and maintain the integrity of the cap.
3. *Excavate underneath the material and bury it:* The seabed underneath the dumped material can be excavated, allowing the material to fall into the depression created. The material can then be covered with sediment, leaving no hummocky features on the seabed. This is an option under consideration by the Sanctuary Manager of the Gulf of the Farallons off the California coast for remediating radioactive waste barrels dumped to depths of 1,000 fathoms (79). This option is of particular interest to the Farallon Islands because of the great depths of the dump site; the barrels' lack of structural integrity, which makes recovery difficult; and the artificial reef that the barrels have produced, which attracts fish and other organisms to the site as a habitat. If the material is buried underneath the seabed, this latter problem is addressed.

Relocation of the material from all sea sites to a common location

Two types of sites are being considered in the relocation option (46). First, the material could be moved inside a small fjord that has a shallow inlet to the open sea. The inlet could be dammed, cutting off circulation to the open sea. As with any of the options, there are significant risks and costs associated with this option that would have to be weighed against possible benefits. Risks, not only to human health but also to the environment, are associated with cutting off a water body from adjacent open waters. The factors of greatest relevance that must be considered are listed in figure 2-8 and table 2-8.

A second possible location may be the region of underwater caves along the Novaya Zemlya coast. The material from all existing dump sites could be collected and placed in the caves. The caves could be sealed off to prevent any water flow. The same calculation of risks and costs versus benefits would have to be conducted.

Retrieval of the material and transportation to land for storage, treatment, and/or disposal

The material could be recovered and transported to a shore-based facility for storage, treatment, and temporary or ultimate disposal. The first step in treatment could include sorting the material to segregate it into different categories or sizes appropriate for containment or disposal.

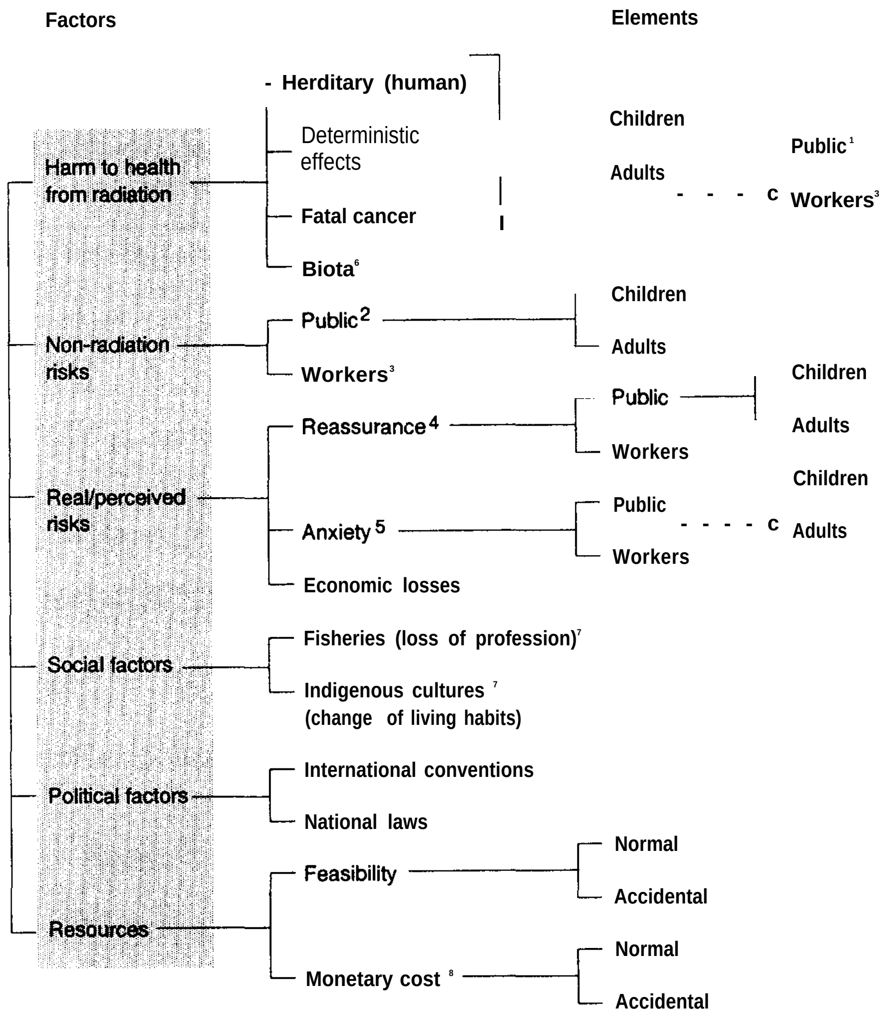
The IAEA Remedial Measures Working Group meeting in late January 1995 reviewed several underwater retrieval technologies, including videos of actual operations in retrieving hazardous materials. Several types of platforms are being used to service or retrieve underwater objects. Of particular concern to most experts is anticipating how these technologies may perform or operate under sea ice conditions (6). Until the actual conditions of the dumped wastes and their environments are better understood, however, the specific retrieval needs—if any—will not be clear.

Factors to Consider in Choosing the Most Appropriate Mitigation Option

Before any intervention measure is initiated, it is important to know whether the measure is justified (i.e., will do more good than harm) and whether the approach selected maximizes protection of human health and the environment. Several factors need to be considered at each juncture of the decision framework (figure 2-7) for evaluating mitigation options. Figure 2-8 lists factors recommended by the IAEA for consideration and to the right of each factor, the various elements associated with it. More detailed explanations of these elements can be found in table 2-8 which describes the specifics that must be considered and why they are important.

All of the elements and their associated comments must be considered and calculated to determine the impact that a particular factor can have in influencing the choice among all applicable mitigation options. Once these factors have

FIGURE 2-8: Factors to Consider in Selecting an Appropriate Mitigation Option



NOTE: Superscript numbers correspond to the elements listed in Table 2-6.

SOURCE: Office of Technology Assessment, adapted from International Atomic Energy Agency (IAEA), "Report of Working Party 3," materials given to members of the International Arctic Seas Assessment Project's Working Group on Remediation Measures in preparation for the initial meeting, Vienna, Austria, January 23-27, 1995

TABLE 2-8: Elements to Consider in Assessing Intervention Measures

Element	Comment
1. The avoidable individual and collective doses from exposure to radiation and risks of potential exposure situations for members of the public	Dose reductions and risk reductions from potential doses that would be achieved through intervention are estimated here. The assessments must consider critical group doses and population doses.
2. Individual and collective physical (non-radiological) risks to the public caused by the intervention measure	
3. Individual and collective risks to workers in carrying out the intervention measure	These risks can be both radiological and nonradiological, and can involve both normal risks and those due to accidents.
4. Reassurance of the public and the workers provided by implementation of the intervention measutre	Removal of stress caused by situations of real or perceived hazard.
5. Anxiety caused by implementation of the intervention measure	Note that the intervention measure may transfer anxiety from one population group to another (e.g., if the waste is moved from the sea to land).
6. Impact of intervention measures on the environment, live, and other natural resources	
7. Individual and social disruption caused by implementation of the intervention measure	Note that individual and social disruption may also occur if no intervention takes place. This could happen if living habits of the population are changed or fishing grounds must be moved.
8. Monetary cost of the intervention measure	

SOURCE: Office of Technology Assessment, adapted from International Atomic Energy Agency, "Report of Working Party 3," materials given to members of the International Arctic Seas Assessment Project's Working Group on Remediation Measures in preparation for its initial meeting, Vienna, Austria, January 23–27, 1995.

been calculated or assessed, decisionmakers can work their way through the decision framework described in figure 2-7 to decide which option or set of options is appropriate for addressing the contamination at a particular dump site. Decisions on these sites not only must be considered in terms of the costs and benefits of different interventions at a particular site, but must be integrated into a larger plan for the prevention or mitigation of nuclear waste problems in the wider region. In other words, prevention of future dumping or of releases of nuclear wastes must also be considered an option competing with remediation for limited resources.

As mentioned, there are areas in which data are either lacking or uncertain. Consequently, it is difficult to calculate factors and their elements precisely, a difficulty that affects risk assessment and inhibits accurate decisionmaking. This problem is the primary driver for devising and maintaining an accurate system to monitor the dump sites.

CONCLUSIONS

Progress has been made in assessing the extent of current contamination in the Arctic and North Pacific, and available information suggests that the anthropogenic radionuclide contamination measurable in the Arctic comes primarily from nuclear weapons testing, from European nuclear waste reprocessing discharges, and from the Chernobyl accident. Nuclear wastes dumped by the former Soviet Union, listed in the Yablokov report, seem to have led to only very local contamination near the dump sites so far, but a thorough inspection has not yet been done at each site.

Questions about potential future contamination remain, and further information is required to address them. Data about source terms, containment, and transport factors are needed for ongoing modeling efforts and for a thorough risk assessment. Inspections of the dump sites are necessary complements to expert assessments of the size of the source terms. A system of monitoring can provide some of the needed information as well as early warning of releases.

Decisions about remediation will require consideration of many different factors in addition to the potential impacts from the dumped wastes if no remediation action is taken (ongoing risk assessment efforts through ONR and IASAP). Note that there are currently no internationally agreed upon values for what constitutes too much radiation at an ocean dump site. Information about the conditions around the sites and the current disposition of the wastes will be critical in considering the feasibility and cost of remediation or mitigation options. The management framework developed by the IAEA (figure 2-7) can be used to organize these and other factors (social, political) that must be weighed in decisionmaking. Such factors must ultimately include other potential sources of nuclear waste contamination of the environment, such as land-based sources of high-level wastes awaiting disposal or disposition elsewhere (see chapter 4).

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Environmental and Health Effects of Nuclear Waste Dumping in the Arctic 3

At the heart of the tremendous interest in the nuclear waste dumping that was carried out by the former Soviet Union in the Arctic and North Pacific are concerns over the potential human health effects or ecological impacts. People have wondered how seriously the dumped wastes might contaminate the environment, and whether they pose current or future hazards to human health or ecosystems.

Understanding both current and future risks to human health requires information about the nature and amount of radionuclides released into the environment, and information about their transport through the environment and through food chains to reach human beings. Understanding risks to ecosystems requires additional information about the effects of radiation on the variety of different organisms that make up the ecosystems.

Important questions remain at each step described above. Since the release of the Yablokov report describing dumping in the Arctic, more has been learned about some of the wastes, but their condition and likely radionuclide release rates remain largely unknown. As described in chapter 2, current levels of radionuclides in the seawater and sediment in Arctic seas do not suggest that significant releases have occurred. Even though current risks do not appear to have increased as a result of the dumping, release rates and pathways to people remain to be evaluated to understand the magnitude of future risks.

Models used to approximate the behavior of agents in the environment require a tremendous amount of site-specific information. Much of the specific information required is not yet known for the Arctic environment or for particular dump sites, although it is being gathered. Several different efforts are underway to model the environmental transport of radionuclides dumped in the Arctic as well as those released at sites in Russia along rivers that drain into the Arctic.

The most likely route of human exposure to radionuclides in the seas is through the food chain. Thus, in addition to information about radionuclide movement through the physical environment, data specific to the Arctic regions must be compiled about biological pathways to human beings. The marine food web is complex, and most available data were collected in temperate, rather than Arctic, settings. Therefore, information is required about the way in which radionuclides are transferred—and sometimes concentrated—through the food chain under the special local and regional conditions existing there.

People of the world are not equally at risk from radionuclides dumped in Arctic seas or in the Russian Far East. Current and future investigations have to focus on gathering relevant information about the dietary habits and other characteristics of the populations who are most likely to be exposed, such as Native northern populations and others who rely on Arctic marine resources. This information will be critical for a thorough risk assessment to estimate the most likely effects on human health.

If the released radionuclides come in contact with people in amounts sufficient to cause health effects, these effects are most likely to be cancers. Radiation is a known cause of cancer and other health effects at high doses, but at the low doses that might occur from environmental contamination, the effects are difficult to study and therefore less certain. For the protection of public health, international experts have developed recommended dose limits for the general public from human practices. These can be used to consider potential radiation exposures and the degree of hazard they might pose.

Radiation effects on Arctic ecosystems are still not well known. Sensitivity to radiation varies among species, but in general, plant and animal populations do not appear to be more sensitive than humans to the effects of radionuclides in the environment (26,28). Relevant data from Arctic environments are extremely limited.

No comprehensive risk assessment of the impacts likely from the radioactive waste dumping has yet taken place. Ideally, the process of carrying out a thorough risk assessment would entail evaluating the available information to address a specific question about risk. What is the likelihood of a certain specific population experiencing a health effect such as cancer? A systematic attempt to address such questions would help make clear the data gaps that remain. Until such a careful analysis is carried out, it will remain difficult to integrate the increasingly available information to arrive at a clear answer about future risks.

Several rough approximations of risk from the dumped radioactive wastes have been made; these suggest that even worst-case scenarios for sudden release of the wastes do not pose a severe global hazard. However, they are made in the absence of specific information that could elucidate which populations are most at risk and what the risks might be. A more thorough assessment is required to answer these questions.

As more information is gathered and the risk assessment is carried out, it is critical that the public be involved in the process. Genuine efforts must be made to ensure that the potentially affected communities participate in decision making, provide input, and have access to the information collected.

After a brief review of the health effects of radiation, this chapter examines current understanding of the health and ecological effects of the radioactive contamination that has occurred from the dumping of nuclear waste in the Arctic and North Pacific (or that might result from future contamination events). Some of the major gaps in information and understanding are also identified.

HUMAN HEALTH EFFECTS FROM RADIATION

Radiation and Radioactivity

Radiation is the transport of energy through space. The energy can be in the form of particles or electromagnetic waves. When radiation transfers enough energy to displace electrons from atoms and break the bonds that hold molecules together, it is called ionizing radiation. Ionizing radiation may be released when unstable atoms called radionuclides decay to more stable forms or may be produced in man-made devices such as x-ray tubes. Because biological systems are highly structured and specific at the molecular level, the changes caused by ionizing radiation are usually damaging to the function of the cell, tissue, or organ involved.

Ionizing radiation is frequently categorized into particles and electromagnetic waves. Particulate radiation includes alpha particles, beta particles, neutrons, and protons and ionizes matter by direct atomic collisions. Both alpha and beta particles have mass and can travel only short distances in air or human tissue because they rapidly transfer their energy through ionizing collisions. Both x-rays and gamma rays are electromagnetic waves or photons; they are referred to as penetrating radiation because they travel long distances and can penetrate dense material. Penetrating radiation ionizes matter as it passes through tissue and interacts with atoms, imparting energy.

Radioactivity is the property of certain unstable atoms (radionuclides) to disintegrate spontaneously, releasing radiation and forming a different "daughter" nuclide. Radionuclides share the chemical characteristics of their stable forms in the periodic table, except that they give off energy (radiation) as they decay to more stable states. For example, carbon-14 is an atom that is produced both in the atmosphere by the interaction of cosmic rays with matter and in nuclear reactors. It behaves like carbon-12 in almost every way except that it is unstable. When it decays, it emits ionizing radiation, resulting in stable nitrogen-14. Daughter nuclides can also be unstable, proceeding to undergo radioactive decay themselves. Strontium-90, a man-made radionuclide, decays to yttrium-90 with the emission of radiation. Yttrium-90 in turn decays to zirconium-90 as more radiation is released (6).

Radiation Health Effects

The release of radioactive contamination into the environment is of concern because of the potential harm to people and ecosystems from radionuclides. Radionuclides are carcinogens and, at high doses, can also cause rapid sickness and death.

The health effects of exposure to radiation depend on many factors, including the type of radiation, the amount of energy it delivers, the length of time over which exposure occurs, the organs or tissues the radiation interacts with, and characteristics of the exposed person (host factors such as age). Most credible scenarios for radiation doses to people from environmental contamination are based on internal exposure rather than external—that is, radionuclides that are inhaled or ingested rather than those that are outside a person. Radionuclides in the body are referred to as internal emitters, because they continue to impart energy to the surrounding tissue from within and, thus, can continue to harm or alter cells for extended periods.

Mechanism of Action

The hazards posed by radiation depend on its interaction with living tissue. At the molecular level, the electrons set in motion by ionizing radiation can directly impact cellular macromolecules such as DNA (deoxyribonucleic acid). Radiation can also act indirectly by ionizing water molecules to create reactive molecules (free radicals) that can in turn attack DNA or other cellular components as oxidizing agents. Both direct and indirect mechanisms cause damage to the cell, particularly as a result of damage to DNA.

The mechanism of damage to DNA and other important cellular macromolecules is not unique to radiation. Normal cellular processes, as well as many other agents, cause similar oxidative damage. As a result, natural processes exist that can rapidly repair DNA damage. Serious effects can result, however, when the damage is too great for such repair processes or when a lesion is not repaired.

When ionizing radiation passes through an organism, several different results are possible. If changes or damages wrought by the ionization are not fully repaired, the cell can be killed or prevented from reproducing. Alternatively, the cell can be modified while still being able to reproduce. These situations describe two categories of effects from radiation—"deterministic" and "stochastic."

Deterministic Effects

Deterministic end points are almost all due to high doses that overwhelm cellular repair processes and cause cell death. Damage that kills one or a few cells may not even be noticeable, but beyond a certain threshold, the loss of cells will be reflected in loss of tissue function, possible organ impairment, and death. Below the threshold the probability of such harm is zero, but above some dose level at which tissue function is lost, the severity of the harm will increase with dose (28). Thus, at high doses of radiation, the threshold for damage in several tissues is exceeded, and severe biological effects are predictably observed.

When humans are exposed to relatively high doses of radiation (greater than 50 rads[1]; see the discussion of units used to describe radioactivity and radiation dose in box 3-1) to the whole body, deterministic effects of radiation will occur within hours, days, or weeks. These effects are called acute radiation syndrome and include nausea, vomiting, fatigue, and a lowered white blood cell count. The symptoms and their severity depend on the dose of radiation received. Death can result from infection, dehydration, or low white blood cell count, and is increasingly likely at doses greater than 100 rads. An estimate of 300 rads has been made for the median lethal dose to humans within 60 days (35).

BOX 3–1: Units Used to Describe Radioactivity and Radiation Doses

An array of different terms and units are used to convey radiation levels and the doses of radiation to which people are exposed. In 1980 the International Commission on Radiation Units and Measurements adopted the International System of Units (known as SI units) for radiation quantities and units to be used internationally (69). Adoption of the SI nomenclature in the radiation field in the United States has been slow, with the result that both the previous conventional system and the SI system are currently in use. Conventional units are used throughout this report, with the SI conversion factors provided in this box and equivalencies provided as necessary.

Radioactivity is the phenomenon of radioactive disintegration in which a nuclide is transformed into a different nuclide by absorbing or emitting a particle. The activity of a radioactive material is the number of nuclear disintegrations per unit time. The conventional unit used to express activity is the curie (Ci), which is 3.7×10^{10} nuclear transformations per second and approximates the activity of 1 gram of radium-226. The SI unit for activity is the becquerel (Bq), where each becquerel is one nuclear transformation per second (thus, 1 curie = 3.7×10^{10} Bq).

The half-life of a radioactive substance is the time required for it to lose 50 percent of its activity by decay. Each radionuclide has a unique half-life. Activity and half-life are related, so that radionuclides with higher specific activity (activity per gram) have shorter half-lives, and vice versa.

Levels of contamination are frequently reported in terms of activity (curies or becquerels) per unit volume or area. For example, measurements of the activity in the Kara Sea by the Joint Russian-Norwegian Commission in 1992 found levels of cesium-137 at 3–20 Bq/m^3 in sea water (8×10^{-11} –5.4×10^{-10} Ci/m^3) (30). Such measurements convey the amount of a radioactive substance present in a certain medium. Alone, however, they provide no information about risks to human health. To understand possible risks to health requires a host of additional information that can be used to calculate and interpret a radiation dose.

(continued)

[1] 1 rad = 0.01 joule/kg = 0.01 gray.

BOX 3–1: Units Used to Describe Radioactivity and Radiation Doses (Cont'd.)

For any potential harm from radioactivity, radiation must interact with the cells and tissues of the human body and deliver a dose. Several different units are used to describe radiation dose. Absorbed dose is the energy absorbed per unit mass, given in units called rad. SI units for absorbed dose are gray (Gy), and 1 Gy is equivalent to 100 rads.[a] The biological effect of radiation is related to the absorbed dose, but it also depends upon several other factors, such as the type and energy of the radiation causing the dose. A "radiation weighting factor" is applied to the absorbed dose to account for differences in the relative biological effectiveness observed experimentally, for example, between low-energy x-rays and alpha particles, which deposit much greater amounts of energy over the distance they travel. Adjusted with the weighting factor, the measurement of dose is called the equivalent dose, and is measured in units called rem. The SI unit for equivalent dose is the sievert (Sv); 1 Sv = 100 rem. Since the probability of stochastic effects also depends upon the organ or tissue irradiated, still other weighting factors are used to account for differences in the effect of radiation on different tissues in the body. This dose, now weighted to account both for tissue differences and differences in the energy and type of radiation, is called the effective dose (formerly effective dose equivalent) (28).

Some additional dosimetric terms are also used in this report. The committed effective dose takes into account the continued doses to the body when radionuclides are taken into the body and become internal emitters. The collective effective dose relates to groups of people, rather than individuals, taking account of the number of people exposed by multiplying the average dose to the exposed group by the number of people in the group. The unit of this quantity is the person-rem, which is an effort to represent the total consequences of the exposure to a population. Sometimes the collective effective dose is accumulated over a long time, spanning successive generations, depending upon the quantity and half-life of the radionuclides (28).

[a]One rad = 0.01 joule/kg = 0.01 Gy.

SOURCE: Office of Technology Assessment, 1995.

Stochastic Effects

At doses lower than those that produce acute symptoms, the effects of radiation on human health are less predictable. If a damaged DNA site is misrepaired or not repaired, and the modified cell is still able to reproduce, its propagation may ultimately result in cancer. Development of a cancer is understood to be a multistep process in which modification of a cell's DNA is a critical step that must be followed by other steps to eventually lead to uncontrolled growth. Thus, not every cell with damaged DNA will go on to become cancerous. However, the more cells that contain damaged DNA, or the more damage sites that occur in the DNA of a single cell, the more likely it is that one of them will ultimately develop into a cancer. Once sufficient changes have taken place at the molecular level, cancer develops; cancer from low or moderate doses is no different from one induced by high doses. In other words, the likelihood, but not the severity, of a cancer is roughly proportional to dose and probably has no threshold (28). This type of effect is called stochastic, meaning "of a random or statistical nature."

Numerous studies in humans and animals have established that radiation can cause cancer and that the incidence of cancer increases with increasing radiation dose. What is less certain is the relationship between the size of the dose and the likelihood of developing cancer. At low dose levels such as might be encountered from contamination in the environment, it is almost impossible to collect quantitative data on human risk. Therefore, it has been necessary to extrapolate from data collected on humans exposed to much higher doses and dose rates, such as atomic bomb survivors or medically irradiated people. The need to estimate effects based on data from very different conditions necessarily leads to uncertainties in describing risks.

Other factors add to the difficulty of estimating the risks of low-level radiation. The long period (called a latency period) between a main exposure and the appearance of a tumor makes studies to understand the relationship between dose and cancer likelihood challenging. Furthermore, since cancer causes nearly 20 percent of all deaths in the United States, and cancers resulting from radiation do not have features that distinguish them from those due to other causes, the subtle increases in cancer rates that might be attributable to various environmental causes are difficult to detect (45).

Despite these challenges, efforts have been made to estimate the cancer impacts from low levels of radiation. These estimates have been adjusted repeatedly over the years, particularly as more information has been gleaned from studies of the atomic bomb survivors as they age and experience their greatest risks from cancer. The estimates differ for different cancer sites and for different ages at time of exposure, but overall, the National Research Council's Committee on the Biological Effects of Ionizing Radiations (BEIR) most recently estimated that a single equivalent dose of 10 rem (see box 3-1) to the whole body carries a lifetime excess risk of death from cancer of 0.8 percent, or 8 out of 1,000. If the same dose is accumulated over weeks or months rather than all at once, the risk is estimated to be reduced by as much as a factor of two or more[2] (45). It is important to reiterate that these estimates are based on studies of effects at relatively high doses and high dose rates; "studies of groups chronically exposed to low-level radiation . . . have not shown consistent or conclusive evidence of an associated increase in the risk of cancer" (45). As mentioned above, however, a variety of factors makes it extremely difficult to observe such effects in epidemiological studies.

Genetic effects as well as cancer fall into the category of stochastic effects of radiation. Radiation damages the genetic material in reproductive cells, leading to mutations that can be passed to successive generations. Like the cancer effects of low-dose radiation, the genetic effects of radiation are difficult to study. Because the effects are manifest in the offspring rather than the person exposed to radiation, there can be a long delay in observing them. Massive epidemiological studies with long-term follow-up would be required to gather enough data for statistical analysis. Furthermore, the same mutations that radiation causes can occur spontaneously; therefore, estimating the contribution from radiation is very difficult (45). Studies on the children of atomic bomb survivors failed to detect elevations in rates for genetic abnormalities, but because of the size of the study population, such effects are not ruled out. It is also possible that such effects could manifest themselves in future generations as recessive mutations which are hidden until carried by both parents (8). Based on studies in laboratory animals and studies of the offspring of atomic bomb survivors, the percentage of genetic diseases attributable to natural background radiation is currently estimated to be low; however, these estimates are based on many uncertainties (67).

The embryo is highly sensitive to radiation. Various malformations and developmental disturbances result from irradiation of the embryo at critical stages in the development of each organ. Most notable in studies of atomic bomb survivors has been a dose-dependent increase in intelligence impairment and mental retardation in people irradiated by fairly high doses between the eighth and 15th weeks after conception. To a lesser extent, mental retardation is also seen in those exposed between the 16th and 25th weeks (68). Several epidemiological studies also sug-

[2] Both of these findings are made with respect to low linear energy transfer radiation, such as x-rays and gamma rays.

gest an increased risk for leukemia from irradiation of the fetus in the first trimester of pregnancy (45).

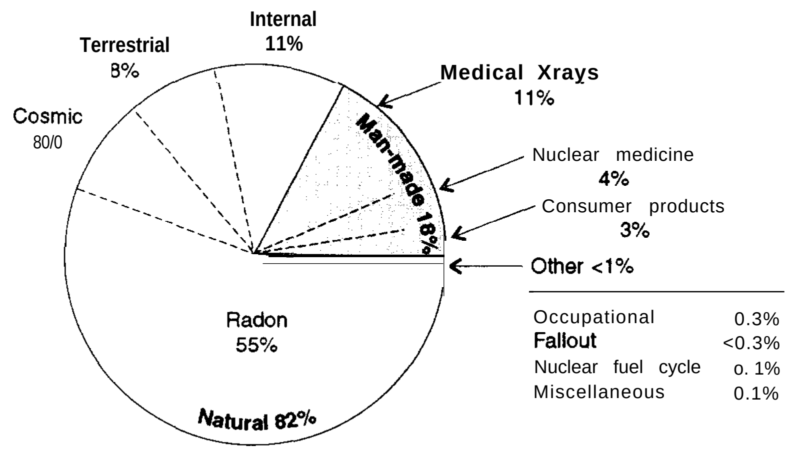
SOURCES OF IONIZING RADIATION

Ionizing radiation is a natural part of our environment, but humans have developed additional sources of potential radiation exposure through the use of nuclear medicine, weapons, and power. In the United States, natural sources of radiation provide most of the average annual effective dose to the population, which is estimated at approximately 360 mrem each year (3.6 millisieverts (mSv); see figure 3-1) (44). These natural sources include radioactive elements present in the earth, cosmic rays given off by the sun and other celestial bodies, and naturally occurring radionuclides in the human body. To some degree, exposure to these natural sources is inevitable, although exposure to some can vary depending on location and other factors. For example, exposure to natural radioactive elements such as the potassium-40 in our bodies from air, food, and water is inevitable (54). On the other hand, people living at higher elevations have greater exposure to cosmic radiation than those living closer to sea level. People receive enhanced radiation exposure during air travel at a rate of about 0.5 rem per hour (44). More background radiation is also found in areas with higher levels of radium, uranium, and potassium in the earth's crust. Location, housing materials, and housing ventilation can influence the exposure to radon and its decay products, which on average make up the largest contribution to average annual effective dose.

Man-made sources constitute the remaining 18 percent of the average effective dose to the U.S. population. Use of x-rays for diagnosis and nuclear medicine such as radiotherapy for cancer are estimated to contribute most to exposures of this type. Occupational exposures, fallout from nuclear testing, and exposures from the nuclear fuel cycle contribute small fractions to the average.

The pie chart of figure 3-1 illustrates the substantial contribution of background radiation to a typical person's total exposure to radiation in the United States (300 mrem or about 82 percent). However, our concern in this study is not with doses averaged over entire populations, but with situations in which subpopulations or individuals, in the United States or elsewhere, might experience increased exposures because of man-made radioactivity released into the environment.

FIGURE 3-1: Contributions of Various Radiation Sources to the Total Average Effective Dose in the U.S. Population



SOURCE: Used with permission from the National Council on Radiation Protection and Measurements, *Ionizing Radiation Exposure of the* Population *of the United States,* NCRP Report No. 93 (Bethesda, MD: 1987).

Radiation Protection Standards and Guidelines

Over the years, guidelines for the protection of populations from the health effects of radiation have been developed and revised as understanding of these effects has evolved. The current recommended dose limits of the International Commission on Radiological Protection (ICRP) are presented in table 3-1. Standards adopted by the U.S. Nuclear Regulatory Commission (NRC) in 1991 and effective in 1994 for limits on radiation exposures from facilities licensed by the NRC are nearly identical (51). The ICRP dose limits are intended as a guide in considering human practices that are carried out as a matter of choice and are not intended to apply to doses that might occur from exposure to natural or artificial radiation already in the environment (28). Nonetheless, the recommended annual dose limits of 2 rem for workers and 0.1 rem (100 mrem) for the general public provide some reference point for considering the scale of other radiation exposures. They are based on an estimate of the probability of fatal cancer after low-dose, low-dose-rate, low linear energy transfer (LET) radiation to the total population of 5×10^{-4} per rem (28). The annual dose limit for the public of 0.1 rem results in a risk of cancer mortality of about 10^{-5} (1 in 10,000) per year (9).

TABLE 3-1: ICRP Recommended Dose Limits

	Dose limit (rem)	
Classification	Occupational	Public
Effective dose	2 per year (averaged over 5 years)	0.1 per year (averaged over any consecutive 5 years)
	5 (in any one year)	
Annual equivalent dose in:		
Lens of the eye	15	1.5
Skin	50	5
Hands and feet	50	

SOURCE: International Commission on Radiological Protection, *1990 Recommendations of the ICRP*, ICRP Publication 60 (New York, NY: Pergamon Press, 1991).

POTENTIAL HEALTH EFFECTS FROM NUCLEAR CONTAMINATION IN THE ARCTIC AND NORTH PACIFIC

For contamination in the environment to result in human health effects, several conditions must be met. The contaminants or their metabolites must be hazardous to biological systems. There must be contact of these contaminants with people. Last, exposure to the contaminants must occur at concentrations and for periods of time sufficient to produce biological effects. Understanding the potential hazard therefore requires understanding the agent, the exposure, and the subject (32).

In trying to understand the potential health impacts of radioactive contamination from nuclear waste dumped in rivers and oceans, it is clear that the dumped radioactive wastes are potentially hazardous to biological systems, posing, as described above, risks of cancer and genetic and teratogenic (causing malformations or developmental disturbances of the fetus) effects, as well as more acute immediate illness at high doses. Many unknowns exist, however, both in the potential contact of these wastes with people and in the exposure concentrations and times that can be anticipated. The following sections examine what has been learned and what remains to be understood about the dumped wastes, the possible pathways of human exposure, and the populations that may be exposed. Efforts that have been carried out to estimate human health risks despite the large data gaps are reviewed, along with information on possible ecological effects.

Assessing Human Exposure

Several means are used to measure or estimate human exposure to hazardous agents. Biological markers can be used in some instances to measure agents in the biological fluids or tissues of exposed individuals. This approach provides the best measure of an individual's actual exposure, but suffers the drawback that some exposure to the substance or agent has already occurred (whole body counts, counts in teeth). A frequent approach to estimating human exposure is environmental monitoring, the practice of measuring levels of an agent in the air, water, and food to which people are exposed. That information is then used to estimate how much of the agent might find its way to or into people based on estimates of breathing rates, skin areas, or water and food ingestion rates. In the absence of, or as a supplement to, information from biological markers or environmental monitoring, knowledge of the source term is also important. The source term refers to the quantities and types of released radionuclides and their physical and chemical conditions (64). This information can provide an upper bound on the amount of the agent released into the environment and perhaps the rate of its release. Estimates can then be made about how the agent might move through the environment and potentially lead to human exposure.

The further a measurement is taken from the potential human target, the more estimates and assumptions are required to anticipate how much human exposure might actually occur. In considering the health and environmental impacts of radioactive waste dumped in the Arctic, two questions must be addressed. Are any significant impacts currently taking place or imminent, and are any serious future impacts likely? Information about current levels of radioactive contamination in the environment can be used to consider questions of current human exposure and effects, and information about the source term can be applied toward considering potential future effects.

Current Levels of Radioactive Contamination in the Environment

As discussed in chapter 2, measurements of radioactivity in seawater and sediments in the Arctic and Russian Far East that have been collected and analyzed to date do not suggest elevated levels indicative of large releases from the dumped wastes. It is not clear, however, that the waters in question have yet been sampled sufficiently and adequately to provide complete confidence in these results. Once all data gathered to date are compiled and compared, it should be clear where extensive sampling has occurred and where more information from additional sampling is needed.

According to the sampling that has taken place and been reported thus far, particularly in the course of three expeditions by the Joint Russian-Norwegian Expert Group for Investigation of Radioactive Contamination in the Northern Areas, the level of cesium-137 (Cs-137) measured in the Kara Sea is between 3 and 20 bequerels per cubic meter (Bq) (8×10^{-11}–5.4×10^{-10} curies/m^3), compatible with levels seen over the years from nuclear test fallout and European reprocessing (30). To consider these values in perspective, intervention levels derived by the International Atomic Energy Agency (IAEA) to control doses to the public in the event of a radiological emergency are 700,000 Bq/m^3 (2×10^{-5} curies/m^3) of Cs-137 in *drinking water*, thousands of times higher than the levels measured in seawater (60). Many samples from cruises carried out over the summer of 1994 are still being analyzed and should be helpful in covering the seas of interest more thoroughly.

Russian Far East

Expeditions in 1993 to sample the waters and sediments of the Far Eastern seas found Cs-137 levels in the surface waters of about 3 Bq/m^3 (8×10^{-11} curies/m^3) and lower levels in the deeper waters (22). These measurements are consistent with expected atmospheric input from fallout and do not suggest Russian waste dumping as a significant source of contamination in the region at this time. Data from a joint expedition of Russia, Korea, the IAEA, and Japan in 1994 are not yet available.

Source Term

Although measurement of current levels of radioactivity in the environment is critical for assessing current risks to human health and the environment, an important step in trying to consider future risks posed by dumped wastes is to know what wastes were dumped, how much, where, and how rapidly they may release radionuclides into the environment. In radiological assessments this information is called the “source term,” referring to the quantity and types of released radionuclides and their physical and chemical conditions (64).

As described elsewhere, the Yablokov report gives information about both liquid and solid wastes dumped in the Barents and Kara Seas in the Russian North, and the Sea of Japan, Sea of Okhotsk, and off the Kamchatka Peninsula in the Russian Far East (13). Aside from providing the total activity at the time of dumping, the report gives little information about the liquid wastes dumped between 1960 and 1991 in the Barents and Kara Seas or those dumped in the Russian Far East since 1966. Because the radionuclide composition is unknown, current contamination levels cannot be estimated. Based on the small volumes and irregular timing of dumping, however, it is unlikely that the dumped liquid wastes were from spent nuclear fuel reprocessing. Rather, it is believed that these were wastes from reactor cooling systems and ship cleaning operations (49). In this case, radioactive contamination is most likely to originate from tritium (hydrogen-3; H-3), with possible additional contamination by activation products such as cobalt-60 (Co-60), nickel-63 (Ni-63), and iron-55 (Fe-55).

The low level and rapid dilution of liquid wastes suggests that they have contributed only minutely to the radiation present in these waters both from man-made sources such as fallout and reprocessing and from the natural radiation expected in seawater.

The solid wastes pose a considerably greater hazard. They included 16 naval reactors from former Soviet Union submarines and the icebreaker *Lenin*, which were dumped in the Kara Sea and shallow fjords of Novaya Zemlya. Six of the reactors still contained their spent fuel, and about 60 percent of the spent nuclear fuel from one of the *Lenin* reactors was disposed of in a reinforced container. The Yablokov report estimates a total radioactivity of 2,300 kCi (kilocuries) of fission products in the spent nuclear fuel and 100 kCi of Co-60 in the reactor components. Almost no other radionuclides were identified, nor was an estimate provided of current levels of radioactivity (13).

Since the release of the Yablokov report in the spring of 1993, great efforts have been made by the international community to better understand the magnitude of the risks that the dumped wastes might pose. The Source Term Working Group of the International Arctic Seas Assessment Project (IASAP, described in chapter 5) has made substantial progress in gathering information relevant to the amount and containment of the dumped radionuclides. In January 1994, the Kurchatov Institute in Russia issued a report to IASAP containing a detailed inventory of radionuclides and information on the structure of the *Lenin*’s dumped reactor section. Then in July 1994, essential details of the structure, operational history, and characteristics of the dumped spent submarine fuel were declassified by Russian authorities. Thereafter, radionuclide inventories of the water-cooled submarine reactors and lead-bismuth cooled reactors were also made available to IASAP (24). Further information on the *Lenin* reactor and the submarine reactors was presented at a November 1994 meeting of the Source Term Working Group by researchers at the Kurchatov Institute and the Institute of Physics and Power Engineering (40).

Experts participating in the Source Term Working Group of IASAP have combined this early information with that provided by the Yablokov report, and made an array of calculations and conservative assumptions based on the submarines’ fuel and working histories to reach a refined estimate of the total activity at the time of dumping of about 991 kCi (40). When decay is considered, the activity estimated to remain in the icebreaker *Lenin* reactor compartment in 1994 was about 59 kCi (41,61). The estimate of the activity remaining in the submarine reactors and spent fuel in 1994 was about 68 kCi (36), giving a total of 127 kCi for the estimated current activity of the high-level wastes described in the Yablokov report. This revised figure can provide a useful basis for estimating releases of these radionuclides into the environment and, potentially, into the food chain and ultimately their contact with humans. Several vital questions about the quantity and condition of the dumped wastes remain outstanding, however.

Some of these questions concern a substance called furfural, a compound prepared from cereal straws and brans. A resin based on furfural was used in the preparation and sealing of some of the dumped reactors, including the spent fuel from the *Lenin* reactor. Estimates quoted in the Yablokov report were that the furfural-based mixture would prevent seawater contact with the spent fuel for up to 500 years (13), but other experts have questioned this claim and few hard data exist to confirm it. Apparently three different organizations within the Russian Federation produce furfural, but their production methods are not necessarily uniform (38). Thus, the precise composition and characteristics of the furfural sealed in various reactors are not known. This information is of great interest because of the role the sealant may play in delaying release of the radionuclides and remains among the critical unanswered questions about the source term. For the purpose of modeling the release of the contaminants over time, both furfural and the concrete are being assumed to last for 100 years (39).

Several other important issues remain unknown, such as the condition of the reactors containing spent fuel, the corrosion rate of the fuel in Arctic seawater, and the thickness of the reactor compartment walls (38). All of these factors are important in estimating how rapidly or slowly radionuclides may be released into the environment and how much of their radioactivity will remain as that occurs. The nature and the condition of other dumped solid wastes are unknown.

The Source Term Working Group is attempting to address these issues, via contracts with experts at the Kurchatov Institute in Moscow and the State Scientific Center of Russia in Obninsk to help gather and analyze additional information. Some officials in the Russian Navy seem to feel that the Yablokov report revealed too much sensitive information, and they are reluctant to declassify additional information requested by IASAP. Nonetheless, the group anticipates concluding its work on the submarines and reactors in late 1995 and then shifting its focus to other wastes described in the Yablokov report (those described only in terms of “Sr-90 [Strontium-90] equivalents”). A final report is expected in early 1996 (42).

Although a considerable array of unknowns about the condition of the dumped wastes remain, there is no evidence to indicate that large releases of radionuclides have occurred. As described in chapter 2, levels of radionuclides measured in the open Barents and Kara Seas do not indicate sources beyond the contributions due to fallout from atmospheric testing and discharges from European reprocessing plants. Expeditions carried out by the Joint Russian-Norwegian Expert Group have thus far visited and sampled near several sites where nuclear waste dumping was described in the Yablokov report. In Tsivolka Bay, where the *Lenin* reactors were reported to be dumped, Co-60—which may have originated from the dumped nuclear waste—was measured in the upper sediments, but components of the *Lenin* were not located (31). Analysis of sediment samples from near the hull of a submarine containing two reactors with spent fuel in Stepovogo Bay suggests some leakage of fission products from the submarine reactors. Increased concentrations of Cs-137 (about 10 times the amounts measured in the open Kara Sea in 1992) and the presence of Co-60 in the bay also suggest leaching from dumped solid radioactive wastes other than the reactors with spent fuel (31). Concentrations of Cs-137 in surface sediments of the Novaya Zemlya Trough, also mentioned in the Yablokov report as a site for nuclear waste dumping, were similar to those in the open Kara Sea in 1992. In the Abrosimov Fjord, three of four reported submarine reactor compartments and three of four dumped barges were located, and there are elevated levels of radionuclides in the sediments near these objects (10).

From the limited information available, any leakage that may have occurred so far from dumped wastes appears, at most, to have led to only very local contamination. More extensive inspection of the dumped objects (particularly, all of the reactors with spent fuel) and sampling of the environment nearby are necessary.

Potential Pathways of Human Exposure

Since effects from radiation can come about only if radioactive contamination comes in contact with humans, understanding health risks to humans from existing or potential sources of radioactive contamination in the environment requires an understanding of the varied pathways through which radionuclides can eventually result in direct external radiation exposure or can be ingested or inhaled. This is a considerable challenge. Given the complexities of human activities and diets, myriad different pathways to humans are conceivable through inhalation, ingestion, direct contact, or proximity.

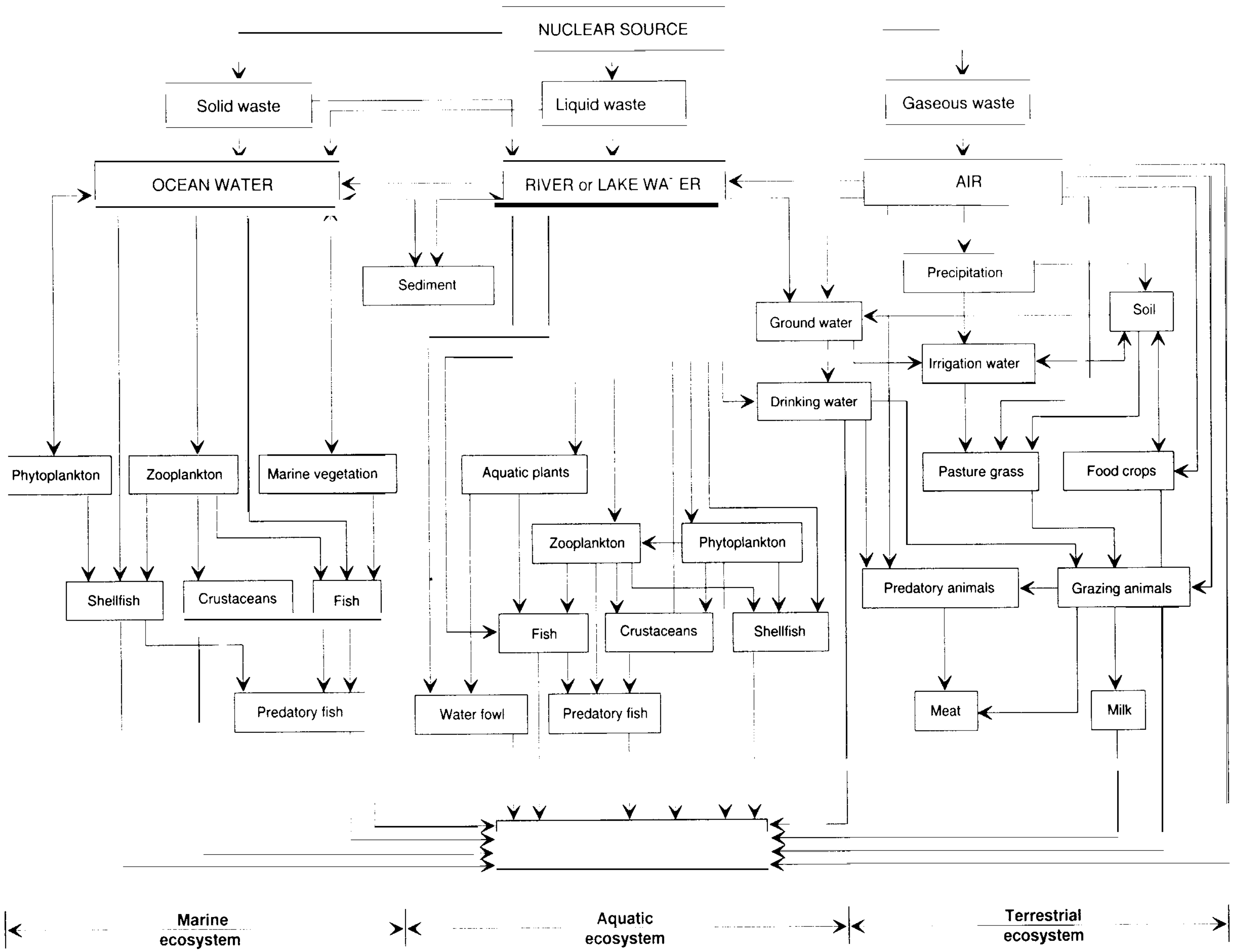
The challenge is not new, however. Pathways to human exposure from radionuclide contamination in the environment have been studied since the 1960s when concerns were raised about widespread environmental contamination from fallout due to nuclear weapons testing. Diagrams such as figure 3-2 were developed to help understand the fate and transport of radionuclides and possible routes through the environment to humans. Such conceptual models can serve as the framework for computational models that approximate the transport of radionuclides from their source to humans. Increasingly, complex dose reconstruction models have been developed and used to try to calculate doses to humans from a variety of sources; such models have become important for nuclear facilities and their regulators.

The most sophisticated computer model is only as good as the data used to construct and test it, however. Since a tremendous number of unknowns remain in this area, the development and particularly the validation of models of environmental transport are limited by these unknowns and associated uncertainties. For example, an estimate of the dose to humans through a cow's grazing in a field contaminated by rainfall through a radioactive cloud requires a good estimate of at least 14 different parameters, from the rate of rainfall to soil-to-plant uptake via root absorption to the quantity of meat and milk consumed by humans (8,9). Each of these parameters must be entered into the model, but some are not known to within an order of magnitude. Since many such parameters must be combined in the models, the uncertainties surrounding them can span orders of magnitude. Frequently, the models are used for situations in which validation prior to decisionmaking is impossible (potential accidents, etc.).

Improvements have come about as experience with models has increased. Most progress has been made in atmospheric environmental modeling, such that concentrations downwind from a continuous point source emission can now be estimated reliably (8). Much more progress is needed to refine and develop models for aquatic and terrestrial systems, however. "Atmospheric diffusion, while so complex that it is not yet fully understood, is a relatively predictable process compared to transport through geologic media, or convection, diffusion, and sorption processes encountered in the aquatic environment."[3] Such statements are made with respect to the modeling of processes in temperate zones. However, such processes are even less understood in Arctic conditions.

"Above all, it needs to be recognized that the Arctic is a very different environment than most people are familiar with. Residence times of materials, in marine and terrestrial ecosystems and in the atmosphere, are generally much longer due to the lack of moisture passing through the system. Paradigms borrowed from experiences of radioactive waste treatment at mid-latitude

[3] M. Eisenbud, Environmental Radioactivity, 3rd ed., (Orlando, FL: Academic Press, 1987)



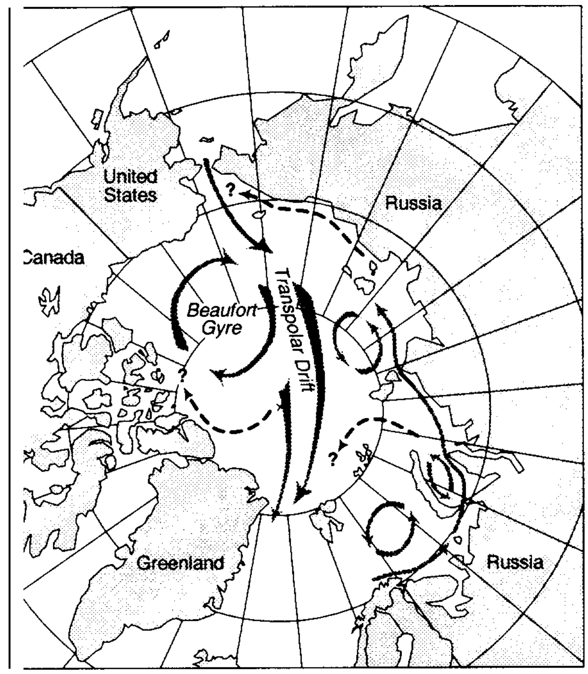
SOURCE: Office of Technology Assessment, 1995, adapted from Peterson, H.T., "Terrestrial and Aquatic Food Chain Pathways," Radiological Assessment: A Textbook on Environmental Dose Analysis, J.E. Till and H.R. Meyer, (eds.), (Oak Ridge, TN: Oak Ridge National Laboratory, 1983).

sites are inappropriate for the Arctic conditions."[4]

Given the nuclear waste dumping that has taken place so far in the oceans and at sites along rivers feeding the oceans, the marine and aquatic environments are those of greatest current interest in trying to understand potential hazards to humans and the environment. In particular, researchers are interested in several potential pathways in sea water or ice through which radionuclides might move, illustrated in figure 3-3. The likelihood of these pathways cart be examined through data collection and modeling. General models alone are unlikely to provide easy answers to questions of the effects that dumping is likely to have. A tremendous amount of detail about a body of water is necessary to begin to describe the mixing that takes place in it. Site specific information is necessary about water depth, bottom shoreline configuration, tidal factors, wind, temperature, and the depth at which the pollutant is introduced, among others. "Each stream, river, bay, lake, sea, and ocean has its own mixing characteristics that vary from place to place and from time to time."[5]

Attempting to understand and predict the dispersion of a radionuclide in a water body is further complicated by other chemical, physical, and biological processes. Do its chemical characteristics make it more likely to be found in solution or in the soils and sediments? The behavior and distribution of radionuclides in water environments depend a great deal on how likely they are to become associated with particles. Contaminants in solution cart be assimilated by plants and animals or can fix themselves to suspended solids, which then become part of the substrate that supports bottom-dwelling communities. Contaminants that adhere to sediments can remain there indefinitely or be a source of contamination later if the sediments are disrupted

FIGURE 3-3: Possible Pathways of Radionuclide Transport Via Sea Water or Ice



Legend: View of Arctic Region. Gray arrows indicate predominant sea and ice currents. Dashed black arrow. illustrate hypothetical sea water or ice transport pathways of contaminants which are currently under study.

SOURCE: Office of Technology Assessment, 1995.

through turbulence or changing chemical conditions (8). Prediction of the dispersion of pollutant species that favor the particulate phase is more difficult than for those that remain in solution. In general, radionuclides of strontium, technetium, antimony, cesium, uranium, and H-3 are relatively soluble and less likely to associate with particles than the radionuclides of lead, thorium, neptunium, plutonium, americium, and curium (54). Beyond generalities, however, radionuclide-specific, site-specific information is necessary to begin to anticipate the behavior of such contaminants.

4 Glenn E. Shaw, professor of Physics, Geophysical Institute, University of Alaska, Fairbanks, Alaska, "Transport of Radioactive Material to Alaska," Radioactive and Other Environmental Threats to *the United States and the* Arctic *Resulting from Past Soviet Activities,* hearing before the Select Committee on Intelligence, United States Senate, Aug. 15, 1992, S. Hrg. 102-1095 (Washington, D.C.: U.S. Government Printing office, 1992).

5 M. Eisenbud, Environmental Radioactivity, 3rd ed., (Orlando, FL: Academic Press, **1987)**

Modeling Environmental Transport

In the face of these challenges, some efforts are being made to use environmental transport models to better understand the potential outcomes from the dumping of nuclear wastes in the Kara Sea, as well as in major rivers emptying into the Arctic Ocean.

A large-scale modeling effort is in progress at the U.S. Naval Research Laboratories funded by the Arctic Nuclear Waste Assessment Program (ANWAP). The model covers the area from the North Pole south to about 30° N latitude, including the Far Eastern seas and the Labrador Sea. It incorporates ocean currents, wind, and ice with a resolution of 1/4°. The model has now been used to simulate inputs from the Ob and Yenisey Rivers, from solid and liquid dump sites in the Kara Sea and the Russian Far East, and from the Sellafield reprocessing plant on the Irish Sea. The simulations suggest movement of the radionuclides out of the Kara Sea along three pathways, and indicate that after 10 years of constant release from dump sites in the Kara Sea, concentrations of radioactivity in seawater near the Alaskan coast would be about 100,000-fold lower than those in the Kara Sea (58). The model continues to be refined and requires additional data from measurements in the oceans to be validated.

Another group funded through ANWAP has focused on modeling radionuclide contamination of the Kara Sea from the Ob and Yenisey River systems. Using existing data, as well as data currently being gathered and analyzed on the characteristics of the radioactive sources and of the rivers and estuaries, the modelers will try to estimate river contributions of Sr-90, Cs-137, and plutonium-239 (Pu-239) to the Kara Sea. The models will address two different scenarios—a steady continuous release of contaminants and a sudden large release of radionuclides as from dam breakage or a flood (see box 2-2 in chapter 2).

Modeling efforts are also under way under the auspices of the Transfer Mechanism and Models Working Group of the IAEA's Arctic Seas Assessment Program. Seven laboratories are involved in efforts using seven different models, and researchers are currently carrying out benchmarking studies to see how the various models compare in cases of instantaneous release and constant release.

As all of these models are developed, it is critical that, where possible, results be compared with empirical data or with alternative models to ascertain the value of these results. Sensitivity analysis—an effort to assess which inputs or components of a model have the most impact on the results—can shed light both on how the model works and, to the extent that it successfully represents the real system, on what environmental factors can benefit most from further study (49). Some uncertainty in the models is inevitable, and should be described and quantified. Uncertainty stemming from natural variability cannot be reduced, but uncertainty arising from gaps in knowledge should be used to direct research toward filling those gaps. Proprietary models are problematic because models benefit greatly from testing, peer review, and open scrutiny of their features.

Transport Through the Food Chain

In addition to trying to understand how radionuclide contaminants in the rivers and oceans will disperse over time through physical mixing and dilution, it is important to consider other factors that will play a role in human exposure to contaminants. Since the radionuclides have been dumped into water environments, exposure through inhalation is an unlikely or fairly remote possibility; exchange of radionuclides into the air can occur to some extent but should contribute very little to human exposure. Exposure through direct contact with radionuclides in the water is possible but, particularly in the icy Arctic waters that are the focus of this study, not likely to be widespread or frequent. Radionuclides may be deposited on beaches by the waters washing them, however, or through transport by windborne spray, as observed near the Sellafield plant in England (56).

The pathway most likely to lead to human contact with radioactive contaminants dumped in the oceans, however, is ingestion. Consumption of marine food that has become contaminated with radionuclides is logically the most probable path of human exposure, but is difficult to assess. Particularly in water environments, understanding the complex interrelationships within food webs and the predator-prey hierarchy leading to humans is daunting (figure 3-4). Whereas the terrestrial food chain leading to humans generally consists of two or three separate steps that can be controlled or modified as in farming, the marine or aquatic environment is less defined or regular (9). The same predator may eat several different types of prey from different "trophic levels," or steps in the food chain. Furthermore, there are species in the aquatic environment that can move considerable distances during their lives. This added complexity leads to use of the term "food web" to describe the complex consumption relationships in aquatic, marine, and estuarine settings (55).

Another factor that makes estimating radionuclide contamination from the food chain difficult is the phenomenon of bioaccumulation. Some environmental transport processes can lead to physical, chemical, or biological concentration of radionuclides to levels that are considerably higher than its initial concentration in air or water at the point of release (55). For example, concentration can occur as a result of purely physical processes, such as adsorption of radionuclides onto silt or suspended solids which then accumulate on the ocean floor (8). In addition, radionuclides can concentrate in organisms that consume other radionuclide-containing organisms, leading to "biomagnification."

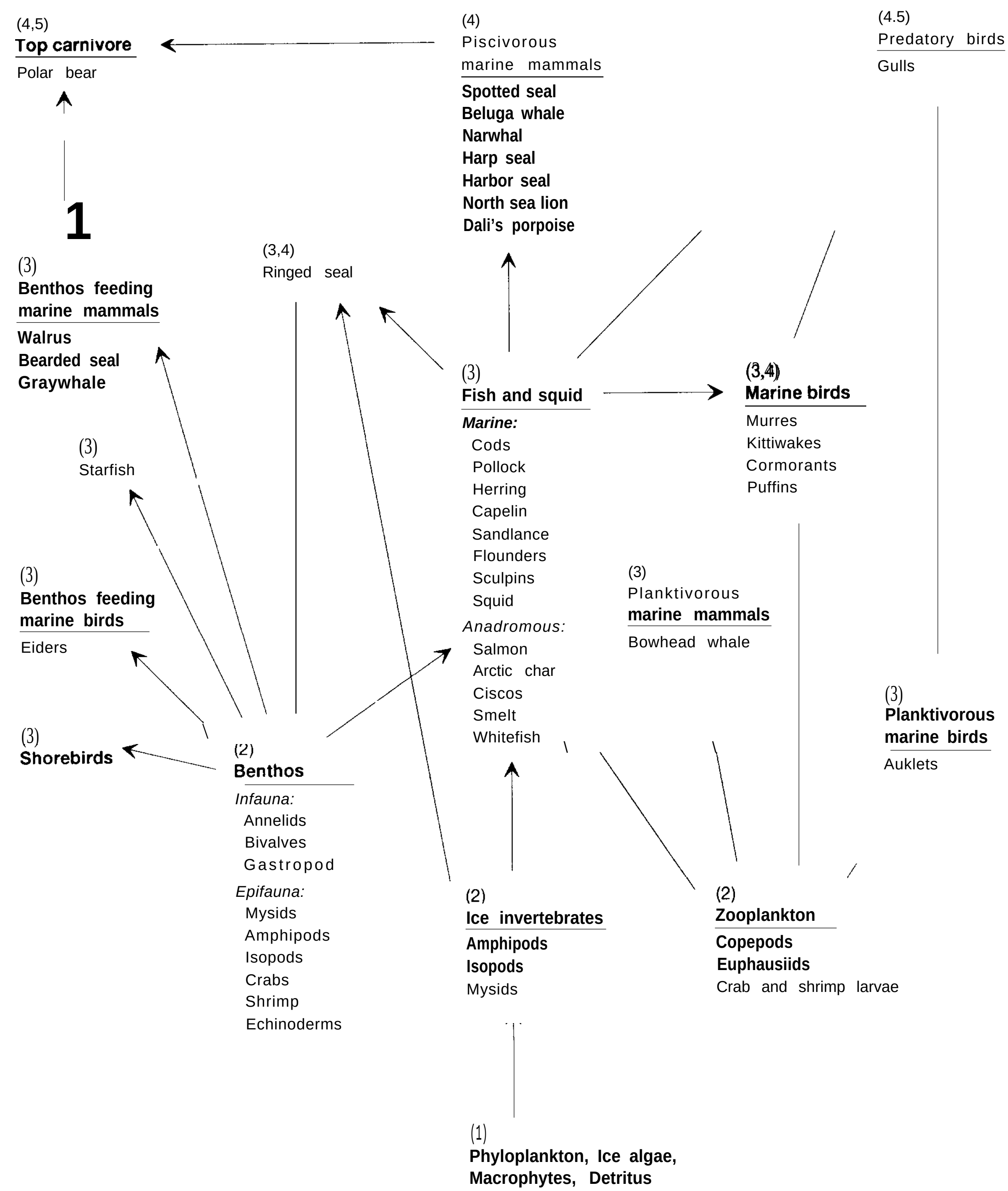
Concentration in biological organisms has been an important focus of study for understanding environmental transport. Concentration factors (CF) are ratios of the concentration of the radionuclide in the organism to its concentration in the ambient medium. They have been measured in a variety of different species and settings, both through laboratory research and in natural systems, and should be measured under conditions in which the organism has reached equilibrium with the environment (see table 3-2). These factors tend to vary widely, partly because the uptake of radionuclides by organisms in water can be strongly influenced by the presence of chemical analogs in the water. For example, the high concentration of potassium (K) in seawater means that the uptake of Cs-137 in marine environments is lower than that observed in freshwater or estuarine (brackish) settings (8). Given the variability in CFs observed in different studies, some site-specific information is required to select an appropriate value.

In analyzing the concentrations of radionuclides that may accumulate in an organism and thence into a pathway for human consumption, it is important to consider where the radionuclides collect in the animal and whether this is relevant to the human diet. For example, clams, oysters, and scallops concentrate Sr-90, but the concentration occurs in their shells, which are ordinarily not consumed (8). In general, muscle tissue tends to have the lowest concentration of radionuclides, whereas liver, kidney, and other organs involved in storage or excretion have the highest concentrations (54). Thus, a CF for the specific tissues consumed by humans is far more useful than one derived for the entire organism.

Generalizations about concentration factors across organism types must also be avoided, and data must be gathered that is specific to the diet of the people in question. Several types of seaweed growing in waters near the nuclear waste discharges of Sellafield were observed to concentrate radionuclides. However, different species of seaweed concentrated different radioactive elements to varying degrees so it was important to know which type people actually ate (7). It is critical to gather both site-specific and species-specific information, coupled with good information about the diet of critical populations.

Without site-specific information about the food web and the diets of critical populations, only a few generalizations are possible about the radionuclides that might be of most concern for human exposure through aquatic and marine food webs (see box 3-2). In any one generation,

FIGURE 3-4: Arctic Marine Ecosystem Food Web



NOTE: Numbers in parentheses indicate trophic level in ascending order. Examples of each major category of biota are also listed

SOURCE: adapted from Becker, P., "Characterization of the Arctic Environment," Proceedings of Workshop on Arctic Contamination, *Arctic Research of the United States, 8: 66-76, 1993.*

TABLE 3-2: Concentration Factors in Marine Organisms

Element	Fish	Crustaceans	Mollusks
H-3	1	1	1
Cs	100	30	30
Sr	5	2	1
Co	50	5,000	5,000
Fe	3,000	5,000	30,000
Mn	400	500	5,000
Mo	40	100	100
Ni	670	1,000	2,000
Zn	5,000	50,000	30,000
I	10	10	10
Am	250[a] 25[b] 5[c]	500	20,000
Cm	250[a] 25[b] 5[c]	500	30,000
Np	250[a] 25[b] 5[c]	100	400
Pu	250[a] 25[b] 5[c]	300	3,000

[a] Bottom-feeding fish.
[b] Planktivorous fish.
[c] Piscivorous fish.

SOURCES: T. Poston and D. Klopfer, "Concentration Factors Used in the Assessment of Radiation Dose to Consumers of Fish: A Review of 27 Radionuclides," *Health Physics* 55:751–766, 1988. Ministry of Agriculture, Fisheries, and Food, *Radioactivity in North European Waters: Report of Working Group 2 of CEC Project MARINA.* (Lowestoft, UK: 1989).

the largest contributions to committed doses[6] from dietary contamination are most likely to come from radionuclides of only moderately long half-lives (tens of days to tens of years), such as cesium, ruthenium, strontium, and zirconium; also from H-3, and in certain circumstances, from iodine-131 and actinides (56).

In summary, considerable information crucial to understanding the transport and fate of radioactive contaminants is lacking. Much of this information must be site specific to be of most use in modeling or otherwise anticipating likely pathways for radionuclides. Information about local physical and chemical characteristics of the water body, resident biota and their concentration factors, and the behavior of the specific radionuclides in the specific environment is needed. Data needs must be considered in the context of the routes of exposure most likely to lead to human beings, by taking into account the diets and habits of people and exploring the most appropriate transport pathways.

Possible Critical Populations

Estimates or analyses of risk from environmental contaminants usually focus on "critical populations," groups who are most likely to be exposed (or to have the highest exposures) to the agent of interest. Who are the populations with greatest likelihood of exposure to radionuclides dumped in the Arctic and North Pacific Oceans? Without an exhaustive understanding of the life-style, habits, and diet of everyone, common sense suggests that those with the largest proportion of seafood, shellfish, and marine mammals in their diets might have the greatest potential exposure to radionuclides released in the ocean. Similarly, those relying most heavily on fish and aquatic organisms from freshwater sources might be most exposed to radionuclides released into rivers. This describes, in particular, Native northern peoples all over the Arctic, including those in Russia, Canada, Greenland, and the United States (Alaska). In keeping with the scope of this report, the focus here is on possible critical populations in Alaska.

In Alaska, many of the Native people continue traditional life-styles that involve a significant dietary component from fishing and marine mammals.[7] A study of the diet of Alaskan Native adults in the late 1980s indicated a high consumption of fish—a mean daily intake more than

[6] Committed doses take into account doses received over time from internal emitters (see box 3-1).

[7] Game meats such as caribou also constitute an important part of the diet, particularly in the winter months. Caribou meat in the Arctic frequently contains appreciable levels of radionuclides because of the caribou's consumption of lichens (see later text).

BOX 3–2: Radionuclides of Potential Biological Impact in Dumped Nuclear Waste

No comprehensive listing of the various radioactive elements present in nuclear wastes dumped in the Arctic and North Pacific Oceans exists. However, it is possible to surmise some of the constituents, based on what is known about the nature of the waste types discarded there. The wastes dumped by the Russian Navy were primarily wastes generated in the use of nuclear reactors to power submarines. Other wastes that may contribute to contamination in the oceans are from the reprocessing of spent nuclear fuel to recover plutonium for use in weapons production. The following table notes those radionuclides that might be of most concern from a human health and ecological perspective, because of physical and chemical characteristics of the elements.

	Radionuclide	Half-Life
Fission products[a]		
	Ruthenium-103	40 days
	Ruthenium-106	373 days
	Cerium-144	284 days
	Zirconium-95	64 days
	Strontium-90[b]	29 years
	Yttrium-90	64 hours
	Cesium-137[b]	30 years
	Iodine-129	16,000,000 years
	Technetium-99	213,000 years
Activation products		
	Zinc-65	244 days
	Iron-55	2.7 years
	Iron-59	45 days
	Cobalt-57	271 days
	Cobalt-58	71 days
	Cobalt-60	5.3 years
	Nickel-59	76,000 years
	Nickel-63	100 years
	Manganese-54	312 days
	Chromium-51	28 days
	Carbon-14	5,730 years
Actinides		
	Plutonium-239	24,411 years
	Neptunium-239	2.3 days
	Americium-241	432 years
	Americium-243	7,370 years
	Curium-242	163 days

(continued)

BOX 3–2: Radionuclides of Potential Biological Impact in Dumped Nuclear Waste (Cont'd.)

NOTES: a) Fission products are radioactive fragments produced when a nucleus is split. Activation products are produced when neutrons released during fission react with elements nearby. These elements can be located in the shielding and containment, fuel cladding, and reactor structural materials. Actinides are elements numbered 89 and above on the periodic table and include the transuranium elements produced by neutron bombardment of uranium. They tend to have longer half-lives and therefore will be contributing radioactivity for longer periods of time.

b) Cesium-137 and strontium-90 deserve special mention because they make up a significant amount of fission products and because of their potential to deliver internal doses over a long time. With half-lives of about 30 years each, either can be taken up in the body and do harm to body tissues for extended periods before being cleared by tissues or decaying. Strontium behaves like calcium in the body, eventually being deposited in the bone where it can provide a source of radiation for years. Cesium behaves like an analog of potassium in the body; it is rapidly absorbed into the bloodstream and distributed to active tissues where it and its decay product barium-137 emit beta and gamma irradiation. In adult body organs, the effective half-life of strontium-90 is 18 years (bone), and the effective half-life of cesium-137 is 70 days (whole body) (68). The effective half-life takes into account both the physical half-life of the radionuclide and the time required for metabolic processes to eliminate the material, so that it reflects the actual time that the radioactive substance is in contact with the body. In general, cesium-137 and strontium-90 are of less concern for accumulating in marine biota than in freshwater because in seawater they are much more diluted by potassium and calcium ions, their chemical analogs. Conversely, radionuclides of elements that are biologically essential but in scarce supply in a given environment will accumulate significantly in organisms (72).

SOURCES: M. Benedict, T. Pigford, and H. Levi, *Nuclear Chemical Engineering*, 2nd ed. (New York: McGraw-Hill, 1981); International Atomic Energy Agency, *Assessing the Impact of Deep Sea Disposal of Low Level Radioactive Waste on Living Marine Resources*, Technical Reports Series No. 288 (Vienna: 1988); Robert C. Weast, (ed.), *CRC Handbook of Chemistry and Physics*, 69th ed. (Boca Raton, FL: CRC Press, 1989); F.W. Whicker and V. Shultz, *Radioecology: Nuclear Energy and the Environment, Volume I.* (Boca Raton, FL: CRC Press, 1982).

six times the U.S. national average intake (46).[8] Ongoing studies also indicate that sea mammal consumption continues to be a very significant part of the diet in some communities (47).

Some sampling and studies have been carried out to determine the levels of radionuclides present in the Alaskan marine environment and food chain. Funded primarily by the Office of Naval Research's ANWAP, the National Oceanic and Atmospheric Administration (NOAA) has overseen the analysis of five relevant sample sets to date (16,18). Analysis of sediment samples from the Beaufort Sea in 1993 indicated a range of Cs-137 from nondetectable up to 12 Bq/kg dry weight (3.2×10^{-10} curies/kg), lower than or comparable to measurements in sediment samples collected in the Kara Sea in 1992. Almost 100 times more gamma and beta radioactivity was attributable to the decay of naturally occurring K-40 than to Cs-137. Ratios of plutonium isotopes measured in the samples indicated global fallout as the principal and perhaps sole source of plutonium. Analysis of bottom-dwelling animals from the same area for plutonium isotopes and Cs-137 showed levels that were almost all non-detectable by high resolution gamma spectroscopy. Chemical separation techniques resulted in Cs-137 activities ranging from 0.3 to 1.1 Bq/kg (8.1×10^{-12}–2.9×10^{-11} Ci/kg). In comparison, Cs-137 activities in mussels and oysters collected in 1990 in coastal areas of the contiguous United States had an average value of 0.2 Bq/kg, with a range of 0.02 to 0.4 Bq/kg (70).

In 1994, samples were collected from larger animals that serve as subsistence food sources, including bowhead whale (blubber, lung, and liver), king eider (bone and muscle), and bearded seal (blubber and kidney) (16). Very low levels of both anthropogenic and naturally-occurring radionuclides were found, with the highest measurement in bowhead whale liver samples of 0.44 Bq/kg of Cs-137 activity (screening values from the Food and Drug Administration, U.S. Department of Agriculture Chernobyl task force are 370 Bq/kg of Cs-137 in food) (60). A limited number

[8] This study did not include communities from the North Slope, Interior Alaska, or the Aleutian Chain, however, where diets may differ somewhat.

of samples from anadromous[9] and marine fish gathered across the Arctic had Cs-137 levels of generally less than 1 Bq/kg dry weight. Exceptions were Arctic cod (2.6 Bq/kg), Arctic char (4.2 Bq/kg) from a Siberian river, and Arctic cisco from Prudhoe Bay (2.9 Bq/kg). Arctic cisco and Arctic char are important subsistence species in both Alaska and Russia, and Arctic cod is ecologically important throughout the Arctic seas. Activity levels of plutonium isotopes and americium-241 were below the detection limits of the analysis.

Fish and bottom-dwelling animals from the southeastern Bering Sea and Norton Sound in 1994 showed nondetectable levels of Cs-137—except in the case of fish where values were generally less than 1 Bq/kg. Additional samples, including bowhead whale, caribou, and polar bear collected in the spring and summer of 1995 by the North Slope Borough in Alaska, are still undergoing analysis (16). All told, the findings to date suggest very low levels of contaminants in these foods, with global fallout rather than other nuclear events (Chernobyl, waste dumping or discharges, etc.) as apparent sources (15).

Apart from the sporadic sampling done recently as a result of increasing concerns about contaminants in the food chain in Alaska, no routine monitoring of the marine environment is carried out, nor is there monitoring of the food chain, including subsistence food resources. Recommendations for such monitoring are included in a recent report by the Alaska State Emergency Response Commission considering radiological threats to Alaska (2) and have been proposed to ANWAP (14). While sampling carried out thus far has been adequate to describe the background levels of radionuclides in the Bering Sea, including Bristol Bay and the Norton Sound, sampling in the Beaufort and Chukchi seas has been much less comprehensive, and as a result the data base is not yet adequate to describe background levels of radionuclides (17).

A cooperative effort between NOAA and the North Slope Borough of Alaska is under way in which tissue samples from animals harvested for food will be analyzed and information about the findings disseminated to local residents. Contingent on FY 95 funding from ANWAP, the effort may include workshops that can provide a forum to hear the concerns of the communities and discuss the interpretations of collected data (16,52).

Clearly, a variety of other Arctic populations might also face potential exposures as radionuclides from dumped wastes are transported through the environment. In particular, Native people throughout the Arctic continue traditional life-styles that might make exposure from the marine food web more likely. More than 28 different groups of Native peoples live in the European and Siberian North and the Russian Far East. Since the 1920s and 1930s these groups have been treated as distinct, with special ordinances applied to them. Two of the groups, the Komi and the Yakuts, are larger (populations of 344,500 and 382,000, respectively, according to the 1989 census) and were given their own autonomous republics within the USSR. More than 26 smaller groups subsist as hunters, trappers, and reindeer herders, although the tundra, taiga, and forest regions of their homelands are increasingly damaged by industrial development, particularly oil and gas. Populations of the groups in 1989 ranged from 190 to 34,665 (29). In Russia's Siberian Arctic, for example, a nomadic Nenets tribe of at least 5,000 reindeer herders still live on the Yamal Peninsula as they did in the fifth century, eating fish, reindeer, and other food foraged from the land and rivers. Other Nenets have settled to live as fishermen (62). In the summer months, nomadic reindeer herders as well as settled community dwellers are large consumers of fish.

Indeed, all along the Arctic coast of Russia, both Native people and "newcomers" depend heavily upon fishing for their food supplies. This dependence has increased in recent years. The

[9] Anadromous fish (e.g. salmon) are born in fresh water, live as adults in salt water, and return to fresh water to reproduce.

demise of the Soviet Union has lead to decreases in incoming food supplies from other regions. The converse is that fish caught commercially are sold locally even more than in the past, because shipping and transportation have become more difficult[10]. Thus, although people living traditional subsistence life-styles could be expected to have the highest exposures to contaminants in fish, even those in cities along the coasts have significant dietary input from fish. Consumption of sea mammals is limited primarily to the Chukchi people in the far northeast (34,53).

In Canada, concerns about radionuclide exposures of the population through the diet have focused primarily on the terrestrial route, but an effort to examine the variety of sources of radioactivity in the Canadian Arctic has taken place through the Canadian Department of National Health and Welfare. The total population of the Canadian Arctic region is about 85,000, roughly half of whom are Native peoples, many continuing traditional food-gathering activities (66). The recently completed study examined the available data on environmental radioactivity and arrived at estimates of radiation doses to groups in six different communities, five of them Native (or First Nation) communities, with one non-Native community as a reference point (20). Estimates of doses were made for each community for a typical adult (eating a mixed diet of subsistence, or "country" foods, and non-country foods), a 1-year-old child, and an adult whose diet consists almost entirely of country foods. Estimated doses from all sources ranged from slightly more than 200 to 1,400 mrem a year. The average estimated dose to the hypothetical child was about 45 percent higher than to the adult with a mixed diet, while estimated doses to the adult eating only country foods were 75 percent higher than those to the adult eating the mixed diet. The ingestion of polonium-210 through the food chain was the most important contributor to dose, as has been found in other studies (see box 3-3). Table 3-3 shows typical concentrations of naturally occurring radionuclides in seawater.

The study drew attention to "significant gaps in the radiological monitoring database, inconsistencies in the information of dietary quantities and components of native diets, particularly for children, and possible reservations regarding the applicability of the dose conversion factors to the Arctic circumstances" (20). These concerns and data gaps appear to be equally relevant, if not more so, to information about exposures elsewhere in the Arctic—for example, in Alaska.

Concern about dietary radionuclide exposures of people with traditional or subsistence life-styles exists in the context of a well-known precedent: the concentration of Cs-137 from fallout in the lichen-reindeer-human food chain. In the 1960s researchers discovered that reindeer herders in several northern countries had elevated levels of Cs-137 in their bodies (1). Subsequent studies revealed that lichens have considerable ability to absorb and retain atmospheric particulates. They have a large surface area and a long lifespan, with no deciduous portions through which to shed radionuclides annually. Lichens are the primary food source for reindeer and caribou during the winter months. About a quarter of the cesium eaten by caribou is absorbed in the gastrointestinal tract and concentrates mostly in muscle tissue (63). Reindeer and caribou consumers ingest the meat and, thus, take the cesium into their bodies, where it is distributed to the tissues and remains in the body delivering a radiation dose for some time. Several studies have monitored Cs-137 levels in the bodies of reindeer herders over time, observing fluctuations correlating with the atmospheric testing of nuclear devices and variations in diet (19,66). In northern Alaskan Eskimos, estimated annual doses from Cs-137 in fallout reached 140 mrad in 1964 and 1966; by 1979 this annual dose had decreased to 8 mrad because of changes in diet and slow decreases in the amount of Cs-137 present in lichen (19). The lichen-reindeer-human saga has

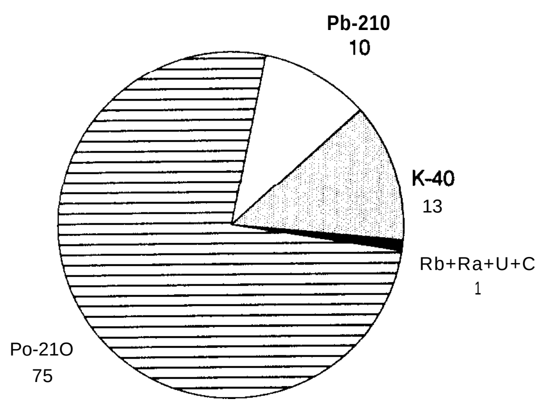
[10] There is an important commercial fishery in Ob Bay; fishing is done through the ice in the winter. As transport mechanisms have broken down, some people are flying in and buying fish privately and then reselling these fish elsewhere, although this is illegal (53).

BOX 3–3: Naturally Occuring Radiation in Seafood Diets

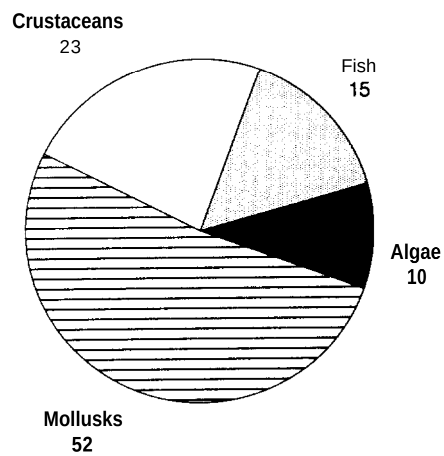
When considering contributions to human exposure from man-made radionuclides in the aquatic or marine food chain, it is important to note that people whose consumption of seafood is high can receive a significant portion of natural radiation from this source. Ocean waters and sediments contain naturally occurring radionuclides that can be concentrated through the food web just as anthropogenic radionuclides are. A rough estimate of annual dose to a person eating a daily diet of 600 grams of fish, 100 grams each of crustaceans, mollusks, and seaweed; 3 grams of plankton; and 60 grams of deep-sea fish is an annual dose of about 200 mrem per year from naturally occurring radionuclides (54). Most of the contribution is from Polonium-21 O, particularly from mollusks (see figure). For comparison, doses of this size are about twice the International Commission on Radiological Protection recommended limit of effective dose to members of the public from human practices (28).

SOURCE: Office of Technology Assessment, 1995.

(a) **Contribution by nuclides (%)**



(a) **Contribution by dietary items (%)**



Estimated relative contributions of (a) naturally occurring radionuclides and (b) dietary items to the annual dose rate to critical groups consuming 800 grams of fish and 100 grams of crustaceans, mollusks, and algae per day.

Source: Pentreath, R. J., "Radionuclides in the Aquatic Environment, " Radionuclides in the Rood Chain, M.W. Carter (cd.) (New York: Springer-Verlag, 1988).

TABLE 3-3: Naturally Occuring Radionuclides in Seawater—Typical Concentrations

Radionuclide	Concentration (picocuries[a] per liter)
K-40	320
H-3	0.6–3.0
Rb-87	2.9
U-234	1.3
U-238	1.2
C-14	0.2
Ra-228	$(0.1–10) \times 10^{-2}$
Pb-210	$(1.0–6.8) \times 10^{-2}$
U-235	5×10^{-2}
Ra-226	$(4.0–4.5) \times 10^{-2}$
Po-210	$(0.6–4.2) \times 10^{-2}$
Rn-222	2×10^{-2}
Th-228	$(0.2–3.1) \times 10^{-3}$
Th-230	$(0.6–14) \times 10^{-4}$
Th-232	$(0.1–7.8) \times 10^{-4}$

[a] 1 picocurie = 1×10^{-12} curies = 0.037 becquerels

SOURCE: adapted from R.B. Clark, *Marine Pollution,* 2nd ed. (Oxford: Clarendon Press, 1989).

been instructive as an example of increased exposure resulting from special dietary situations and suggests the need for vigilance in examining potential pathways for increased exposures.

In considering risks from environmental contaminants in the food chain, three important harmful effects must be considered that do not result directly from exposure to radiation. One is the fact that when a certain food is avoided because of concerns that it may be contaminated, other foods must be substituted. If these are less nutritious, are more expensive, or have more hazardous contaminants in them, the substitution has had a negative impact that must be weighed against the possible negative effects of eating the first foodstuff.

A second important result of concerns over contamination in food is one that may have particular impact on Native people living subsistence life-styles. Traditional foods and their hunting are a critical component of Native culture. Consuming subsistence foods is of course normal and natural, and part of a healthy life-style. Events centered around gathering or sharing foods (e.g., whale festivals) are important community events. To suggest that eating the foods could be harmful or should be avoided for some reason could cause tremendous disruption of life-style and contribute to disintegration of the culture (23,48).

A third important impact, related to the second, is the great psychological stress that can result from fear of contaminants in food and the surrounding environment. Many people in the Chernobyl and Chelyabinsk (see box 2-4 in chapter 2) populations have health problems they believe are caused by exposure to nuclear contamination. They suffer physically and have a changed outlook on life (11,12). Whether or not their health problems are caused by radioactive contamination, the people of the region observe a heavy toll of physical effects, which also leads to psychological stress. Similar impacts are possible in other areas, such as Alaska, where people fear they are experiencing health effects from radiation exposure. Many Alaska Natives have concerns about previous exposures to radiation such as those from nuclear weapons testing fall-out in the 1950s and 1960s (21). They are very concerned that these exposures have had a health impact on their communities. The potential for additional exposures can only add to those concerns and the stress experienced.

In summary, a tremendous number of unknowns remain in considering the populations that might be most at risk of exposure to radionuclides dumped into the Arctic and North Pacific Oceans. Detailed studies of the dietary habits of many coastal peoples are almost nonexistent, as is any monitoring of the locally harvested foods and good information about the size of the harvests. Without such information, it is difficult to estimate what exposures are currently taking place from background and fallout radiation, and what concerns might be appropriate regarding future dissemination of the dumped wastes.

Risk Assessments Completed or in Progress

A thorough assessment of the risks posed by nuclear waste dumping in the Arctic and North Pacific would incorporate understanding of the source term, detailed information on the pathways through which human exposure might occur, and knowledge of the critical populations to arrive at an estimate of the likely risk. Such assessments have been carried out in the past for other sources, as described in box 3-4. However, the preceding sections describe the fact that vital information, particularly about Arctic pathways and peoples, is sorely lacking. In its absence, several efforts have nonetheless been made by various investigators to estimate the risks in an effort to get a rough sense of the appropriate levels of concern.

Several of these estimates use population doses such as the collective effective dose to consider the potential total cancer impacts on populations rather than the risks to particular individuals. As described in box 3-1, the collective effective dose is calculated by multiplying the average dose to the exposed group by the number of people in the group. It could therefore be the same for a very low dose to a large population or a higher dose to a smaller population. Use of the word *commitment* takes into account the fact that when radioactive material enters the body, the material gives a dose to the person for a certain period of time. Collective doses are most frequently used for the purpose of comparing estimates of total cancer impacts of one radiological source with another, using units of person-rem.

Two such estimates were presented at a conference addressing the issue of radioactive dumping in the Arctic in June 1993. A crude estimate of global cancer risks from Arctic contamination was carried out based on a worst-case scenario of instant release of the calculated 1993 inventory of radionuclides in the dumped reactors (43). The analysis multiplied World Health Organization dose conversion factors (DCFs) for each radionuclide by the estimated radionuclide inventory to arrive at collective dose commitments. The collective dose commitments were summed and multiplied by a cancer risk factor for ionizing radiation of 0.05 fatal cancer per 100 rem (28) to arrive at an estimate of 0.6 fatal cancer from exposure to the radionuclide inventory from the nuclear wastes dumped in the Arctic. The authors compared this to an estimate of 17,000 fatal radiation-induced cancers that could occur as a result of the Chernobyl accident (43).

Another estimate of risks was based on the same radionuclide activity inventory. Baxter et al. used the inputs of Mount et al. (43), with a 16-box model called ARCTIC2, which incorporates oceanographic and hydrographic information about the relevant seas (3). The model output

BOX 3–4: Dose Assessment from Anthropogenic Radionuclides in the Ocean: Precedents

Despite the many challenges associated with trying to assess the potential radiation doses from ocean discharges or dumping of radionuclides, two notable precedents exist. One such assessment was carried out on the Northeast Atlantic Dump Site, by the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD). The other was the result of Project MARINA, an effort to assess the impact of several sources of radioactivity in marine waters on European Community populations.

The Northeast Atlantic dump sites are deep sea sites used by eight European countries to dump low-level nuclear wastes between 1949 and 1982. The NEA is requested to review the suitability of the dump sites in use every five years, considering the likely radiological impact of dumping operations on both humans and the environment. Such an assessment was carried out for NEA by the multinational Coordinated Research and Surveillance Program (CRESP) in 1985 (50).

(continued)

BOX 3–4: Dose Assessment from Anthropogenic Radionuclides in the Ocean: Precedents (Cont'd.)

Because surveillance data indicated no significant radionuclide concentrations in water, sediment, or biota, a source term model was developed to estimate a release rate from the dumped objects. An oceanographic model then was used to predict radionuclide concentrations in water and sediment as a function of time, and the data generated were used to estimate doses to critical groups. Calculations were carried out for three scenarios including the past dumping, the past dumping plus five additional years at the rates typical of past dumping, and past dumping plus five years at rates 10 times those typical of the past. The following table shows the estimated peak annual doses to individuals in potentially exposed groups as they were calculated in the assessment. The peak doses calculated were to those eating mollusks in the Antarctic and fell orders of magnitude below the 100 mrem (0.1 rem) dose limit of the International Commission on Radiological Protection for members of the public.

Source	Estimated source term at release (curies)	Estimated peak annual doses[a] to individuals (mrem)	Pathway, location
Northeast Atlantic dump site	1.1 million	0.002	Consumption of mollusks Antarctica
Sellafield	>5.2 million	30-350[b]	Fish and shellfish, Irish Sea
Fallout from weapons testing	55 million	0.1–1.0	Fish, north European waters
Naturally occurring radiation		200	Mollusks, crustaceans

[a]Committed effective dose arising from intakes of radionuclides in the same year.

[b]Doses from Sellafield were calculated to have peaked in the early 1980s and to be well below 100 mrem by 1986.

SOURCES: Ministry of Agriculture, Fisheries, and Food, *Radioactivity in North European Waters: Report of Working Group 2 of CEC Project MARINA*, Fisheries Research Data Report No. 20, (Lowestoft, U.K., 1989); Nuclear Energy Agency, *Review of the Continued Suitability of the Dumping Site for Radioactive Waste in the North-East Atlantic* (Organization for Economic Cooperation and Development, 1985).

Both monitoring data and simple models were used to assess the likely doses to critical groups from marine pathways in the European Community in Project MARINA (37). The assessment considered radioactivity from several different sources, including liquid wastes from nuclear fuel reprocessing plants, liquid wastes from nuclear powerplants and other nuclear industry sites, wastes from solid waste disposal in the northeast Atlantic (referred to above), fallout from Chernobyl, and naturally occurring radionuclides. The table shows the estimated doses calculated in this effort due to discharges from the nuclear fuel reprocessing plant at Sellafield and from weapons testing fallout and naturally occurring radiation.

provides radionuclide concentration data, which are used with IAEA-recommended concentration factors to estimate corresponding concentrations in fish. Radionuclide intake in humans is then estimated based on fisheries data, with assumptions made about typical fish consumption. Finally, conversions to dose were made with gut transfer factors and DCFs from the International Commission on Radiological Protection.

The results from this modeling and risk estimate found a range of collective dose commitment from a maximum of 15,000 person-rem (for instantaneous release of all dumped activity according to the Yablokov report) from Cs-137 down to much lower values with more realistic assumptions. Individual doses for fish eaters ranged from about 6 mrem per year to 0.1 mrem per year. As discussed in box 3-3, individuals who consume large amounts of seafoods can receive about 200 mrem a year from naturally occurring radionuclides. Similar estimates were made for the other radionuclides in the dumped wastes, with the conclusion that Co-60 and Cs-137 would dominate the contribution to total dose commitment from an instantaneous release, whereas C-14 would create most of the dose commitment after a slower release (500 years). The authors concluded that the amount of radioactivity due to wastes disposed in the Arctic seas will be low—either comparable to or less than those from natural or other man-made sources (3).

Two other dose assessments are presented in the Joint Russian-Norwegian Expert Group report from the 1993 expedition to the Kara Sea. In one assessment, doses to critical groups are calculated based on current levels of radioactive contamination in the Barents and Kara Seas. The estimates rely on dynamic models of radionuclide migration and accumulation through living organisms (31). The models take into account temperature, stable chemical analogs, and concentration factors. Average and maximum concentrations of Cs-137 and Sr-90 in the Barents and Kara Seas from 1961 to 1990 were used with experimental and calculated concentration factors and assumptions about fish consumption to arrive at estimates of dose. Based on measured seawater radionuclide concentrations during these years, dose maxima were observed that resulted from the heaviest fallout of weapons testing in the early 1960s and from a peak in nuclear waste disposal at Sellafield in the early 1980s. Results are presented in terms of annual risk of fatal cancer and do not exceed 8×10^{-7} (31).

A second estimate of potential doses by the Joint Russian-Norwegian Expert Group is based on consideration of release of the dumped wastes; it represents ongoing work to model different release scenarios, transport processes, sedimentation, uptake in various marine species, and consumption of these species by humans. The model is being developed by Riso National Laboratory, Denmark, in collaboration with the Norwegian Radiation Protection Authority and the Institute of Marine Research in Norway. The model is based on two different regional box models covering European coastal waters, the Arctic Ocean, and the North Atlantic, with input of experimental data from the Barents Sea. Differential equations describe the transfer of radionuclides between regions in the mode. Radioactive decay, transfer to and from sediments, and burial by additional sedimentation are taken into account. Because data on the source term remain limited, the current model assumes the presence of only four radionuclides (Cs-137, Co-60, Sr-90, and H-3) in equal amounts of activity at the time of discharge. Parts of the model have been tested for reliability with measured observations, but this has not yet been done for the Kara Sea with site-specific information.

Two different release scenarios have been considered with this model. One assumes instant release of all the radionuclides at the time of dumping. The second assumes release over a period of 100 years. According to preliminary estimates from this model, “the collective dose will be small for both scenarios.” However, investigators acknowledge that incomplete information still severely limits the ability to estimate the potential total dose (31).

In a pilot study by the North Atlantic Treaty Organization (NATO) Committee on the Challenges of Modern Society, another estimate of the potential cancer mortality from dumped spent nuclear fuel is presented (49). Because many characteristics of the spent fuel and its containment are still unknown, the estimate necessarily incorporates several assumptions about release rates and exposure routes. If no fission products are released for years, the estimated total collective dose commitment from Cs-137 and Sr-90 combined is 300 person-rem through the food chain. The contribution of Pu-239 to collective effective dose is estimated to be about 170 person-rem, and the contribution of Am-241 estimated to be about the same. The total collective effective dose commitment from the dumped spent nuclear fuel is summarized as less than 1,000 person-rem to the world population, and it is noted that this is equivalent to a few seconds of natural background radiation.

The term "risk assessment" is used rather loosely to describe a variety of analyses ranging from back-of-the-envelope calculations to exhaustive consideration of all possibilities to arrive at an estimate of the probability of an event and associated uncertainties. Back-of-the-envelope estimates provide some useful information but clearly have considerable weaknesses. In estimating the total cancer mortality or collective dose, they assume distribution of the radiation dose over the global population. This permits a form of comparison with other sources of environmental radiation, such as fallout from weapons testing or natural radiation. It does not convey, however, the range of doses that individuals may experience and the potential local impacts on small communities. Also, by smoothing over the myriad uncertainties and information gaps using rough guesses, these estimates suggest an ease and confidence in assessing risks that are misleading.

Nonetheless, in the absence of more thorough and detailed risk assessments, the rough estimates carried out thus far do provide valuable information in considering the potential scale of the radiological impact. They suggest that the global effects of the dumping that has taken place to date are unlikely to be catastrophic, on the scale of a Chernobyl, and may not be detectable against the effects from other radiation, both natural and man-made. It is clear, however, that more information is necessary to better understand the range of risks to individuals and to local communities.

ECOLOGICAL EFFECTS OF RADIATION IN THE ARCTIC AND NORTH PACIFIC REGIONS

Particularly in an environment such as the Arctic, where Native people continuing traditional lifestyles rely heavily on the local ecosystems for food and other aspects of survival, it is artificial to evaluate the risks to human health independent of the impacts on the surrounding ecology. In these settings, humans and other populations (sea mammals, caribou, fish, etc.) are interconnected, with humans dependent on the other populations that make up their environment. For this reason, it is of particular interest to understand what impacts from environmental radioactive contamination may result to other populations in the ecosystem.

Earlier sections indicated that radionuclides can be transported and even concentrated through the food chain to lead to human exposure. Beyond this, however, how are the populations that make up the food chain and ecosystem affected by radiation exposure? As with the study of radioactivity's effects on humans, the study of radioactive impacts on plants and animals began to be of concern after the first nuclear detonations occurred in the 1940s. After many early studies focusing only on acute effects, emphasis had shifted by the late 1950s to more ecologically relevant research—longer-term experiments with much lower dose rates and more attention to responses other than mortality (26). Considerable activity continued in this field in the United States until the 1970s when many such programs were scaled back.

Repeatedly, as standards were developed to protect human beings from the hazardous effects of exposure to radiation, it was assumed that these safety levels would also prove protective to other species, if not individual members of those species (27). The most recent ICRP statement on the subject follows:

> The Commission believes that the standard of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk. Occasionally, individual members of non-human species might be harmed, but not to the

extent of endangering whole species or creating imbalance between species.[11]

A recent IAEA publication examined this assumption, reviewing the relevant literature for aquatic and terrestrial biota (26). Several effects of radiation on plants and animals were evident from the literature. For example, reproduction (including the processes from gametogenesis through embryonic development) is likely to be the most limiting end point in terms of population maintenance for both terrestrial and aquatic organisms. Also the total accumulated dose at which a given response was observed increased as the dose rate declined. Furthermore, sensitivity to the effects of radiation varies among species. In the case of aquatic organisms, radiosensitivity increases with increasing complexity. The publication concluded:

> There is no convincing evidence from the scientific literature that chronic radiation dose rates below 1 mGy [milligray] per day [0.1 rad/day] will harm animal or plant populations. It is highly probable that limitation of the exposure of the most exposed humans (the critical human group), living on and receiving full sustenance from the local area, to 1 millisievert per year [100 mrem/year] will lead to dose rates to plants and animals in the same area of less than 1 mGy/d[ay]. Therefore, specific radiation protection standards for non-human biota are not needed.[12]

The document concludes, therefore, that plant and animal populations appear to be no more sensitive than humans to the effects of radiation in the environment. The literature from which this is drawn, however, is severely lacking in studies carried out in the extreme environment of the Arctic.

Because of the special conditions in the Arctic, relationships or radionuclide behavior based on observations in nonpolar regions cannot necessarily be expected to hold. For example, radioactive fallout deposited on land is cleansed much more slowly in Arctic than in more temperate regions. The reason for this difference lies in the relatively ineffective natural dissipative processes in the Arctic compared with other regions. Short growing seasons and limited supplies of heat, nutrients, and moisture lead to slower biological turnover rates that aid in the dispersal of radionuclides (63). Similarly, concentration factors in organisms might be different in food webs unique to the Arctic environment.

Some studies have examined the effects of low temperature and salinity on radiation responses in several aquatic animals. Changes in salinity tend to increase metabolic demands and thus make the animals more sensitive to radiation. Salinity itself, however, can be protective since nonradioactive chemical analogs of radionuclides that might otherwise be taken up and stored in tissues can dilute the radionuclide concentration (65). Low temperatures lengthen cell cycle times and slow the development of lethal biochemical lesions, but they may also slow repair processes (25). Whether these factors combine to make Arctic fauna more or less sensitive to radiation effects is not clear. In particular, improved information about the doses to reproductive tissues in critical species is needed, along with an understanding of the distribution of radionuclides in these tissues (25).

Effects on fertility in aquatic organisms are first observed in sensitive organisms at dose rates between 0.2 and 5 milligrays (mGy) per hour (0.2 and 0.5 rad per hour), comparable to the range observed in some mammals and indicating that aquatic organisms are not necessarily more radiation resistant than mammals (25). Data still more useful for assessing the impacts of radiation on populations would be studies on the "intrinsic rate of natural increase," or *r*, which takes into account both the death and the birth rates. Such data are almost nonexistent. In the

[11] International Commission on Radiological Protection (ICRP), *1990 Recommendations of the International Commission on Radiological Protection*, ICRP Publication No. 60 (New York, NY: Pergamon Press, 1991).

[12] International Atomic Energy Agency (IAEA), *Effects of Ionizing Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards*, Technical Reports Series No. 332 (Vienna: IAEA, 1992).

freshwater crustacean *Daphnia pulex*, however, *r* was reduced to zero at about 70 rad per hour.

The Arctic and sub-Arctic ecosystems are inherently more dynamic and unstable than more temperate regions. Interdependent populations of many animals fluctuate with different periodicities, leading to intermittent peaks and crises (33). Since many unknowns remain about the populations most vulnerable to the effects of radiation in the Arctic environment, it is not evident how the effects of environmental radiation would manifest themselves against this background. At this point, no "sentinel organisms" have been identified that can serve as early warnings of radiation threats to the Arctic ecology.

The only published information on actual evaluations of the effects of nuclear waste disposal in the deep sea on marine organisms has been reports on the Northeast Atlantic dump site used by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD). For more than 40 years, low-level radioactive waste from nuclear powerplant operations, fuel fabrication and reprocessing, industrial and medical use, and dismantling and decontamination of nuclear plant equipment have been dumped at deep-sea sites in the Northeast Atlantic. Periodically, the Nuclear Energy Agency reviews the continued suitability of the site, assessing the likely radiological impact of the dumping on both humans and the environment (50). Modeling is used to estimate the dispersion of radionuclides and the dose rates to organisms from past dumping practices as well as from potential future dumping at the site. According to the modeling, which is carried out with conservative assumptions, the dose rates received by fish, mollusks, and crustaceans from both past and projected dumping would not result in discernible environmental damage. Peak doses from the dumping of low-level waste, except for benthic mollusks at the site, were within the range of doses received through natural background radiation in the deep sea (25).

CONCLUSIONS

The nuclear wastes dumped in the Arctic and Far East raise questions about impacts on human health and the environment, both currently and in the future. Current risks appear to be very low since there is no indication of significant leakage or migration of radionuclides from the dump sites. More thorough investigation of the sites is necessary to confirm this.

There is not yet a clear answer to questions of what the future health and ecological impacts of nuclear wastes dumped in the Arctic and North Pacific will be. Estimates and approximations of future impacts based on the information available do not suggest a noticeable effect on human health or on plant and animal populations. However, many unknowns remain, from the status of the dumped wastes, to the likely movement of the radionuclides through the environment, to the dietary intakes of those most likely to be exposed.

Decisions about public health must often be made in the absence of complete information, however. In this case, concerns for public health suggest several important needs. One is the need to prevent further such releases of nuclear wastes into the environment, in accord with the London Convention. Despite the uncertainties in and controversy about the effects of low-dose exposure to radiation, there is general agreement among relevant international commissions and national regulatory bodies that radiation exposures should be "as low as reasonably achievable (ALARA), economic and social factors being taken into account."[13] This concept of ALARA stems from scientific consensus that it is unlikely that the presence or absence of a true threshold for cancer in human populations from radiation exposure can be proved. In the absence of a threshold the principles of prevention dictate minimizing exposure to the extent possible by weighing the other factors involved. As discussed in chapter 2, once radionuclides have been released into the

[13] International Commission on Radiological Protection (ICRP), *1990 Recommendations of the International Commission on Radiological Protection*, ICRP Publication No. 60 (New York, NY: Pergamon Press, 1991).

environment it is very difficult to completely anticipate or characterize their movement through environmental pathways and eventual human exposure to them. Preventing their release to the extent possible is an obvious way of minimizing human exposure and, thus, human health risk.

The second need is to fill some remaining information gaps to determine whether the estimates of negligible effect are well grounded. These include inspecting each of the dumped nuclear reactors containing spent fuel to ascertain its condition, any local contamination that may have occurred, and the anticipated release rates of radionuclides. Other dumped wastes should also be located, and their contents determined to the extent possible. Where it is learned that releases may have occurred, strategic monitoring of critical pathways and the food chain should take place to ensure protection of populations.

As more information is gathered and as monitoring systems are considered, it is critical that the public be involved in the process. Genuine efforts are needed to ensure that potentially affected communities participate in decisionmaking, provide input, and have access to the collected information. Protecting public health in circumstances of limited or inadequate information involves:

1. *Understanding the concerns of critical populations:* What potential sources of exposure are of most concern to the people? What is their understanding of the hazard and its source? What information can they provide about foods and habits that can help improve the understanding of potential exposures?
2. *Communicating the state of knowledge to critical populations*: What is known and what gaps in understanding remain? How can these be made known to people without scientific training who distrust many sources of information?
3. *Setting up a system of monitoring that the population accepts and understands:* Does the system address the concerns of the community, and is access to the collected information provided?
4. *Using public input to design a warning system*: What is the best way to advise people of information from the monitoring system? At what point and in what manner should people be cautioned about potential exposures?

As research and efforts to assess risk continue, they must be carried out with complete openness about both current knowledge and knowledge gaps, and with sincere efforts to involve the public in future decisionmaking.

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Sources and Risks of Potential Future Contamination 4

Most research and data collection efforts to date have focused on past radioactive contamination and releases. Beyond the contamination that already exists, however, lies the further risk that future releases, dumping, or accidents could significantly add to this problem. While past dumping and releases have received recent attention from scientists and governments, the risk of future releases has not been subject to the same scrutiny or study.

The following discussion is a review of the nature and general magnitude of this future risk and of what we know or don't know about actions that have been, could be, or should be taken. The discussion is not quantitative because the data that have been collected so far are limited. It is, however, illustrative of several areas of potential future contamination. Even though the potential for significant contamination may be problematic, the risks are real, and in many cases, the proverbial ounce of prevention could well be worth pounds of cure.

According to information currently available, certain areas are at risk of future contamination from Russian nuclear activities in the Arctic and North Pacific regions. OTA has selected three of these areas for focus and analysis in this study because they appear to be the most significant at this time. These are: 1) the Russian Northern and Pacific Fleets and their vulnerabilities during the downsizing and dismantlement now under way; 2) the management of spent nuclear fuel and waste from these fleets and concerns about effective containment safety, security, or future releases; and 3) concerns about possible future accidents or releases from Russian civilian nuclear power plants, particularly those located in the Arctic.

Based on the limited data currently available, it appears important to evaluate appropriate measures for the prevention of future releases, dumping, or accidents like those that have occurred in the past. For example, the situation with regard to the management of spent fuel and other radioactive waste from the Russian nuclear fleet presents a special concern. There are serious problems in Russia related to: submarine dismantlement and the removal of spent fuel from submarine reactors; the storage of spent fuel aboard service ships that are used in the submarine defueling process; spent fuel handling and storage at naval bases in the north and Far East;[1] the lack of capacity at land-based storage facili-

[1] The northern naval bases are mainly on the Kola Peninsula, near the Norwegian border and adjacent to the Barents Sea; the Far Eastern bases are mainly near Vladivostok on the Sea of Japan and Kamchatka.

ties; the question of what to do with damaged fuel and nonstandard fuel for which no reprocessing system exists; the transport of spent fuel; and the system to transfer spent fuel to, and reprocess it at Mayak in the Ural Mountains.

Within the Russian Navy, older nuclear submarines have been retired and decommissioned over the past several years at an increasing rate. Over 120 submarines have been taken out of service, and about 100 nuclear submarines are in various stages of decommissioning. Only about 40 of these have had their spent fuel removed, and some decommissioned submarines have been out of service with nuclear fuel aboard for over 15 years. The most serious factor contributing to this condition is that almost all spent fuel storage facilities at the nuclear fleet bases are full, and there are difficulties in transporting fuel to reprocessing sites.

The Office of Technology Assessment (OTA) has begun to identify some high-priority problems associated with the management of spent fuel from the Russian nuclear fleet through discussions with Russian officials and experts. These problems were reviewed at a special OTA workshop on this subject in Washington, D.C., in January 1995, where Russian officials presented their analysis of the problem and discussed approaches to solutions with technical counterparts from the United States.[2] Some key problems with refueling and storage relate to the current backlog of spent fuel and decommissioned submarines awaiting defueling. There is a lack of fuel reloading and storage equipment (including service ships, transfer bases, and land-based storage), and what does exist is poorly maintained.

In recent years, the Russians have not been able to transport spent fuel to the normal reprocessing plant at Mayak, and spent fuel storage facilities are near capacity. This has become a serious problem for fuel management operations in the Navy and at the Murmansk Shipping Company (MSC) and could affect ship operations in the future. For example, there are indications that GOSATOMNADZOR (GAN), the Russian nuclear regulatory agency, plans to demand submarine defueling as a first step in decommissioning. This may further delay the processing of decommissioning submarines.

In addition, the Russians are experiencing problems with the current situation that result in long-term, in-core fuel storage aboard retired submarines. In some cases, reactor cores and other reactor components of retired submarines are close to or beyond their useful lifetimes. GAN characterizes the technical condition of these systems as "intolerable." Under such circumstances, extended in-core storage of spent fuel may increase the incidence of fuel failure due to radiation or thermal damage to the cladding and to cladding corrosion. According to GAN, these problems often cannot be observed or controlled because of the lack of reactor monitoring equipment. However, the Ministry of Atomic Energy (MINATOM) and the Navy claim that fuel that has not been damaged during reactor operations is unlikely to fail during in-core storage.[3] They also claim that there is even some advantage of in-core storage: after three to five years of storage, fuel can be placed directly in dry storage or sent to Mayak for reprocessing. However, some fuel is already damaged, and no complete analysis of this overall problem is available.

Another key problem is with transportation of spent fuel because of a shortage of railcars for upgraded transportation casks,[4] facilities for loading and transporting the casks, organizational problems at fuel transfer bases, and lack of upgrades in the transportation infrastructure. This problem has recently received attention at the Northern Icebreaker Fleet base at Murmansk,

[2] See "Summary of Workshop on Russian Naval Spent Nuclear Fuel and Waste Management," U.S. Congress, Office of Technology Assessment, Environment Program (April 1995).

[3] This view is supported by experiments: for example, spent fuel has been kept without deterioration in-core on the icebreaker Sibir' for three years (53).

[4] The Russians have recently introduced a redesigned transportation cask to meet international safety standards.

and several spent fuel shipments have occurred in 1995. The situation in the Far East, however, remains serious, and no shipments appear possible in the short term.

Nonstandard or damaged fuel rods from submarine and icebreaker reactors present another set of problems. Such fuel includes zirconium-uranium alloy fuel, fuel from liquid metal reactors, damaged and failed fuel assemblies, and fuel in damaged reactor cores. Russia does not have current technology to reprocess or dispose of nonstandard or damaged fuel. Also, removing damaged fuel from reactors for temporary storage, and selecting or developing appropriate future treatment or storage technologies, are both challenging and costly. This process is proceeding at a very slow rate because of a lack of resources. Additional evaluation of specific situations and some focused research or development are probably needed to ensure future safe management. The question of future risks from operations to dismantle nuclear submarines and manage spent fuel has recently been addressed in a North Atlantic Treaty Organization (NATO) study (49). Box 4-1 presents analyses of the hypothetical accidents used in this study.

Institutional issues are exacerbating difficulties in the spent fuel management system, as is the problem of identifying the necessary resources to apply to solutions. However, other areas may also pose future risks, but they have not been as well documented or evaluated. For example, the major Russian nuclear test site at Novaya Zemlya contains significant residuals of past weapons testing. During 1955 through 1990, the former Soviet Union (fSU) conducted at least 90 atmospheric tests there (including the largest-yield explosion ever); 42 underground tests (most of which were in tunnels into mountains), and three underwater tests (62). Although there is clear evidence of radiation fallout from atmospheric tests spread over major portions of the globe, the migration of radionuclides from underground tests has not been documented. Some researchers, however, recommend that surveys or monitoring at the test sites may be warranted.

Other sources of radioactivity that have caused concern because they may add to future releases include a large number of so-called peaceful nuclear explosions in Russia that were used for various purposes such as excavation and construction over a period of a several decades. Whether radionuclide residuals from these migrate beyond local sites is problematic, and no careful investigations have been made. Another concern is the extensive use of radioisotope-powered generators by the Russians in a large number of lighthouses in the Arctic. Poor operational, safety, and waste disposal practices could lead to releases from these devises, but no significant threats have so far been identified (49).

The following sections, therefore, present currently available information and analyses of the areas on which OTA has focused its evaluation.

THE RUSSIAN NUCLEAR FLEET

The Russian fleet of nuclear-powered submarines and surface ships (including icebreakers) is the largest in the world, with a total of 140 active vessels at the end of 1994. During the 1970s and 1980s, the size of the Russian nuclear fleet was substantially larger than that of the United States. However, today, the U.S. nuclear fleet—with about 117 vessels—is only slightly smaller. Only three other nations have nuclear fleets—the United Kingdom with 16 submarines, France with 11, and China with one (36). Both the United States and the former Soviet Union began building nuclear-powered submarines in the 1950s and had roughly the same number by the 1970s. In the 1970s and 1980s the Soviet nuclear fleet grew faster and larger than that of the United States. Soviet nuclear fleet strength peaked in 1989, just before the dissolution of the U.S.S.R.

Today's Russian nuclear fleet consists of about 128 active nuclear-powered submarines, five icebreakers, and six other surface ships. An equal or larger number of nuclear-powered ships make up the inactive fleet and are in various stages of lay-up or decommissioning. Much of the inactive fleet consists of submarines awaiting

BOX 4-1: Case Study: Risk Assessment of Moored Submarines

A recent study by the North Atlantic Treaty Organization (NATO) includes two risk assessments that evaluate the impact of hypothetical accidents related to decommissioned Russian nuclear submarines moored in the vicinity of the Kola Peninsula. The first assessment used probabilistic methods to evaluate the risk and long-term impact of radionuclide leakage from 60 nuclear submarines that would have been laid up at Northern Fleet bases located on the Kola Fjord. The model included various exposure pathways such as inhalation, external radiation, and food consumption. Due to the lack of operational data from the Russian Navy, a somewhat arbitrary accident probability of .001 per year per ship was assumed. This probability is equal to the accident probability of the least safe land-based commercial European nuclear power reactors. This hypothetical accident would be initiated by large-scale atmospheric emissions caused by cooling system failure followed by overheating of the core, or perhaps by criticality occurring during defueling of the reactor. The study concluded that in northeastern Scandinavia, the risk of additional fatalities from nuclear reactor accidents in moored nuclear submarines is comparable to those due to the operation of land-based commercial nuclear reactors used for electrical production. In southern Scandinavia, the risk of cancer-related casualties would be 100 times lower from submarine-based accidents than the risk due to nuclear reactors used for electrical production. However, the Russian population exposure in Murmansk and elsewhere on the Kola Peninsula would be higher due to submarine-related accidents.

The second study consisted of a simulation of a real accident at an exact location near the city of Murmansk on the Kola Peninsula. The probabilistic model described above provides useful information regarding mortality risks; however, the risk of injury from a real accident would be significantly higher. This study used historical weather data to predict air mass dispersion patterns. The scenario used in the simulation considered the consequences of an accidental release of radionuclides into the atmosphere from a nuclear submarine being serviced at docks just outside Murmansk. The release was arbitrarily chosen to occur on July 15, 1994. The resulting air dispersion model predicted the formation of a radiation cloud and deposition matrix that would cause both external and inhaled radionuclide exposure. During the first 48 hours, only individuals in the immediate Murmansk area would be exposed to effective radiation doses at milliSievert levels. After that, the radiation cloud would drift north into the Barents Sea. However, two days later the weather patterns might shift, and contaminated air masses would be transported south again across major parts of Finland and northwestern Russia. The authors of the study were careful to note that uncertainties in real-time modeling would lead to a factor of uncertainty of five to 10 times the reported values.

The study concludes that risks associated with the operation of nuclear vessels in Russia's Northern Fleet and icebreakers are difficult to estimate. Accidents that lead to large releases of radioactivity would clearly have significant local consequences, but their cross-border, international impacts would be modest. However, NATO's analysis of the present rate of submarine decommissioning and of the Northern Fleet's capacity for defueling, storing, and transporting nuclear waste indicates that a problem of "considerable magnitude" exists locally in northwest Russia.

SOURCE: North Atlantic Treaty Organization, Committee on the Challenges of Modern Society, *Cross-Border Environmental Problems Emanating from Defense-Related Installations and Activities*, Final Report, Volume I: Radioactive Contamination, Phase I: 1993–1995, (Kjeller, Norway: NATO, 1995).

dismantlement and disposal of their nuclear fuel, reactor compartments, and nuclear waste. The nuclear fuel or waste from poorly managed, laid-up ships could pose a threat to the Arctic or North Pacific environment if accidents or releases of radioactivity occurred.

The total number of nuclear submarines taken out of service is similarly being driven by the

Russian government's policies aimed at reducing the size of the Russian Navy. The actual pace of nuclear submarine decommissioning is, however, subject to speculation and the anticipated impact of the (yet to-be-ratified) START (Strategic Arms Reduction Treaty) II. Bottlenecks in spent fuel and radioactive waste management have slowed down the pace of retirement.

Location and Condition of the Russian Nuclear Fleet

Although some naval units of the fSU have come under the control of former Soviet Republics other than Russia, the two major fleets and the entire nuclear Navy (in the north on the Kola Peninsula and on the Pacific Coast) are wholly Russian. In addition, Russia operates the world's largest fleet of civilian nuclear-powered icebreakers. These ships are operated by the Murmansk Shipping Company and based at its Atomflot facility on the Kola Peninsula. These icebreakers have always been an important component of the Soviet fleet because of the need to operate during winter months.

The Russian Navy is organized into four fleets: the Northern, Pacific, Baltic, and Black Sea Fleets. Like the U.S. Navy, each fleet is further subdivided into strategic and nonstrategic elements. The ballistic missile submarine force (SSBNs) represents the strategic fleet elements. There are no nuclear-powered submarines in service in the Baltic or Black Sea Fleet. Thus, with the breakup of the former Soviet Union, all nuclear-powered submarines and ships remain under Russian Navy command.

The nuclear-powered ships are divided between the Northern Fleet headquartered in Severomorsk on the Kola Peninsula in northwestern Russia near the Norwegian border and the Pacific Fleet headquartered in Vladivostok. Traditionally, submarine forces have been allocated two-thirds to the Northern Fleet and one-third to the Pacific Fleet (36).

Table 4-1 summarizes the types and fleet command of active Russian nuclear vessels as of January 1995. OTA estimates that as of early 1995, a total of 128 nuclear-powered submarines were in active service, 88 in the Northern Fleet and 40 in the Pacific Fleet. In addition, a total of 121 submarines from the Northern (70) and Pacific (51) Fleets have been decommissioned, laid up, or sunk (see table 4-5). A few of these decommissioned submarines are in shipyards for

TABLE 4-1: Russian Nuclear Fleet as of January 1995

Nuclear ships			Northern Fleet/MSC	Pacific Fleet
Ship class and type		**Total**	**Active**	**Active**
SSBN	Ballistic missile submarines	48	32	16
SSGN	Guided missile submarines	22	14	8
SSN/ SSAN	Torpedo attack submarines	58	42	16
CGN	Nuclear cruisers	3	2	1
AGBN	Nuclear icebreakers	7	7	0
AGN	Auxiliary transport	1	1	0
AGBM	Auxiliary missile range	1	0	1
	Total	**140**	**98**	**42**

KEY: MSC = Murmansk Shipping Company

SOURCES: *Jane's Fighting Ships, 1994–95*, Captain Richard Sharpe (ed.), 97th edition (Surrey, U.K.: Jane's Information Group, 1994) ; J. Handler, "Working Paper on: The Future of the Russian Nuclear-Powered Submarine Force," (Draft), Greenpeace Disarmament Campaign, May 15, 1995; T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994); V.A. Danilian, Russian Federation Pacific Fleet, Information presented at the Office of Technology Assessment Workshop on Spent Nuclear Fuel and Waste Management, Washington, DC, Jan. 17–18, 1995.

overhaul and upgrade, but the vast majority are tied up at dockside waiting for defueling and dismantlement.

Both the United States and Russia are currently engaged in major efforts to reduce their nuclear arsenals and the size of their military forces. These efforts are driven by agreements or treaties, budget constraints, obsolescence, and general reduction of Cold War justifications for military forces. Many naval nuclear ships of both countries have been retired or inactivated on a regular basis for more than a decade, and this activity will probably continue for more than a decade in the future. Ships are inactivated when they reach the end of their useful lifetime, when policies are implemented to reduce forces, or when such reduction is necessary to comply with treaty requirements that limit ballistic missile capacity. START I and II have provisions calling for reduction in nuclear warhead launchers over specific time periods. START I came into force in December 1994; START II, which was signed in January 1993, has yet to be ratified by either the United States or Russia. These treaties, however, specify a limit only on the number of deployable nuclear weapons—thus, they would require the destruction of launch tubes, but not the dismantlement of submarines or any other actions on nuclear-powered vessels. Some analysts, however, have projected probable actions by the Russian Navy to comply with START I (and START II when it is ratified), as well as actions that will result from general demilitarization and budget reductions in Russia in the future.

Table 4-2 contains a simplified forecast of the Russian nuclear fleet from 1994 to 2003. The data presented in this table are based on various sources (2,12,29,36,48). The data indicate that significant deactivation of nuclear submarines (which has been under way since 1991) will continue in the near future and that another 70 to 80 additional ships or submarines will be added to the current retired fleet (to be dismantled) over the next decade.

The relatively rapid decommissioning of nuclear submarines in the recent past has placed

TABLE 4-2: Projections of Russian Nuclear Fleet Composition and Numbers of Vessels, 1994 through 2003 (Based on an Interpretation of Actions Following Treaty Agreements)

Year	Ballistic missile submarines	Cruise missile submarines	Attack/ auxiliary submarines	Cruisers	Icebreakers	Other	Total nuclear fleet	Cumulative retirements
1990	61	46	74	3	7	2	193[a]	39
1994	48	22	58	3	7	2	140[b]	102[c]
2000	21	14	45	3	8	1	92[d]	157[e]
2003	18	13	26	3	8	1	69[f]	180[g]

[a] See G. Baham, "Nuclear Fleet of the fSU: A Preliminary Analysis of Dismantlement Activities," Staff Paper prepared for OTA, February 1995.

[b] Submarine numbers were obtained from J. Handler, "Working Paper on: The Future of the Russian Nuclear-Powered Submarine Force," (Draft), Greenpeace Disarmament Campaign, May 15, 1995. Remaining data were obtained from *Jane's Fighting Ships, 1994–95*, Captain Richard Sharpe (ed.), 97th edition (Surrey, U.K.: Jane's Information Group, 1994).

[c] This figure includes 101 nuclear submarines and one icebreaker; it does not include 20 nuclear submarines that are in "active service" but laid up and planned for decommissioning.

[d] This figure includes 26 Victor III-class SSNs and 14 Oscar-class SSGNs in the total, some of which may be retired by this date. In addition, three SSN class nuclear-powered submarines which are under construction are included in this total. For more information, see J. Handler, "Working Paper on: The Future of the Russian Nuclear-Powered Submarine Force" (Draft), Greenpeace Disarmament Campaign, May 15, 1995.

[e] This figure includes 154 nuclear submarines, one icebreaker, one cruiser, and one auxiliary.

[f] This projected total assumes a 20-year service life and includes 5 Typhoon and 13 Delta class SSBNs. Also 8 Victor III class SSNs and 13 Oscar class SSGNs were included in the total count, some of which may be retired by this date. In addition, new construction of five SSN class nuclear-powered submarines is included.

[g] This figure includes 177 nuclear submarines, one cruiser, one auxiliary, and one nuclear icebreaker.

SOURCE: Office of Technology Assessment, 1995.

considerable demands on the logistical infrastructure of the Russian Navy. Two factors complicating decommissioning are the simultaneous retirement of a large number of older, first- and second-generation, general-purpose, nuclear-powered submarines. The normal lifetime of these submarines is 20 years according to a Russian Navy source (11). The second factor is the deterioration of economic conditions since the breakup of the Soviet Union. The severely restricted budgets of the past several years have taken a toll on the logistical infrastructure of the Navy.

The Russian Navy operates ten nuclear submarine bases on the Kola Peninsula and five on the Pacific Coast, which provide home ports for its fleet. The maintenance support for these bases is provided by an network of shipyards and repair facilities. The bases provide routine provisioning of consumable items and minor repair services while the submarine is between at-sea deployments. In addition, the critical role of repair facilities and submarine tenders is to keep the nuclear reactor fully serviced, as well as performing repairs on defective systems. These tasks include removal of irradiated liquid and solid waste, as well as replacement of spent nuclear fuel with fresh fuel. Fuel removal is the riskiest part of nuclear submarine maintenance. Spent nuclear fuel represents the majority of radioactivity in the reactor core. In the U.S. Navy, removal of fuel is normally performed in a naval shipyard during dry-docking. The Russian Navy, however, refuels submarines while afloat using service ships equipped for specialized maintenance procedures.

Russia's Northern Fleet

At the end of 1994, the Northern Fleet had 88 nuclear submarines consisting of 32 SSBNs, and 56 SSGN/SSN[5] general-purpose vessels assigned to the Northern Fleet. A total of 70 nuclear submarines have been retired, including three that were sunk. The locations of major Northern Fleet submarine bases are described in box 4-2. Nuclear-powered submarines and surface ships are stationed at nine major bases located from the Norwegian border on the Barents Sea to Gremikha on the east end of the Kola Peninsula in the vicinity of Murmansk (48). Three bases—at Zapadnaya Litsa, Sevmorput, and the shipyard at Severodvinsk—are connected by rail. All others, except Gremikha, have road connections. The maps in figure 4-1 illustrate the general location of Russian nuclear facilities in the regions of Murmansk and Arkhangel'sk.

Nuclear submarine repair and waste storage facilities are located in the same region. The Northern Fleet is served by the shipyards at Severodvinsk, as well as a number of dedicated naval facilities. Radioactive waste is stored at six Northern Fleet locations on the Kola Peninsula (48). The base at Zapadnaya Litsa generates more waste than all the other bases on the Kola Peninsula. These shipyards and other Northern Fleet facilities are discussed in box 4-3.

Two shipyards in the north are engaged in decommissioning Russian nuclear submarines—*Nerpa*, along the Kola Fjord leading to Murmansk; and *Zvezdochka*, at Severodvinsk in Arkhangel'sk Oblast.

Russia's Pacific Fleet

There were 16 SSBNs and 24 SSGN/SSN general-purpose nuclear submarines assigned to the Pacific Fleet at the end of 1994. A total of 51 nuclear submarines have been retired. Some of the "active" assignments are not fully operational, but they have not been officially decommissioned either (29). Traditionally, the Soviet Navy kept about one-third of its nuclear-powered fleet in the Far East. The headquarters of the Pacific Fleet is located in Vladivostok on the Sea of Japan. Figure 4-2, a map of the Russian Pacific Coast, illustrates the location of major naval facilities.

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[5] SSBN (Nuclear Ballistic Missile Submarine); SSGN (Nuclear Guided Missile Submarine); and SSN (Nuclear Attack Submarine). See table 4-1 for additional definitions for nuclear-powered ships and submarines.

BOX 4-2: Bases Serving the Northern Fleet of the Russian Navy

Zapadnaya Litsa: This fjord contains the oldest submarine operating facility in the former Soviet Union, also called Murmansk-150, probably commissioned in 1958. Four additional facilities are located along this 16-km-long and 1- to 2-km-wide body of water, including those at Nerpichya Bay, Bolshaya Lopatka Bay, Malaya Lopatka Bay (repair facility), and Andreeva Bay (waste storage). The Russian Navy's six Typhoon SSBNs are based at Nerpichya Bay. Bolshaya Lopatka services general-purpose, guided missile and attack nuclear submarines. Malaya Lopatka is a repair facility, and the Andreeva Bay Base stores nuclear waste materials.

Ara Bay: This is a 10-km fjord about 48 km north-northwest of Murmansk and 16 km east of Zapadnaya Litsa on the Barents Sea coast. The bay contains a small general-purpose nuclear submarine base.

Ura Bay: Ura Bay contains a complex of three facilities for servicing nuclear submarines. Ura Bay is the largest, with two smaller facilities at Chan Ruchey and Vidyaevo.

Sayda Bay: The naval base at Gadzievo is located on the eastern side of Sayda Bay facing the town. Strategic missile submarines are stationed at this facility. Laid-up nuclear submarines are kept at three piers south of the town on the opposite side of the bay.

Olenya Bay: The naval base at Olenya Bay (Murmansk-60) is a small fjord, 6-km-long, located 3 to 4 km south of Sayda Bay and ending at Kut Bay.

Pala Bay: Pala Bay is a small, 4-km-long fjord that juts to the southwest at the entrance to Olenya Bay. The town of Polyarny is located to the east, on the Murmansk Fjord. Delta and Yankee class submarines have been stationed here in the past. Several decommissioned submarines are stored here.

Severomorsk: Severomorsk is the headquarters of the Russian Northern Fleet. It is located on the eastern side of Kola Fjord, 25 km north of the City of Murmansk. Severomorsk is a city of 70,000 in the greater metropolitan area of Murmansk, which has 600,000 inhabitants. The base is also one of the major storage facilities for armaments for the Northern Fleet.

Gremikha: Gremikha, also known as "Yokanga base," is located at the eastern end of the Kola Peninsula on the Barents Sea, 300 km east of the mouth of Kola Fjord. This base has no road or rail access and must be reached by sea. The Alfa class SSNs were based here, before they were laid up, the Oscar class has also been based here.

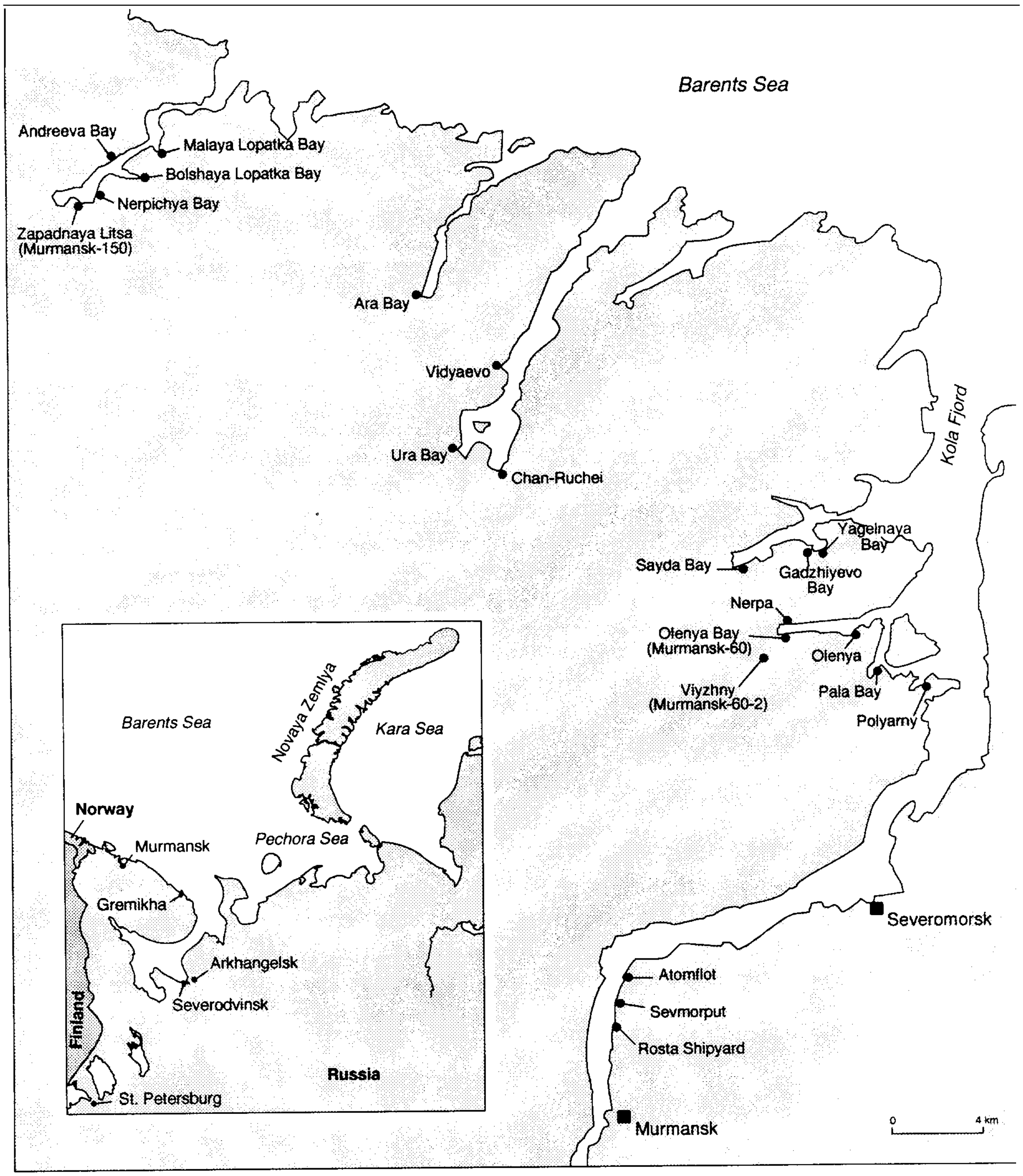
SOURCE: T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994); J. Handler, "The Northern Fleet's Nuclear Submarine Bases," *Jane's Intelligence Review-Europe*, Dec. 1993.

The location of major bases for submarine operations in the Pacific Fleet is described in box 4-4. Nuclear-powered submarines and surface ships have been stationed at four major bases (Rybachiy, Vladimir Bay, Zavety Ilyicha, and Pavlovsk), and several minor bases from the Kamchatka Peninsula to Vladivostok on the Sea of Japan, near the Chinese border (31). Pacific fleet shipyards and other facilities are shown in box 4-5.

Murmansk Shipping Company Facilities

The operations of the Murmansk Shipping Company (MSC), a private company and operator of the Russian nuclear-powered icebreaker fleet, are conducted out of the Atomflot facility, which is located north of the city of Murmansk. The base is situated on the Murmansk Fjord, which has waterborne access to the Barents Sea via the Kola Fjord. Atomflot is a self-contained facility for supporting the operations of the icebreaker fleet. It contains workshops, liquid and solid waste processing systems, and warehouses for resupply of the ships. Major machinery and hull repairs are performed at dry docks in the City of Murmansk. Zvezdochka shipyard at Severodvinsk makes major repairs to icebreaker reactors.

FIGURE 4-1: Northern Fleet Nuclear Submarine Bases



Source: Office of Technology Assessment, 1995, adapted from Handler, J., "The Northern Fleet's Nuclear Submarine Bases," *Jane's Intelligence Review-Europe,* Dec. 1993.

BOX 4-3: Northern Fleet Shipyards, Repair, Refueling, and Nuclear Waste Storage Facilities

Zapadnaya Litsa[a]: Radioactive waste is stored here in containers placed in a concrete bunker. Reported past practices were to cover bunker sections in concrete and seal them as they were filled up.

Olenya Bay: The Nerpa,[a,b] refit yard is located in the town of Olenya Bay. This base has been designated for dismantlement under START I. A small nuclear waste storage facility is located on the southern end of Kut Bay on the beach of the yard.

Pala Bay: Shkval Repair Yard[a] is connected to the Polyarny base at Pala Bay. It is a large repair and refit facility located at the end of the bay for SSN attack class submarines. A naval waste storage site is located on the east side of the bay. Two waste transport ships are used for storage and movement of nuclear-contaminated materials from the refit facility.

Sevmorput: The naval shipyard at Sevmorput[a] is located at Rosta on the Kola Fjord, southwest of the Severomorsk headquarters and just north of the City of Murmansk. New and spent fuel assemblies are stored at the shipyard for refueling operations. Spent fuel has been shipped directly from here to Mayak for reprocessing in the past. New fuel assemblies for the entire Northern Fleet are usually stored here until they are picked up by service ships.

Gremikha: Gremikha[a] lies in ice-free waters but has no significant rail or road access. Cutbacks in the Navy's budget have affected the local inhabitants, and many have left the area. Between 17 and 19 decommissioned nuclear submarines are stored here, as well as several officially operational ships waiting for decommissioning. Nuclear waste from refueling operations is also stored on the base.

Severodvinsk: The town of Severodvinsk had 170,000 inhabitants at the end of 1993. There are two major shipyards in Severodvinsk: Sevmash[a] and Zvezdochka[b]. They are located at the north end of the town. The Akula class SSN are constructed at the Sevmash yard. The Yagry Island docks in the Zvezdochka yard are also designated for the dismantlement of SSBNs under START I. Approximately one ship is now being processed at this site per year.

[a] These are also refueling facilities.
[b] Submarine dismantled yards.

SOURCE: T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994).

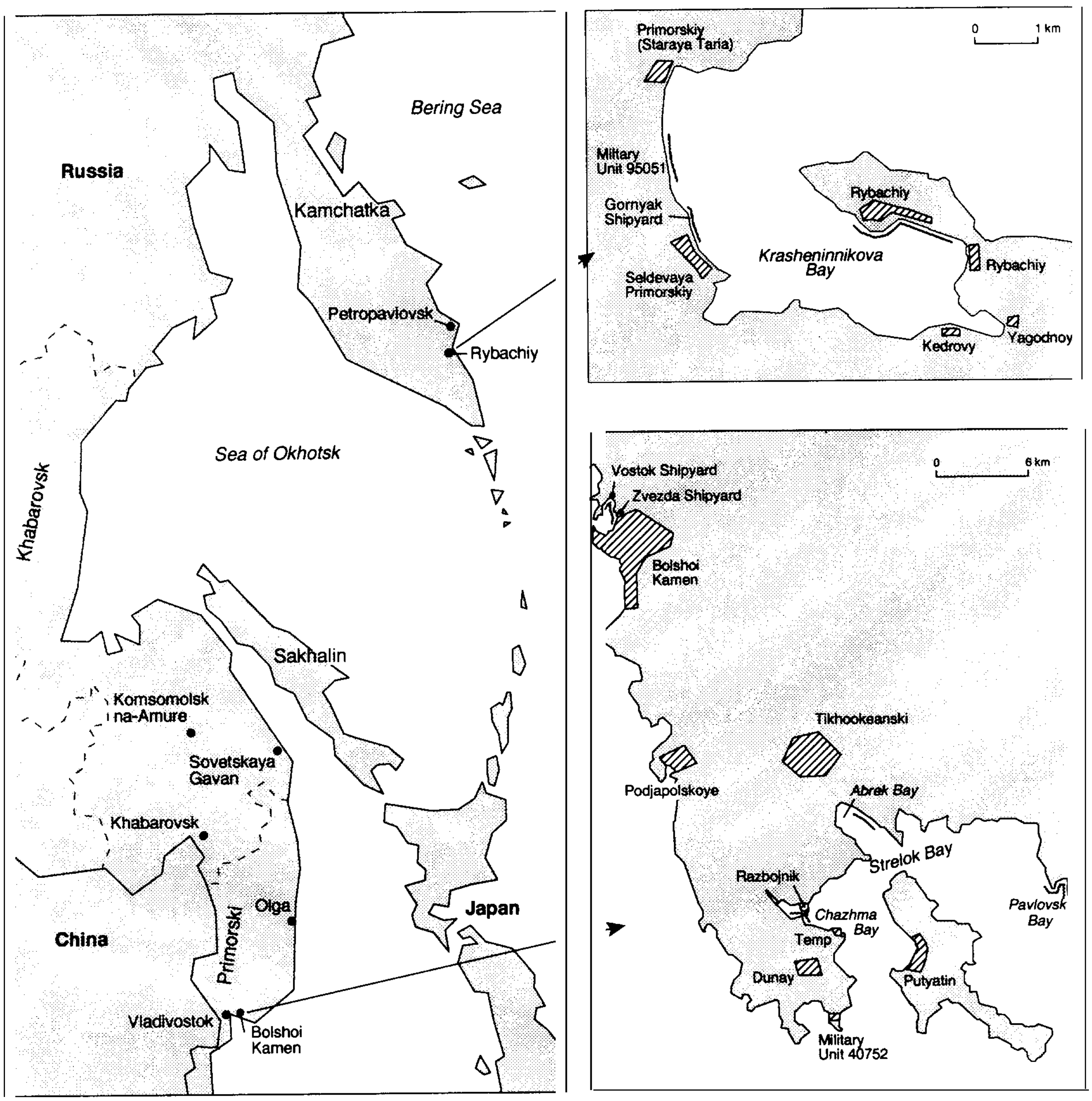
Nuclear waste storage and handling is performed with the assistance of the five support service ships listed in box 4-6. In addition, MSC has storage facilities for low- and medium-level waste. Table 4-3 describes the current status of its five support service ships.

Decommissioning of Nuclear Submarines

The Russian Navy laid up and began to decommission 15 to 25 nuclear submarines per year from 1990 to 1994. Many of these ships had reached the end of their useful life and had outdated weapons systems and power plant technology. If current plans are followed, an average of six nuclear submarines per year will probably be taken out of service by the Russian Navy during the next decade.

Normal operation of the current Russian fleets would require the replacement of about 20 reactor cores per year, 10 for each fleet (49). However, storage facilities currently have room for only several additional reactor cores. The policy of the Russian Navy has been to reserve even this limited core storage space on service ships and shore facilities to refuel *operational* submarines only. Therefore, no spent fuel storage is available for decommissioned submarine reactors. It is likely that spent fuel on decommissioned submarines will not be removed for at least three to five

FIGURE 4-2: Pacific Fleet Nuclear Submarine B



Source: Office of Technology Assessment, adapted from Handler, J., "Russia's Pacific Fleet-Submerine Bases and Facilities," Jane's *Intelligence* ***Review-Europe,*** Apr. 1994

BOX 4-4: Nuclear Submarine Bases of the Russian Pacific Fleet

Krasheninnikova Bay (near Petropavlovsk): Rybachiy is a major nuclear submarine base on the Kamchatka Peninsula. The base is located 15 km southwest of the City of Petropavlovsk across Avachinskaya Bay.

Postovaya Bay (near Sovetskaya Gavan): Further south of the Kamchatka Peninsula in the Khabarovsk Kray is a small town called Zavety Ilyicha. The town is located on Postovaya Bay between the seaport of Vanino and Sovetskaya Gavan. Zavety Ilyicha was a small submarine base during the 1980s. The four submarines operating out of the base were retired in 1990. Their fuel has not yet been offloaded. The Pacific Fleet has committed to removing the submarines. The first was removed in October 1993.

Vladimir Bay (near Olga): This small submarine base is located 300 km northeast of Vladivostok, just south of Olga on the Japan Sea coast. Vladimir Bay is relatively isolated with poor road and rail access. The deep natural harbor is ice free during the winter months. The nuclear submarine facility is located on the north end of the bay. A few submarines still operated from here as of late 1993. Plans to offload fuel from decommissioned submarines were abandoned by the Navy due to protests from local residents.

Strelok Bay (Pavlovsk): A major submarine base is located 65 km southeast of Vladivostok at Pavlovsk. It housed nine SSBNs as of 1990 as well as additional general-purpose nuclear submarines. According to Pacific Fleet press officer Captain First Rank V. Ryzhkov, as of autumn 1992 these older nuclear-powered submarines were awaiting retirement. A report from the Pacific Fleet press office indicates that all of the Yankee and Delta class SSBNs stationed here will be retired. In addition, three submarines damaged in nuclear accidents are stored here. Additional sealed reactor compartments from dismantled submarines are stored at Razbojnik.

Vladivostok: Pacific Fleet headquarters and operations center.

SOURCE: J. Handler, "Trip Report: Greenpeace Visit to Moscow and Russian Far East, July–November 1992: Russian Navy Nuclear Submarine Safety, Construction, Defense Conversion, Decommissioning, and Nuclear Waste Disposal Problems" (Washington, D.C.: Greenpeace, Feb. 15, 1993).

BOX 4-5: Pacific Fleet Shipyards, Repair, Refueling, and Nuclear Waste Storage Facilities

Nuclear submarine facilities are listed from the Kamchatka Peninsula in the North to Vladivostok in the South along the Pacific Coast.

Krasheninnikova Bay (near Rybachiy): A major radioactive waste site for the Pacific Fleet. Is located at the southern end of Krasheninnikova Bay, across from the naval base at Rybachiy. The unit contains three burial trenches for solid radioactive waste, fresh fuel storage, and piers for operating its three refueling support ships and two liquid waste tankers. Shipyard 30 at Gornyak is a nuclear submarine shipyard located in the southwestern corner of the bay.

Shkotovo-22 (Military Unit 40752): On the Shkotovo Peninsula near Dunay is a large waste disposal site. Spent nuclear submarine fuel is usually kept here prior to shipment for reprocessing at Chelyabinsk by rail. This facility has several support ships attached to it.

(continued)

BOX 4-5: Pacific Fleet Shipyards, Repair, Refueling, and Nuclear Waste Storage Facilities (Cont'd.)

Chazhma Ship Repair Facility:[a] Chazhma Bay is a small refit and refueling facility also located near the settlements of Dunay and Temp on the east end of the Shkotovo Peninsula facing Strelok Bay. A serious nuclear incident occurred here on August 10, 1985, during the refueling of an Echo II submarine reactor. While removing the reactor lid, control rods were partially withdrawn accidentally; the reactor overheated and caused an explosion that killed 10 men and contaminated the surrounding environment over an area up to 5 to 30 km from the site.

Zvezda or Bolshoi Kamen:[a] This is a major nuclear submarine overhaul and refueling shipyard. Bolshoi Kamen is a designated submarine dismantlement facility under START I.

[a] Refueling facility.

SOURCE: J. Handler, "Radioactive Waste Situation in the Russian Pacific Fleet," Greenpeace trip report, Nuclear Free Seas Campaign (Washington, D.C.: Greenpeace, Oct. 27, 1994).

BOX 4-6: Service Ships of the Nuclear Icebreaker Fleet

Imandra is a 130-m-long service ship used for storing fresh and spent fuel assemblies. The ship was built by the Admiralty shipyard in St. Petersburg and put into service in 1981. The total capacity of 1,500 assemblies allows the ship to store fuel from up to six icebreaker reactors. The ship uses a dry storage system with waterproof receptacles each holding five fuel assemblies floating in a pool of water.

Lotta is a service ship 122 m long built in 1961. The ship was upgraded in 1993 to handle the transfer of fuel assemblies into the newest railway shipping containers (TUK-18) for spent fuel shipment to Mayak. The ship has 16 sections with 68 containers in each. Used fuel assemblies are stored aboard the *Lotta* for a minimum of three years. The ship has 65 damaged fuel assemblies stored on-board, which cannot be processed by the Mayak facility. These were transferred from the *Imandra* in 1985.

Serebryanka is a 102-m-long tanker used for offloading liquid radioactive waste directly from nuclear-powered icebreakers or the service ship *Imandra.* The ship has eight tanks, each with a capacity of 851 m^3, and was used for discharging liquid waste directly into the Barents Sea until 1986.

The ***Volodarsky*** is the oldest ship in the Murmansk Shipping Company fleet. The 96-m ship was constructed in 1929 and is of riveted steel plate construction. Until 1986 the ship was used to transport solid radioactive waste from Atomflot to the west side of Novaya Zemlya for dumping into the Barents Sea. The ship has 14.5 metric tons of low- and medium-level waste stored aboard.

The ***Lepse*** is a spent fuel service ship of 87-m length built in 1934 and converted in 1962. The *Lepse* is a special case: between 319 and 321 damaged fuel assemblies were stored on the *Lepse*. These fuel assemblies expanded due to lack of proper cooling before they were put in built-in storage locations. The result was that the damaged assemblies could not be removed. They remain aboard the *Lepse*, enclosed within a concrete cover to reduce radiation emissions.

SOURCE: T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994).

TABLE 4-3: Spent Fuel, Liquid, and Solid Radioactive Waste Storage at *Atomflot*				
Ship	**Displacement (metric tons)**	**Fuel assemblies**	**Liquid waste (cubic meters)**	**Solid waste (metric tons)**
Imandra	9,500	1,500	545	0
Lotta	N/A	4,080[a]	0	0
Serebryanka	4,000	0	851	0
Volodarskij	5,500	0	0	14.5
Lepse	5,000	642[b]	46	? (36 containers)
Ship storage		6,222	1,442	14.5 (+ 36 containers)
Land storage		0	357	<1 (incinerated)

[a] The capacity is 5,440, or 75% filled with undamaged fuel, of which 840 assemblies are naval fuel.

[b] Of which 50% are not extractable.

KEY: N/A = Not available.

SOURCES: T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994); O. Bukharin, "Nuclear Fuel Management in the Russian Navy," staff paper prepared for OTA, November 1994.

years after the reactor is shut down, and no additional shipboard or land-based storage will be provided for spent fuel (42).

Refueling Practices

Submarines are refueled according to the schedules authorized by each fleet's commander-in-chief. Under past routine Russian naval operations, refueling was conducted every seven to 10 years and coincided with submarine refit and overhaul.[6] Starting in the 1980s, the Navy also began defueling many retired submarines. In the past, submarines undergoing overhaul at shipyards were refueled in dry docks. However, more recently, the standard approach has been to refuel while floating. Fuel is now changed not at shipyards but with Navy floating refueling facilities (every three to five years) (see table 4-4). Icebreakers are usually refueled every three to four years at the MSC's Atomflot base by using service ships to transfer and store fuel awaiting shipment for reprocessing. Table 4-4 presents a list of 10 refueling facilities operated by the Russian Navy and MSC.

In the Navy, the submarine service ships used for defueling are also known as "floating technical bases" or workshops (see box 4-7). These service ships are known in the West as *PM-124* and *Malina* class submarine support ships. The PM-124 class is a converted Finnish-built cargo barge. In its two steel aft compartments, the ship can carry fuel from approximately two reactor cores (560 fuel assemblies). The PM-124 ships are now about 30 years old and are considered beyond their useful lifetimes.[7]

Three Malina class ships—PM-63 and PM-12 in the north and PM-74 in the Pacific—are relatively modern and can serve nuclear vessels of any type. Malina class ships are the Navy's preferred ships for use in current fuel management operations.[8] (There are, however, problems with the condition of these ships as well.) Malina class ships are equipped with two 15-metric ton cranes to handle reactor cores and equipment; each can carry fuel from approximately six reactor cores (1,400 fuel assemblies).

In a typical refueling operation, the submarine is docked between the submarine service ship and the pier of the refueling facility. (The facility

[6] Refueling of submarines occurs frequently, every two and a half to five years. In case of a reactor accident, fuel management strategy is decided by an expert council.

[7] The PM-48, PM-124 (both based in Kamchatka), and PM-80 (based in Primorye) are out of service because of accidents and worn-out conditions. Only the PM-125 and PM-133 are used for fuel management operations in the Pacific (27).

[8] The years of production of the PM ships are 1984 (PM-63), 1986 (PM-74), and 1991 (PM-12). (35).

TABLE 4-4: Refueling Facilities

Northern Fleet	Pacific Fleet	Murmansk Shipping Company
Zapadnaya Litsa	Zvezda repair yard (Shkotovo-17 near Bolshoi Kamen)	Atomflot base
Nerpa shipyard (Olenya Bay)	Chazhma Bay repair facility (Shkotovo-22, Chazhma Bay)	
Shipyard No. 10 Shkval (Polyarny, Pala Bay)	Shipyard No. 30 at the Gornyak complex (Krasheninnikova Bay)	
Sevmash shipyard (Severodvinsk)		
Gremikha		
Shipyard No. 35 at Sevmorput (Murmansk)[a]		

[a] Because the plant is located near residential areas. refueling activities at Sevmorput were terminated by the Murmansk authorities in 1991. The last refueling took place on December 31, 1991.

SOURCES: T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994); J. Handler, "The Northern Fleet—Nuclear Submarine Bases," *Jane's Intelligence Review-Europe*, Dec. 1993.

BOX 4-7: Service Ships of the Russian Nuclear Navy

Malina class nuclear submarine support ships are 137-m (450-feet) long, with 10,500-ton displacement. Each ship has a storage capacity of 1,400 fuel assemblies. The ships were constructed by the Nikolayev Shipyard in the Ukraine. Each carries two 15-ton cranes for removal and replacement of fuel assemblies.

PM-63	Northern Fleet	Severodvinsk (1984)
PM-74	Pacific Fleet	Krasheninnikova Bay, Kamchatka (1986)
PM-12	Northern Fleet	Olenya Bay, Zapadnaya Litsa (1991)

PM-124 class (Project 326) lighters are nuclear-submarine support barges with a capacity of 560 fuel assembles each. These units can also store up to 200 m^3 of liquid radioactive waste.

PM-124	Northern Fleet	Zvezdochka shipyard, Severodvinsk
PM-78	Northern Fleet	Zvezdochka shipyard, Severodvinsk
PM[a]	Northern Fleet	Zvezdochka shipyard, Severodvinsk
PM-80	Pacific Fleet	Shkotovo waste site
PM-125	Pacific Fleet	Shkotovo waste site
PM-133	Pacific Fleet	Shkotovo waste site
PM-48	Pacific Fleet	Krasheninnikova Bay, Kamchatka

(continued)

BOX 4-7: Service Ships of the Russian Nuclear Navy (Cont'd.)

Pinega class nuclear-submarine support ships are 122-m (400-feet) long with 5,500-ton displacement. Each is used for transporting liquid radioactive waste. The ships were constructed at Szczecin, Poland.

Amur	Northern Fleet	Pala Guba, Kola Fjord (1986)
Pinega	Pacific Fleet	Bolshoi Kamen, Vladivostok (1987)

Vala class special tankers are 73-m (240 feet) long with a displacement of 2,030 tons. The ships were constructed between 1964 and 1971 for the purpose of transportation and disposal of liquid radioactive waste.

TNT-5	Pacific Fleet	Bolshoi Kamen, Vladivostok
NT-27	Pacific Fleet	Bolshoi Kamen, Vladivostok
TNT-11	Pacific Fleet	Krasheninnikova Bay, Kamchatka
TNT-23	Pacific Fleet	Krasheninnikova Bay, Kamchatka
TNT-12	Northern Fleet	Pala Guba, Kola Fjord
TNT-19	Northern Fleet	Unknown
TNT-29	Northern Fleet	Unknown

[a] Designation unknown.
SOURCES: J. Handler, "Russia's Pacific Fleet—Problems with Nuclear Waste," *Jane's Intelligence Review,* Mar. 1995; J. Handler, "Russia's Pacific Fleet—Submarine Bases and Facilities," *Jane's Intelligence Review-Europe,* Apr. 1994; *Jane's Fighting Ships, 1994–95,* Captain Richard Sharpe (ed.), 97th edition (Surrey, U.K.: Jane's Information Group, 1994); T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994).

provides electric power, fresh water, and other support services.) Refueling begins with the removal of a portion of the submarine hull and lifting of the reactor lid.[9] Measures are taken to prevent release of radioactive aerosols to the environment (26). In the next step, the primary cooling circuit is disconnected and spent fuel is removed from the reactor vessel. Fuel is removed assembly by assembly using the cranes of the service ship with the help of special metal sleeves to shield spent fuel. Spent fuel assemblies are accommodated inside cylindrical cases, which are placed in the storage compartments of the service ship. After defueling, the reactor vessel is cleaned out and the reactor section is overhauled. Reactor waste is loaded on the service ship.[10] Finally (with an operational ship), fresh fuel is inserted into the reactor vessel, the primary cooling circuit is filled with new coolant, the reactor lid is installed to seal the reactor, and the portion of the hull is welded in place.

Typically, it takes approximately one month to defuel, and two to three months to refuel, one submarine (27). (Refueling of an icebreaker is reported to take approximately 45 days. Five to seven days are needed to remove spent fuel, and two to three days to insert fresh fuel; the remainder is required for auxiliary operations (53).

[9] Immediately after reactor shutdown and prior to refueling, fuel is kept in a reactor core to allow for decay of short-lived fission products. During this initial period cooling of the fuel is provided by reactor pumps.

[10] Liquid waste—50–80 metric tons of washing water, etc., from a twin-reactor propulsion unit—is filtered and discharged into the sea. Solid waste (155–200 cubic meters) and spent fuel (2–3 cubic meters) are stored aboard the service ship.

Refueling Problems

The rate of refueling operations has declined following reductions in operational schedules for the Russian nuclear fleet. For example, with a refueling capacity of four to five submarines per year, the Pacific Fleet in the past refueled three to four submarines per year. In 1994 and early 1995, spent fuel was removed from only one decommissioned submarine (11).[11] The Navy is facing significant delays in defueling/refueling submarines due to the following problems:

1. *Lack of fuel transfer and storage equipment:* In the past, many pieces of refueling and spent fuel storage equipment were produced outside Russia. The breakup of the Soviet Union and dissolution of the Warsaw Pact have interrupted the equipment supply. For example, Malina class submarine service ships were produced at the Nikolayev shipyard in Ukraine. A new Malina class ship for the Pacific Fleet had been ordered from Nikolayev. Because of the breakup of the Soviet Union, construction was never completed.
2. *Saturation of the spent fuel storage capacity:* Because the central storage facilities and some submarine support ships are full (see below), they cannot take any newly removed spent fuel. After submarine reactors are shut down, it is necessary to keep auxiliary cooling systems running to remove heat generated within the reactor core. To accomplish this heat removal, it is likely that circulation within both of the reactor coolant loops must be maintained at a reduced level. Many Russian submarines thus will have such continued standby operations in place for many years. This creates further risks of accidents or unintentional releases of radionuclides in the future.
3. *Difficulties of removing fuel from submarines with damaged reactor cores:* There are three submarines in the Pacific that cannot be defueled because of damaged reactor cores. Experts believe that major portions of these submarines will have to be treated as waste and buried. The work requires significant R&D and has not been started.

Radioactive Waste Disposal

Reactor compartments that have been prepared for flotation are currently stored near naval bases or beached in several locations on the Kola Peninsula and along the Pacific Coast from Vladivostok north to the Kamchatka Peninsula. In recent years, once the reactor compartment has been sealed, the Russian Navy has stored the reactors floating in open bays or along rivers near naval bases. To provide greater flotation, one additional sealed compartment on each end of the reactor compartment remains attached to the package. The advantages of this method are that the sealed package is less likely to sink than the entire submarine, and it is easier to handle and transport by water. Disadvantages include the possibility that over periods of decades to hundreds of years, seawater corrosion will penetrate the sealed reactor compartment and allow the exchange of water with the environment. In the United States, dismantled submarine reactor compartments are sealed and shipped to a dry, shallow, land burial site in Hanford, Washington.

Several Russian studies have proposed various methods for establishing reactor compartment disposal facilities. These include placing reactor compartments in concrete-lined trenches or in underground storage (42). One plan is to put some reactor compartments in tunnels near submarine bases in the north and Far East. However, the prospects for implementation of this program remain uncertain. The Russian regions of Murmansk and Arkhangel'sk have reportedly agreed to the siting of permanent storage facilities for radioactive waste on the southwestern tip of the island of Novaya Zemlya at the Bashmachnaya Bay (48).

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[11] It has been reported that only one defueling/refueling operation was conducted in 1993 in the Pacific Fleet, compared to five refuelings and three defuelings in 1990 (27).

In a recent meeting of regional authorities,[12] Russian officials decided to pursue studies related to the development of a long-term solid waste storage facility on Novaya Zemlya. The facility would consist of deep burial trenches covered with gravel. The proposed site is located on Bashmachnaya Bay, on the southwestern part of Yuzhny Island.

Evaluations were previously conducted of five potential sites on the Kola Peninsula. A site at Guba Ivanovskaya near Gremikha was chosen and subsequently rejected by GAN.

Some Russian geologists believe that permafrost is a suitable storage medium for high-level solid waste. Novaya Zemlya permafrost is 200 meters thick, stable over the long term, with no water migration. However, Western opinion is more skeptical. The Bellona Foundation notes that the facility will have to be far more complex than a simple "hole in the ground."

Dismantlement of Submarine Hulls

In recent years the Russian Navy has been dismantling decommissioned nuclear submarines at several sites. Dismantlement takes place in Northern Fleet facilities on the Kola Peninsula and Arkhangel'sk (Nerpa and Zvezdochka yards) and in Pacific Fleet facilities in the Vladivostok area (Bolshoi Kamen yard). A review of the decommissioning procedures used by the Russians, as well as the status of the activities, is presented below.

The U.S. Navy is also conducting a major nuclear submarine dismantlement program. The current program began in 1992 and calls for the United States to dismantle completely 100 nuclear submarines at a total cost of approximately $2.7 billion (30). The U.S. program, unlike the current Russian activity, will result in burying sealed reactor compartments in an underground site at the Hanford, Washington, nuclear facility run by the Department of Energy. The remainder of the U.S. submarine hulls and equipment will be disassembled, cut into pieces, and either recycled, scrapped, or treated as hazardous waste. Spent fuel removed from dismantled U.S. nuclear submarines is currently being stored at the dismantlement shipyard on Puget Sound, Washington, awaiting the results of an Environmental Impact Statement to determine where long-term storage facilities will be located.

The Zvezdochka shipyard at Yagry Island in Severodvinsk and the Nerpa repair yard on Olenya Bay are the primary facilities for dismantlement of Russian Northern Fleet nuclear submarines. The Russian Pacific Fleet has also begun dismantling submarines at the Bolshoi Kamen shipyard near Vladivostok. As of January 1995, only 15 of the retired submarines had been dismantled completely. A total of 101 submarines in both fleets are in various stages of decommissioning (see table 4-2). Seventy of these decommissioned submarines had *not* had spent fuel removed from their reactors. Although a large number of submarines have been decommissioned, the defueling and dismantling process has been slow. Some of the decommissioned submarines have been out of service with spent nuclear fuel still on-board for more than 15 years (30). By the end of 1994 there were 20 additional submarines classified by Western sources as in service which were actually laid up (see table 4-5).

Between 1995 and 2003, this backlog is expected to continue to grow.[13] An additional 70 to 80 submarines will probably be decommissioned due to both age and consolidation of the fleet. The total number of decommissioned submarines could increase to around 180. At the current rate of dismantlement—about five per year—it will take one to two decades to complete dismantlement of all of the nuclear submarines that will be decommissioned by the year 2003.

[12] A meeting of the interagency Committee for Ecology of Murmansk was held at the Murmansk City Hall on June 21, 1995. The committee was briefed by MSC, the Kola Nuclear Power Plant, the Russian Navy, and government officials from the region.

[13] The decommissioning rate will be slower than in the past several years. Refer to table 4-2 for a more detailed explanation of the projected composition of the Russian nuclear fleet.

TABLE 4-5: Russian Nuclear Submarines Decommisioned as of January 1995
Northern and Pacific Fleets

Status of decommissioned nuclear submarines	Total	Northern Fleet	Pacific Fleet
Dismantled and defueled	15	6	9
Defueled (waiting for dismantlement) or sunk	36	20	16
Decommissioned or laid-up (with fuel on board)	70	44	26
Total submarines out of service	121[a]	70	51

[a] Table 4-2 which is based on Western sources of information, indicates that 101 nuclear submarines were retired from service as of January 1, 1995. The additional 20 nuclear subs should be classified as "in-service, inactive" according to the Russian sources cited above. These vessels are currently laid-up and planned for decommissioning.

SOURCES: V. Litovkin, "93 Nuclear Submarines," *Izvestia*, July 9, 1993:6; V. Danilian and V.L. Vysotsky, "Problems of Spent Nuclear Fuel Management in the Pacific Fleet of the Russian Navy," paper presented at the OTA Workshop on Spent Nuclear Fuel and Waste Management, Jan. 17–18, 1995, Washington, D.C.; G. Baham, "Nuclear Fleet of the fSU: A Preliminary Analysis of Dismantlement Activities," Staff Paper prepared for OTA, February 1995; Gosatomnadzor, "Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993," approved by Order of the Russian Federal Nuclear Inspectorate [Gosatomnadzor] No. 61 from May 13, 1994, translated by Greenpeace International; North Atlantic Treaty Organization, Committee on the Challenges of Modern Society, *Cross-Border Environmental Problems Emanating from Defense-Related Installations and Activities*, Final Report, Volume I: Radioactive Contamination, Phase I: 1993–1995 (Kjeller, Norway: NATO, 1995).

The Nerpa shipyard, located in Olenya Bay, is planning to expand its submarine dismantling facilities to accommodate new equipment provided by the United States, using Nunn-Lugar funds. The goal is to expand processing at Nerpa to dismantle up to five submarines per year. The first submarine dismantled by Nerpa in early 1995 took five months for the reactor compartment to be cut out of the hull and prepared for flotation.

MANAGING SPENT FUEL FROM THE RUSSIAN FLEET: ISSUES AND OPPORTUNITIES FOR COOPERATION

A key activity associated with the Russian nuclear fleet of submarines and icebreakers is management of the nuclear fuel. During normal operations of the fleet, each reactor must be refueled periodically. And when submarines and other ships are being dismantled—as they are now—the spent fuel must be removed and stored or processed in some way. This spent nuclear fuel is highly radioactive, and accidents or releases of radioactivity are possible during the multiple steps required unless all parts of the system are technologically sound and operated under high standards of safety and protection. Russian naval reactors and fuels represent a variety of designs and manufactures and therefore present unique handling, storage, and disposal problems. Box 4-8 describes the reactor and fuel designs (see table 4-6), and box 4-9 discusses the integration of naval fuel into the Russian national nuclear fuel cycle. Figure 4-3 presents a schematic diagram of the Russian naval nuclear fuel management process.

Other problems are evident with service ships and land-based facilities that were designed for interim storage and are now used for long-term storage. Also, submarines that were to be defueled immediately after being taken out of service have become long-term spent fuel storage facilities themselves. An approach that would include safety and operational analyses reflecting changes in facility missions has not been developed.

BOX 4-8: Naval Reactor and Fuel Designs

Soviet/Russian submarines have been equipped with reactors of several designs. Several submarines of the November and Alfa classes were powered with lead-bismuth-cooled reactors (liquid metal reactors, LMRs). High power density in an LMR and its compact design allowed reduction in submarine size while retaining the power of the naval propulsion unit. As a result, Alfa class ships were very fast. However, maintenance problems associated with neutron activation in bismuth and reactor accidents have led to early retirement of the LMR-powered submarines.[a]

At present, probably all nuclear-powered vessels in Russia use one or two pressurized water reactors (PWRs). There are three generations of naval PWRs. Reactors of the first generation were deployed between 1957 and 1968, and all have been decommissioned. Reactors of the second generation were deployed between 1968 and 1987 with many still in service; third-generation reactors have been installed on submarines since 1987. The best described is a 135-MW KLT-40 reactor, which has been installed on icebreakers since 1970. This is a pressurized water reactor with the following principal components: a pressure vessel, a reactor lid that carries five reactivity control assemblies and four actuators for an emergency core cooling system, and a fuel core. Steam for the propulsion unit is produced in four vertical steam generators. It is thought that submarine reactors have designs similar to that of KLT-40 but are smaller in size.

It is believed that a reactor core consists of 180 to 270 fuel assemblies, containing several fuel rods each. In older designs, fuel rods were round. Newer reactor core designs utilize fuel rods of cross, plate, or cane shapes.[b] The level of enrichment of uranium fuel varies significantly depending on reactor core design. (Apparently, a reactor system of a specific design may use reactor cores of different types.) Reactors of the first and second generations were fueled with 21 percent uranium-235 (U-235). Reactors of the third generation have cores consisting of two to three enrichment zones, with enrichment levels varying between 21 and 45 percent U-235. Standard naval reactor fuel in Russia is stainless steel- or zirconium-clad Cermet material (dispersed fuel), in which uranium dioxide particles are embedded in a nonfissile aluminum matrix.[c]

Some reactors are fueled with weapons-grade (more than 90 percent U-235) or near-weapons-grade (70 to 80 percent U-235) uranium. For example, liquid metal reactors were almost certainly fueled with weapons-grade uranium. Also, some icebreaker fuels are zirconium-clad, uranium-zirconium metallic alloys with uranium enriched to 90 percent U-235.[d] (Also, at times, reactors might have been fueled with experimental fuels whose enrichment could differ significantly from that of regular fuel for this type of reactor core.)

Some reactors, however, are fueled with relatively low enriched uranium: for example, in the proposed design of a floating desalination facility, two KLT-40 reactors of the facility's power unit are designed to be fueled with 1.8 metric tons of uranium dioxide enriched to 8.5 to 10 percent U-235.

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[a] One common failure mode involved localized overcooling and solidification of the coolant.

[b] Such shapes increase the surface of fuel rods and, in this way, improve the core's heat transfer characteristics.

[c] Typically, Cermet fuels offer better mechanical integrity, swelling resistance, and containment of fission products than uranium alloys. They also have superior heat conductivity when compared with uranium ceramics.

[d] For example, HEU-fueled icebreakers have cores containing 151 kg of 90 percent enriched uranium. According to reactor designers, the reactor of the nuclear-powered ship *Sevmorput* is fueled with 200 kg of 90 percent enriched uranium.

SOURCES: V. Kovalenko, "Braving the Chill of the Market," *Nuclear Engineering International*, Jan. 1993; J. Handler, Greenpeace, personal communication, October 1994; U.S. Department of Energy, Office of Foreign Intelligence, *Radioactive Waste Management in the Former USSR: Volume III*, prepared by D.J. Bradley, PNL-8074 (Richland, WA: Pacific Northwest Laboratory, 1992); O. Bukharin, "Nuclear Fuel Management in the Russian Navy," Staff Paper prepared for OTA, November 1994.

TABLE 4-6: Russian Nuclear Naval Propulsion Reactor Design

Type of vessel	Number / type reactors	Power per reactor, MW_t	Fuel enrichment, percentage Uranium-235
Submarines, first generation (1958 to 1968)			
Hotel, Echo, November	2 PWR / VM-A	70 MWt	20
Submarines, second generation (1968 to present)			
Charlie	1 PWR / VM-4	70 to 90	20
Victor, Delta, Yankee	2 PWR / mod VM-4		
Submarines, third generation (1987 to present)			
Typhoon, Oscar	2 PWR / OK-650	190	20 to 45
Akula, Sierra, Mike	1 PWR / OK-650		
Other submarines			
Papa (1969 to late 1980s)	2 PWR / unknown	177	unknown
November-645 (1963 to 1968)	2 LMR / VT-1	73	weapon-grade
Alfa (1969 to present)	2 LMR / OK-550 or BM-40A	155	weapon-grade
X-Ray, Uniform, AC-12 (1982 to present)	1 PWR / unknown	10 (X-Ray)	unknown
Cruisers (1980 to present)			
Kirov	2 PWR / KN-3	300	unknown
Auxiliary ships (1988 to present)			
Kapusta	2 PWR / unknown	171	unknown
Sevmorput	1 PWR / KLT-40	135	up to 90
Icebreakers			
Lenin (1959 to 65)	2-3 PWR / OK-150 and OK-900	90	5
Arctica (1975 to present)	2 PWR / KLT-40	135	up to 90
Taymyr (1989 to present)	1 PWR / KLT-40	135	up to 90

KEY: PWR=pressurized water reactor; LMR-liquid metal reactor

SOURCE: O. Bukharin, “Nuclear Fuel Management in the Russian Navy,” staff paper prepared for OTA, November 1994.

BOX 4-9: Naval Fuel: Integration into the National Nuclear Fuel Cycle

The naval fuel cycle is closely integrated with the nuclear fuel cycles of military material production reactors and commercial nuclear power reactors. For a significant fraction of naval reactor fuel, the design of the fuel cycle was as follows:

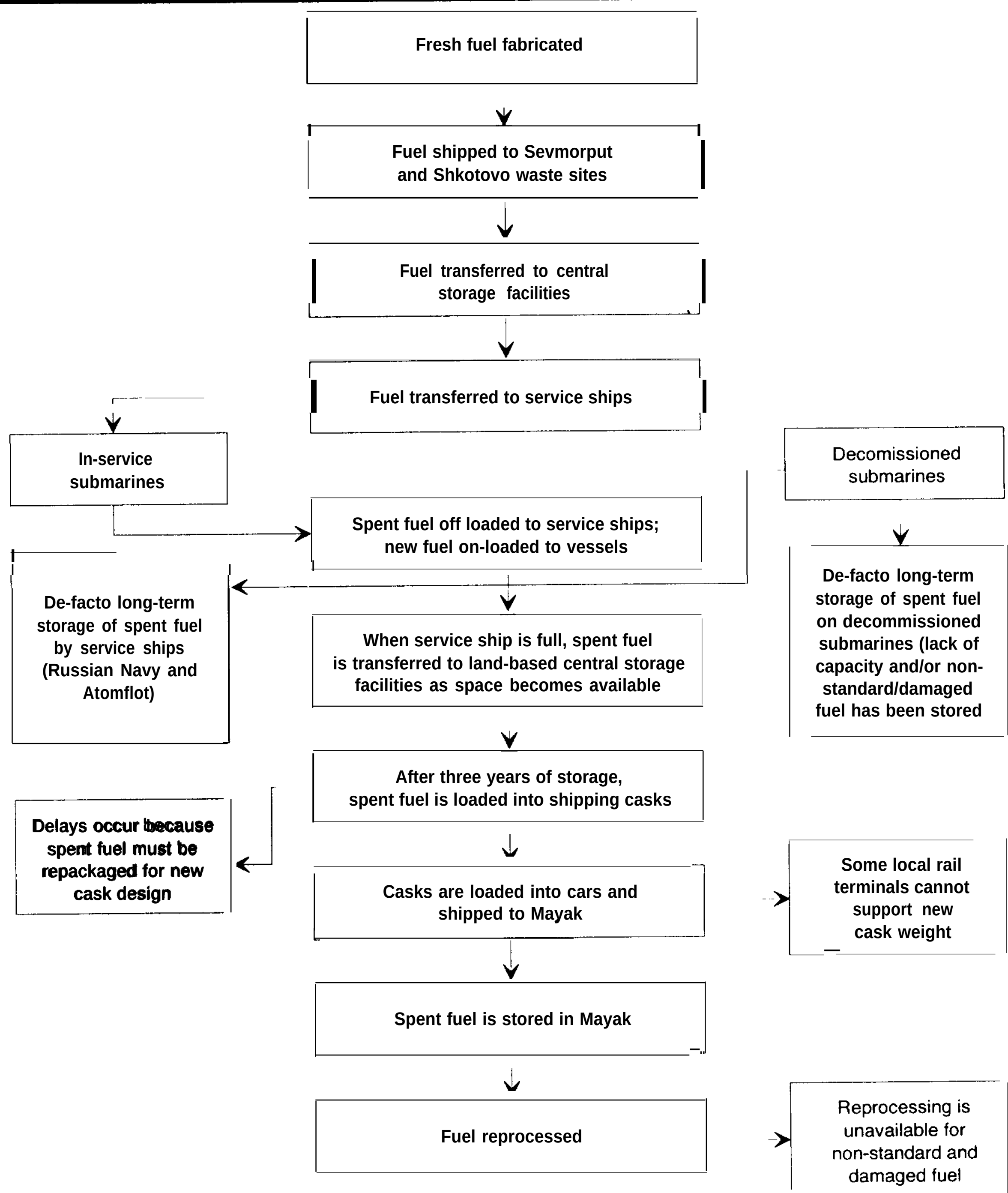
- Uranium feed for naval fuel was produced by recovering uranium from irradiated Highly Enriched Uranium (HEU) fuel from two tritium production reactors at Mayak (Chelyabinsk-65) and HEU spike rods from plutonium production reactors in Krasnoyarsk-26 and Tomsk-7.
- Irradiated HEU fuel was reprocessed at the RT-1 plant at Chelyabinsk-65.
- Recovered uranium (approximately 50 percent enriched) was sent to the Machine-Building Plant at Electrostal near Moscow for fabrication into fuel rods and assemblies.
- After irradiation in a reactor and a few years of temporary storage, fuel was sent to Mayak for reprocessing.
- Naval reactor fuel was reprocessed together with spent fuel from research, BN-350/600, and VVER-440 reactors.
- Separated plutonium was placed in storage at the Mayak site.
- Recovered uranium was sent to the Ust'-Kamenogorsk plant for fabrication into fuel pellets of RBMK reactors.

The fuel cycle design was different for weapons-grade uranium fuel. HEU feed was derived from the national stocks. Approximately 1.5 metric tons of HEU were used for fabrication of naval and research reactor fuel annually. Some of this fuel was reprocessed after irradiation.

This nuclear fuel cycle scheme worked reliably until the early 1990s, when the disintegration of the Soviet Union and reductions in military requirements resulted in remarkable changes. Naval fuel requirements have dropped to a few reactor cores per year. (Reportedly, in 1994, the Murmansk Shipping Company, which procures approximately two reactor cores of fresh fuel per year, became the principal customer at the Electrostal naval fuel production line.) Also, in 1992, the Ust'-Kamenogorsk fuel fabrication plant terminated fabrication of reactor fuel using reprocessed uranium.

SOURCES: E. Mikerin, Information provided at Workshop in Rome, June 1992; E. Mikerin, MINATOM, personal communication, May 1992.

FIGURE 4-3: Russian Naval Reactor Fuel Cycle - Key Steps



Source: Office of Technology Assessment, 1995

Management of Spent Fuel

Institutional Arrangements

Naval fuel management in Russia involves the work of several executive agencies and is regulated by GOSATOMNADZOR, the national nuclear regulatory agency (see box 4-10). The lines of responsibilities for fuel management operations are not always obvious. MINATOM is responsible for fresh fuel until it is delivered to the Navy, GOSCOMOBORONPROM, or the MSC. (Reportedly, in the case of a new submarine, fresh fuel is controlled by GOSCOMOBORONPROM until it is loaded into the reactor at a GOSCOMOBORONPROM shipyard in the presence of Navy representatives. After that, responsibility for the submarine and the fuel is assumed by the Navy. (In other cases, the Navy is responsible for fuel from the moment it arrives at the central storage facility to the moment spent fuel is returned to Mayak.) The responsibility for transportation is shared by the Navy, MINATOM, and the Ministry of Railways. After the spent fuel has arrived at Mayak, MINATOM is solely responsible for subsequent operations (reprocessing, etc.). Similar arrangements exist between MINATOM and MSC.

BOX 4-10: Russian Entities with Responsibility for Navy Nuclear Reactors and Fuel

1. *Ministry of Atomic Energy (MINATOM)*: MINATOM's Main Directorates of Nuclear Reactors, Fuel Production, and Isotope Production, and others are involved in virtually all stages of the naval fuel cycle. Specifically, MINATOM's responsibilities include the following:

- R&D of reactors and fuels;
- development of an infrastructure to support reactor and fuel operations;
- production of naval fuel;
- production and use of spent fuel shipping casks;
- reprocessing of spent fuel; and
- development of a regulatory framework for fuel management and coordination of regulatory activities with Gosatomnadzor.

2. *The Navy (Ministry of Defense)*: The Navy assumes responsibility for fuel from the moment it arrives at a central storage facility until it is shipped to Mayak for reprocessing. Specifically, the Navy is responsible for the safety, security, and quality of the following operations:

- storage of fresh fuel;
- refueling and defueling;
- reactor use of fuel;
- interim storage of spent fuel; and
- loading of fuel into shipping casks and shipping fuel to Mayak.[a]

3. *Murmansk Shipping Company (Ministry of Transportation)*: The company is a private enterprise. However, its nuclear icebreaker fleet remains federal property. Its fuel management responsibilities are similar to those of the Navy.

4. *State Committee for Defense Industries (Goscomoboronprom)*: The Committee's Department of Shipbuilding operates all major shipyards and is responsible for loading fresh fuel into newly built submarines and submarines undergoing major overhaul. The committee's research institutes and design bureaus (e.g., Krylov's Institute of Shipbuilding) are responsible for the integration of reactor systems and fuel management with the technologies and operations of naval vessels.

5. *Ministry of Railways*: The Ministry's Department of Special Cargo shares responsibility for transportation of fresh and spent fuel.

(continued)

BOX 4-10: Russian Entities with Responsibility for Navy Nuclear Reactors and Fuel (Cont'd.)

6. *State Committee for the Supervision of Radiation and Nuclear Safety (Gosatomnadzor)*: The Committee is charged with developing nuclear and radiation safety rules and standards, supervising nuclear safeguards, licensing and inspecting nuclear installations, and coordinating and supporting safety-related research. Gosatomnadzor reports directly to the President. The principal divisions of Gosatomnadzor, involved in the supervision of naval fuel management, include the headquarters' departments of transport reactors, fuel cycle facilities, radiation safety, and material control and accounting, as well as the regional offices of the North-West, Ural, and Central districts. Gosatomnadzor monitors fabrication of naval fuel, refueling, spent fuel storage, shipment, and reprocessing. Gosatomnadzor coordinates these activities, with the Ministry of Environment, Ministry of Health, Committee for Epidemiological Protection, MINATOM, and the Ministry of Defense. As of 1994, Gosatomnadzor was complaining about the lack of cooperation from the Navy.[b] However, the strength of the Committee is increasing as testified by its role in addressing the issues of naval fuel shipments and storage.

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[a] Reportedly, the Navy provides the guard force to escort spent fuel shipments. MINATOM (Mayak) owns the shipping casks.
[b] As of May 1994, the Ministry of Defense denied Gosatomnadzor access to its naval vessels.

SOURCES: O. Bukharin, "Nuclear Fuel Management in the Russian Navy," Staff Paper prepared for OTA, November 1994; J. Handler, "Radioactive Waste Situation in the Russian Pacific Fleet," Greenpeace trip report, Nuclear Free Seas Campaign (Washington, D.C.: Greenpeace, Oct. 27, 1994); Gosatomnadzor, "Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993," approved by Order of the Russian Federal Nuclear Inspectorate [Gosatomnadzor] No. 61 from May 13, 1994, translated by Greenpeace International.

There is another mechanism for organizing the interagency work. The Russian government's decree on the national program of radioactive waste management (No. 824, 14 August 1993) designated MINATOM as a principal state customer for the program. In this capacity, MINATOM has contracted with the Ministry of Defense, Ministry of Environmental Protection, GOSCOMOBORONPROM, GOSATOMNADZOR, and other agencies to carry out projects related to spent fuel management. The Ministry of Finance was to provide MINATOM with the required funding. The mechanism, however, does not work very well. For example, because of the lack of funding, MINATOM has not been able to pay contractors for the work they have done.

Storage of Spent Fuel in the Navy

The Russian Navy is expected to have a backlog of 300 to 350 cores of spent fuel by the year 2000. Both land-based facilities and service ships or barges are used for temporary spent fuel storage for the Russian nuclear fleet. The service ships are the same ones used for at-sea defueling/refueling. In early 1993, it was reported that about 30,000 spent fuel elements, equal to 140 reactor cores, were in storage in the various facilities of the Russian Northern and Pacific Fleets. Table 4-7 summarizes the spent fuel status in both fleets.

Immediately after its removal from submarine reactors, spent fuel is put in containers—steel cylinders with lead tops. Containers are used both for interim storage of fuel and as part of the spent fuel shipping casks. On service ships, fuel is usually stored in dry, water-cooled compartments in which watertight containers with fuel are suspended from the ceiling in tanks filled with cooling water.

After a service ship is filled to capacity, fuel is transferred to the land-based central sites at the Zapadnaya Litsa and Gremikha bases in the North and the Shkotovo waste site in the Pacific. In the past, most fuel assemblies were directly exposed to cooling water (and, later, encased fuel assemblies). Safe handling of the fuel in temporary storage requires complex monitoring and

TABLE 4-7: Spent Fuel Storage Facilities

Site	Storage facility	Storage fuel assemblies[a]
Northern Fleet:		
Zapadnaya Litsa, Kola Peninsula	Two land-based concrete tanks (another tank is not operational)	20,489
	PM-124 class service ship[b]	560
	Malina class PM-12	1,400
Gremikha,[c] Kola Peninsula	N/A	N/A
Zvezdochka, Severodvinsk	Three PM-124 class service ships	1,680
	Malina class PM-63	1,400
Atomflot, Murmansk	*Lotta* service ship (submarine fuel)	476
Murmansk Shipping Company (MSC):		
Atomflot base, Murmansk	*Imandra* service ship	1,500
	Lotta service ship	5,440
	Lepse service ship	621
Pacific Fleet:		
Shkotovo waste site (military unit 40752), Primorye	Land-based storage	8,400
	Three PM-124 class service ships[d]	1,680
Kamchatka waste site (military unit 95051), Kamchatka	One PM-124 service ship	560
	Malina class PM-174	1,400

[a] The numbers for the Northern Fleet and MSC are from the Bellona report (pp. 45-47). The Yablokov report estimates 21,000 fuel assemblies stored in the Northern Fleet (3,000 containers with seven fuel assemblies each) and 8,400 fuel assemblies (1,200 containers) in the Pacific Fleet. According to the report, the stores are overloaded.

[b] PM class ships are designed for short-term storage of spent fuel. In some cases, fuel has been on these ships for long periods of time.

[c] LMR fuel is believed to be stored at Gremikha.

[d] The PM-80 (Shkotovo) and PM-32 (Kamchatka) hold 118 and 32 damaged fuel assemblies, respectively, that are difficult to remove (Gosatomnadzor, "Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993," approved by Order of the Russian Federal Nuclear Inspectorate [Gosatomnadzor] No. 61 from May 13, 1994, translated by Greenpeace International).

KEY: N/A = Not available.

SOURCES: T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994); Government Commission on Matters Related to Radioactive Waste Disposal at Sea ("Yablokov commission"), created by Decree No. 613 of the Russian Federation President, October 24, 1992, *Facts and Problems Related to Radioactive Waste Disposal in Seas Adjacent to the Territory of the Russian Federation* (Moscow, Russia: 1993), translated by Paul Gallager and Elena Bloomstein (Albuquerque, NM: Small World Publishers, Inc.).

auxiliary systems. The water pool must be provided with a supply of cold water or an internal cooling system. A system is needed to remove contaminants that would accelerate corrosion of the spent fuel. The system must be monitored for radiation to detect leaks. Leaking fuel requires special handling. This process also produces a significant amount of radioactive waste. Finally, any leaks from the pool to the environment must be prevented (49). Storage accidents due to thermal stresses in fuel and corrosion of storage equipment have led the Navy to move most fuel into dry storage.[14] (The Northern Fleet retains some land-based wet storage capacity.)

At the Shkotovo waste site in the Pacific, spent fuel is stored in a horizontal array of cylindrical cells in a concrete floor of the storage building. Each cell accommodates a container with seven fuel assemblies. Presently, 1,075 out of 1,200 cells are loaded with spent fuel. At Zapadnaya Litsa, fuel has been moved into storage facilities designed to hold liquid radioactive waste. (The buildings have never been used for waste storage because liquid waste was previously discharged into the sea.)

As of the end of 1993, spent fuel had been removed from 36 out of 103 decommissioned submarines.[15] The high rates of submarine deactivation and low defueling capacity of the Navy mean that many tens of reactor cores of spent fuel will remain inside shutdown reactors of floating submarines for a long time.

Spent Fuel Storage at the Murmansk Shipping Company

The Murmansk Shipping Company (MSC) is a private Russian enterprise engaged in the operation of nuclear-powered icebreakers and other commercial ships. MSC currently performs all spent fuel management related to its icebreakers. Discharged icebreaker fuel is initially stored onboard the service ship *Imandra* (capacity 1,500 fuel assemblies), which is designed to refuel icebreakers at the Atomflot base.[16] After approximately six months of storage on the *Imandra*, fuel is transferred to the service ship *Lotta* (capacity 5,440 fuel assemblies).[17] *Lotta*, like *Imandra*, is an ice-class vessel. *Lotta* has been equipped to handle the new TUK-18 fuel casks. Spent fuel is stored aboard *Lotta* for two to three years. On both *Imandra* and *Lotta*, fuel is stored in dry, water-cooled storage (as described above).[18] The ships are relatively modern and in good condition.

The service ship *Lepse*, however, is older and not as well maintained. It also contains a large amount of highly contaminated damaged fuel. The *Lepse* has 643 fuel assemblies aboard. No additional spent fuel has been loaded on the *Lepse* since 1982. One of the two *Lepse* storage compartments contains spent fuel from the damaged core of the icebreaker *Lenin*.[19] To control radiation releases from damaged fuel assemblies, the entire storage section, which contains 317 fuel assemblies, was encased in concrete. The other compartment also contains a large amount of damaged fuel, about 30 percent of the 643 fuel assemblies. Thus, between 80 to 90 percent of the spent fuel aboard the *Lepse* is either damaged or nonextractable because it has been encased in concrete. To develop a remediation plan for it, MSC must inventory the remaining accessible spent fuel to determine which fuel assemblies, if any, are removable using existing equipment.

MSC was also constructing a land-based storage facility for interim (20 to 25 years) storage of spent fuel. The building was 90 percent complete when the Russian nuclear regulatory agency,

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[14] In 1986, corrosion of fuel handling and storage equipment led to a serious accident at the storage facility at Zapadnaya Litsa (built in the early 1970s). Because of corrosion, several containers with spent fuel fell to the bottom of the storage tank and some of them broke. The accident resulted in a severe contamination problem and had the potential for a nuclear criticality event. (Experts of the Physics and Power Institute in Obninsk have evaluated the probability of a criticality event for such an accident and found it to be small.)

[15] According to Captain V.A.Danilian, the Pacific Fleet has decommissioned 51 submarines (including three with damaged reactor cores) and has defueled 22 submarines [OTA workshop Jan 17–19, Washington D.C.].

[16] *Imandra's* storage capacity consists of six steel compartments, each holding 50 containers for 250 fuel assemblies.

[17] The *Lotta* has 16 storage compartments; each compartment has 68 containers containing five fuel assemblies. Since the mid-1980s, 168 of *Lotta's* containers (840 fuel assemblies) have been used to store submarine fuel.

[18] Thirteen containers (65 fuel assemblies) are not cooled (48).

[19] Reportedly, 319 to 321 fuel assemblies from the icebreaker *Lenin* are stored on the *Lepse*; of these, 10 to 20 fuel assemblies are estimated to be seriously damaged.

GOSATOMNADZOR, indicated that it will not authorize its operation unless the facility is rebuilt to meet modern safety requirements.[20] MSC is now reconstituting its plans for an interim spent fuel storage facility to serve both the icebreakers and the Northern Naval Fleet. Two key issues that must be addressed with a new storage facility are the disposition of zirconium-uranium (Zr-U) fuel and damaged fuel now stored aboard service ships. Neither type of fuel can be reprocessed currently at Mayak, and no long-term storage is available.

MSC projects that there will be 13 cores of Zr-U fuel aboard its service ships within three to five years. Therefore, unless this fuel is moved to a land-based storage site at Atomflot, it prevents MSC from conducting normal refueling operations for its icebreakers. One plan under consideration is to use the *Lotta* to transfer the Zr-U fuel to newly acquired dry storage casks (possibly of Western design), which could then be stored safely at Atomflot.

A new MSC storage facility could also be used to store any damaged fuel removed from the *Lepse*. In June 1995, MSC tendered an engineering study of options for cleaning up the *Lepse*. The European Union (EU) has provided $320,000 for engineering work in support of this effort. The goal of the effort is to inventory completely the spent fuel, perform a risk assessment, and suggest options for a course of action. Although Western contractors will be involved in the effort, MSC has insisted that any research and engineering work specifically include Russian subcontractors: OKBM (fuel design), Kurchatov Institute (science director), and VNII[21] Promtechnologia (waste disposal). The U.S. Environmental Protection Agency (EPA) is considering supporting the risk assessment phase of the project.

Shipment and Disposition of Spent Fuel from the Russian Nuclear Fleet

Spent Fuel Shipment

Spent fuel from the Russian nuclear fleet has regularly been shipped to reprocessing facilities. After one to three years of storage, the standard practice is to ship naval spent fuel to the RT-1 plant at Mayak for reprocessing. In the past, spent fuel was shipped from the facilities at Zapadnaya Litsa, Sevmorput', and Severodvinsk in the North. In the Pacific Fleet, fuel was shipped from an installation, a short distance away from the Shkotovo waste site (27).

At storage facilities, containers with spent fuel were loaded by cranes into shipping casks and delivered to rail terminals for loading on specially designed flatbed cars. The cars were formed in a special train and sent on a several-day journey to Mayak.

In the past, the principal types of shipping casks in use were TUK-11 and TUK-12 (see table 4-8). One train with TUK-11/12 casks could carry approximately 500 fuel assemblies. The TUK-11 and TUK-12 casks were manufactured between 1967 and 1985. GOSATOMNADZOR banned their use in October 1993 because of the following safety concerns: 1) vulnerability of the casks to low temperature (below -5°C); 2) potential for cask rupture in an accident involving a head-on collision or car toppling; 3) inadequate quality of production of the casks; and 4) worn-out conditions of the casks, railcars, and railway equipment (22).

Recently, the obsolete TUK-11 and TUK-12 casks have been replaced by new casks of the TUK-18 type. One train of TUK-18 casks carries approximately 600 fuel assemblies, an equivalent of 1.5-2 reactor cores of spent fuel. TUK-18 casks also meet international standards and can withstand serious rail accidents. The Northern and Pacific Fleets have received 18 and 32 new casks, respectively. The number of casks is suffi-

[20] According to GOSATOMNADZOR, the facility would not survive an airplane crash or other similar disaster (53).
[21] All Russian Scientific Research Institute.

TABLE 4-8: Spent Fuel Shipping Casks

	TUK-11	TUK-12	TUK-18
Designation of fuel containers/number of containers per shipping cask	22 or 22M/one container	24 or 24M/one container	ChT-4/ seven containers
Number of fuel assemblies per container/number of containers per shipping cask	7/7	7/7	7/49
Shipping cask weight (metric tons)	8.9	8.9	40
Designation of railcars/ number of shipping casks per one car	TK-4 or TK-7/4 casks per car	TK-4 or TK-7/4 casks per car	TK-VG-18/3 casks per car
Number of casks per train/ number of fuel assemblies per shipment	18 cars/504 fuel assemblies	18 cars/504 fuel assemblies	4-8 cars/588 to 1,176 fuel assemblies

SOURCE: O. Bukharin, "Nuclear Fuel Management in the Russian Navy," unpublished contractor paper prepared for Office of Technology Assessment, U.S. Congress, Washington, DC, November 1994.

cient to make two trains. However, the number of corresponding railcars is sufficient for only one train.

The Military Industrial Commission, the defense planning arm of the Soviet government, had directed the Navy to start using new casks in 1983. The Navy, however, did not assign these plans high priority. Subsequently, the start-up was rescheduled and failed in 1985, 1988, and 1990. The principal technical problems of transition relate to the need for 1) new spent fuel and cask handling equipment, and 2) upgrade of the local road and railway networks (because TUK-18 casks are significantly larger and heavier than TUK-11 and TUK-12 casks).

These problems were overcome at the Northern Fleet shipyard, Severodvinsk: the first consignment of spent fuel in TUK-18 casks was sent to Mayak in May 1994 by train. TUK-18 casks were also used in the fall of 1994 to ship spent fuel from a shutdown reactor of the naval training facility at Paldiski (Estonia).

By the beginning of 1995, new fuel handling equipment was installed and tested with non-nuclear substitute casks aboard the MSC ship *Lotta*. The first train with spent fuel (which also carried some spent fuel from the Navy) departed from Atomflot for Mayak in March 1995. A total of five shipments are planned from Murmansk by MSC in 1995.

MSC's management has proposed that the company could become a central fuel transfer point in the North, which would serve both the nuclear icebreakers and the Northern Naval Fleet. According to the proposed scheme, submarine fuel would be transferred from the Navy's service ships to the *Lotta* prior to reloading in TUK-18 shipping casks. Because MSC believes that its company has a well developed technological and transportation infrastructure, competent personnel, and a valid operating license, consolidation of all marine nuclear fuel transfer operations would help to avoid duplication of facilities, increase the rate of shipments, and improve the safety of fuel reloading operations.

Implementation of this plan, however, might be impeded by the Zr-U fuel problem. Zr-U fuel cannot be reprocessed using existing facilities and practices in Russia. Currently, the spent fuel has to be stored aboard the service ships, *Lotta* and *Imandra*. The fuel (13 cores total) would fill most of the storage capacity of the two ships and limit MSC's ability to serve as a spent fuel transfer point. (The ships have a combined storage capacity of 20 reactor cores of spent fuel. Of these, a space for three cores must be reserved for freshly discharged fuel.) MSC's management proposes to resolve this problem by moving Zr-U fuel to new land-based storage facilities. The fuel would be placed in dry storage in multiple-purpose casks that would be installed at the Atomflot base. The casks could also accommodate damaged fuel from the *Lepse*. MSC, however, needs outside funding and/or equipment to implement this plan.

The situation in the Pacific is more serious. The last shipment of spent fuel from the Shkotovo waste site took place in 1993. As of beginning 1995, new fuel handling equipment was installed at the fuel storage facility at the Shkotovo waste site, and similar work has been started at the rail terminal. There is, however, the need to upgrade several kilometers of railway connecting the base to the central railway system and to complete upgrading of the road between the storage facility and the rail terminal.[22] These seemingly simple construction projects might be difficult to implement because of lack of funding. The Navy is also considering an alternative that would involve sending spent fuel by sea to the shipyard Zvezda, which would serve as a rail terminal for shipments to Mayak. The poor technical condition of the piers at Zvezda and the lack of funding in the Navy to pay the shipyard for fuel transfer operations may complicate the implementation of this plan.[23] If, however, the Navy cannot resolve the problem of shipments, a new interim storage facility would have to be built.[24]

The problem of shipments is compounded by the increasing costs of reprocessing spent fuel. In 1994, Mayak increased the costs of reprocessing from $500,000 to $1.5 million (1.5 billion to 7 billion rubles) per shipment (1.5 to 2 reactor cores or a few hundred kilograms of heavy metals). The increase was caused by financial problems in the nuclear industry, increases in federal taxes, and inflation.

Disposition of Spent Fuel

In Russia, naval spent fuel is normally reprocessed at the RT-1 chemical separation plant at Mayak in the Urals. The Mayak complex was brought into operation in 1949 to produce plutonium and, later, tritium for nuclear weapons. During the period 1959–60, Mayak and the Institute of Inorganic Materials (Moscow) began research on reprocessing of irradiated highly enriched uranium (HEU) fuel such as that used in the nuclear fleet. The research resulted in a technology to reprocess naval fuels, and a corresponding production line was brought into operation in 1976. It was the first production line of the RT-1 reprocessing plant.[25]

At present, the reprocessing complex includes three lines for processing fuel from commercial reactors (MTM models VVER-440,[26] BN-350/600) and from naval, research, and HEU-fueled reactors. In addition to the reprocessing lines, the complex includes facilities for short-term storage of spent fuel, waste storage and treatment facili-

[22] Approximately 1.5 kilometers out of 3.5 kilometers of road have been constructed.
[23] The Navy already has a large debt to the Zvezda shipyard.
[24] The estimated time to construct a storage facility is six months.
[25] In 1978, the RT-1 plant began reprocessing of spent fuel of model name VVER-440 reactors.
[26] A Russian acronym: VVER=vodo-vodyanoy energeticheskiy reaktor (water (-moderated and -cooled) power reactor). The nameplate capacity of the MTM (MINTYAZHMASH) model VVER-440 line is 400 metric tons per year of VVER-440 fuel. The historic average throughput is 200 metric tons per year. Recently, however, the plant operated at 25 to 30 percent of its capacity. Reprocessing of VVER-440 fuel from Finland and Eastern Europe is the principal source of income for the Mayak complex.

ties, storage facilities for recovered plutonium and uranium, and other support facilities.[27]

The Mayak facility uses a system designed to reprocess standard uranium-aluminum naval reactor fuels. The facility previously had the capacity to process four to five reactor cores of spent naval fuel per year. Mayak can now process 12 to 15 metric tons of heavy metal (MTHM) per year. This corresponds to 24 to 30 reactor cores per year. At the current size of the fleet, normal fleet operations of the Navy and MSC should not require reprocessing more than about 10 to 20 cores per year. Thus, sufficient capacity exists for reprocessing additional fuel from decommissioned submarines as soon as the pace of dismantlement operations increases.

Mayak, however, cannot presently reprocess Zr-U fuel and damaged (or failed) fuels with its current system.[28] One problem with Zr-U alloy fuels is associated with the difficulty of dissolving them in nitric acid. The Institute of Inorganic Materials in Moscow has been researching several technologies to resolve this problem. A preferred method involving thermal treatment of the Zr-U fuel has been identified. However, MINATOM has not been able to secure funding for construction of a pilot facility at the RT-1 plant in Mayak. In the interim, MSC is pushing for the implementation of a plan to move all Zr-U fuel off its service ships into a land-based storage facility. The fuel would be housed in dry storage casks that would safely contain the fuel for dozens of years until suitable processing facilities, or long-term storage, can be arranged.

Potential for U.S.-Russian Cooperation in Spent Fuel Management

OTA sponsored a workshop in January 1995 with Russian and U.S. expert participants to discuss problems with spent fuel management in both countries. One outcome was the suggestion that cooperative projects might be useful and could lead to a number of mutual benefits. Addressing the many problems related to naval reactor fuel management is of major importance from the viewpoint of environmental cleanup, prevention of potentially serious accidents involving spent fuel, and progress of the submarine decommissioning program. Some factors are important to the United States as well as Russia; however, direct technical assistance to Russia has limitations. Other countries in Europe, especially Norway, and Japan are also interested in cooperative work to solve these problems. Assistance programs are difficult to manage and ensure that support ends up where it is most needed. Also, certain assistance efforts are complicated by the military nature of nuclear naval activities.

Box 4-11 describes some possible steps that could be introduced to address the above problems. Most of these are recognized by Russian experts and others as critical and necessary. The problem with spent fuel and radioactive waste in the Russian Navy is not new. (Even with the high rate of defueling/refueling in the late 1980s and the supposedly low rate of fuel shipment, it has taken several years to accumulate approximately 120 reactor cores currently in storage in the Navy and MSC.) The Navy had plans to modernize its waste and spent fuel management facilities back in the 1980s. Later, in the early 1990s, the problem was addressed in several major reports and programs. These documents call for development of a general concept of spent fuel management, construction of spent fuel handling equipment and fuel transfer bases, use of new shipping casks, development of technologies to dispose of nonstandard fuels and damaged reactor cores, work on long-term storage of spent fuel and geologic disposal of radioactive waste, and development of a special training center (10). Resolutions have been passed and plans have been developed on both regional and site levels

[27] Mayak has a 400-metric ton wet storage facility for VVER-440 fuel; a 2,000-metric ton interim storage facility is about 70 percent complete (65).

[28] Reprocessing of fuel assemblies with surface contamination is prohibited to avoid contamination of the production line.

BOX 4-11: Possible Steps for Improving Spent Fuel Management and Reducing Accident Risks

1. In the area of refueling and spent fuel storage:

- Procurement of new refueling equipment (e.g., PM-type service ships)
- Characterization of stored fuel and storage facilities (amounts, types, and condition of fuel, and status of available storage facilities) and safety upgrades at the existing facilities
- Analysis of options for and construction of interim storage facilities (if needed)[a]
- Development of a regulatory framework determining safety criteria for safe storage of spent naval fuel (how long and under what conditions storage of spent fuel is safe)
- Defueling of deactivated submarines if fuel or submarine conditions are unsatisfactory, and development of techniques for safe storage and monitoring of fuel when defueling can be postponed
- Transfer of the *Lepse* to a land-based facility
- Development of plans to decontaminate and dispose of contaminated storage facilities, the *Lepse,* and facilities with damaged fuel

These measures could be coordinated with a general concept of fuel and radioactive waste management to include the disposition of nonstandard, damaged, and failed fuels.

2. In the area of spent fuel shipments (if needed):

- Installation of equipment to work with TUK-18 casks in the north and in the Pacific
- Upgrades of the local transportation infrastructures

3. In the area of disposition of spent fuel

4. Other necessary factors include sufficient funding, clear division of institutional responsibilities, and improvements in personnel training and human resource management.

[a] Some Russian experts are concerned that additional facilities may result in a future decontamination and decommissioning problem. These experts believe that any available funds should be spent to carry out the standard approach (shipping spent fuel to Mayak and reprocessing). Multipurpose spent-fuel casks may answer some of these concerns should the storage situation become critical.

SOURCE: O. Bukharin, "Nuclear Fuel Management in the Russian Navy," Staff Paper prepared for OTA, November 1994.

as well.[29] MINATOM, as a lead agency, has contracted various institutions and agencies to do the work. However, continuing problems with funding have largely stalled the progress.

The OTA workshop, thus, sought to identify areas in which cooperative work could be started soon, would offer clear mutual benefits, and could be supported by general agreement that its further pursuit would be worthwhile.

1. With regard to management of damaged spent fuel where technologies and systems are not currently in place, it is clear that damaged fuel is a major technological and management issue. In this regard, *a vulnerability assessment could be conducted to determine priorities with respect to off-loading damaged fuel from Russian submarines, surface ships, and fuel service ships.* Similar recent efforts regarding the problem of spent fuel include the identification of a critical situation aboard the service ship *Lepse* at Atomflot. This ship has damaged fuel stored that has been in place for up to 28 years. One of its two compartments, which contains seriously damaged spent fuel, has been filled with concrete, thus

[29] The following measures are planned at the Severodvinsk site to improve spent fuel management operations: 1) to upgrade refueling facilities at Sevmash, Sever, and Naval Repair Yard 412 (1993/94); 2) to develop procedures and a system of regulations for the removal of reactor core from submarines that are decommissioned at Severodvinsk; 3) to upgrade the transportation system at the naval base Belomorskaya; 4) to upgrade the railway system at the Belomorskaya naval base (48), the Sevmash site, and the 1944 Severodvinsk-Isagorka rail link; 5) to build new storage facilities; and 6) to build new service ships (6,48).

making the fuel assemblies very difficult to extract.

2. It may also be useful to investigate *technologies* (some of which are available in the United States) *to assess the status of damaged fuel* (i.e., corrosion and potential for criticality). Remote sensing technologies (e.g., mini-cameras and remote techniques) could be useful for the inspection of damaged fuel—an approach commonly used in the United States but apparently not readily available within the Russian nuclear fleet.
3. It would be constructive to develop *a case study and risk analysis of fuel management technologies using the service ship Lepse* (a service ship used for the nuclear icebreaker fleet that contains seriously damaged spent fuel). The *Lepse* is a commercial, not a defense, vessel; therefore, it would be easier for an international group to work on than a Navy submarine.
4. Another possibly useful collaborative project concerns *technologies that are needed to remove, off-load, and condition damaged fuel for local storage, for transport to a central storage facility, or for transport to a site for reprocessing*. Clearly, a decision will have to be made as to which option is preferred for matching the conditioning process to the intended fate of the spent fuel. On this subject, the United States could offer some lessons learned from its research on Three Mile Island to provide feasible conditioning options for the Russians to consider.
5. Both Russia and the United States could benefit from *an analysis of the commercial availability of dry storage and transportation technologies that could handle damaged and nonstandard fuel.* U.S. industry has examples of such systems and recently related applications. Mutual identification and development of these technologies would likely benefit both countries. Multipurpose casks for dry storage and shipment developed in the West are of particular interest to Russia.

Management of Liquid and Solid Radioactive Waste from the Nuclear Fleet

In addition to spent fuel management, other radioactive waste management problems from the Russian nuclear fleet are evident. As stated in the Yablokov report, past practices of the fSU's nuclear fleet resulted in direct at-sea discharges of low-level liquid radioactive waste (LRW). In the report, general areas of liquid waste disposal are identified in the Barents Sea in the north and the Sea of Japan, the Sea of Okhotsk, and the North Pacific Ocean in the east (23).

Recent reports state that the Northern Fleet stopped discharging LRW into the Arctic seas in 1992 (23). In the far east, an instance of liquid waste dumping occurred in October 1993, but no further discharges have been documented. In the north, two treatment plants for LRW were built at Zvezdochka (shipyard in Severodvinsk) and Sevmash (a Navy base) in the 1960s but never used and are now obsolete. At Sevmash there are five floating tanks for Northern Fleet LRW, each with a capacity of 19 to 24 m^3.

Also in the north, at Atomflot—Murmansk Shipping Company's repair, maintenance, and wastewater treatment facility 2 km north of Murmansk—LRW (primarily from icebreakers) is treated to remove cesium-137 (Cs-137) and strontium-90 (Sr-90), so that the effluent can be discharged to the Murmansk Fjord. Since 1990, a two-stage absorption system has been used with a capacity of 1 m^3 per hour and a yearly capacity of 1,200 m3 (4).

Although this treatment facility is primarily for icebreaker waste, it is the only facility available to also treat LRW from naval reactors. MSC has treated all of its LRW but cannot handle the backlog (or the amount generated annually) by submarines in the Northern Fleet. Atomflot says that it has the technical infrastructure to play a critical role in managing LRW on a regional scale. As a stopgap measure, the Northern Fleet uses two service ships to store its LRW.

Planned Liquid Waste Treatment in the North

Plans for a new treatment facility at the Atomflot complex have been under development for the past few years. The facility design currently proposed is based on an evaporation technology developed by the Institute of Chemical Processing Technology in Ekaterinburg and the Kurchatov Institute in Moscow. The current proposal would increase the capacity of LRW that could be handled to 5,000 m^3 per year. The new facility would be designed to handle three types of liquid waste: primary loop coolant from pressurized water reactors (PWRs), decontamination solutions, and salt water generated by Russian naval reactors. The LRW treatment capacity would handle both the icebreaker fleet and the Northern Fleet's needs (Murmansk and Arkhangel'sk Oblasts). The design of this expanded facility is now under way with assistance from both the United States and Norway. Its construction is planned to begin in late 1995.

The Russians had planned a new facility to handle the different types of LRW from submarines and icebreakers. It appears that the current design cannot process large quantities of the submarine waste, which contains salt water. The MSC now plans to build its new facility in two phases. The second phase (currently funded only by MSC) would extend the capacity from 5,000 to 8,000 m^3 a year (an additional 3,000 m^3). MSC plans to launch a commercial project with IVO International of Finland. This project would involve the use of a technology developed to remove Cs-137 from the primary loop coolant in the naval training reactor at Paldiski, Estonia. The facility would be upgraded and installed on the tanker *Serebryanka*. The capacity of the upgraded system is estimated as 1,000 to 2,000 cubic meters per year. Project cost is estimated at about $1 million. The combined output of the two facilities would handle all LRW generated from ship operations as well as a significant amount (several thousand cubic meters annually) generated in the submarine dismantlement process.

Since Russia has not been able to provide the necessary funds for the expansion of this facility, to date, the United States' and Norway's proposed cooperative effort to fund the expansion has received considerable attention over the past year. The Murmansk Initiative, as it is called, has involved technical exchanges, meetings, expert site visits, and other activities in 1994 and 1995. A facility expansion concept paper was prepared, and an engineering design has been funded. A discussion of the U.S.-Norwegian-Russian initiative can be found in chapter 5. This effort is one of the first examples of international cooperative work directed toward the prevention of further radioactive waste dumping in the Arctic.

Planned Liquid Waste Treatment in the Far East

Liquid radioactive waste treatment and storage capabilities are also in dire need of upgrading and improvement to service Russia's Far Eastern nuclear fleet. In 1993, Russia and Japan began a bilateral cooperative project to address this need. They developed a design and implementation plan for a new liquid waste treatment facility. An international tender was issued for the facility in 1994, and bids were due in late 1995. Russia has also undertaken interim measures to reduce pressures on sea dumping. Thus far, the United States has not participated in support for this facility as it has for the one at Murmansk (37).

■ Solid Low-Level and Intermediate-Level Radioactive Waste

Solid waste is generated during the replacement of fuel assemblies on icebreaker reactors, from repairs in the reactor section, and in the replacement of cooling water filters, cables, and gaskets. It is also generated from processing waste related to the storage of fuel assemblies. Contaminated clothes and work equipment are also part of the waste stream. Of the waste generated, 70 percent is low-level, 25 percent is intermediate-level, and 5 percent is high-level radioactive waste (48). Until 1986, all low- and intermediate-level solid waste from nuclear vessels was dumped into the sea. Since that time, solid waste has been stored, in some cases treated (e.g., incinerated), and in some cases disposed.

For example, at some sites in the north, radioactive waste is currently stored in containers placed side-by-side in a concrete bunker. Once the bunker is filled, it is sealed and covered. The largest storage facility for solid waste has reached 85 percent of its capacity. Large items that cannot fit easily into containers (reactor parts, cooling pipes, control instruments, and equipment employed in replacing used fuel assemblies) are placed on the ground without any protection or safeguards against drainage into the sea (48).

Given the range of activities taking place in and around the Arctic Sea and the apparent lack of secured, monitored storage, there appears to be a need for a regional depot to store low- and intermediate-level radioactive waste. Similar needs exist in the Far East.

A number of waste treatment facilities are in place. There is an incinerator at Atomflot for low- and intermediate-level waste. The waste volume is reduced 80 percent by this incinerator. The waste gases are filtered, and the ashes and filters are stored in containers (48). Some solid radioactive waste mainly from decommissioned submarines is also being incinerated at a naval facility in the north. Incinerator gases are controlled and led through special filters. When the radioactivity of the gases is too high, the facility shuts down—a frequent occurrence. Facility operation appears to be erratic; the facility reportedly runs for only one month a year due to filtration system overload and system shutdown.

There are also discharges of radioactive gases in connection with repairs at reactors and replacement of fuel assemblies. Such is the case at Severodvinsk where the annual discharge of such gases is estimated to be up to 10,000 m^3 from the labs and from storage of used fuel assemblies (48).

Russian sources have listed the following steps as necessary to manage waste generated in the Murmansk and Arkhangel'sk Oblasts: (4)

- develop new storage facilities,
- install preliminary radioactive waste treatment equipment at the point of waste generation,
- implement waste minimization and decontamination methods,
- develop safe transport facilities that meet international standards,
- develop a complex for radioactive waste treatment at Atomflot,
- develop solid waste supercompaction (1,500-2,000 metric tons of force) instead of the currently used incineration of lower-pressure (100 tons of force) compaction methods,
- construct a specialized ship for transporting solid radioactive waste packages to their final repository, and
- construct a radioactive waste repository for solid wastes in permafrost in Novaya Zemlya.

RUSSIAN NUCLEAR POWER PLANTS—SAFETY CONCERNS AND RISK REDUCTION EFFORTS

Background

Since the major nuclear reactor accident at Chernobyl, many nations have taken actions to help improve safety and reduce the risk of future accidents in all states of the former Soviet Union. Specific activities in Russia, discussed in this section, deserve particular attention in the context of preventing future radioactive contamination in the Arctic since Chernobyl releases are among the most widespread contaminants measured today throughout the general region.

Russia has 29 nuclear power units at nine reactor sites (see figure 4-4 for reactor locations).[30] In 1993, with these reactors operating at 65 percent capacity, they provided 12.5 percent of the electricity produced in the country.[31] There are two main reactor types in Russia: the

[30] Note, however, that the map lists only 24 reactors since it does not show either the four reactors at Bilibino or the one at Beloyarsk.

[31] In the United States in 1993, net electricity generated from nuclear power generating units was 21.2 percent of net electricity generated from utilities (63). For a discussion of older nuclear power plants in the United States (60).

RBMK and the VVER.[32] Box 4-12 and table 4-9 describe the types and locations of Russian power reactors. The Chernobyl reactor 4 that exploded in April 1986 in Ukraine was an RBMK reactor, and 11 of this type are now operating in Russia. The RBMK is a graphite-moderated, light-water-cooled reactor. Spent fuel from these reactors is replaced while the reactor is in operation, unlike PWRs, which must be shut down before refueling takes place. Experts outside Russia have criticized the RBMK design, especially since the Chernobyl accident, and have proposed several remedies ranging from safety improvements in existing reactors to substitution of new reactors with different designs, to outright replacement with other fuel sources.[33]

It is difficult to draw firm conclusions about the safety levels of all Russian reactors in general. Some have argued that Russian reactors are more geared toward prevention than reaction to a possible accident. For example, the higher water inventory in the VVER reactors, compared to Western-design PWRs, means that the heat-up process following an accident in which replenishment of makeup water is not available allows more time for corrective measures to be taken before possible damage to the fuel. Therefore, the need for containment and other postaccident mechanisms becomes somewhat compensated (3). However, this design advantage does not offset the need for improvements in Russian nuclear power plants (NPPs) suggested by many international experts. These include new monitoring and safety procedures that comply with international standards, reliable operating systems, well-trained operators, and sufficient funding for maintenance and spare parts.

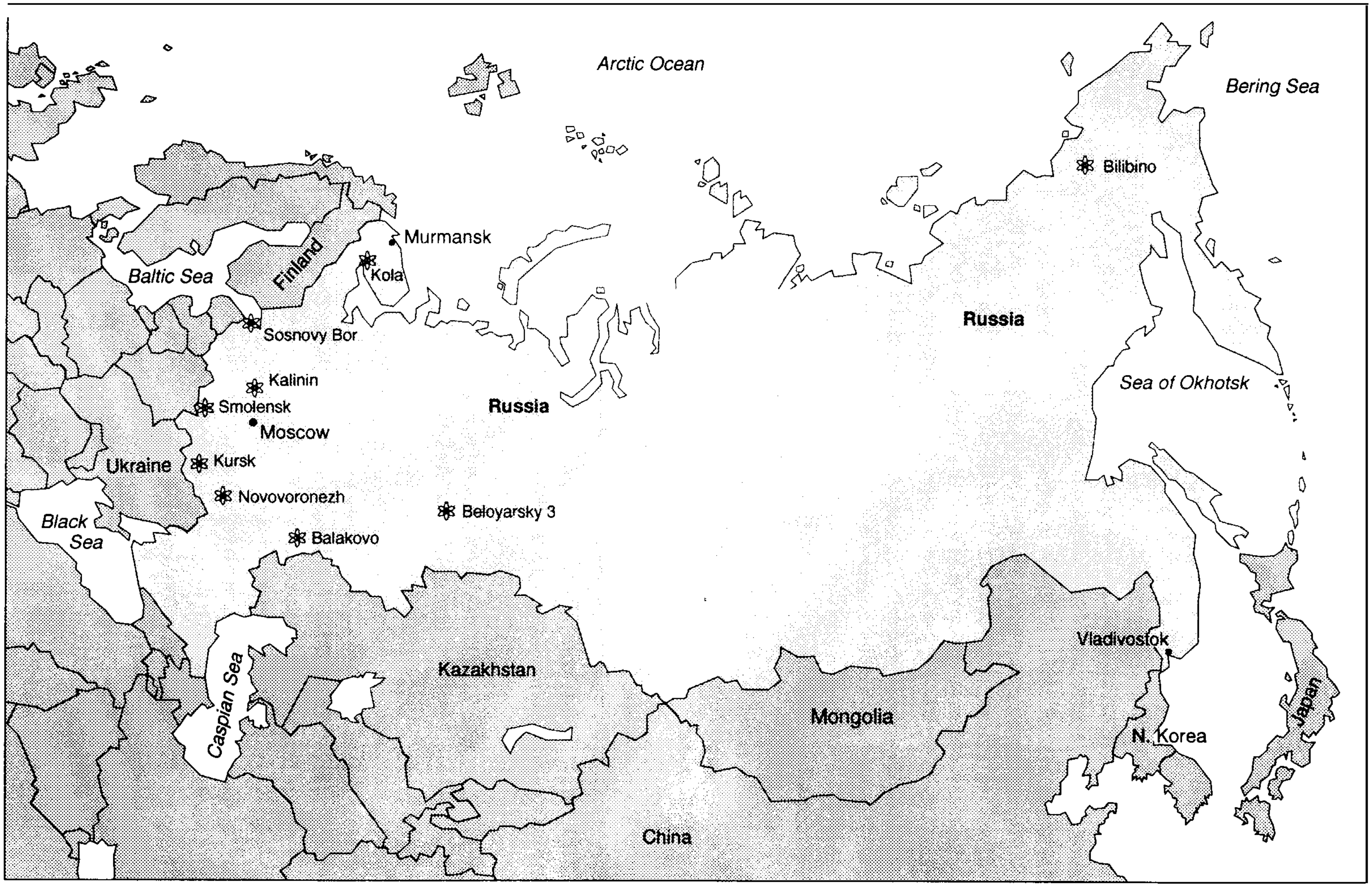
Very few probabilistic risk assessments have been done to date and made available to the West for Russian reactors; thus, accident risk claims have not been established quantitatively. The Nuclear Regulatory Commission (NRC) hopes to convince Russia of the need to conduct such assessments. Another complicating factor in assessing the safety of Russian reactors is the fact that after January 1, 1993, the flow of information on plant design and accidents at these plants effectively dried up. Although the Soviet Union did sign certain international reporting conventions, the nations of the former Soviet Union effectively ceased making international accident reports in early 1993. When an event occurs, such reports are usually made to the Organization for Economic Cooperation and Development (OECD)'s Nuclear Energy Agency or to the International Atomic Energy Agency (IAEA), which rates and analyzes the incident (52).

Evaluations of U.S. efforts to improve the current conditions of reactor safety in Russia vary. A Gore-Chernomyrdin Commission (GCC) Nuclear Energy Committee report, the product of the December 15–16, 1994, GCC meetings, recognized these efforts, outlined in a December 1993 agreement, as unsuccessful. The December 1993 agreement was entitled, "On Raising Operational Safety, on Measures to Lower the Risk and on Norms of Nuclear Reactor Safety with Respect to Civilian Nuclear Power Plants of Russia." This agreement sought to facilitate cooperation under the Lisbon Initiative.[34] However, at the December 1994 GCC meetings, Russia accepted U.S. explanations for failure to complete projects planned for 1994 (9,20).

[32] A Russian acronym: RBMK=reaktor bol'shoy moshchnosti kipyashchiy (large-capacity boiling (-water) reactor).

[33] The two main safety concerns about the RBMK are: 1) core neutronics, or nuclear reactions in the core and 2) hydraulics of the pressure tubes. With regard to core neutronics, the RBMK has a positive void coefficient, which means that reactions speed up when water is lost from the core, for example, through excessive boiling or a loss-of-coolant accident. This happens because water serves to absorb neutrons; therefore, when water is lost, the number of neutrons increases, thereby speeding up the chain reaction. (Neutrons promote fission by hitting a uranium atom and causing it to split.) At Chernobyl unit 4 in April 1986, the chain reaction multiplied rapidly, generating high temperatures that caused an explosion. The second main concern, hydraulics of the pressure tubes, has to do with the possibility of fuel channel rupture. When reactivity speeds up, there is the possibility that several tubes might rupture simultaneously and pressure in the cavity below the reactor cover might increase enough to lift the head off, causing all the tubes to break and lifting out the control rods—a scenario that occurred at Chernobyl.

[34] The Lisbon Initiative refers to the current U.S. bilateral assistance program with the former Soviet Union in the area of nuclear reactor safety, which is discussed later in this chapter.



Source: Office of Technology Assessment, 1995.

BOX 4-12: Nuclear Power Reactors in Russia

Currently, Russia operates 11 RBMKs[1] at three sites: four near St. Petersburg, four at Kursk (south of Moscow), and three at Smolensk (southwest of Moscow). The St. Petersburg units, located in Sosnovy Bor, St. Petersburg Oblast, are the only ones out of the 29 operating units in Russia that are run by a separate utility company, the Leningrad Nuclear Power Plant Utility. The Ministry of Atomic Energy (MINATOM) operates all other power plants through an organization known as the Rosenergoatom Consortium. Each of the 11 RBMK units has a capacity of 925 net MW_e (megawatts of electricity). The first St. Petersburg unit came online in December 1973, and the last in February of 1981. The earliest Kursk unit dates from December 1976, and the latest from December 1985. The Smolensk units are somewhat newer, dating from December 1982 to January 1990.

The EPG-6 is a reactor type similar to the RBMK. It too is graphite moderated and boiling water cooled. The four existing reactors of this type are found at Bilibino on the Chukchi Peninsula in the Russian Oblast of Magadan, which is about 100 miles north of the Arctic Circle in the Russian Far East. Each of the Bilibino units has a capacity of 11 net MW_e. Unit A at Bilibino began operation in January 1974, unit B in December 1974, Unit C in December 1975, and Unit D in December 1976.

The other main type of reactor in the former Soviet Union is the VVER,[2] which is a pressurized water reactor (PWR) design, the main reactor type in the West. It is water moderated and cooled. The oldest version of this reactor is the VVER 440/230, followed by the 440/213, both of which produce 440 MW_e of electricity. The oldest of the VVER reactors, the 440/230, like the RBMK, is considered by many Western observers to have safety problems. It lacks an emergency core cooling system to prevent the core from melting after a loss-of-coolant accident. Moreover, the reactor vessel is vulnerable to radiation-induced embrittlement, which increases the risk of fracture in the vessel. It also lacks containment vessels to prevent the escape of radioactive materials after severe accidents. It should be noted, however, that the model 230 has several positive features. Since it has a large water inventory and low power density, it can more easily ride out problems such as a “station blackout” when there is a loss of the power needed to run pumps that cool the core. The model 230 also has an “accident localization system” to condense steam and reduce the release of radiation after an incident in which most pipes in the reactor system break, thereby mitigating the danger inherent in a design that has no containment vessel.

The VVER 440/213, a newer model, includes an emergency core cooling system, an improved reactor vessel, and an improved accident localization system. This model, however, still lacks full containment (except in the case of those models sent to Finland and Cuba).

The Kola NPP, with four reactors, is located in the Murmansk region above the Arctic Circle near the northeastern border of Norway. Two of these reactors are the oldest generation units, VVER 440/230s. They came online in June 1973 and December 1974, respectively. The other two units are VVER 440/213 units, which began operation in March 1981 and October 1984, respectively. At the end of 1994, only two of the Kola power units were operational, and prospects are problematic for continued operation of the remaining units because of difficulties in collecting fees owed by Murmansk Oblast industries.

The newest generation of VVER reactors in Russia is the VVER-1000, which is most like a Western nuclear power station. It runs at 1,000 MW_e, and its design includes a full containment vessel and rapid-acting scram systems. Experts believe that this design could approximate Western safety standards, given some modifications, such as increased fire protection and improved protection of critical instrumentation and control circuits.

(continued)

BOX 4-12: Nuclear Power Reactors in Russia (Cont'd.)

Novovoronezh NPP, located in southwestern Russia, has two 440/230 reactors, which began operation in December 1971 and 1972, respectively, and one VVER-1000, which began operation in May 1980. Kalinin NPP, located northwest of Moscow, has two VVER-1000 units. Unit 1 came online in May 1984 and unit 2 in December 1986. Balakovo NPP, which is located along the Volga River southeast of Moscow, has four VVER-1000 units; the first began operation in December 1985, and the last, Balakovo 4, became commercially operable in April 1993. Balakovo 4 is the newest of all Russia's reactors and the first one built since 1990.

Only one other type of reactor, the BN-600, a fast breeder reactor, is operating in Russia. It is known as "Beloyarsky 3" and is located in the Ural Mountain area, about 900 miles east of Moscow. It has a capacity of 560 net MW_e and has been in operation since April 1980.

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[1] RBMK = Reaktor bol'shoy moshchnosti kipyashchiy (large-capacity boiling [-water] reactor).
[2] VVER = Vodo-vodyanoy energeticheskiy reaktor (water [-moderated and -cooled] power reactor).

SOURCES: U.S. Department of Energy, Energy Information Administration, *EIA World Nuclear Outlook, 1994*, DOE/EIA-0436(94) (Washington, DC: US Government Printing Office, December 1994); U.S. Congress, Office of Technology Assessment, *Fueling Reform: Energy Technologies for the Former East Bloc*, OTA-ETI-599 (Washington, DC: U.S. Government Printing Office, July 1994); U.S. Congress, General Accounting Office, *Nuclear Safety: International Assistance Efforts to Make Soviet-Designed Reactors Safer*, GAO/RCED-94-234 (Washington, DC: U.S. Government Printing Office, September 1994); "Funding Crisis Could Cause Nuclear Station Shutdown," Moscow Ostankino Television, First Channel Network, in FBIS Report/Central Eurasia (FBIS-SOV-94-227) Nov. 25, 1994, p. 35.

Russian officials have stated that the United States unilaterally determines priorities, and pays too much attention to analysis and not enough to practical solutions. As an example, they point to 1994 when no supplies or equipment were sent, although some had been sent in 1993 (9). However, the Chairman of GOSATOMNADZOR told a September 1993 meeting of Group of Twenty-Four (G-24) representatives that the bilateral assistance implemented in the regulatory field was timely and effective, compared with other Western assistance (58). One possible reason that the NRC is actually ahead of schedule is that unlike the Department of Energy (DOE) and its contractors, NRC has not been hampered by liability problems (52).

One of the biggest impediments to the development of a safety culture in Russia lies in the human arena: the current low pay and low morale of plant employees work to undermine a concern for safety. Socioeconomics is a formidable consideration. The prospect of shutdown at a station such as Chernobyl in Ukraine, which is responsible for 7 percent of national energy production, carries with it the implication of social unrest, given the extensive loss of jobs (staff of 5,800) that would ensue. Also, in the former Soviet Union, nuclear power plants, like many workplaces there, are responsible for providing a host of social services for their employees. This makes their closure a much more painful and, potentially, more politically and economically destabilizing measure.

According to former NRC Chairman Ivan Selin, the three most important elements for shoring up a strong safety culture are as follows: 1) technical excellence and operational safety enforced by a tough, independent regulator, and supported by timely plant operator wage payments and payments to utilities for electricity produced; 2) a sound economic climate that allows for a sufficiently profitable nuclear program capable of underwriting first-rate training, maintenance, and equipment, and incorporates a new energy pricing mechanism to encourage energy conservation; and 3) solid organization and management, including high-quality staffing, training, and responsible leadership. He rec-

TABLE 4-9: Russian Nuclear Generating Units Operable as of December 31, 1994

Unit name	Location	Capacity (net MW_e)	Date of operation	Reactor type	Reactor model
Balakovo 1	Balakovo, Saratov	950	December 1985	PWR	VVER-1000
Balakovo 2		950	October 1987	PWR	VVER-1000
Balakovo 3		950	December 1988	PWR	VVER-1000
Balakovo 4		950	April 1993	PWR	VVER-1000
Beloyarsky 3	Zarechny, Sverdlovsk	560	April 1980	FBR	BN-600
Bilibino A	Bilibino, Chukotka	11	January 1974	LGR	EPG-6
Bilibino B		11	December 1974	LGR	EPG-6
Bilibino C		11	December 1975	LGR	EPG-6
Bilibino D		11	December 1976	LGR	EPG-6
Kalinin 1	Udomlya, Tver	950	May 1984	PWR	VVER-1000
Kalinin 2		950	December 1986	PWR	VVER-1000
Kola 1	Polyarniye Zori, Murmansk	411	June 1973	PWR	VVER-440/230
Kola 2		411	December 1974	PWR	VVER-440/230
Kola 3		411	March 1981	PWR	VVER-440/213
Kola 4		411	October 1984	PWR	VVER-440/213
Kursk 1[a]	Kurchatov, Kursk	925	December 1976	LGR	RBMK-1000
Kursk 2		925	January 1979	LGR	RBMK-1000
Kursk 3		925	October 1983	LGR	RBMK-1000
Kursk 4		925	December 1985	LGR	RBMK-1000
Leningrad 1[a]	Sosnovy Bor, St. Petersburg	925	December 1973	LGR	RBMK-1000
Leningrad 2[a]		925	July 1975	LGR	RBMK-1000
Leningrad 3		925	December 1979	LGR	RBMK-1000
Leningrad 4		925	February 1981	LGR	RBMK-1000
Novovoronezh 3	Novovoronezhsky, Voronezh	385	December 1971	PWR	VVER-440/230
Novovoronezh 4		385	December 1972	PWR	VVER-440/230
Novovoronezh 5		950	May 1980	PWR	VVER-1000
Smolensk 1	Desnogorsk, Smolensk	925	December 1982	LGR	RBMK-1000
Smolensk 2		925	May 1985	LGR	RBMK-1000
Smolensk 3		925	January 1990	LGR	RBMK-1000
Total: 29 units		**19,843**			

[a] Under reconstruction.

KEY: LGR=light-water-cooled, graphite-moderated; PWR=pressurized light-water-moderated and cooled; FBR=fast breeder reactor.

SOURCES: U.S. Department of Energy, Energy Information Administration, *EIA World Nuclear Outlook, 1994*, DOE/EIA-0436(94) (Washington, D.C.: U.S. Government Printing Office, December 1994); Gosatomnadzor, "Characteristics of the Status of Safety at Nuclear Power Plants in Russia (for 1994)," (Moscow, Russia: GAN, circa 1994).

ommends that Western assistance efforts be directed toward longer-term initiatives, such as ensuring adequate resources and sound institutional and management arrangements, rather than short-term approaches, such as technical fixes, operational improvements, and regulatory procedures (51,54). Other experts agree that with the volatile socioeconomic situation in Russia, assistance money might be wasted if it is used on technologies that the Russians are financially incapable of maintaining or regulating properly.

International Programs Addressing Reactor Safety

Group of Seven and Other Multilateral Efforts

The Group of Seven (G-7) summit in Munich in July 1992 was a seminal conference in the evolution of reactor safety. At that summit, participating countries designed an emergency action plan for the safety of Soviet-designed reactors. Operational improvements including near-term technical assistance and training are part of the plan, as are regulatory improvements. In response to suggestions made at the conference, donor countries conducted assessments on: 1) the feasibility of alternative energy sources and conservation practices, to allow for the replacement of the oldest and least safe plants; and 2) the potential for upgrading newer reactors to meet international safety norms.

The World Bank, the European Bank for Reconstruction and Development (EBRD), and the International Energy Agency (IEA) have been conducting these studies, which were completed recently. However, according to the Center for Strategic and International Studies' Congressional Study Group and Task Force on Nuclear Energy Safety Challenges in the Former Soviet Union, the studies provide neither detailed practical options on which to base U.S. policy nor convincing arguments that might persuade countries in the Newly Independent States (NIS) and Eastern Europe to shut down the riskiest reactors before their planned life spans are completed. Apparently, the G-7 and the authors of the studies themselves concur in this opinion (7).

International Convention on Nuclear Safety

Additional multilateral efforts include the International Convention on Nuclear Safety, an agreement that would urge shutdowns at nuclear power plants that do not meet certain safety standards. These are not detailed technical standards. Instead, the standards that the convention stipulates are general safety principles, including the establishment of a legislative framework on safety and an independent regulator; procedures to ensure continuous evaluation of the technical aspects of reactor safety (e.g., this would require countries to establish procedures to evaluate the effect of site selection on the environment and to ensure protection against radiation releases); and a safety management system (e.g., establishing a quality assurance program, training in safety, and emergency preparedness plans). Work on the convention began in 1991 in the wake of the dissolution of the Soviet Union. As of September 21, 1994, 40 nations had signed the convention including the United States, Russia, and Ukraine. With its signing by 40 nations, the agreement can now go before each nation's legislative body or parliament for ratification. The agreement calls on signers to submit an immediate report on all nuclear power facilities and, if necessary, to execute speedy improvements to upgrade the sites. The convention also sets up a framework for the review of a nation's atomic sites by other nations, with special provisions for such a request from neighboring countries, which may be concerned about the health of their populations and crops. The convention does not provide for an international enforcement mechanism and has no penalties for noncompliance, so as not to infringe on national sovereignty. As drafted, the convention designates IAEA as Secretariat to the meetings of involved countries (1,59).

There are several other multilateral programs whose goal is to promote nuclear safety within the former Soviet Union. Most are smaller and more specifically targeted than the above efforts.

The U.S. Nuclear Safety Assistance Program

The Joint Coordinating Committee for Civilian Nuclear Reactor Safety (JCCCNRS) is a cooperative exchange program between the United States and the Soviet Union, which was initiated in 1988. It was established in accordance with a Memorandum of Cooperation under the Agreement between the United States and the U.S.S.R. on Scientific and Technical Cooperation in the Field of Peaceful Uses of Atomic Energy (PUAEA)—an agreement signed in 1972. Not until the late 1970s, however, was the nuclear safety issue incorporated in the Peaceful Uses Agreement, and even then action on cooperation in nuclear safety was delayed due to the Soviet invasion of Afghanistan in 1979.

After the Chernobyl accident in 1986, renewed zeal was focused on the issue of nuclear safety within the framework of the PUAEA. On April 26, 1988, two years to the day after Chernobyl, the JCCCNRS was created under the Peaceful Uses Agreement. Russia and Ukraine have been formal successors to the U.S.S.R. on both the Peaceful Uses Agreement and the JCCCNRS. Representatives from both the atomic energy and the regulatory ministries in each country act as co-chairs of the JCCCNRS. Similarly, DOE and NRC are the co-chairs from the United States. Although the dissolution of the Soviet Union in late 1991 had little impact on the progress of activity under the JCCCNRS Memorandum of Cooperation, it did usher in new operational and regulatory organizations in the former Soviet Union and introduced economic problems with negative consequences for nuclear safety, including a lack of money for maintenance and shortages of spare parts.

A conference in May 1992 in Lisbon, Portugal, represented a turning point in U.S. nuclear safety assistance to the NIS. The U.S. program changed from a program of cooperative exchanges to one of specific, targeted assistance. Commonly called the Lisbon Initiative, the current U.S. nuclear safety assistance effort began as an outgrowth of JCCCNRS and has in many ways superseded JCCCNRS work. Nevertheless, JCCCNRS still exists and retains some of its original working groups.

The May 1992 Lisbon meeting and the corresponding U.S. commitments made at the G-7 conference in Munich in July 1992 are the basis for the current DOE-led program in nuclear safety assistance to the NIS, the Program for Improving the Safety of Soviet-Designed Reactors, under the International Nuclear Safety Program (INSP). INSP activities are conducted according to the guidance and policies of the State Department, the U.S. Agency for International Development (U.S. AID), and the Nuclear Regulatory Commission. All four agencies work together to achieve the objectives of the INSP, which are the following: 1) to strengthen operations and upgrade physical conditions at plants, 2) to promote a safety culture, and 3) to facilitate the development of a safety infrastructure.

In addition, at the Vancouver Summit in May 1993 the United States and Russia laid the groundwork for the U.S.-Russia Commission on Economic and Technological Cooperation, better known as the Gore-Chernomyrdin Commission. The first meeting of the GCC took place in Washington, D.C., in September 1993. At that meeting, Vice President Gore and Prime Minister Chernomyrdin agreed on a joint study on alternate sources of energy in Russia, which is being carried out by U.S. AID in close cooperation with the World Bank and other organizations. Also at that first GCC meeting, the Nuclear Safety Subcommittee, co-chaired by DOE and NRC for the United States and MINATOM and GAN for Russia, was formed.

Activities within the Department of Energy

The International Nuclear Safety Program is a Department of Energy effort to cooperate with partners in other countries to improve nuclear safety worldwide. Activities directed toward raising the level of safety at Soviet-designed nuclear power plants play a major role in this worldwide effort. The overall objectives of the Program for Improving the Safety of Soviet-Designed Reactors include the following: 1) to strengthen operation and upgrade physical conditions at plants, 2) to promote a safety culture, and 3) to facilitate the development of a safety infrastructure. The thrust of the program involves encouraging these countries to help themselves. Work under the program is organized according to the following major program elements:

1. *Management and Operations:* Major activities involve development and implementation of the following: emergency operating instructions (EOIs); practices and procedures for the safe conduct of plant operations; and training programs, including those based on the use of simulators, with training centers at the Balakovo Nuclear Power Plant in Russia and the Khmelnitsky Nuclear Power Plant in Ukraine. The program also seeks to improve emergency response capabilities through integration and through training and assistance in deficient areas.
2. *Engineering and Technology*: The focus is on the transfer of techniques, practices and procedures, and tools and equipment to upgrade plant safety. Training in the use of transferred items will also be provided to help countries help themselves in the future. Generally, when a hardware backfit is necessary for safety improvement, a single plant is selected for a "pilot demonstration" of the technology transfer. Under certain circumstances, however, (e.g., when insufficient economic incentives exist for the transfer of specific technologies), similar safety upgrade projects may be carried out at multiple plants. Upgrades in safety-related systems include fire safety, confinement, reactor protection, emergency power, and emergency feedwater systems. In pursuing upgrades in the safety-related systems of older reactors, caution is taken so as not to encourage continued operation of these reactors. The program element "engineering and technology" also encompasses the establishment of national technical standards. Examination of areas such as design control, technical and material specifications, nuclear equipment manufacturing, configuration management, and nondestructive testing methods will be performed to determine where practices should be changed to ensure sufficient levels of quality.
3. *Plant Safety Evaluation:* Safety evaluation is an area of the program receiving increasing emphasis (19). The idea is to develop the methodologies, techniques, and expertise necessary for safety analyses to be performed consistent with international standards. Plant-specific analyses will likely draw on more general studies that have already been completed by the IAEA. Priority of work will be decided with a view to furthering projects by the EBRD. Activities will include probabilistic risk assessments and assistance with the prioritization of future plant modernizations.
4. *Fuel Cycle Safety:* This element of the INSP Soviet-Designed Reactor Safety Program deals exclusively with Ukraine. The objective of the Fuel Cycle Safety Program is to address safety issues surrounding interim storage of spent fuel in Ukraine. Assistance and training to both Ukrainian power plant operators and regulators will include efforts toward the licensing of additional spent fuel storage capacity, the procurement and delivery of dry cask storage prototypes and related equipment for use at the Zaporozhye plant, and assistance as requested by Ukrainian regulators. Analysis and strategic planning regarding the adequacy and safety performance of spent fuel storage systems are fundamental to the program.
5. *Nuclear Safety Legislative and Regulatory Framework:* The major emphasis of this program element is on Russia. The focus is on the development of a legal framework that promotes the following: adherence to international nuclear safety and liability conventions and treaties; domestic indemnification for nuclear safety liability (domestic indemnification legislation would allow for broader use of Western safety technology); and establishment of strong, independent regulatory bodies. The program will encourage the habit of incorporating regulatory compliance at all stages of engineering and operations. It will also ensure that an appropriate regulatory framework exists to support other INSP project elements. Evaluation of the legislative and regulatory status in the host country will

take place in cooperation with the U.S.NRC program. Should improvements in the regulatory framework of the host country be deemed necessary, assistance will be provided to complement related ongoing NRC activities.

Activities within the Nuclear Regulatory Commission

The Nuclear Regulatory Commission programs, begun in October 1992 under the Lisbon Initiative assistance effort in Russia, include the following:

1. *Licensing Basis and Safety Analysis:* This involves training and technical assistance on NRC practices and processes for the licensing of nuclear power plants, research reactors, and other facilities involved in the use of radioactive materials. This program was the first-ranked priority project requested by the Russians and has witnessed nine teams of GAN representatives travel to the United States during 1993–94.
2. *Inspection Program Activities:* These provide training and technical assistance on the NRC inspection program. Four training team visits, two Russian teams to the United States and two U.S. teams to Russia, took place during 1993–94. Also, NRC officials participated in a joint pilot team inspection at a Russian plant.
3. *Creation of an Emergency Support Center:* Assistance is provided in establishing incident response programs. Again, team exchanges took place in both directions.
4. *Analytical Support Activities:* These assist in the implementation and application of analytical methodologies to the performance of safety analyses. NRC has solicited a contractor to provide technical support in the procurement and installation of engineering work stations. These will be useful for performing severe accident analyses, which employ U.S. computer codes that have been modified for the Russian nuclear power plants. A national laboratory has agreed to provide some analytical code training.
5. *Establishment of a Regulatory Training Program:* Assistance is provided in the establishment of a regulatory training program in Russia. Nine microcomputer systems, to be used for computer-based training, were delivered to Moscow in July 1993 and more are being sent. Also in July 1993, four GAN officials completed a three-week assignment at the NRC Technical Training Center (TTC), at which they learned about the training of NRC personnel. In August of that year, four more GAN officials spent two weeks at the facility learning about the use of training aids such as simulators and the use of equipment for developing and presenting course materials. Another contingent of GAN technical personnel visited TTC in November 1993. When further funding is available, implementation will begin on an agreement to acquire and deliver an analytical simulator, developed by a joint U.S.-Russian venture.
6. *Creation and Development of a Materials Control and Accounting System:* Not part of JCCCNRS, this program offers assistance in nuclear materials accounting and control under the Safe and Secure Dismantlement of Nuclear Weapons program.
7. *Fire Protection Support:* Technical assistance is provided in the development and review of fire protection inspection methodology and implementation of this methodology at Russian reactors. NRC developed a historical fire protection and postfire safe shutdown licensing analysis document for GAN use.[35] After the fire protection/safe shutdown licensing document, GAN specialists visited NRC and regional fire protection specialists to learn about regulations, licensing practices, and inspection methodologies in this area. Further work in this area has been requested by GAN.

[35] It should be noted, however, that MINATOM refuses to recognize the validity of GAN's licensing procedures. Enabling mechanisms are necessary to make licensing enforceable. Russian domestic legislation probably would be necessary in this area to resolve these differences (52).

8. *Probabilistic Risk Assessment Study for the Kalinin VVER-1000 Power Station (Beta Project):* A risk assessment study on Kalinin is to be developed. A kickoff meeting between the primary Russian and U.S. participants was held in May 1994. The various phases envisioned for the project include the following: Phase 1—Project Organization; Phase 2—Training, Procedures Guide Development, and Data Gathering; Phase 3—System Modeling and Accident Frequency Analysis; and Phase 4—Containment Performance. Statements of work have been done for the first three phases.
9. *Licensing and Inspection of Radioactive Materials:* Key GAN personnel are trained in health and safety issues relating to the licensing and inspection program at NRC for nonmilitary possession, use, and disposal of radioactive materials. This priority area involves on-the-job training in nuclear materials transport, the nuclear fuel cycle, spent fuel storage, nuclear waste programs, and radioisotope practices.
10. *Institutional Strengthening:* General support is provided to GAN in the following areas: document control management and computer utilization, electronic information communication, safety information publication, and the International Council of Nuclear Regulators (NRC agreed to investigate ways to underwrite GAN participation in council activities).

Nuclear Power Plants in the Arctic

The Bilibino Nuclear Power Plant

The two Russian nuclear power plants with potentially the greatest impact on the Alaskan environment are Bilibino in Chukotka Oblast in the Russian Far East and Kola in Murmansk Oblast. Bilibino is about 810 miles from Nome, Alaska; 1,250 miles from Fairbanks; and 1,860 miles from Juneau. Since Bilibino in the Russian Far East is a small-capacity station (each of the four units has a capacity of only 11 net MW_e) (megawatts of electricity), no DOE resources have been expended to assist in upgrading it. There is the possibility, however, that emergency response money will be directed toward this end in the future (55). However, NRC and GAN are cooperating on safety aspects of this facility. They are considering improvements in communication links between Bilibino and Moscow, in conjunction with an emergency support center at GAN headquarters in Moscow. Nuclear power plants in the United States make routine daily status reports to NRC, and NRC is working to establish a similar system in Russia, whereby the plants in Russia report to GAN in Moscow.

As mentioned above, the reactor design at Bilibino is EPG-6, graphite moderated and boiling water cooled, similar to the RBMK but with noteworthy differences. Comparisons to Chernobyl should be made cautiously. Fuel design and uranium enrichment differ between the two reactor types. These differences affect both the risk of an accident and its possible consequences. The possible consequences of an accident depend on the total inventory of fission products in the core at the time of an accident and the fraction and composition of the inventory that actually gets into the atmosphere. At any given time, Bilibino should have only about 1 percent of the total inventory of fission products in the Chernobyl reactor during the accident there in April 1986. Although little is known about the actual risk of accident at Bilibino, possible consequences of an accident, should one occur, could be estimated by using the knowledge available. Some researchers have made preliminary estimates of the consequences of an accident at Bilibino that indicate very low concentrations of radionuclides would be carried as far as Alaska.

All low-level waste is concentrated and stored onsite at Bilibino. High-level waste, including spent fuel, filters, and reactor components, is held onsite in stainless steel-lined concrete tanks. Fuel storage pools are closer to operating reactors than is advised in the United States.

A radiological emergency response plan exists for Bilibino. Unlike U.S. plans, this plan is based on actual postaccident measurements of a release rather than on plant conditions or dose projection models. As a result, prerelease notification of deteriorating plant conditions, which would be included in Alert, Site Area Emergency, or General Emergency reports in the United States, are not possible under the Bilibino emergency response system. The Bilibino plan's accident assessment categories differ from both IAEA International Nuclear Event Scale categories and the U.S. system of classification.[36] Therefore, some have recommended that U.S. officials seeking direct communications with Bilibino personnel and with civil defense (Emergency Situations Office)[37] officials should become familiar with the plan and its accident assessment categories, which are based on a wartime nuclear attack plan. Because of fundamental differences between United States and Russian emergency response philosophies, some have also recommended that a "tabletop" drill be carried out between Alaska and Chukotka. This would allow both sides to test communication links and make sure they understand each other.

In late June 1994, a four–day International Radiological Exercise (RADEX) was convened to test emergency response procedures. Three representatives from Bilibino and from the Chukotka Regional Government participated, as did other representatives from the Arctic Environmental Protection Strategy (AEPS) nations, various Native groups, and the International Atomic Energy Agency.[38] Also, the Office of Naval Research (ONR) is funding Emergency Response Collaboration with the Bilibino Region as one of the projects under its Arctic Nuclear Waste Assessment Project (ANWAP), which is funded by money from the Cooperative Threat Reduction Program. Under this program, in June 1994, Alaska hosted three Bilibino staff and a member of the Chukotka regional government for a visit that coincided with the RADEX tabletop exercise. In September 1994, the principal investigator for the Emergency Response Collaboration project under ANWAP, Mead Treadwell, then Commissioner of Alaska's Department of Environmental Conservation, met with officials of the Finnish Centre for Radiation and Nuclear Safety in Rovaniemi, Finland, and a conceptual agreement was reached on the development of further linkages in emergency response. Russian participation is responsible for about 25 percent of both the effort and the funds that have been expended on the Emergency Response Collaboration with the Bilibino Region project.

Under the current reporting system, accidents at Bilibino would be reported to Moscow, from Moscow to IAEA headquarters in Vienna, from Vienna to Washington, D.C., and from Washington to Alaska. Moreover, under the Convention on Early Notification of a Nuclear Accident, agreed to by the United States, the U.S.S.R., and other states in 1986, the criterion for notification is "radiological safety significance for another state," as understood by the originating state. Russian officials might reasonably argue that, given the small size of the Bilibino plant and its distance from the United States, even a severe accident there would not constitute "radiological safety significance" for another state and, therefore, would go unreported. Alaska is pushing for direct notification from Bilibino.

Improved radiation monitoring is, of course, integral to the detection and notification process. Also under ANWAP, efforts are under way to improve radiation monitoring. ONR support has made possible cooperation between the University of Alaska and the DOE Los Alamos National Laboratory in the installation of two atmospheric radiation monitors for winter capability testing. If these are successful, installation will be established at Bilibino, and personnel from the

[36] Bilibino does not use the IAEA scale, but the Russian Federation does use it when sending information to other countries and IAEA.

[37] Peacetime radiological emergency response capabilities may be shifting away from the Civil Defense Committee, since there is a reduced emphasis on civil defense with the end of the Cold War (57).

[38] AEPS was established in 1989 and consists of eight countries, including the United States, Canada, Denmark, Finland, Iceland, Norway, Russia, and Sweden. In 1991 in Rovaniemi, Finland, these countries agreed on a strategy that includes objectives and an action plan, calling for four implementing working groups, including the Emergency Prevention, Preparedness and Response Working Group, which was involved in the RADEX exercise.

Department of Environmental Conservation and the University of Alaska at Fairbanks will maintain the equipment.[39]

The Russians have announced some plans to expand power generation capacity at Bilibino to 120 MW_e, by replacing the four 11-MW_e reactors with three 40-MW_e reactors. One plan under study by MINATOM would involve construction of floating nuclear power plants similar in basic design to those used in Russia's nuclear-powered icebreakers. The floating plants would be built in a shipyard and towed to northern Siberian locations such as Bilibino. It is not clear whether or when funds would be available for these projects. The existing reactors have a 25-year design life, and the first one is scheduled for decommissioning in 2003. Plans for both decommissioning and expansion are due in 1998. A concern at the present time is that Bilibino is in an area of high seismic activity, and the reactor lacks containment. In June 1992, Y.G. Vishnevskiy, Chairman of the Russian State Nuclear Inspectorate (GAN) stated that:

> generating units of the Bilibino NPP completely fail safety rules and standards. They have outlived their original life and must be immediately shut down, especially since they are located in a seismic zone.[40]

Although the basic reactor design would remain the same in the proposed replacement systems, containment for each new reactor would be included in the changes. Prior to the expansion, installation of automatic monitoring equipment is planned for 1996. Russian authorities have also announced plans for waste management facilities at or near the plant site, but details are not clear. Bilibino management believes it would require at least $16 million to make all the modifications at the plant necessary to meet the most recent Russian power plant standards (57,63). However, despite the proposed improvements, Magadan officials fear that the quality of radiation control at Bilibino may be compromised for several reasons: 1) declining socioeconomic conditions have led many qualified specialists to leave Bilibino; and 2) the relatively recent separation of Chukotka from Magadan Oblast administration, and Chukotka authorities' refusal to accept the services of Magadan radiological labs, mean a reduction in access to, and regulation from, other facilities (57).

DOE's program for Bilibino, under the INSP, includes a project to develop a training center there. The project, which has been proposed for FY 1995, includes assistance to determine Bilibino's needs in terms of training and the delivery of training center equipment.

The Kola Nuclear Power Plant

The Kola plant is located near the northeastern border of Norway in Polyarnye Zori, Murmansk Oblast. Kola has two of the oldest-generation VVERs, the VVER 440/230, which has neither containment nor emergency core cooling. It also has two VVER 440/213s, which lack containment but do have systems for emergency core cooling. Kola is responsible for between 60 and 70 percent of the combined production of electricity (thermal and electrical) in Murmansk Oblast. Each reactor has one to two emergency stops per year on average. In 1992, there were 39 reported incidents, six of which were first-level incidents on the IAEA Event Scale and one of which was second-level. IAEA investigated the four Kola reactors in 1991 and determined that the chances of reactor meltdown at the two oldest reactors, the VVER 440/230, was 25 percent over the course of 23 years. These two reactors are currently 21 and 22 years old and are planned to continue in operation until 2003 and 2004.

[39] In Moscow in September 1994, principal investigator Treadwell presented a paper at the Ministry for Civil Defense Affairs, Emergencies and Elimination of Consequences of Natural Disasters (EMERCOM) meeting. Conference members endorsed the idea of a monitoring network. Follow-up meetings with the Russian ministries of Foreign Affairs, HYDROMET, MINATOM, Emergency Response, and Environment, and U.S. DOE and the State Department took place. The result was a request for a more specific proposal for the installation of radionuclide monitoring systems (15).

[40] Y.G. Vishnevskiy, June 1992, quoted in "Fact Sheet: Bilibino Nuclear Heat and Electric Power Plant," communication from U.S. Senator T. Stevens' Office, June 1993.

Poor maintenance practices, as well as technical weaknesses due to reactor design, contribute to safety hazards at Kola. A Bellona Foundation inspection on September 14, 1992, revealed large cracks in the concrete halls of the reactor, lack of proper illumination, cables and wires in disarray, elevated levels of radiation, and insufficient supplies of fire extinguishing equipment. Video cameras monitoring reactor hall no.1 were out of operation in August 1993. According to a 1992 report of the Russian Ministry of Security, formerly the KGB (Committee for State Security), the operators at Kola do not recognize the importance of their work. The report sharply criticized both MINATOM and the Russian government for operational problems at the plant, including the lack of qualified instructors to teach employees safety precautions. Several operators in control room no.1 had never even participated in courses on ways to handle a crisis. Also, the report noted that reactor construction at Kola is a safety risk in itself and recommended shutting down the reactors as soon as possible.

According to the Norwegian government, which operates a monitoring station located on the border with Russia, the Kola plant nearly suffered a meltdown in February 1993 when backup power to cooling systems failed. Norway has claimed that Kola is "one of the four or five most dangerous plants in the world."[41]

In the fall of 1994, a commission of MINATOM spent a week checking the station and concluded that Kola was not ready to operate in winter conditions. Equipment stocks were insufficient, and there were few funds for procuring fuel. Only one reactor was operational (8). The plant has had considerable economic problems since its customers stopped paying for the electricity they receive. The Petshenga nickel and the Severo nickel smelting works were largely responsible for the 14.5 billion rubles (approximately $2.96 million according to exchange rates on April 1, 1995) in outstanding claims in 1993. Paying workers' wages and purchasing fuel nearly forced shutdown of the Kola plant at that time. A number of debtor enterprises recently got together and took out a credit of 30 billion rubles (approximately $6.12 million) to repay the debt in part (18,48). Three out of four Kola reactors were shut down in September 1994, due in large part to financial concerns (39).

However, reports on the status of safety at the plant vary. An IAEA commission that inspected the Kola, Balakovo, Novovoronezh, and Kalinin stations in late 1994 is said to have found that there was no breach of internationally accepted operational procedures, and it did not report serious nuclear safety problems (33).

Regarding waste management, cooling water is discharged into Imandra Lake via a 1-km-long canal, and contaminated water is stored in tanks onsite. Low- and intermediate-level waste is stored near the power plant, and there is a plant for solidifying this waste before storage. Some low-level waste is burned in an incinerator. Spent fuel assemblies are stored in water pools beside each reactor. They remain there for three years and are then sent to Mayak for reprocessing (48).

Kola, along with Sosnovy Bor, has been scheduled to receive a new generation of PWRs, the first of which is the VVER-640. Apparently, the local population on the Kola peninsula has given its approval to plans for a second plant, AES-2, which is to be built near the first plant, AES-1, on the shores of Lake Imandra. The first unit of the new facility, which will include three VVER-640 reactors, has been scheduled to start up when units 1 and 2 at AES-1 should be decommissioned. The other two units would come online later. The Kola-2 project is estimated to cost $3.5 billion–$4 billion, with Germany's Siemens Company helping to supply equipment.[42] AES-1, when all units are in opera-

[41] "Russia's Arctic Struggles with Nuclear Legacy," *AP Newswire*, Dec. 6, 1994.

[42] Siemens has entered into a joint venture with the Russian nuclear industry, forming the company Nuklearkontrol to produce automatic systems for controlling technological processes at nuclear power plants. Services will include development, delivery, and maintenance of automatic systems. Siemens also plans to produce computer software for automatic control systems.

tion, produces 60 percent of the region's electricity (16,34,38).

Other advances in plant safety are being made. An acoustic system to register leakages in the primary cooling circuit of the two oldest reactors is being installed (48). Negotiations are under way for the G-7 to contribute funds to the Nuclear Safety Account (NSA) administered by the EBRD for upgrades at Kola reactors 1 and 2 (VVER 440/230) (13). Norway has contributed $2.4 million to the NSA and has strongly emphasized that the Kola facility be given high priority. Experts from EBRD, Norway, and Finland visited Kola in November 1993 to lay the groundwork for a program there.

EBRD announced in late April 1995 that it would give $25 million to the Kola plant for safety improvements, including equipment for radiation control and fire risk minimization (14). Norway contributed $24 million in bilateral assistance to Kola in 1993 and 1994 to improve plant safety. This money helped to pay for a diesel generator for emergency power, wireless telephones, and training in safety routines. Norway is also providing assistance in the transfer of technology and expertise on conservation measures and alternative sources of energy, so that dependence on nuclear power decreases.

The Norwegian State Inspection for Radioactive Security is seeking cooperation with Russia in the inspection of the Kola and Sosnovy Bor power plants and has suggested investments in support of the radiation supervision bodies in Murmansk and at the Sosnovy Bor plant (50). Russia, Norway, and Finland scheduled five days of training exercises in May 1995 to coordinate actions in case of an accident on the Kola Peninsula. Rosenergoatom and the Ministry for Emergency Situations are in charge of the training exercises (56). Cooperation in the nuclear safety arena with Finland includes an arrangement to send daily status reports from the Kola plant to Finland (57).

DOE's projects specifically regarding the Kola plant include a plan to build a full-scope simulator. The scope of work for the simulator project had been agreed upon by March 1995, and specifications are in progress. Confinement system upgrades have been undertaken, including projects to provide confinement isolation valves and postaccident radiation monitors, and measures to ensure confinement leaktightness. Engineered safety system upgrades at Kola include a project to provide a reliable DC power supply for VVER 440/230 reactors 1 and 2 (66).

CONCLUSIONS

In the main, the Russian Federation has the responsibility of addressing the issues of prevention of future accidents or nuclear waste discharges associated with the nuclear fleets and power plants in the Arctic. The Russian government must also finance the decommissioning and dismantlement of a few hundred nuclear-powered submarines and ships, provide reprocessing facilities for the spent nuclear fuel from power plants and naval reactors, construct new liquid and solid waste treatment facilities, and upgrade the safety of shore-based nuclear plants to comply with international standards. Russia has made efforts to address these problems and has most of the required expertise but lacks funding or, in some cases, the safety and environmental protection culture to give these problems high priority.

Nuclear Fleet Decommissioning

The rapid retirement and decommissioning of first- and second-generation submarines of the nuclear fleet since the breakup of the former Soviet Union in 1991 has caused serious problems.

In recent years, only a small percentage of laid-up nuclear submarines have been decommissioned. Many of these submarines have not had their spent fuel removed from the reactor core. The condition of submarine reactor vessels is not well known outside Russian Navy circles. Northern Fleet submarines are docked along the fjords of the Kola Peninsula, near the cities of Murmansk and Severodvinsk. Pacific Fleet laid-up submarines are concentrated on the Kamchatka Peninsula and near the city of Vladivostok. Russian sources estimate that at the present rate, it will take decades to defuel and dismantle their decommissioned nuclear ships and submarines. The possibility of serious accidents will be greatly increased until these laid-up submarines, many of which have not been defueled, are fully decommissioned and secured.

As of late 1994, about 121 first- and second-generation nuclear submarines had been decommissioned; however, only about 38 of these have had their spent fuel removed from the reactor core. Presumably, the bulk of these submarine reactor plants have kept their main coolant loop systems running and continuously manned at dockside. After shutdown of the reactor, this is necessary to prevent heat buildup and accelerated corrosion of reactor fuel elements. Prior to defueling, each reactor must be monitored continuously to maintain proper water chemistry. The purpose is to minimize long-term corrosion of the fuel element containment vessel. The greatest risk of accidental explosion and release of radionuclides occurs during the defueling/refueling process. However, indefinite fuel storage in submarine reactors is risky. Besides the possibility of corrosion-related failures and subsequent leakage to the environment, the entire ship's hull must be treated as high-level nuclear waste until the spent fuel is removed. Failure to take timely action will result in the need to provide long-term storage for dozens of reactor compartments whose reactor cores are filled with spent fuel.

Four of these laid-up submarines have had serious accidents during the fuel removal process, including an incident at Chazhma Bay in the Far East, and will now require special handling to store the reactor cores safely. Safe dismantling and disposal of reactor compartments containing damaged fuel is much more difficult and costly than a plant with spent fuel removed.

Spent Fuel Management

Spent nuclear fuel management as practiced in Russia includes at least four stages: 1) defueling at shipyards and on service ships; 2) loading into transportation casks; 3) shipment by rail to the reprocessing facilities at Mayak in the Ural Mountains; and 4) reprocessing into fresh fuel elements. OTA's analysis indicates that there are massive bottlenecks in the management of spent nuclear fuel. The major problems presently associated with these stages are:

1. *Defueling and Storage:* The principal problems relate to the existing backlog of spent fuel, high rates of submarine deactivation, and lack or poor quality of fuel reloading and storage equipment (including land-based stores, service ships and refueling equipment, and spent fuel transfer bases). The continuing presence of spent fuel on deactivated submarines and poorly maintained floating storage facilities increases the possibility of an accident and complicates removal of the fuel in the future.
2. *Spent Fuel Shipments:* Removal of spent fuel from naval and icebreaker bases is impeded by the difficulties of transition to new TUK-18 shipping casks, installing new fuel transfer equipment, and upgrading local transportation links and other infrastructure.
3. *Nonstandard and Damaged Fuel:* Several technical issues relate to uranium-zirconium alloy and to damaged or failed fuels. Although the volume of such nonstandard fuels is not very large, its management and final disposition require additional research and technology development.
4. *Costs:* Because of the budget deficit and economic crisis, financing of spent fuel management operations is difficult. There are also institutional problems related to the question of which agency (MINATOM, Ministry of Defense, MSC, Goscomoboronprom) will pay for various stages of fuel management operations.
5. *Personnel and Social Problems:* The severe climate, the underdeveloped social and economic infrastructure of naval facilities and associated towns, relatively low salaries, and the decreasing social prestige of the military have resulted in the exodus of qualified personnel from the Navy and the shipbuilding industry. There is also a problem of training. It

was suggested that because of insufficient training the possibility of a serious accident due to human error (similar to the Chazhma Bay explosion)[43] may have increased over the past several years (26).

Recently, some progress has been made by Russia in identifying the choke points in its nuclear fuel cycle and taking corrective action, particularly in the Northern Fleet and at Murmansk Shipping Company. These efforts have benefited from a high level of international attention, assistance, and bilateral cooperative efforts with Russia's Scandinavian neighbors (particularly Norway), the European Union, and the United States. Nurturing and expansion of these efforts might achieve a significant reduction in risk of future accidents. Progress in fuel management in the Pacific Fleet has been far less encouraging to date. Although Japan has pledged $100 million to assist in waste management, very little has been achieved to date.

Liquid Low-Level Radioactive Waste

Liquid low-level radioactive waste (LLW) processing facilities are urgently required to relieve the overcrowded storage sites at naval facilities on the Kola Peninsula and in the Vladivostok area.

Until 1993, the (former) Soviet Union dumped liquid low-level waste generated from the operation and maintenance of its naval reactors into the ocean. Although facilities had been constructed by the Soviets for treatment of naval LRW, they were never put in operation. The dumped waste fluids included primary loop coolant from PWR cores, as well as decontamination solutions used in cleaning the primary loop.

The Murmansk Trilateral Initiative, which provides support to MSC to upgrade its LRW processing capabilities has recently been initiated. A design phase contract was signed in June 1995. Under the current plan, the next step is for the United States and Norway to each contribute $750,000, a total of $1.5 million for construction. This will be used to upgrade MSC's liquid LLW processing capacity to handle the liquid waste generated by MSC and the Northern Fleet. However, this is only a beginning, and no comprehensive plan for solving all of the related fuel handling and processing, transportation, or dismantlement problems has been developed. The Russians have demonstrated that they have the technology to solve their own problems; what is needed, however, is a framework for long-term planning, commitments regarding implementation of international standards, and reliable project financing.

Solid Radioactive Waste

Storage and handling of low-level solid radioactive waste (SRW) also requires attention, particularly with respect to long-term management of the problems on a regional basis. The dismantlement of nuclear submarine hulls and sealing of reactor compartments for long-term storage is proceeding at a very slow pace. As of the end of 1994, only 15 decommissioned nuclear submarines had been completely dismantled. Although Russian shipyards have the capacity and technology required to handle this problem, dismantlement has not been adequately funded. It is not clear how the Russian government will provide the funds needed for safe and comprehensive dismantlement in the future.

If submarine dismantlement continues as planned, permanent storage for low- and intermediate-level nuclear waste, including reactor compartments, will require at least one and possibly two regional facilities. Long-term storage facilities for reactor compartments, which are now stored in open water near Russian naval facilities, will be necessary.

[43] On Aug. 10, 1985, an Echo-II SSGN reactor exploded during a refueling operation at the Chazhma Bay repair and refueling facility. The explosion resulted from inadvertent removal of control rods from the reactor core.

Civilian Nuclear Reactor Safety

Russian nuclear reactor safety is a major concern of the international community. The widespread contamination resulting from the Chernobyl Nuclear Power Plant accident in 1986 has precipitated major international interest in the safety of nuclear reactors operating in the fSU. Much of the international support is focused on the prevention of potential accidents in the future. Western experts have concluded that the Russian plants need modernization or replacement to achieve parity with the West. However, based on current Russian government plans, it will be approximately a decade before a significant number of the oldest reactors are replaced with upgraded units. The rate of replacement will be influenced heavily by the pace of recovery of the overall Russian economy.

Reactor accidents at several nuclear powerplant sites would potentially be direct threats to the Arctic environment. Two old-generation VVER-type pressurized water reactors are located on the Kola Peninsula in Murmansk Oblast. The Kola plant provides two-thirds of the electrical power to Murmansk Oblast. While these two older plants are still operating, newer plants incorporate more international safety standards and operating procedures. Norway, which closely monitors operations at Kola from its nearby border, claims that these reactor units constitute "one of the four or five most dangerous plants in the world."[44]

Bilibino, a small-capacity reactor site with four 11-MW, EPG-6 boiling-water-type, units is also located within the Arctic Circle in the Siberian Far East. Although the Bilibino reactors are graphite moderated, boiling water cooled, and similar in design to the much larger Chernobyl RBMK units, they present less of a safety risk, due mainly to the remote location and the small size of the plants.

International action focused on building a safety culture in Russian civilian nuclear programs has had mixed results to date. The most significant international assistance has come through the European Union and the G-7. The G-7 summit conducted in Munich in 1992 produced an emergency action plan for enhancing the safety of Soviet reactor designs. G-7 countries have pledged funding totaling more than $1 billion.

Norway and the United States are significant bilateral contributors to programs addressing radioactive contamination and reactor safety in the fSU. Early in 1995, the Norwegian government created an action plan to address the remediation of dumped nuclear waste, the operational safety of reactors, and the hazards of weapons-related activities. The United States has funded programs administered by DOE and NRC. The bulk of this funding has been directed toward implementing technical fixes, operational improvements, and installing regulatory procedures at fSU reactor sites. Many experts argue that programs should be directed toward longer-term initiatives, such as ensuring adequate Russian cash flow to operate the plants, as well as establishing sound institutional and management underpinning for nuclear powerplant operations.

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Institutional Framework and Policies 5

Many national and international institutions are engaged in efforts to develop solutions to the problems of past nuclear waste dumping and discharges into the sea and to ensure careful and safe management of nuclear activities, materials, and wastes in the future. Whether some institutions are more effective than others, and whether their initiatives can bring improvements, are problematic. The improvements needed—and, thus, the goals of many programs—are not clear and sometimes represent compromises among conflicting purposes. Because the problems are international it is much more difficult to harmonize the policies and goals of each affected nation. In addition, a multitude of unilateral, bilateral, and multilateral organizations have developed over many years, each with missions that have evolved and changed over time to meet the challenges of the day and to reflect the unique conflicts or cooperative moods of the times.

Within this complex backdrop, the United States and the international community are attempting to focus attention and resources on the problem of nuclear contamination in the Arctic and North Pacific. The focus now is principally on research and data collection. While this focus can lead to better knowledge and understanding, it cannot soon provide all the answers to reasonable concerns about future impacts on human health and the environment. Therefore research initiatives should be supplemented to some degree by actions that could monitor conditions; provide periodic warnings if they are necessary; and prevent future accidents or releases.

Until now, the United States has focused most organized efforts and made the greatest advances through research initiatives. There are some gaps in the research program relating to regions covered (not much effort in the Far East and North Pacific, for example), pathways investigated (biological pathways and ice transport), and other areas, but the program is evolving as a reasonably comprehensive investigation of key problems. Much work can still be performed by the United States but more cooperation with Russia is needed—especially in the area of increased access to specific dump sites and dumped material.

Minimal efforts are currently under way in the area of monitoring and warning initiatives. It is in this area that international cooperation is imperative if an effective assessment and response program is to follow. International institutions may be the most appropriate to carry out such initiatives, but one must ensure long-term consistent support of a program of rigorous scientific implementation if they are to be useful.

Some efforts are under way on prevention initiatives but, because most of the key decisions must be made by Russia, it is difficult to engender support for assistance from the United States and other countries. The Office of Technology Assessment (OTA) has identified some possible joint projects that could benefit both the United States and Russia and could be mutually supported. Other countries such as Norway might also be encouraged to support joint prevention projects. Another approach would be to more closely tie prevention projects to demilitarization assistance under the Nunn-Lugar program. This would require some rethinking of justifications, but it might prove beneficial to U.S. interests as a means of preventing future environmental releases and simultaneously encouraging military dismantlement. In addition, support for prevention projects could be used to encourage more cooperation in some other areas (i.e., to gain access to dump sites for advancing research objectives).

One of the more significant prevention programs that has been in effect for the past several years in Russia relating to radioactive contamination is in the area of nuclear power plant safety. The United States and other countries have been funding programs to improve reactor safety in Russia with some success in overall efforts to prevent another Chernobyl. Efforts by the State of Alaska have also been successful in improving regional cooperation and information exchange. Improvements have mainly been in areas of added auxiliary equipment, technical and regulatory training, monitoring and warning systems, and regulatory oversight of existing reactors. This is of particular importance at some sites in the far north where funding is limited and operations are of marginal quality. Here, again, the more substantial improvements that might include replacing old designs and equipment with safer systems, require much more resources and major policy choices that Russia itself must make.

Crucial to U.S. and other international assistance efforts is the need for Russia to strengthen its institutional system responsible for environmental protection and for establishing a nuclear safety culture. Prior to the dissolution of the Soviet Union, most government agencies and institutes responsible for managing nuclear materials operated behind a wall of secrecy with little or no external regulatory oversight. Today, Russia is only beginning to develop the legal framework necessary to effectively enforce basic environmental protection laws, regulate the use of nuclear energy, and manage radioactive materials and wastes. Similarly lacking are liability protection laws capable of facilitating the implementation of nuclear safety initiatives. Currently, various pieces of legislation are being drafted in the Russian Parliament or State Duma that would, in principle, help improve Russia's regulatory system for nuclear and environmental protection. If enacted, these legislative proposals, for example, will make government agencies and research institutes accountable for their nuclear material and radioactive waste management activities.

A number of current policies and programs have been developed in an attempt to address various parts of the overall radioactive contamination problem. For decades, national security and strategic implications largely determined U.S. and international interest in the Arctic. After the dissolution of the Soviet Union, and in response to various reports documenting that country's radioactive waste dumping practices, the United States and other members of the international community began to support domestic and cooperative approaches. The State of Alaska also plays an important role at the regional level. A number of policies and programs have been adopted to assess past, and to prevent future, radioactive contamination in the Arctic and North Pacific regions.

In addition to government efforts, two other types of organizations considered useful for improving environmental cooperation include multilateral lending institutions and nongovernmental organizations (NGOs). With few exceptions, most assistance work by lending groups to date has focused on financing projects that embrace economic reform, privatization efforts, and prodemocracy policies. Their progress has been impaired by internal organizational obstacles or by Russia's socioeconomic and institutional inadequacies. Although recent improvements in current lending approaches appear somewhat promising, little interest, if any, seems to exist thus far among multilateral lending organizations in supporting projects addressing radioactive contamination. The U.S. assistance provided to Russian environmental NGOs, on the other hand, appears successful in providing opportunities to access information and work on technical and scientific environmental issues, including radioactive contamination.

In sum, all three areas—research, monitoring, and prevention—are critical to protecting human health and the environment from widespread and indiscriminate radioactive contamination in the Arctic and North Pacific. Past practices by many nations have given a warning to the international community that was never anticipated. Specific dumping activities by the former Soviet Union have yet to show a direct connection to human health impacts but have nonetheless raised concerns and questions that will require years for even partially satisfactory answers. To facilitate their review and analysis in this chapter, OTA has grouped these policies and programs into three major categories: 1) research initiatives; 2) monitoring and early warning initiatives; and 3) prevention initiatives.

U.S. INITIATIVES AND PROGRAMS SUPPORTING RESEARCH ON RADIOACTIVE CONTAMINATION IN THE ARCTIC

Executive Branch Initiatives

For more than a century following the acquisition of Alaska from Russia in 1867, U.S. Arctic policy focused primarily on the strategic and national security importance of the region, with little emphasis on environmental protection. This policy was conducted without a formal mandate or statement until 1971, when the U.S. government released the National Security Decision Memorandum 144. With the promulgation of the National Security Decision Directive 90 of 1983 and the 1986 Policy Memorandum,[1] the U.S. officially expanded its focus on the Arctic to include research and development of renewable and nonrenewable resources[2] (61,62). The main objectives of these directives included, among others:

- ensuring the protection of national security interests including freedom of navigation in the Arctic seas and the super adjacent airspace;
- maintaining peace throughout the region;
- promoting rational development of Arctic resources for the nation's benefit;
- fostering scientific research to improve our knowledge of the Arctic; and
- developing the infrastructure needed to support defense, social, and economic endeavors.

[1] Prepared by the now-defunct Interagency Arctic Policy Group.

[2] According to recent reports, the Arctic accounts for about 25 percent of current U.S. oil production; 12 percent of natural gas; and extensive coal, peat, and mineral resources, including zinc, lead, and silver. In terms of renewable resources, for example, the Arctic Ocean contains nearly 5 percent of the world's fish supplies, making it an essential source of fisheries products for the United States and particularly the State of Alaska, which reports the largest volume and total value of fish landings for the entire nation (60, 61).

Despite these directives, official U.S. Arctic policy continued to have a strong national defense approach, with little or no support for research on Arctic radioactive contamination issues until 1994. Responding to documentation of Arctic pollution from decades of radioactive waste disposal practices of the former Soviet Union, the U.S. government recently reviewed its policy on Arctic research (16). Of particular concern was the former Soviet Union's release of radioactive materials and wastes into the lands, rivers, and seas of the Arctic and in certain locations of the Pacific Ocean. The National Security Council was requested by the State Department to conduct the review (25).

Based on the National Security Council's report, on September 24, 1994, the State Department announced a new U.S. policy for the Arctic region, emphasizing for the first time a commitment to approaches on environmental protection, institution building, and international cooperation (63,64,94). The Arctic Subgroup of the Interagency Working Group on Global Environmental Affairs in the U.S. State Department is responsible for coordinating and implementing the objectives of the new policy. With the promulgation of this new policy, the U.S. government intends to accomplish the following objectives:

1. expand cooperative research and environmental protection efforts while providing for environmentally sustainable development;
2. further scientific research through development of an integrated Arctic research budget that supports both national and international science projects;
3. improve efforts to conserve Arctic wildlife and protect their habitats, with particular attention to polar bears, walruses, seals, caribou, migratory birds, and boreal forests;
4. strengthen international cooperation for preparing and responding to environmental disasters;
5. support international cooperation in monitoring, assessment, and environmental research;
6. involve the State of Alaska more directly in the Arctic policy process;
7. support participation by Alaska's Natives in Arctic policy deliberations affecting their environment, culture, and quality of life; and
8. improve overall international cooperation, especially U.S.-Russian collaboration on matters of Arctic protection (169).

The 1994 policy for the Arctic region issued by the State Department became the first official attempt by the United States to develop a coordinated research effort on contamination of the Arctic. Yet, like earlier executive directives, the new policy does not mandate any specific research plan, or provide the funds necessary to assess Arctic contamination from nuclear activities of the former Soviet Union (8,156). The most significant U.S. Arctic research institutional initiatives are shown in figure 5-1.

Efforts by the U.S. Congress

Arctic Research Policy Act of 1984

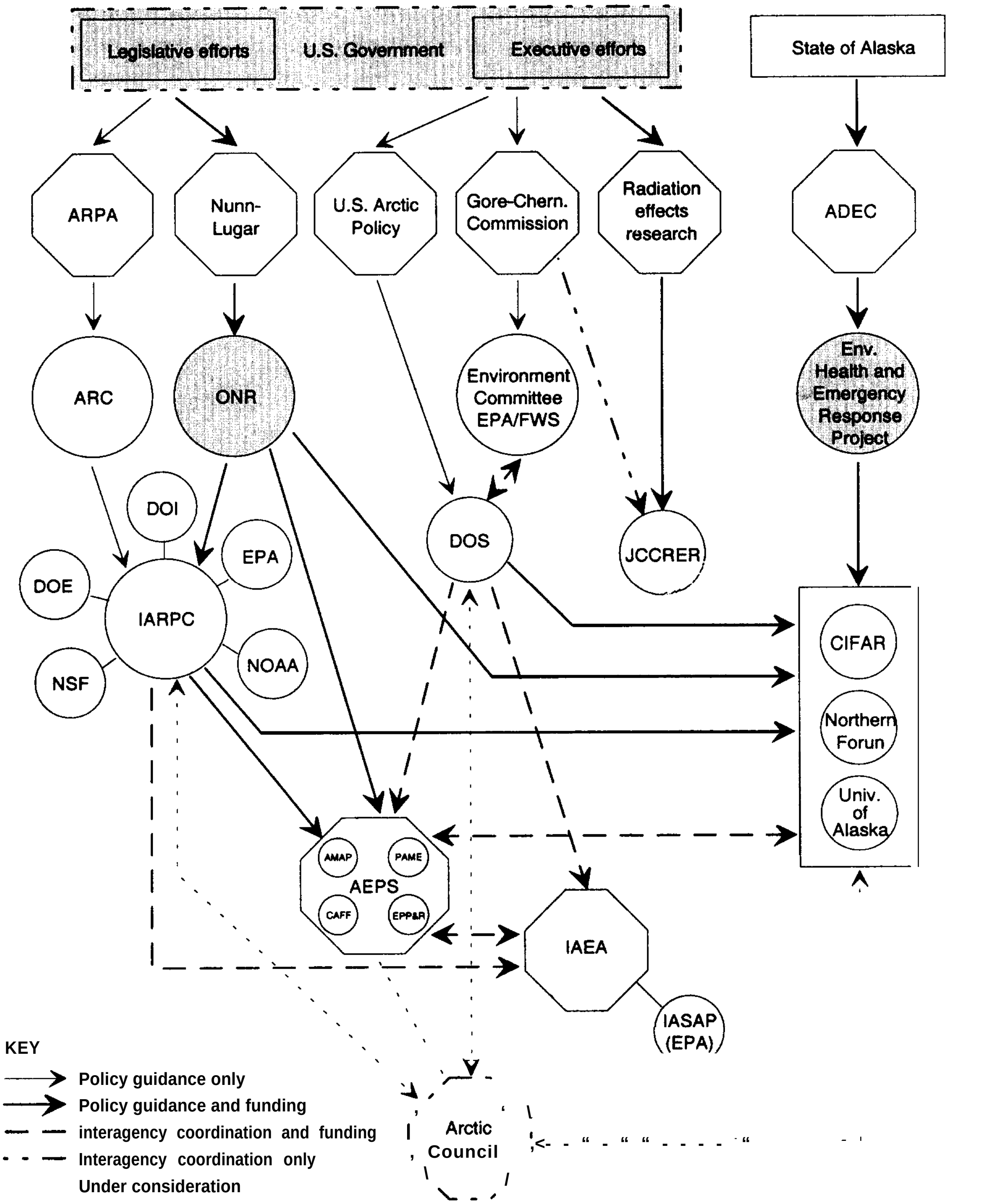
Prior to enactment of the Arctic Research Policy Act[3] by Congress in 1984, no coordinating body or source of information existed on the extent of federal Arctic research programs in the United States. The idea of establishing such a coordinating body was first issued in a report by the National Academy of Sciences' Arctic Research Policy Committee. Using the Academy's report as a basis, members of the Alaskan and Washington State congressional delegations[4] introduced a bill in 1981 entitled "The Arctic Research Policy Act" (157). After nearly three years of debate, the bill was signed into law, becoming the primary instrument for the development and coordination of U.S. research policy, priorities, and goals in the Arctic.

By enacting the Arctic Research Policy Act in 1984, Congress created the institutional infra-

[3] Public Law 98-373.

[4] Senators Frank Murkowski and Ted Stevens for the State of Alaska and Senators Slade Gorton and Henry Jackson for the State of Washington.

FIGURE 5-1: Major Initiatives Supporting Arctic Contamination Research



NOTE: ADEC: Alaska Department of Environmental Conservation; AEPS: Arctic Environmental Protection Strategy; AID: Agency for International Development; ARC: Arctic Research Commission; ARPA: Arctic Research Policy Act; CIFAR: Cooperative Institute for Arctic Research; DOE: U.S. Department of Energy; 001: U.S. Department of the Interior; EPA: U.S. Environmental Protection Agency; IARPC: Interagency Arctic Research Policy Committee; IAEA: International Atomic Energy Agency; JCCRER: Joint Coordination Committee for Radiation Effects Research: NOAA: National Oceanographic and Atmospheric Administration; NSF: National Science Foundation; ONR: office of Naval Research.

SOURCE: Office of Technology Assessment, 1995

structure required to coordinate and conduct federal research programs in the Arctic: the Arctic Research Commission (ARC) and the Interagency Arctic Research Policy Committee (IARPC). According to the congressional mandate, the Arctic Research Commission is the body responsible for coordinating and promoting Arctic research programs in ways that consider all parties involved, including federal agencies, the State of Alaska, and Native Arctic communities. The Interagency Arctic Research Policy Committee or IARPC, on the other hand, consists of all federal agencies with Arctic research programs and is responsible for identifying funds to support Arctic research activities. Internationally, IARPC is also the U.S. representative to the Arctic Environmental Protection Strategy—an effort by the eight Arctic nations (United States, Canada, Denmark, Finland, Iceland, Norway, Russia, and Sweden) to assess and develop means to control and prevent further deterioration of this ecosystem.

Despite establishing the institutional infrastructure for coordinating federal Arctic research programs, the U.S. Congress did not specify any funding source to support the implementation of its Arctic Research Policy Act (ARPA). In fact, little guidance was provided on the extent to which federal agencies were to commit resources to support the congressional mandate. Because of the lack of specific funding authority,[5] approving requests to fund Arctic radioactive contamination research is generally difficult, depending on the particular agency mission to which such requests are made and, more importantly, given the increasing unavailability of financial resources among IARPC's member agencies.

Arctic Research Commission

The Arctic Research Commission is composed of seven commissioners appointed by the U.S. President for the purpose of advising federal agencies on Arctic research policy and programs. They include four commissioners from academic or research institutions, two from private firms associated with Arctic development projects and one U.S. Native representative. Three individuals make up the commission's staff: an executive director and administrative officer in the Washington area office and a senior staff officer in Anchorage, Alaska. A group of advisers serving on a voluntary basis provides information and advice on scientific and research issues of concern to the commission and assists in the review of documents (13,20).

The Arctic Research Policy Act provides ARC with implementing authority but only an administrative budget.[6] ARC is statutorily responsible for developing U.S. Arctic research policy and for assisting all federal agencies with Arctic programs in the implementation of such policy. Reviewing the federal Arctic budget request and reporting to the Congress on the extent of government agency compliance with ARPA are also commission functions. In addition to serving as liaison between federal agencies or organizations and their Alaskan counterparts, ARC supports and promotes international cooperation in Arctic research (14,20). Despite these functions, and because ARPA does not provide research funding, the commission's efforts to persuade federal agencies with Arctic programs to contribute funds from their budgets has become pivotal for ensuring the implementation of Arctic contamination research projects (20,91).

The Arctic Research Commission was the first ARPA-related organization to recognize radioactive contamination as a key component of the U.S. Arctic research agenda. In its Arctic Resolution of August 11, 1992, ARC indicated the need for the United States to address those sources or activities responsible for contaminating the Arctic environment. The commission listed the following as major Russian sources of contamination:

[5] Although Congress initially considered proposals authorizing funding for Arctic research, the Arctic Research Policy Act, as enacted, did not include any provision of funds for such purpose.

[6] Congress appropriates the commission's operational funds ($530,000 in FY 1993) through the National Science Foundation budget. These funds are expended by the commission with administrative support from the General Services Administration (13, 20).

1) the use of nuclear weapons for civil excavation; 2) dumping of nuclear waste from weapons production facilities; 3) disposal of nuclear waste and reactors from nuclear vessels into the Kara Sea; 4) discharge of industrial chemical pollutants into air, water bodies, and soil. The commission also recognized the need to study human diseases and casualties associated with radiation accidents and overexposure to fissile materials. In a January 1994 report, the commission reiterated the need to examine the environmental and human health impacts from these activities through the establishment of a "multiagency, internationally coordinated scientific monitoring and assessment" program (13).

Despite its success in having these recommendations included in the U.S. Arctic research agenda, the limited financial support by federal agencies for radioactive contamination research and monitoring continues to be a commission concern. In the view of an ARC representative, the failure of U.S. agencies to consider Arctic environmental contamination as a priority research area constitutes the greatest barrier encountered by the commission in its efforts to gather funds for research and monitoring programs (20).

Interagency Arctic Research Policy Committee

In stressing that federal Arctic research programs be coordinated to the greatest level possible as mandated under ARPA, the U.S. Congress established the Interagency Arctic Research Policy Committee (also known as IARPC or the Interagency Committee). The IARPC consists of fourteen federal agencies[7] under the chairmanship of the director of the National Science Foundation (NSF). Working-level meetings are led or chaired by the NSF Office of Polar Programs.

ARPA authorizes the Interagency Committee to prepare and revise the U.S. overall Arctic Research Plan. Under this plan, IARPC provides Congress with a detailed agenda of the federal government's comprehensive research activities and programs on the Arctic for the ensuing five-year period. The first Arctic Research Plan report was introduced to Congress by the President in July 1987. The next review, which is being prepared, will be submitted to Congress later in 1995.

As required under ARPA, the IARPC, in consultation with the Arctic Research Commission, also reviews the Arctic plan every two years and reports to Congress. These revisions, the third of which was recently completed, describe all significant research activities implemented by each participating federal agency in the Interagency Committee. Biennial revision reports inform the Congress about research strategies planned for adoption by federal agencies in the succeeding two years. They are also helpful in coordinating and implementing research activities among U.S. government agencies (57,62).

Arctic radioactive contamination on the U.S. federal research agenda

Prior to 1990, there were no comprehensive efforts by U.S. government agencies to address Arctic environmental pollution in general, or radioactive contamination by the former Soviet Union in particular. The need to adopt a comprehensive Arctic research strategy in the United States was officially recognized for the first time at the Interagency Committee's June 1990 meeting. Without a comprehensive multiagency approach, participating agency members agreed, it would be extremely difficult to ensure mid- and long-term funding for Arctic research programs. Committee members concluded that opportunities for partnerships with the private sector and Arctic residents would also be affected (60,61). After agreeing to set forth an integrated approach starting in 1992, IARPC

[7] The 14 federal agencies comprising IARPC are: the Department of Agriculture, Department of Commerce, Department of Defense, Department of Energy, Department of Health and Human Services, Department of Interior, Department of State, Department of Transportation, U.S. Environmental Protection Agency, National Aeronautics and Space Administration, National Science Foundation, Smithsonian Institution, Office of Management and Budget, and the Office of Science and Technology Policy.

identified three major areas in which such an approach would be most useful: circulation and productivity, geodynamics, and monitoring.[8] More recent Committee work builds upon this initial effort by expanding the areas needed for having a successful integrated multidisciplinary approach to five: 1) data information and management, 2) data rescue and synthesis, 3) observation and monitoring, 4) process-oriented research and development of models, and 5) impact analysis and determination of risk (63,64,65).

Radioactive contamination of the Arctic by the former Soviet Union became part of the U.S. research agenda for the first time in 1992. Instrumental in this decision was the concern raised by various published reports, particularly the Yablokov report[9]—released by the Russian government as a white paper in 1993 (discussed in chapter 2), which documented nuclear and chemical contamination from activities of the former Soviet Union (fSU) in the Arctic. To respond to the growing concern of the U.S. and other nations, and consistent with ARC's 1992 Arctic Resolution, the Interagency Committee assumed responsibility for assessing Arctic contamination as part of its Monitoring of the Arctic Program. To guide U.S. efforts, in 1992 the Interagency Committee issued a policy statement and an agenda for action.

One of the first steps taken by the Interagency Committee to implement its agenda for action was to host an international workshop on Arctic contamination in Anchorage, Alaska, in May 1993. The conference provided U.S. and international agencies with an opportunity to learn the extent of the Arctic contamination problem and identify relevant research needs. Participating IARPC agencies benefited considerably since the workshop permitted review and information exchange on existing programs, which could be used as a baseline to support Arctic contamination research and monitoring efforts.

In 1993, IARPC also issued a list of long-term goals as the basis for making the U.S. Arctic Research Plan more effective. As part of this effort, the Interagency Committee pointed out for the first time the need to assess the contamination of the Arctic environment and the potential impacts on its residents. Inherent in this approach, as with previous Arctic research programs, is the expectation that the funding needed to implement these goals would be the responsibility of individual federal agencies. The long-term goals of U.S. Arctic research policy as issued by IARPC included the following:

- Ensure that Arctic research programs are integrated and interagency in nature.
- Promote the development and maintenance of U.S. scientific and operational capabilities for conducting Arctic research and for supporting national security needs.
- Encourage improvements in environmental protection measures and mitigation technology.
- Promote ecologically sound exploitation of Arctic resources. Develop an understanding, through research, of the roles the Arctic plays in the global environment.
- Improve the science base that now exists about 1) the interaction between Arctic Natives and their environment; 2) the possible adverse effects of transported contaminants and changes in global climate; and 3) approaches to respond to the health needs of these Arctic residents.
- Encourage the participation of Arctic Natives in the planning and conduct of research activities, informing them of the results whenever these become available.
- Develop and maintain the body of information (e.g., databases, networks) gathered from Arctic research activities.
- Promote mutually beneficial international research programs and cooperation (60,61).

[8] One additional area identified as part of this effort was the Bering Land Bridge.

[9] This unprecedented study provides an extensive review of the Soviet Union's dumping of damaged submarine reactors and nuclear waste, including spent fuel from its nuclear fleet, into the Kara Sea, the sea of Japan, and other sites.

Today, most of the research activities by IARPC member agencies in the Arctic are conducted within the framework of these long-term goals. Its proposed program on radioactive contamination research for FY 1996 through FY 1999, shown in box 5-1, also reflects these principles.

Internationally, IARPC participates in a number of cooperative efforts but with limited funding and institutional support. IARPC is the U.S. representative to the Arctic Environmental Protection Strategy (AEPS)—an effort adopted by the eight circumpolar nations to assess the extent of Arctic contamination and encourage its monitoring and control. IARPC's roles in this strategy are to coordinate and support U.S. participation and to cooperate in Arctic research activities with other circumpolar nations. Another IARPC role is to attract funds for U.S. member agencies to support the AEPS program, in particular its Arctic Monitoring and Assessment Program, but so far it has met limited success. (The Arctic Environmental Protection Strategy is discussed in detail later in this chapter.)

Another international effort supported by IARPC is the Global Resources Information Database (GRID) at the United Nations Environmental Program. Through its Arctic Environmental Data Directory Working Group, IARPC has for the past two years helped GRID identify and facilitate access to existing databases of Arctic environmental data among Arctic nations. With funding from the State Department[10] and the ONR Arctic Nuclear Waste Assessment Program discussed below, the U.S. Geological Survey is currently developing, in consultation with IARPC, a cooperative effort between U.S. and Russian scientists to establish a similar database in Russia (91). Current funding limitations also preclude expanding the number of experts presently working on this project.

Department of Defense Arctic Nuclear Waste Assessment Program

Congress authorized, as part of the $400-million Department of Defense (DOD) Appropriations Act for FY 1993 (the "Nunn-Lugar program"), the provision of at least $10 million to assess the nature and extent of nuclear contamination by the former Soviet Union in the Arctic region. Of great congressional interest was the need to: 1) assess the actual and potential impacts that nuclear contamination resulting from practices of the former Soviet Union might have on the Arctic environment and, in particular, Alaska; and 2) identify approaches that would lead to the safe disposal of reactors from nuclear submarines, nuclear weapons materials, and nuclear reactor fuel and processing waste. (Issues associated with Russia's nuclear submarine reactors and their associated fuels are discussed in detail in chapter 4.) DOD was also required to provide periodic updates of its activities to the congressional committees on Appropriations, Intelligence, and Armed Services.

In 1993, DOD became the first federal agency explicitly tasked by Congress with the responsibility for investigating radioactive contamination in the Arctic. To implement this congressional mandate, DOD's Defense Nuclear Agency delegated the Office of Naval Research (ONR) the responsibility to establish and manage the $10-million Arctic Nuclear Waste Assessment Program (ANWAP). As part of this new responsibility, ONR created a core research program under the Naval Research Laboratory to scientifically evaluate past radioactive releases and to develop models for predicting possible future dispersion. To supplement the work of its core program, ONR also invited proposals for Arctic-related field research work from government and private institutions. This component of the ONR program was characterized by some degree of interagency coordination since all submitted proposals were first reviewed by IARPC prior to ONR funding approval.

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[10] $50,000

BOX 5-1: Arctic Contamination Research and Assessment Program

To increase Arctic radioactive contamination research, and consistent with its "Agenda for Action" workshop findings and the new U.S. Arctic policy, the Interagency Committee has proposed a new initiative for FY 1996 known as the Arctic Contamination Research and Assessment Program (ARCORA). Considered by its proponents as an expansion of existing research programs rather than a separate entity, this proposed strategy embodies U.S. plans to research and assess the sources, transport, fate, and environmental and health effects of pollutants discharged directly into the Arctic or accumulated from non-Arctic sources (64). However, the program's budget request of $33 million annually was not approved by the Administration. If it were supported in the future, the major radioactive contamination research and monitoring activities under ARCORA, along with their proposing agencies and funding levels, would include the following:

1. *The National Oceanic and Atmospheric Administration (NOAA):* As part of its role in the Interagency Committee's ARCORA program, NOAA proposes to carry out the following activities:
   - Establish an integrated monitoring and modeling program to evaluate industrial and urban contamination sources and their effects on the Arctic's marine and atmospheric ecosystem and identify cost-effective measures for their control. An estimated $4.5 million annually for the FY 1996–99 period is expected to be needed to implement this work.
   - Fund through the interagency National Ice Center a $2-million research program to study the role of sea ice in pollutant transport within the Arctic. Data will be gathered by using satellite, remote sensing, and buoy technologies.
   - Expand the agency's Arctic Marine Mammal Tissue Archive Project to include both the monitoring of selected Arctic marine species (e.g., mammals, birds, fish) and the evaluation of measures to control the transfer of contaminants in the food web. NOAA has requested $4 million for this work.
   - Enhance NOAA's National Status and Trends Program to include sampling of contaminants such as synthetic chlorinated pollutants and petroleum hydrocarbons in the Arctic's atmosphere, coastal environment, and biota. The agency expects this $4.5-million program, in combination with its assessments of coastal ecosystem health and coastal resource use, to be useful in future emergency response and resource development approaches.
2. *The U.S. Environmental Protection Agency (EPA):* Until recently, the EPA contributed significantly to Arctic research through various activities including its Arctic Contaminant Research Program. The agency has now decided to "*redirect*" its Arctic program to promote, along with other government and private bodies, the identification of pollution effects and the application of environmentally sound technologies. Under the proposed ARCORA initiative, EPA plans to request a total of $1 million to support a two-year Alaska-based Environmental Monitoring Assessment Program.[a]
3. *Office of Naval Research (ONR):* In FY 1995, the Department of Defense's Office of Naval Research continues to assess the radioactive contamination caused by the former Soviet Union in the Arctic and North Pacific regions, as well as its potential adverse impacts on Alaska. This $10-million program is currently funded by DOD in addition to the $33 million ARCORA proposal.
4. *National Science Foundation (NSF):* In addition to supporting future workshops on Arctic radioactive contamination, the NSF plans to fund various research projects associated with ocean and atmospheric transport in the Arctic. A total of $3 million annually for FY 1996 through FY 1999 would be needed to support NSF's research activities under ARCORA.
5. *U.S. Department of Energy (DOE):* As part of the Interagency Committee's Arctic research agenda, DOE proposes to request $1 million annually to expand its Atmospheric Radiation Measurement Program in Alaska's North Slope. The purpose of this expansion would be to study and monitor other atmospheric processes (e.g., Arctic haze and aerosols) in addition to atmospheric radiation.

(continued)

BOX 5-1: Arctic Contamination Research and Assessment Program (Cont'd.)

6. *U.S. Department of Interior (DOI):* DOI, the federal agency responsible for managing most of the U.S. Arctic resources, plans to support Arctic contamination research in five major areas at a cost of $8 million. The activities to be carried out by DOI's implementing agencies—the U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service (FWS), and National Biological Survey (NBS)—include the following:

- Characterization and analyses by USGS of sediment properties (e.g., morphology, geology, deposition, geochemistry, and erosion) at various seafloor locations used for waste disposal in the Arctic Ocean. The proposed budget for this activity is $2 million annually for FY 1996–99.
- Evaluation by USGS of the migration potential of radioactive and nonradioactive pollutants disposed at the sites considered in the previous project. Contaminant uptake by biota and releases to atmospheres will also be studied. DOI requested a total of $1.4 million annually for this work.
- Assessment of the Arctic's contamination by key pollutants including radioactivity, heavy metals, organochlorines, and petroleum hydrocarbons. This work, to be conducted by USGS, will require about $1.5 million.
- Establishment of a contaminant data synthesis, communication, and repository center on the Arctic. The center is to be supported initially with information from existing data management programs.[b] Subsequently, this center will include activities such as: rescue and documentation of critical international Arctic data sets; conversion of Arctic data from analog into digital form; assembling of a geographic information system; and verification of statistical models. USGS also plans to improve access and cooperation with other organizations that maintain Arctic data. The estimated cost of this ARCORA activity is $1.5 million annually for FY 1996 through FY 1999.
- Evaluation of impacts of radioactive and nonradioactive contaminants on various Arctic animal species. With a proposed annual operating budget of $1.5 million, FWS and NBS plan, among other endeavors, to: 1) study and monitor radionuclides and other pollutants in fish, whales, walruses, polar bears, and other animals; and 2) determine the distribution of these pollutants in walrus prey in the Bering and Chukchi Seas.

According to its proponents, the ARCORA program will focus on evaluating the impacts of Arctic contamination on Alaska, followed by their impacts on the Arctic as a whole, and eventually their global impacts. If funding is approved, two of the most immediate benefits expected from ARCORA's implementation are the development of an Arctic contamination research and monitoring strategy and the development of a data management system. Similarly relevant, its proponents claim, is that ARCORA will help provide the scientific basis needed to formulate a more successful national and international Arctic contamination policy (35,40,64,91,94,96).

[a]This program is discussed in more detail in the section of this chapter dealing with monitoring and early warning efforts.

[b]Namely, the USGS Arctic Environmental Directory and Arctic Data Interactive programs.

SOURCE: Office of Technology Assessment, 1995.

The $10 million funded for ANWAP in FY 1993 was followed by $10 million for both FY 1994 and FY 1995 by means of Congressional action in DOD appropriation bills for those years.

The overall implementation of ANWAP is multiagency in nature. Funds are obligated through the Department of Defense in coordination with, among others, the Department of Energy (DOE), the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), and the national laboratories. ONR field research work is carried out in concert with the Secretary of Defense for Atomic Energy, the Defense Nuclear Agency, and the Interagency Arctic Research and Policy Committee. Many other federal agencies[11] and officials from the State of Alaska have also participated in an advisory capacity.

In carrying out ANWAP objectives, ONR has sponsored a variety of important research activities and has awarded contracts to more than 40 individuals or research groups. The initial emphasis of the ONR program involved collecting, evaluating, and assembling into a usable form the extensive data available on the Arctic environment. The more than 10,000 water and sediment samples from various oceanographic expeditions sponsored by the program are also providing ONR-supported investigation with data for determining background radiation levels, possible leakage from nuclear dump sites, and potential migration patterns of dumped radionuclides in the Arctic.

With its initial results, from the three years of funding to date, expected to be published in the spring of 1997, ANWAP's efforts to date comprise nearly 70 different field, laboratory, modeling and data analysis projects; three major workshops on nuclear contamination of the Arctic Ocean; and extensive collaboration with researchers from Russia, Norway, Germany, Canada, and the International Atomic Energy Agency (26,40,98,145). ANWAP also supports the Arctic Monitoring Assessment Program (AMAP) of the Arctic Environmental Protection Strategy program—nearly $390,000 total for FY 1994 and FY 1995.[12] Table 5-1 shows examples of the variety of scientific research and monitoring projects supported by ONR. According to many experts, ANWAP represents a significant first step toward increasing our understanding of the Arctic contamination problem.

Attempts are now under way to expand ANWAP's scope of research and interagency cooperation efforts. Program implementation has been made possible by the $10 million appropriated by Congress annually for FY 1993-95. In FY 1995, ONR is attempting to further strengthen its Arctic contamination research program by emphasizing scientific collaboration with Russian scientists and by expanding its sampling and monitoring activities to include the North Pacific region and major Russian riverine systems such as the Ob and Yenisey River basins (160). Funding for Russian participation in ANWAP will exceed $1 million in 1995 compared to $500,000 in 1993. These funds will support various Arctic environmental data exchanges and several scientific research projects including "comparative surveys of the Kara, Laptev, and East Siberian Seas, human health study in the Tamyr Region, radiological assessment of certain large mammals, monitoring feasibility studies, and radionuclide source term characterization" (145). Sampling of nonradioactive contaminants in the Arctic might be considered if the program is continued with additional funding in the future.

Because of the budgetary constraints ONR does not plan to expand its work beyond the objectives stipulated by Congress. Any expansion of the program's scope of research and of international cooperation in the future will probably not occur without additional congressional support (155). As of this writing no decision has been made about funding ANWAP for FY 1996 and beyond. And although the U.S. Vice President and the Russian Prime Minister at the June 1995 Gore-Chernomyrdin Commission meeting in Moscow highlighted ANWAP as a "premier example of cooperation in support of the U.S.-Russian Bilateral Agreement on Prevention of Pollution in the Arctic," no funding was proposed (145).

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[11] These include, for example, the Department of State, Defense Nuclear Agency, Naval Sea Systems Command, Central Intelligence Agency, U.S. Coast Guard, Department of the Interior, U.S. Geological Survey, and National Science Foundation.

[12] ONR provided $40,000 in FY 1994 to AMAP for the development of AMAP's radionuclide contaminant database. In FY 1995, ONR assistance totaled $349,000; of this amount, $261,000 went to database development and the remaining $88,000 to a cooperative U.S./Russian AMAP human health study (40).

TABLE 5-1: Projects Supported by ONR to Assess the Arctic's Radioactive Contamination Problem and Identify Possible Monitoring Strategies

Performing institution	Type of project	Project objectives
Alaska Department of Environmental Conservation	Monitoring	Installation of atmospheric radionuclide monitoring stations in the Russian Bilibino region to improve regional emergency-response cooperation and information exchange
Barnard College	Research	Evaluation of the role played by river runoff and sea ice melt in transporting pollutants into the Arctic
Geomar Research Center for Marine Geosciences	Research	Assessment of sediment transport mechanisms and their morphologic effect on the Arctic's seafloor
Institute of Developmental Biology, Russian Academy of Sciences	Research	Study of exposure and possible effects of radionuclides in certain mammals of northern Russia
Lamont-Doherty Earth Observatory	Research	1) Study of circulation patterns and productivity in certain areas of the Arctic Ocean; and 2) assessment of the pathways by which radioactive wastes dumped in the Arctic might enter the Arctic environment
Lawrence Livermore National Laboratory	Research	Preparation of a risk assessment for the Arctic's radioactive waste dump sites, focusing in particular on possible impacts to indigenous populations and possible monitoring strategies
Mississippi State University	Research	Establishing an international study group to investigate radioactive waste dump sites in the North Pacific (including the Sea of Japan and the Sea of Okhotsk) and identifying possible alternative disposal methods
National Oceanic and Atmospheric Administration	Research	Identification of sources, their associated contamination, and strategies for conducting long-term monitoring in the Arctic and North Pacific regions
Naval Research Laboratory	Research	NRL is carrying out several projects for the Office of Naval Research's Nuclear Waste Assessment Program, including: ■ Developing a geographical information system to archive and evaluate data obtained under the Arctic Nuclear Waste Assessment Program ■ Assessing radioactive contamination in the Kara Sea and in the region where the Ob and Yenesey Rivers discharge into the Arctic Ocean ■ Identifying existing technologies for marine radiation monitoring ■ Developing and validating a numerical modeling system to study and quantify past and potential dispersion of radionuclides from Russia's nuclear waste dump sites and land-based sources
Ohio State University and Canada's Bedford Institute of Oceanography	Research	Evaluation of sources of radioactivity in the Murmansk region
Oregon State University	Research	Analysis of sediment cores from the Laptev, East Siberian, and Chukchi Seas to determine recent radionuclide distribution and fate patterns
Pacific Northwest Laboratories	Research	Improvements to the radionuclide transport model for the Ob and Yenesey River systems
Russian Scientific Research Institute of Hydrogeology and Engineering Geology	Research	Assessment of the distribution of radionuclides in the Ob and Yenesey River basins, and determination of current and future transport

TABLE 5-1: Projects Supported by ONR to Assess the Arctic's Radioactive Contamination Problem and Identify Possible Monitoring Strategies (Cont'd.)

Science Applications International Corporation	Research	Assessment of transport processes and pathways of Soviet-dumped pollutants in the northwest Pacific Ocean off Kamchatka Peninsula
Texas A&M	Research	Quantification of man-made and natural radionuclides in the Kara and Laptev Seas
U.S. Army Cold Regions Research Engineering Laboratory	Research	Quantification of radionuclide transport in sea ice
U.S. Department of the Interior	Research	Biological and sediment sampling at certain Russian Arctic riverine deltas and islands
University of Alaska	Research	1) evaluation of impacts by river ice and estuarine ice on certain Arctic and East Siberian seas; and 2) development, testing, and identification of possible applications of a remote-sensing methodology for detecting radioactive waste disposal sites
University of California	Research	Measurement of the geographic distribution (including sea ice, seawater, and sediment) of radionuclides being discharged into the Arctic from major Russian rivers
University of Miami	Research	Assessment of the potential for marine microorganisms to uptake radionuclides discharged from dumped Soviet nuclear reactors or from radioactive dump sites
University of Rhode Island	Research	Assessment of sources, fate, and transport of radionuclides in the Arctic Ocean, including the Canadian Basin
University of Washington	Research	Assessment of the fate of contaminants from river plumes on the Arctic's continental shelf
Woods Hole Oceanographic Institution	Research	Assessment of radionuclide-contaminant transport into the Arctic from major Russian rivers, particularly the Ob River

SOURCES: Office of Naval Research, "Arctic Nuclear Waste Assessment Program: Project Summary, 1994 Research," Washington, DC, 1994; C.D. Hollister, Woods Hole Oceanographic Institution, personal communication, August 15, 1995; Office of Technology Assessment.

Alaska's Initiatives in Research on Arctic Radioactive Contamination

Traditionally, the Deputy Commissioner of the Alaska Department of Environmental Conservation is the individual assigned by the Governor to represent and coordinate all Arctic environmental protection efforts involving the state. The Deputy Commissioner participates in state, national, and international forums. These responsibilities include, among others, coordinating Alaska's participation in the Arctic Environmental Protection Strategy's Arctic Monitoring and Assessment Program (AMAP); representing Alaska in meetings held by the Arctic Research Commission; and assisting federal agencies (e.g., State Department, National Security Council) in the development and review of national Arctic policy (150).

The State of Alaska participates actively in a variety of regional, national, and international efforts to assess and monitor the status of the Arctic contamination problem. Within the region, the State of Alaska appropriates funds to the University of Alaska and its operating agencies to conduct Arctic research. According to a January 1995 ARC report, about $10 million of the $11.4 million provided by the state to the University of Alaska was programmed for Arctic research. Other agencies supporting state research efforts in the Arctic include the Department of Fish and Game (about $3.5 million) and the Alaska Science and Technology Foundation (more than $72 million since its inception in 1989) (12,150).

The Environmental Health and Emergency Response Project is the major regional undertaking supported by the State of Alaska to address Arctic contamination issues and concerns. The project was officially established by the Governor at the Northern Forum meeting in September 1992,[13] to cooperate and coordinate Arctic protection efforts among northern regional governments. The project also emphasizes the identification of existing and potential public health and safety hazards, and the sharing of environmental data among all the regional governments participating in the Northern Forum (5, 93).

In the national arena, Alaska plans to participate in the proposed $1-million Regional Environmental Monitoring Assessment Project, a program sponsored by the U.S. Environmental Protection Agency and the U.S. Fish and Wildlife Service to assess environmental contamination in the North Slope area. The State of Alaska, through its Department of Environmental Conservation, also participates in the Risk Assessment Group of ONR's Arctic Nuclear Waste Assessment Program (40). Box 5-2 describes two of the major Arctic cooperative research efforts in which the State of Alaska participates.

Internationally, most of Alaska's efforts are focused on supporting the work of the AEPS, in particular its Arctic Monitoring and Assessment Program (AMAP). Some of the international projects known to have extensive Alaskan participation include the following:

1. reviewing state databases known to contain information about air pollution sources and contaminated sites found throughout the state, and reporting the results to the AMAP Secretariat;
2. providing the AMAP Secretariat with radiation data collected by state monitors and by the monitors planned for installation at the Bilibino nuclear power plant as part of a cooperative agreement with that Russian facility; and
3. paying the salary of an expert who would help to complete the chapter on heavy metals that the United States is required to submit as part of the AMAP report now under preparation (150).

Evaluation of Current U.S. Federal and State Arctic Research Initiatives

For more than a century following the acquisition of Alaska from Russia in 1867, U.S. Arctic policy lacked a formal mandate and focused primarily on the strategic and national security importance of this region. Little emphasis was given to protection of the Arctic environment from waste disposal activities, including dumping of radioactive materials. Even when Congress passed the Arctic Research Policy Act in 1984, calling for the coordination of all federal research efforts, U.S. policy continued to emphasize national defense rather than environmental contamination research.

In response to the growing concerns raised by reports documenting the radioactive and chemical contamination of the Arctic by the former Soviet Union, the United States has opted since 1992 to address this problem in a number of ways. For example, the Interagency Committee and the Arctic Research Commission have put forth various efforts (e.g., expert workshops; long-term research goals; research recommendations) to establish a coordinated radioactive contamination research plan. As part of renewing its 1983 policies, the U.S. government, through the State Department, issued a new Arctic policy in September 1994, emphasizing its commitment to the environmental protection of the Arctic eco-

[13] The Northern Forum is a nongovernmental organization composed of 23 governors from northern and Arctic regions. The regional governments participating in the Northern Forum are: Alaska (U.S.); Lapland (Finland); Hokkaido (Japan); Yukon and Alberta (Canada); S. Trondelag and the Northern Counties Association (Norway); Dornod (Mongolia); Heilongjiang (People's Republic of China); Vaserbotten (Sweden); the Republic of Korea; and the Russian regional governments of: Chukotka Autonomous Okrug, Evenk Autonomous Okrug, Khabarovsk Krai, Magadan Oblast, Nenets Autonomous Okrug, Kamchatka Oblast, Sakha Republic, Sakhalin Oblast, Komi Republic, Leningrad Oblast, Khantiy Mansiisk Autonomous Okrug, and the Jewish Autonomous Region (93, 135).

BOX 5-2: Alaska's Initiatives on Arctic Radioactive Contamination Research

Rapid Assessment of Potentially Significant Pollution Sources in the Russian Far East

The Russian Rapid Assessment Project is an Alaskan initiative to work with the eight regional governments of the Russian Far East in the identification and collection of data from those areas in Russia considered of greatest risk to human health and the environment in the region. This initiative also seeks to provide the basis for long-term cooperation between the United States and Russian national and regional governments. On the completion of the project, the data collected and mapped are expected to benefit the Arctic Monitoring and Assessment Program as well as the state's efforts to prepare an emergency response program.

Implementation of the Russian Rapid Assessment Project involves a complex array of jurisdictions. For instance, the State of Alaska is responsible for overseeing and partially financing the project. The U.S. Environmental Protection Agency and the U.S. State Department have provided funds ($100,000 and $140,000, respectively) for its implementation. At least seven Far East regions of Russia are participating in the project: the Chukotka Autonomous Region, Kamchatka Oblast, Khabarovsk Krai, Magadan Oblast, Primorski Krai, Sakhalin Oblast, and the Sakha Republic (184,185). According to experts, the project has provided a great opportunity for local government officials to learn about pollution sources in their regions since the number of contaminated sites that might be involved ranges from a few dozen (Sakhalin and Magadan Oblasts), to several hundred (Kamchatka), to several thousand (Primorsky Krai).

As originally proposed, the implementation of this effort is twofold. The first phase consisted of training two Russian representatives selected by a sponsoring committee or department from each Far East region on the use of computers to collect and store pollution data. The second phase involves assisting Alaskan scientists to enter the collected data into a computer mapping system (global information system, or GIS) so the Russians can subsequently reproduce maps of their pollution sites and areas of contamination. Training of regional representatives was carried out by the University of Alaska's Environmental Resources Institute (ENRI) in June 1994 (117,118,126,185).

Thus far, the Rapid Assessment Project appears to be a promising cooperative effort; environmental monitoring data previously collected by regional organizations is being mapped for the first time. Assurances by project staff of the availability of data on Alaska's contaminated sites to the participating Far East regions have played a key role in the Russians' willingness to reciprocate. Plans are under way to develop an agreement—to be signed at a future meeting—by which all participating regions have access to any monitoring information and results, including maps and databases (126).

After the training of Russian participants, ENRI personnel provide computers and payments of about $125 for each project participant until each has received $1,500. Once the project is completed, computers will be returned to the State of Alaska unless the program is extended to cover other Russian regions. Scheduled for release in September 1995, the final report and contamination maps are expected to be highly useful to regional government officials, local concerned individuals, and various international research efforts including the Arctic Monitoring Assessment Program (117,118,184,185).

Despite progress made in improving logistics, the Russian information infrastructure continues to hinder project implementation. Some data from the Russian regions are already being received and integrated into the GIS system. According to Office of Technology Assessment research, several barriers still impede more effective data transfer. These include an inefficient mail service system, an unreliable telephone and fax system, and a limited computer communication system (e.g., Internet/E-mail) (185).

(continued)

BOX 5-2: Alaska's Initiatives on Arctic Radioactive Contamination Research (Cont'd.)

The Cooperative Institute for Arctic Research

The Cooperative Institute for Arctic Research (CIFAR) was established in 1994 as a cooperative effort among the National Oceanic and Atmospheric Administration (NOAA), the University of Alaska-Fairbanks, and the Alaska Department of Environmental Conservation for the purpose of coordinating and integrating Arctic research activities in Alaska.

In addition to NOAA support, CIFAR received $352,000 in FY 1994 and $205,000 in FY 1995 from ONR's Arctic Nuclear Waste Assessment Program to conduct various research activities through 1998. One such project involves analysis of data on contaminant levels, pollutant transport, and associated ecological effects on the coastal and continental shelf areas of the Beaufort and Chukchi Seas collected under the Outer Continental Shelf Environmental Assessment Program from 1975 to 1985. On completing this effort, CIFAR plans to convene an international conference in the spring of 1997 to highlight the results of the Arctic Nuclear Waste Assessment Program (30,40).

CIFAR also proposes to expand Alaska's monitoring program in Barrow to include other areas of Arctic Alaska and to sample other significant pollutants such as persistent organic pollutants and metals. As part of this activity, CIFAR plans to explore opportunities for real-time data exchange with institutions in the Russian Federation and other Arctic nations by use of the Internet (30,96).

SOURCE: Office of Technology Assessment, 1995.

system. Like the policy efforts issued during the 1980s, these new policy initiatives failed to provide or identify funding sources for implementing any radioactive contamination research project.

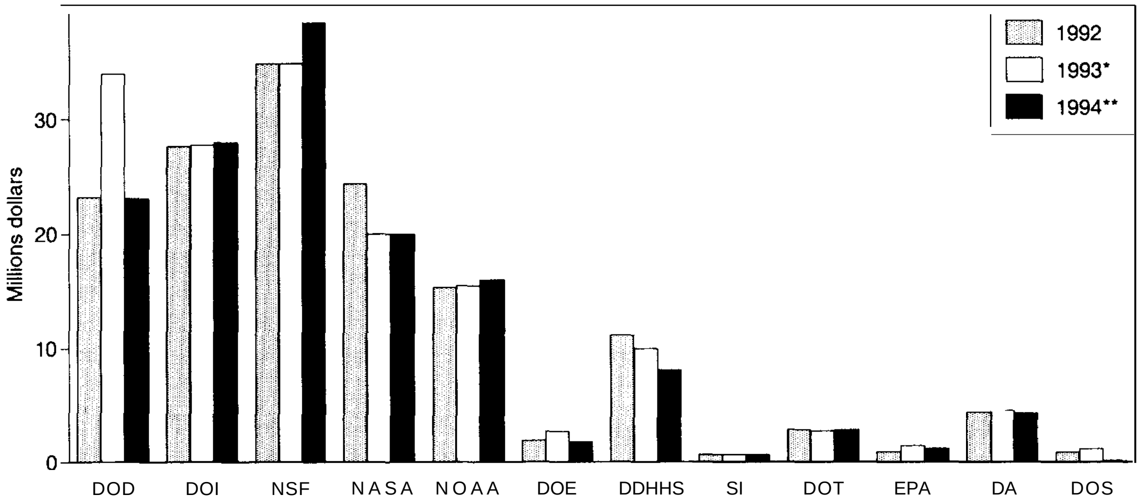
Unlike ARPA and U.S. government Arctic policy, the Office of Naval Research has conducted extensive research on radioactive contamination in the Arctic for the last three years. In addition to data collection and analysis through workshops and information exchanges, ONR has also supported extensive sampling of environmental conditions in neighboring areas of Alaska and certain coastal and riverine areas of the Arctic known to have been used by the former Soviet Union to dispose of radioactive contaminated materials. Although research efforts are now more systematic than in years past, they do not fully characterize the status and trends of pollutants in the Arctic.

Despite U.S. policy development efforts, attracting funds for Arctic contamination research continues to be difficult for the Interagency Committee and the Arctic Research Commission (20,91,94,96). According to OTA research, funds provided by federal agencies to carry out their responsibilities under the Interagency Committee are considerably less than those for overall Arctic research.[14] In fact, the level of funding available for Arctic contamination research totaled $16 million for FY 1993 through FY 1995, $10 million of which corresponded to congressional authorizations supporting ONR's Arctic Nuclear Waste Assessment Program. IARPC agencies, such as the National Science Foundation, provided the remaining $6 million. The overall federal Arctic research budget for the same period, on the other hand, averaged nearly $170 million. Figure 5-2 shows the U.S. Arctic research budget, by agency, for FY 1992-94.

According to the currently proposed IARPC budget request, implementation of the Arctic Contamination Research and Assessment pro-

[14] Due to funding limitations, unilateral efforts by the United States to assess radioactive contamination in the Arctic have been limited primarily to a few workshops, several information exchanges, and a small number of field research projects.

FIGURE 5-2: Total Federal Arctic Research Budget, by Agency, FY 1992-1994



KEY: DOA: Department of Agriculture; DDHHS: Department of Health and Human services; DOD: Department of Defense; DOE: Department of Energy; DOI: Department of the Interior; DOS: Department of State; DOT: Department of Transportation: EPA: Environmental Protection Agency; NASA: National Atmospheric and Space Administration; NOAA: National Oceanic and Atmospheric Administration; SI: Smithsonian Institution.
SOURCES: C. Myers, National Science Foundation, personal communication, Mar. 3 and June 15, 1995; Interagency Research Policy Committee, National Science Foundation, "United States Arctic Research Plan, Biennial Revision: 1996-2000," final draft report, May 1995.

gram (box 5-1) would require about $33 million for FY 1995. Nearly 85 percent ($27.8 million) is expected to come from NOAA and the Department of Interior; NSF will provide about 9 percent of this total ($3 million). The level of funding needed for FY 1996-99 is calculated to be relatively similar to the FY 1995 budget request. While contributions from DOE and EPA will not exceed $1 million, it is unknown whether the ONR program participation ($10 million in past) will continue (63,64,66).

Funding uncertainties and limitations are obstacles for U.S. agencies in their attempts to assess radioactive contamination and evaluate its potential adverse impacts, In light of recent budget-cutting measures among federal agencies, little expectation exists of future increases in funds to programs responsible for assessing the Arctic's radioactive contamination problem,

Most experts anticipate that the search for funds to support Arctic contamination projects will become more difficult, particularly in light of the present climate of competing priorities and budgetary hardships among federal agencies with Arctic programs.

U.S.-Russian Bilateral Cooperative Initiatives on Arctic Contamination Research

For several decades prior to the breakup of the Soviet Union, U.S. efforts had been centered on mobilization of the vast economic and military resources needed to enable the nation to withstand any potential threats. After the dissolution of the Soviet Union—as an indication that the Cold War was over—the U.S. Congress embarked on an effort to assist the newly independent states, and particularly Russia, in partnerships with the United States and other Western nations. This assistance was geared primarily to support the establishment of democratic institutions and economic reforms and policies. U.S. assistance efforts also embraced strategies for safe dismantlement and destruction of nuclear weapons. Figure 5-1 shows the relationship between U.S. national and international efforts to support Arctic research and monitoring.

The Gore-Chernomyrdin Commission

As part of the April 3-4, 1993, summit meeting in Vancouver, Canada, the Presidents of Russia and the United States agreed to forge a new mutually cooperative venture between the two nations. Because the venture was to be guided primarily by high-level government officials, a U.S.-Russian Joint Commission on Economic and Technological Cooperation was established under the leadership of U.S. Vice President Albert Gore and Russian Prime Minister Viktor Chernomyrdin. Since its creation, the Gore-Chernomyrdin Commission (GCC), as the joint venture is known, has lacked the funding mechanism or budget required to support any of the cooperative initiatives undertaken under its jurisdiction (8,51).

The GCC was established shortly after the Vancouver summit. The first commission meeting took place in Washington in September 1993. Since then, the meeting site has alternated between Russia and the United States. The fifth and most recent meeting was held in Moscow in June 1995.

The scope and complexity of the commission have expanded since the presidential summit in Vancouver. Created to provide a framework for cooperating in the areas of space, energy, and high technology, the Gore-Chernomyrdin Commission has to date expanded to include five additional areas of interest (business development, defense conversion, health, environment, and agriculture). Today, the commission has working committees for each of these issues which are chaired by Cabinet members (figure 5-3). The Environment Committee, headed by the administrator of the U.S. Environmental Protection Agency, is the GCC branch responsible for developing and implementing the U.S. portion of cooperative environmental plans with Russia (54,180).

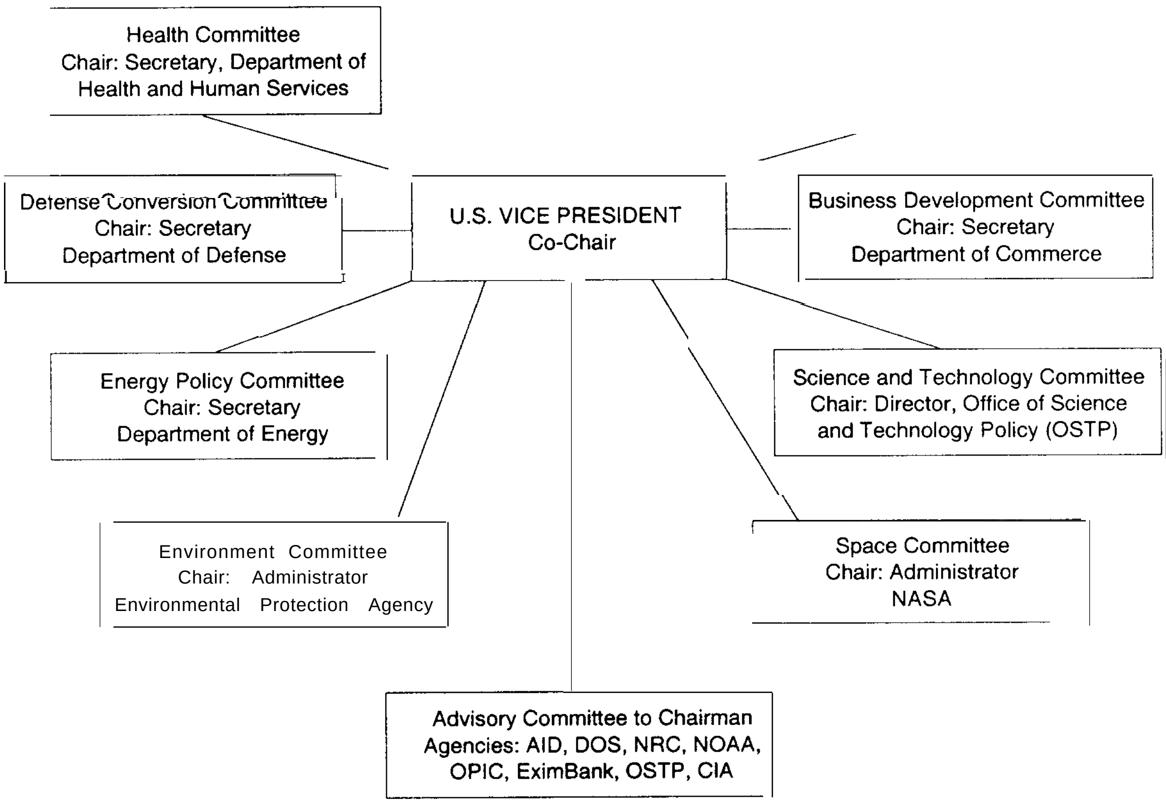
Little progress, however, has been attained thus far by the commission in the field of Arctic nuclear contamination. Most of its work, particularly that of the Environment Committee, appears focused on the areas of sustainable management of natural resources, conservation of biodiversity, and environmental technical assistance and education. Among the activities of current interest to the GCC, for example, are: the application of remote sensing data and technologies; training in pollution control, risk assessment, and environmental law and economics; cleanup of the oil spill in the Komi Republic; and more recently, the phasing out of leaded gasoline. Of the various bilateral research initiatives supported by the United States under the Gore-Chernomyrdin Commission, only one relates to researching the radioactive contamination problem in the Arctic: the U.S.-Russian Agreement on Cooperation in the Field of Environmental Protection of 1994.

A cooperative research accord that might be beneficial to U.S. efforts in assessing radioactive contamination is the agreement between the United States and the fSU to cooperate in research on radiation effects, described in box 5-3. This agreement is a bilateral, stand-alone, government-to-government accord whose implementation is coordinated with the GCC’s Health Committee. No GCC funds are provided for implementation of this agreement. The Environment Committee has also been active in facilitating opportunities for U.S. and Russian military and defense communities to cooperate in solving environmental problems (51,145,180); to prevent future radioactive contamination, the committee is assisting the Russians with improvements in radioactive waste management and nuclear reactor safety—a subject discussed later in this chapter.

U.S.-Russian agreement on cooperation in the field of environmental protection

In May 23, 1972, the United States and the Soviet Union signed the U.S.-U.S.S.R. Environmental Agreement, an unprecedented protocol designed to build long-term cooperation in the field of environmental research and ecological protection. Despite the unfavorable diplomatic conditions that existed between the two nations throughout the Cold War, the 1972 agreement proved successful in fostering collaboration

FIGURE 5-3: Organizational Structure of the U.S. Component of the Gore-Chernomyrdin Commission



KEY: AID: Agency for International Development; CIA: Central Intelligence Agency; DOS: Department of State; EPA: U.S. Environmental Protection Agency; Exim Bank: Export-Import Bank: NRC: Nuclear Regulatory Agency; NOAA: National Oceanic end Atmospheric Administration; OPIC: Overseas Private Investment Corporation.

SOURCE: Office of Technology Assessment, 1995.

BOX 5-3: U.S.-Russian Agreement on Cooperation in Research on Radiation Effects

The breakup of the Soviet Union has provided U.S. and Russian radiation research experts with an unprecedented opportunity to overcome some of the limitations of the scientific studies used for determining chronic radiation exposures and predicting radiation health risks.[a] Prior to the breakup of the Soviet Union, there was little opportunity to study localities where populations were known to be externally and internally exposed to low radiation levels over long periods of time. One example of such a location is the radioactively contaminated area in Russia's southern Urals. Recognizing the importance that preservation and analysis of radiation exposure data from the southern Urals may have in answering questions concerning chronic low-level exposures, the U.S. Secretary of State and the Russian Foreign Minister, at their January 1994 Moscow summit, entered into an historic binational agreement to cooperate on matters relating to radiation effects research. This five-year accord,[b] known as the *Agreement Between the Government of the United States of America and the Government of the Russian Federation on Cooperation in Research on Radiation Effects for the Purpose of Minimizing the Consequences of Radioactive Contamination on Health and the Environment,* identifies six major areas of cooperation:

1. health effects studies of radiation-exposed workers and community members;
2. preservation of existing data and development of relevant databases and information systems;
3. environmental studies reconstructing past doses to human populations and assessing impacts of radioactivity on the environment;
4. health communication of risk assessment information;
5. policy analysis, including review of detection and reporting mechanisms; and
6. support of scientific research capable of identifying means to reduce the environmental and human health impacts of radioactive contamination.

The Joint Coordinating Committee for Radiation Effects Research (JCCRER) was established to implement the agreement.[c] The JCCRER is responsible for coordinating and reviewing "all aspects of cooperation under the Agreement" and for arranging working groups, conferences, and seminars to discuss and study radioactive effects issues.[d] According to Article III.5, the JCCRER may also develop "*projects and programs for radiation effects research, exchanges of scientific and technical safety information, personnel and equipment, and procedures for addressing and resolving questions of such matters as payment of costs under this cooperation, and patent and/or publication rights for joint activities administered under this Agreement . . .*" All programs of cooperation developed under the JCCRER are to be established on an annual basis and implemented the following year.[e]

Collaboration under the agreement is multiagency in nature and coordinated with the Gore-Chernomyrdin Commission's Health Committee. U.S. technical participation in the committee is carried out by the Department of Energy, Nuclear Regulatory Commission, Department of Defense, and Department of Health and Human Services. The Russian agencies currently represented at the JCCRER consist of the Ministry for Civil Defense Affairs, Emergencies, and Elimination of Consequences of Natural Disasters (EMERCOM); Ministry of Atomic Energy; and the Ministry of Health and the Medical Industry. The Department of Energy and EMERCOM are the executive agents responsible for coordinating the overall research plan and activities agreed to by the United States and Russia under the accord.

The text of the agreement provides ample flexibility to the parties to determine the type of funding mechanism to be employed to fund administrative and research activities. The U.S. government has budgeted more than $1 million to implement activities under this agreement during FY 1995; funding for subsequent years will be determined on a year-by-year basis. During the first JCCRER held in Bethesda, Maryland, on October 24–25, 1994, Russia indicated its intent to provide a relatively similar level of financial support through a centralized funding authority under EMERCOM. The availability of information on the progress made by the Russian government in carrying out this intent has not been addressed during this first year of work under the agreement.

(continued)

BOX 5-3: U.S.-Russian Agreement on Cooperation in Research on Radiation Effects (Cont'd.)

For the purpose of demonstrating successful collaborative research, the JCCRER plans to focus on implementing, at least for the first year, only a small number of radiation research projects. The areas of study would include feasibility studies on updating dose reconstruction models, estimating carcinogenic-noncarcinogenic effects and potential risks, and assessing radionuclide metabolism in exposed residents. The Russian communities to be studied will consist of the residents living along the Techa River and the southern Ural region, an area extensively contaminated by radioactivity from waste discharges and accidents, and the Mayak industrial nuclear complex, where many plant workers are thought to have been exposed to excessive radiation levels. Radiation effects among Mayak's nonworking population are also considered in JCCRER's initial program of cooperation (52,87,88,179)

Since the signing of the agreement, the JCCRER Executive Committee and Project Research Teams have focused on improving understanding of the Russian scientific approach and on developing the institutional relationship needed to collaborate successfully with the Russians. To this end, the Executive Committee recently conducted two workshops, one in Florida to discuss implementation of selected occupational exposure projects at the Mayak facility. The second workshop, conducted in July 1995 in St. Petersburg, Russia, focused on how the research on radiation effects along the Techa River population and community studies will be performed (179).

[a]Our knowledge about the health effects and possible risks associated with radiation exposure is based largely on medical studies of survivors from the Hiroshima and Nagasaki bomb explosions. In addition, the data collected from these studies only pertain directly to populations exposed to high radiation doses for relatively short periods of time. Because of these limitations, scientists extrapolate the data in order to develop regulatory and safety standards for controlling risks associated with low radiation dose and low dose rates. Many critics, however, question the validity of using high-dose and high-dose-rate to determine the risks associated with chronic low radiation exposures since, as indicated in the Agreement's proposed implementation plan of October 1994, high-dose data do "not correspond to the pattern of exposure normally encountered or expected in the nuclear fuel cycle and in other uses of radiation and radioactive materials.

[b]The agreement is to remain in force at least until 1999, at which time additional five-year extensions can be approved by the U.S. and Russian governments.

[c]In addition to the JCCRER, both governments agreed to create an Executive Committee responsible for JCCRER day-to-day activities and for initiating a few research proposals in the first year of implementation; Scientific Review Groups for reviewing and evaluating the research conducted under the agreement; and Project Research Teams composed of the principal U.S. and Russian scientists carrying out the work.

[d]Articles III.4 and III.5 of the agreement.

[e]Article III.6.

SOURCE: Office of Technology Assessment, 1995.

between the scientific communities in both nations.

By virtue of the Soviet Union's dissolution and as an effort to provide continuity to the collaborative work conducted under the 1972 protocol, Vice President Gore and Russian Prime Minister Chernomyrdin signed on May 23, 1994, the U.S.-Russia Agreement on Cooperation in the Field of Protection of the Environment and Natural Resources. This agreement replaced the 1972 accord with the Soviet Union. The conditions of the agreement will remain in force until May 23, 1999, unless the United States and Russia sign an additional five-year extension. The U.S. Environmental Protection Agency, in consultation with the State Department and other federal agencies, is responsible for administering the accord (144).

The 1994 agreement seeks to support long-term joint cooperation for studies on the harmful environmental impacts of pollution and for the development of "measures to improve the condition of the environment...including work on the areas of pollution prevention and remediation."[15] Of the nearly 20 fields of cooperation included in the new agreement—shown in table 5-2—the fifth area specifically calls for both nations to focus on protecting the Arctic environment by

[15] Article I of "Agreement Between the Government of the United States of America and the Government of the Russian Federation on Cooperation in the Field of Protection of the Environment and Natural Resources," June 23, 1994.

TABLE 5-2: Areas of Cooperation Identified Under the 1994 Agreement on Cooperation in the Field of Environmental Protection

1	Atmosphere; water and soil resources
2	Environmental aspects of agricultural production
3	Preservation, conservation, and management of natural and cultural resources in the context of their relationship to the environment, including the organization of preserves and other specially protected areas
4	Marine and coastal areas and resources
5	Arctic and sub-Arctic areas and resources
6	Environmental impact assessment
7	Global environmental issues, including climate change, depletion of the ozone layer and conservation and restoration of the biological diversity of local, regional, and global ecological systems, including forest ecosystems.
8	Impact of environmental factors on human health and the condition of flora and fauna
9	Application of digital mapping and GIS (geographic information systems) technologies and use of sensor technology in addressing environmental issues
10	Energy-saving measures and creation of alternative energy sources
11	Legal and administrative measures relating to the protection of the environment, including legislation, enforcement, and access to the administrative and judicial systems
12	Participation of the public, including nongovernmental organizations in environmental decisionmaking
13	Education in the field of environmental protection and natural resources
14	Economics and the management of environmental issues and the use of natural resources
15	Role of the military in the field of protection of the environment and natural resources
16	Environmental emergencies
17	Earthquake prediction and assessment of seismic risks
18	Environmental monitoring
19	Any other area of cooperation agreed to by the parties

SOURCE: U.S.–Russia Agreement on Cooperation in the Field of Protection of the Environment and Natural Resources, May 23, 1994.

supporting technical and scientific projects, information exchange, and meetings.

Active collaboration is also found in the area of "Conservation of Nature and the Organization of Reserves" included in the agreement. Under this section of the agreement, various U.S. agencies—such as the Fish and Wildlife Service, the Forest Service, and the Office of Naval Research—have worked with Russian government agencies[16] and nongovernmental institutions to promote natural resource conservation and to improve technical training and research opportunities. The research projects supported include, among others, joint mapping of sea ice and snow cover in the Bering and Chukchi Seas; surveying animal populations of ecological importance to the U.S. and Russian Arctic regions; and conserving the genetic diversity of threatened animal populations such as the Siberian tiger (36,83,84,178).

[16] For example, the Ministry of Environmental Protection and Natural Resources, Ministry of Fisheries, and Russian Academy of Sciences.

The Fish and Wildlife Service also plans to participate in the joint Russian-U.S. scientific expedition planned and funded by the Office of Naval Research for August 1995. Collection of water and sediment samples—also funded by ONR—will take place in the area extending from the Bering Strait, westward of the Chuckchi Sea to the mouth of the Kolyma River in the East Siberian Sea. Collected samples will then be analyzed to assess existing levels of radioactive and chemical contamination, evaluate their long-term effects on the marine plant and animal populations of the area, and study the pathways through which these contaminants are transported within this region of the Arctic (40,84,173).

Despite the increased impetus to carry out collaborative work under the Agreement on Cooperation in the Field of Protection of the Environment and Natural Resources, experts view the current economic hardship experienced by Russia as a major obstacle limiting their participation under the agreement. In the view of an official on the Russian side of the agreement, adoption by the United States of "a significant share of the [financial] burden" associated with implementing the accord is the main reason for the success thus far (36).

MONITORING AND EARLY WARNING INITIATIVES DESIGNED TO ADDRESS RADIOACTIVE CONTAMINATION IN THE ARCTIC

Concerns about Russia's Environmental Monitoring Data

Considerable concern exists among Alaskan residents and Arctic nations about the limited Russian monitoring of environmental contamination, and the inadequacy of its existing data and of the institutional regulatory framework responsible for monitoring and enforcement. Regarding air and water pollution, for example, Russian monitoring efforts were generally limited to samples taken through a federally funded network that consisted of a few monitoring points located in key sites. The Committee for Air and Hydrology was the Russian agency responsible for overseeing the sampling. Under the committee's supervision, samples were analyzed periodically for only 10 different contaminants, and the data were summarized and reported annually. One reason for this appears to be that "Russian environmental laws list allowable limits for numerous pollutants but only 10 are actually considered. All the rest are not actually measured, rather they are estimated." Resource limitations also preclude more extensive sampling and data reporting, as evidenced by the committee's recent decision to reduce the number of monitoring stations in the network due to shrinking federal funds (117,118,126).

The poor quality of data regarding contaminated lands in Russia, particularly in the Far East region, is also of concern among Alaskans and Russian regional governments. The responsibility for monitoring and reporting the nature and extent of pollutants on land in Russia traditionally falls on the polluting facilities. Operating facilities are required to collect and report all samples for laboratory analysis to the Committee of Environmental Protection and Natural Resources (CEPNR). Upon completion of analysis, results are submitted to statistical bureaus where status reports of the region's contamination are prepared.

Because of the limited capacity of its laboratory facilities and funding shortages that prevent the hiring of additional personnel, CEPNR's analytical staff is often forced to test only a few pollutants. Additional contaminants could be tested and regulated, but current funds are too limited for CEPNR to expand its staff and testing activities (126). The inadequacy of regional environmental data and shortage of agency resources also limit the ability to map the status of contamination in Russia's Far East region. In the past, mapping of contamination (e.g., in the Russian Far East) consisted of providing a limited qualitative depiction of what was present at contaminated sites, rather than supplying accurate pollutant levels and the locations of such contamination sources. In most instances, such data also exclude discharges from the military's extensive nuclear and nonnuclear industrial complexes. Data inadequacy, according to a recently published report, only adds to the difficulty of addressing environmental contamination problems in Russia (48,90).

The fragmented nature of the institutional infrastructure responsible for ensuring environmental protection in the Russian Arctic region also precluded interagency cooperation to improve data quality and adequacy. Prior to 1993, the responsibility for environmental protection in the Far East regions of Russia was traditionally organized by medium (e.g., water, air, soil) and therefore carried out by more than one committee, unlike natural resource management, which came under the jurisdiction of one committee. Jurisdiction for air, surface water, groundwater, and environmental protection was generally found in separate committees. Since 1993, Russia has attempted to reorganize all committees with a responsibility for environmental protection into one authority.

Despite Russia's recent attempts to disclose environmental monitoring information, the United States and other Arctic nations are supporting studies to assess the radioactive contamination problem in the Arctic and to formulate monitoring approaches. The following section discusses three major monitoring initiatives: the Regional Environmental Monitoring Assessment Program proposed by the U.S. EPA, the Arctic Environmental Protection Strategy established by the eight circumpolar nations, and the International Arctic Seas Assessment Project sponsored by the International Atomic Energy Agency.

The U.S. Regional Environmental Monitoring Assessment Program

The Environmental Monitoring Assessment Program (EMAP) is a U.S. Environmental Protection Agency project designed to gather data on the condition and long-term trends of ecological resources, including wetlands, forests, and coastal areas. To reflect the increasing concern about contamination of the Arctic environment, and in particular the potential impact that such contamination might have on the health and livelihood of Alaska Natives, EPA, in cooperation with the Fish and Wildlife Service, is proposing to establish a regional version of its nationwide program to be known as the Regional Environmental Monitoring Assessment Program (R-EMAP).[17]

As part of project implementation, EPA plans to first identify those methodologies used in its nationwide monitoring and assessment program that are appropriate for sampling and assessing ecological impacts from pollutants in estuarine environments.[18] Once appropriate methodologies are identified, the R-EMAP program staff proposes to assess the physical, chemical, and biological conditions in 62 randomly selected locations in northwest Alaska. Samples of sediments, fish, birds, and snow, for example, will be analyzed for pollutants such as heavy metals, PCBs (polychlorinated biphenyls), pesticides, and other organic pollutants. In its first year, the program will assess 32 estuarine locations in the Kasegaluk and Elson Lagoons near Barrow, Alaska.

Although the EPA's plan is to undertake an EMAP-like program specifically focused on Alaska, the agency—as well as the Interagency Committee through which the proposal was made—still awaits OMB's approval of the $500,000 annual operating budget needed for its implementation. If funded, R-EMAP might prove helpful to national and international Arctic research programs in which the United States participates. Examples of these include the Arctic Monitoring and Assessment Program established as part of the circumpolar nations' Arctic Environmental Protection Strategy. The Arctic

[17] Regional EMAPs are also proposed for other regions of the United States; however, the only one discussed here deals with the Arctic region.

[18] The Alaska Department of Environmental Conservation and the U.S. Fish and Wildlife Service are cooperating with EPA in developing the design, sampling procedures, and protocols of the project.

contamination research program under the Interagency Arctic Research Policy Committee will also benefit from this project. The Arctic Monitoring and Assessment Program (discussed in detail in the next section) will benefit because 1) the sampling of two Alaskan estuarine systems for pollutants identified under AMAP would take place consistent with AMAP-approved sampling procedures (35,172); and 2) because the monitoring techniques to be developed and tested by EPA could be then adopted for further assessing environmental contamination in the Arctic (35).

The Arctic Environmental Protection Strategy

The concept of establishing a charter among circumpolar nations to promote cooperation for the protection of the Arctic was first voiced in 1989 by the Finnish government at an international conference in Rovaniemi, Finland, attended by all eight Arctic countries (United States, Canada, Denmark, Finland, Iceland, Norway, Russia, and Sweden). After consultative meetings in Sweden and Canada, these eight nations approved the Declaration on Arctic Environmental Protection on June 1, 1991. The Arctic Environmental Protection Strategy, also known as the Rovaniemi process or the Finnish initiative, became the central component of the declaration.[19]

AEPS is a nonbinding legal statement for cooperation on the development and implementation of programs to protect the Arctic environment. Its major objectives include "*preserving environmental quality and natural resources, accommodating environmental protection principles with the needs and traditions of Arctic Native peoples, monitoring environmental conditions, and reducing and eventually eliminating pollution in the Arctic Environment*." To facilitate meeting these objectives, AEPS identifies six major types of pollutants as priorities for action: radioactivity, heavy metals, oil, noise, acidification, and persistent organic contaminants.

Implementation of AEPS requires national and international cooperation and coordination of efforts. To this end, the eight circumpolar nations have formed four major working groups under AEPS to lead their research work in the Arctic. They are: the Arctic Monitoring and Assessment Program; the Conservation of Arctic Flora and Fauna (CAFF); the Protection of the Arctic Marine Environment (PAME); and the Emergency Prevention, Preparedness and Response (EPP&R). Concerns about sustainable development in the Arctic are also addressed by the AEPS. The responsibility for coordinating U.S. participation in these groups falls on the U.S. State Department. The federal agencies leading the U.S. technical cooperative efforts are the Environmental Protection Agency, the National Oceanic and Atmospheric Administration, and the National Science Foundation, through IARPC, for AMAP; the U.S. Fish and Wildlife Service for CAFF; the National Ocean and Atmospheric Administration for PAME; and the U.S. Coast Guard for EPP&R. Cooperation also takes place among AEPS working groups, the eight Arctic countries, and various international organizations (e.g., IAEA, London Convention). Significant collaboration and coordination also exists between the Arctic Nuclear Waste Assessment Program of the Office of Naval Research and the AEPS, particularly AMAP—nearly $390,000 in FY 1994 and 1995—and to some extent PAME (40).

Arctic Monitoring and Assessment Program

The Arctic Monitoring and Assessment Program is the central component of the Rovaniemi process or AEPS. Its three main objectives are to: 1) monitor, assess, and report on the environmental health of the Arctic; 2) document the sources, levels, trends, and pathways of pollutants; and 3) assess the effect on the Arctic environment of man-made pollutants originating in Arctic and lower latitudes. Attempts to achieve these basic objectives must also take into consideration the

[19] Several non-Arctic nations and organizations also participate in the Arctic environmental protection process, generally as observers.

ecological and cultural importance of the Arctic among native peoples.

The objectives of AMAP are implemented through the Arctic Monitoring and Assessment Task Force, consisting of representatives from each of the Arctic countries supporting the Arctic Environmental Protection Strategy. Representatives from native groups, such as the Inuit Circumpolar Conference, the Nordic Saami Council, and the Russian Association of Small Peoples of the North, participate in the Task Force as observers. Representatives from non-Arctic nations (e.g., United Kingdom) and international organizations (e.g., International Arctic Science Committee) involved in Arctic research are also invited as observers (120). With IARPC's support, and in coordination with the NSF and the State Department, NOAA hosted AMAP's Assessment Steering Group and Working Group meetings in Washington last October (96).

As agreed under AEPS, AMAP member nations are responsible for preparing a report on the assessment of the Arctic environment by December 1996. The United States and the Russian Federation were given the lead responsibility for preparing the chapter of the report that assesses heavy metals (e.g., sources, emissions, environmental levels and trends and possible effects).[20] The remaining key portions of the report are the responsibility of Canada and Norway (pathways of contamination), Canada and Sweden (persistent organic pollutants, such as PCBs), Norway and Russia (radioactivity), Finland (acidification), and Denmark (human health). The plan to have the AMAP report finished by December 1996, however, appears overly ambitious to some experts.

AMAP, to date, has focused primarily on the collection of data from sources or activities that emit pollutants. Analytical work to model the mechanisms by which these pollutants affect or might affect the Arctic environment is also under way. To facilitate the research, AMAP has grouped polluting activities into two major categories: land-based and sea-based radioactive contamination sources. Land-based sources include the disposal of radioactive material and the discharge of chemical and industrial pollutants; sea-based sources refer primarily to the shipping and dumping of radioactive waste and of nuclear materials (10).

The United States plays a lead role in various AMAP activities. Together with Russia, the United States is preparing the chapter of the assessment dealing with heavy-metal contamination. According to the U.S. AMAP representative, considerable progress has been made in the preparation of a draft report for the heavy-metal assessment. Several meetings with relevant international experts, particularly from Arctic nations, are under way to collect the additional information required to complete the assessment. The second major U.S. activity under AMAP involves developing the Arctic Data Directory. This undertaking is being led by a data management expert with the U.S. Geological Survey with funding from ONR and the Department of State. One of the objectives of the U.S. work is to provide AMAP countries with the technology and technical assistance required to adapt existing data on the Arctic environment to formats and databases that can be readily accessible by computer (91,120,121).

The overall international budget for AMAP in 1995 is approximately $850,000, but because it is not centrally funded, AMAP is forced to rely on the financial and technical assistance of its members (91,120,121). Norway is the largest contributor, with an annual participation exceeding $500,000. The U.S. financial contribution by IARPC agencies to AMAP for FY1995 is about $150,000, mainly from the Department of State, the National Science Foundation, and the Environmental Protection Agency (94,121,167).

Despite the lead U.S. role in a number of activities, many experts continue to view the U.S. contribution to implement its AMAP data

[20] Other issues of concern to AEPS include for example impacts associated with climate change, oil pollution, and noise.

management activities as seriously underfunded (91,96). Limited funding has not only been reported for U.S. work on the chapter on heavy metals but also for the Arctic data inventory. The Arctic Research Commission concluded recently that ensuring a successful "*and effective* [U.S.] *participation in AMAP and associated AEPS activities*" would require about $500,000 per year (15). Increasing U.S. financial support for AMAP is crucial, especially since U.S. expertise may also be needed for the preparation of other portions of the AMAP report, including a chapter on freshwater contamination (167). Russia's contribution to the program, on the other hand, is expected to remain inconsequential, particularly because of its serious economic difficulties (16) and, to some extent, its failure to consider Arctic radioactive contamination a national research priority. (Russia's environmental regulatory and institutional framework is discussed later in this chapter.)

Conservation of Arctic Flora and Fauna Working Group

The concept of establishing an independent program for protecting and conserving the fauna and flora of the Arctic was first proposed as a memorandum of agreement for signing by the eight Arctic countries meeting in Yellowknife, Canada, in 1990. Support for establishing an independent program quickly dissipated because of the increasing interest on the part of Arctic nations to set forth a comprehensive protection strategy. With the signing of the Arctic Environmental Protection Strategy, and after extensive negotiations, the Conservation of Arctic Flora and Fauna Working Group concept was adopted as an integral component of the strategy (107).

CAFF is composed of a Secretariat and an International Working Group. The Secretariat began operations in January 1994 and is located in Ottawa, Canada. The International Working Group consists of representatives from Arctic government agencies and is headed by a Chair and Vice-Chair. The U.S. Fish and Wildlife Service branch in Anchorage, Alaska, is the U.S. CAFF representative. Native groups have been highly effective in working within CAFF to have their concerns addressed (7,11).

CAFF currently supports the preparation of various documents relating to the Arctic marine environment. These include, among others, an inventory of land-based contamination sources, the preparation of conservation strategies for marine organisms (e.g., the seabird murre), compilation of information on seabird colonies, and preparation of working papers on various circumpolar seabird and fish populations (107). One of Russia's activities under CAFF involves the preparation of a Network of Protected Areas. The results from these projects, considered essential for the work planned by other components of the strategy, will be compiled into a report by Norway and submitted to the AEPS ministerial meeting in late 1995 or early 1996.

Protection of the Arctic Marine Environment Working Group

The Working Group on Protection of the Arctic Marine Environment, led by Norway, first met in Oslo in May 1994, following an invitation by the Norwegian Ministry of Environment. The objective of this component of the Arctic Environmental Protection Strategy is to identify and describe all possible threats to the Arctic marine environment and to provide a review of the international institutional framework that currently exists for protection of the Arctic seas. At their September 1994 London meeting, PAME members officially recognized the Arctic's radioactive contamination by the former Soviet Union and the possibility "of future dumping by the Russian Federation" as critical issues (11).

PAME's principal role in AEPS is to gather data on the effects of man-made contaminants on Arctic wildlife populations and habitats and to submit a final report to AEPS ministers in 1995. PAME is also responsible for examining possible options or actions needed to address the problem and for determining whether existing instruments are sufficient or new as necessary. The five principal areas of research currently supported by PAME are:

1. assessing the impacts of pollution on the marine and terrestrial ecosystems as well as on the Native Peoples of the Arctic. A large portion of this work is being led by Norway;
2. identifying all possible land-based sources of pollution affecting the Arctic, such as oil, gas, and nuclear industries; mining; industrial activities; and coastal development. Canada is leading this portion of the report;
3. collecting data on any sea-based activities within and outside the Arctic but with the potential to impact the Arctic. Preliminary work thus far has been conducted by Norway (primarily on offshore oil and gas activities) and the United States (ocean dumping and incineration);
4. evaluating all relevant international instruments for preventing and remediating Arctic marine pollution; and
5. recommending probable approaches to solutions (10).

PAME members are expected to face various difficult issues as work gets underway. One example is linking environmental threats with the level of protection provided by international instruments and pointing out areas where such instruments are inadequate. Because the major focus of PAME is the marine environment, AEPS member nations such as Canada and the United States suggest that prior to proposing protection measures for adoption by international organizations such as the London Convention, a more comprehensive understanding of the Arctic pollution problem is needed (10).

Another potential area of controversy that may result from implementing PAME's approaches without extensive discussion among AEPS members is the question of maritime zones and boundaries. With the exception of Sweden and Finland, which lack jurisdiction over marine waters north of the Arctic Circle, most AEPS members, including Russia, have declared their maritime zones along their Arctic coasts. Canada, Iceland, and Norway claim jurisdiction over territorial waters extending up to 200 nautical miles. Denmark's decision to define its territorial waters in the Arctic is expected in the near future. In addition to PAME, these obstacles appear potentially relevant to other AEPS programs.

Despite these potential obstacles, PAME's research continues to be key to identifying and monitoring the contaminants and their sources that currently affect the Arctic marine environment, and to supporting the activities of the three other AEPS working groups.

Emergency Prevention, Preparedness and Response Working Group

Consistent with the AEPS objective of ensuring the protection of the Arctic environment, the eight circumpolar countries established a Working Group on Emergency Prevention, Preparedness and Response to address the problem of acute environmental emergencies from land-based and offshore activities such as nuclear accidents and oil spills. Led by Canada and the United States, this group is inventorying and assessing the potential for accidental pollution of the Arctic from a variety of sources (e.g., chemical plants, industries, nuclear power plants) now operating in the Arctic countries. Once completed, the EPP&R work is expected to be used in coordination with other prevention protocols (e.g., the IAEA and the London Convention) to determine more precisely the types of additional safeguards that are needed.

The EPP&R Working Group has begun to conduct an environmental risk assessment of the Arctic region. The study is expected to allow EPP&R researchers to classify and inventory the actual impact and potential risks to the Arctic from any transboundary accidental discharge. Once completed, study results will be employed to determine whether relevant international institutions need to adopt additional measures to ensure the protection of the Arctic environment from accidental spills and releases (10).

International Atomic Energy Agency's Arctic Seas Assessment Project

The United Nations established the International Atomic Energy Agency (IAEA) in 1957 to carry out two primary missions: 1) to enhance and support the peaceful uses of atomic energy throughout its member nations, and 2) to ensure that atomic energy is not used for furthering any military purpose. One year later, at its first Conference on the Law of the Sea, the United Nations proposed expanding IAEA's mission to include responsibility for controlling discharges of radioactive waste into the sea. By the end of the conference, the international community had given IAEA the responsibility for promulgating technical and regulatory standards to prevent the ocean dumping of radioactive substances at levels that would affect human health and the marine environment (68,136). However, it was not until 1993 that IAEA, through the International Arctic Seas Assessment Project, would take its first official look at the Arctic's radioactive contamination caused by the Soviets.[21]

As a result of growing concern about the possible regional and global impacts from radioactive waste dumping sites in the Arctic, the contracting parties attending the London Convention's Fifteenth Consultative Meeting in 1992 requested that IAEA devote attention to the Arctic radioactive contamination problem. In responding to this request, in February 1993 the IAEA established the International Arctic Seas Assessment Project (IASAP). The main focus of the project was to study the health and environmental consequences that may be associated with the dumping of radioactive waste in the Kara and Barents Seas and to identify probable remedial solutions. Initially conceived as a bilateral cooperation effort between Norway and Russia, IASAP today involves the participation of several international organizations and member nations including the United States. IAEA plans to phase out the IASAP project in 1996 with the publication of a final report (69, 70, 71,72,136).

To carry out the project, IAEA's Division of Nuclear Fuel and Waste Management Section adopted the four working groups established at its international meeting on the "Assessment of Actual and Potential Consequences of Dumping of Radioactive Waste into the Arctic Seas" held in Oslo, Norway, in February 1994. The groups are the Impact Assessment and Remedial Measures Working Group, the Source Term Working Group, the Existing Environmental Concentrations Working Group, and the Transfer Mechanisms and Models Working Group. The Impact Assessment and Remedial Measures Working Group is primarily responsible for overseeing the work performed by the other three working groups and for preparing the final report to be submitted to the London Convention in 1996 (136).

The Source Term Working Group, chaired by an official of the U.S. Environmental Protection Agency, is responsible for working with Russian institutions and Russian contractors in a variety of technical research areas. These include reconstructing the history of reactor fuels prior to their dumping; collecting information on the nature and properties of containment systems used to prevent releases from dumped reactors; identifying the types of processing wastes disposed; and conducting exploratory cruises to take direct measurements of the waste packages and surrounding seawater and sediments. This group's findings, which are scheduled to be published later in 1995, are expected to support the modeling work by other IASAP working groups (39,69,136).

Through its working group on Existing Environmental Concentrations, IASAP staff collects information on current radioactive contamination levels in the Arctic for compilation in a global database being developed by its Marine Environ-

[21] Prior to 1993, IAEA work in Eastern Europe and the former Soviet Union focused primarily on the identification and assessment of sites at which uranium mining and milling activities had been conducted. One reason for focusing on this type of radioactive contamination sources was the assumption that nuclear facilities, such as nuclear power plants and research laboratories, were already under regulatory control.

mental Laboratory in Monaco. Attempts to evaluate the reliability of this database, known as "Inventory of Radionuclides in World Oceans," are nearing completion (69,136).

The central element of IASAP's fourth component, the Transfer Mechanism and Models Working Group, is the recently established program called "Modeling of the Radiological Impact of Radioactive Waste Dumping in the Arctic Seas." Under this program, IASAP staff is working with experts from laboratory and modeling groups from IAEA, Russia, Norway, Denmark, and England in the development of assessment models for the Arctic seas. The progress made by this program is still preliminary and awaits more conclusive data from the other IASAP working groups (72,131,136). In addition to coordinating with Norwegian and Russian experts and institutions, IASAP staff plans to provide AMAP with its project results (72).

Future attempts by IASAP could include the study of radioactive contamination in the Sea of Japan. The government of Japan is concerned about past dumping of radioactive wastes in areas near the Sea of Japan and about Russia's continued unsafe accumulation of nuclear wastes from the Pacific fleet and decommissioned submarines in the region (29,92,99). Interest in expanding IASAP to include the study of radioactive contamination of the Sea of Japan was first reported at the Source Term Working Group's meeting held in Vienna in January 1994. Even with the Japanese government's efforts to cooperate with Russia and its intention to fund the building of liquid radioactive waste treatment project, little progress has been made to date toward involving the IAEA in this region. Even if the relevant governments (i.e., Japan, South Korea, and possibly Russia) agreed to participate in the program, it is unknown who would provide the financial resources to develop the research strategy needed to effectively accommodate an institutional infrastructure and marine environment different from the Arctic.

According to the IAEA, the United States is one of the nations providing financial support for IASAP activities. The U.S. contribution for the first year of the program was $135,000, followed by $100,000 for FY 1995 (131). U.S. assistance is also provided in the form of support staff (for example, by the State Department) and facilitating travel to meetings and data gathering for U.S. experts participating in the IASAP program (by the Office of Naval Research) (16,40,131). IAEA is currently seeking funding from other member states (70,72).

Evaluation of IAEA's Arctic Seas Project

Although nuclear contamination data are being progressively disclosed by the Russian Federation, IAEA officials point out that the work to conclusively assess the extent of nuclear contamination in the Russian Federation continues to face difficulties. One major difficulty is incomplete data associated with nuclear contamination. In addition, the data are often scattered throughout a multitude of organizations that, because of recent political changes, appear to have poorly delineated or overlapping responsibilities. The unavailability of data in a language other than Russian has also hampered the agency's contamination assessment work. Another concern is the inability to gain access to data on radioactive waste practices at Russian military sites. According to IAEA officials, this factor constitutes a serious obstacle to developing a comprehensive and accurate assessment of radioactive contamination sources in Russia.

Although IASAP represents the first major attempt by IAEA to address environmental contamination in the Arctic, many view this undertaking as limited since it focuses only on radioactive materials dumped in the Kara Sea. Little or no focus is given to those radioactive contaminants already disposed into rivers emptying into the Arctic. In addition, little information exists on how IAEA plans to implement IASAP's findings once the project is completed.

The Arctic Council

Despite the progress made through existing international initiatives (e.g., AEPS and Northern

Forum), some view their focus as too specific and often lacking an overall coordinated approach and intergovernmental policy forum to deal with the wide variety of issues facing Arctic nations, such as trade, transport, communication, pollution, sustainable development, and the welfare of Native communities. Due to these limitations, Canada and other Arctic nations proposed in May 1993 to establish an Arctic Council to serve as the principal institutional umbrella, under which, existing and new institutional bodies will address, manage, promote, and resolve these issues. Unlike existing initiatives which invite Native community representatives as observers, the Arctic Council would recognize them as permanent members. The Council would also serve as the vehicle to mobilize resources among Arctic countries when needed as, for example, in emergency situations. With the exception of the United States, all Arctic nations have signed by December 1994 the original intent or declaration to create the Council. At the February 1995 Ottawa Summit, the U.S. announced its interest to join Canada and the other Arctic nations to organize the Council (8,20,67). Full participation by the United States is anticipated soon after negotiations are completed.[22]

INSTITUTIONAL INITIATIVES AND PROGRAMS DESIGNED TO PREVENT FUTURE ARCTIC RADIOACTIVE CONTAMINATION

A number of bilateral and multilateral initiatives exist today to collaborate with Russia in the prevention of future radioactive contamination of the Arctic (figure 5-4). Depending on their approach, preventive initiatives may focus on supporting proper storage and processing of radioactive waste to avoid their dumping into the Arctic and North Pacific regions, or on improving the operational safety and emergency response capability of Russia's most dangerous operating nuclear reactors. This section discusses the nature and status of major national and international programs to address both types of prevention approaches.

Initiatives to Improve Radioactive Waste Management

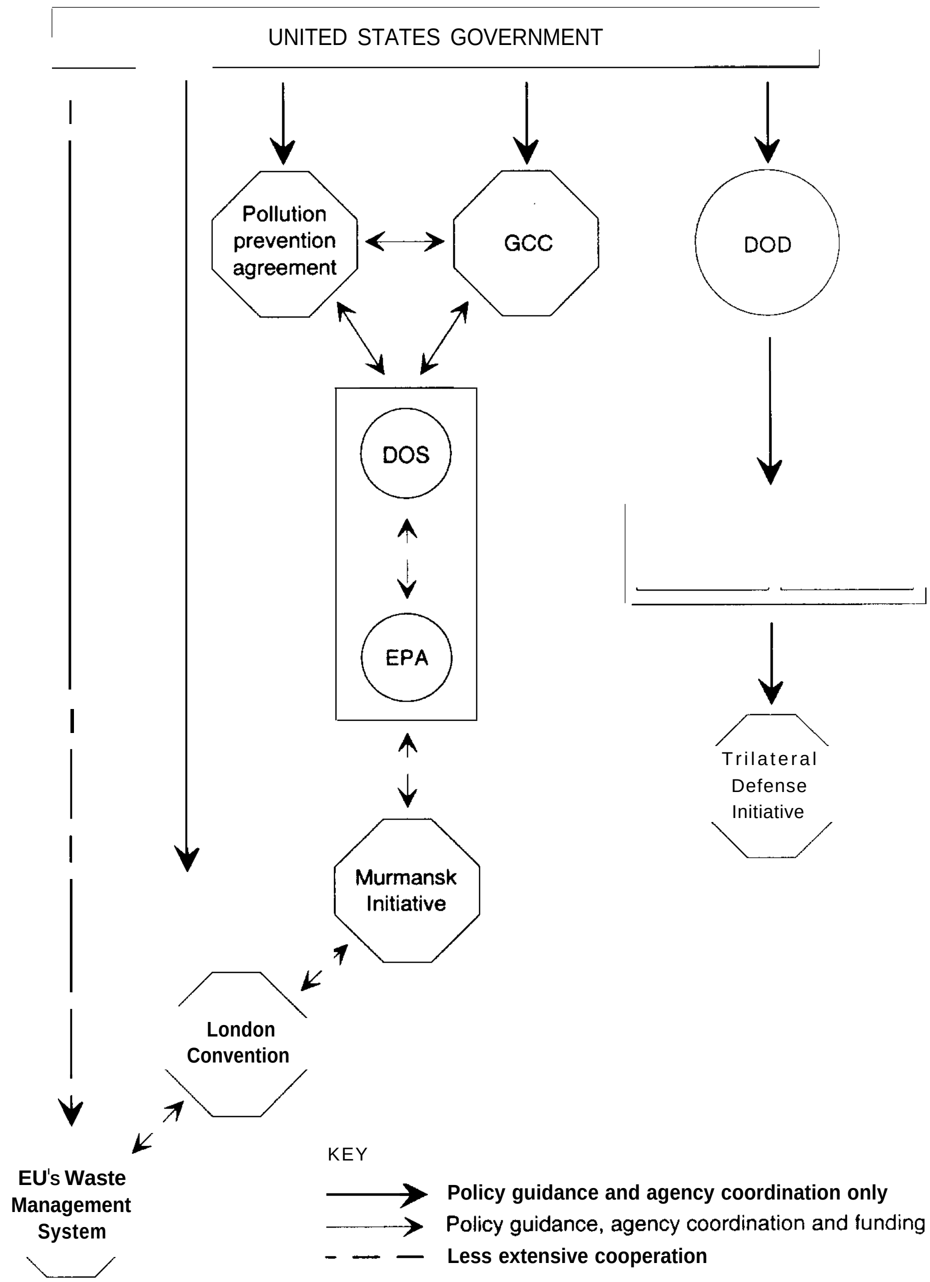
The two major U.S.-supported efforts that are under way to prevent the future disposal of radioactive waste by Russia in the Arctic are the London Convention and the Murmansk Initiative. Box 5-4 describes three other assistance programs of relative significance.

The London Convention

Without exception, the efforts adopted by the international community before 1972 to address concerns about the adverse human and environmental impacts from ocean dumping of contaminated wastes were regional in nature. The "Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter," signed in November 1972, became the first global attempt to address this problem. The main purpose of the protocol, now commonly known as the London Convention, is that all *"contracting Parties shall individually and collectively promote the effective control of all sources of pollution of the marine environment, and pledge themselves especially to take all practicable steps to prevent the pollution of the sea by the dumping of waste and other matter that is liable to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea."* To achieve these objectives, the contracting parties are required by Article II of the London Convention to *"take measures individually, according to their scientific, technical and economic capabilities, and collectively, to pre-*

[22] Although U.S. diplomatic officials voice general agreement with the structure and objectives of the proposed council, discussions are underway to, for example, incorporate the Arctic Environmental Protection Strategy and its working groups under the Council's umbrella and to rotate the Secretariat functions of the Council rather than establish a permanent Secretariat. The possibility of high-level representation by the United States at Council functions is also unknown.

FIGURE 5-4: Major Initiatives to Improve Russia's Nuclear Waste Management



KEY: DOE: Department of Energy; DOS: Department of State; EPA: U.S. Environmental Protection Agency; EU: European Union: GCC: Gore-Chernomyrdin Commission.
SOURCE: Office of Technology Assessment, 1995

BOX 5-4: Other Relevant Efforts to Improve Russia's Radioactive Waste Management

Norwegian–U.S.–Russian Proposed Initiative Addressing Civilian and Military Sources of Nuclear Contamination

Of the Arctic countries, Norway is the most concerned about the need to address radioactive contamination in Russia, particularly in the Arctic region. Of primary concern to Norway are the suspect operational safety of nuclear facilities and the unsafe management of nuclear materials and wastes reported at nuclear facilities operating near Norway's borders. The nearby northern and Arctic regions of Russia are of primary concern because of the unusual concentration of past and potential radioactive contamination from civilian and military nuclear sources. These include numerous nuclear-powered ships and submarines; fissile material and nuclear waste storage sites; operating nuclear power plants of questionable, operational safety; and unknown quantities of radioactive materials discharged into regional lands, rivers, and seas. In 1992, for example, Norway cooperated with Russia in sponsoring an expedition to measure the radioactive contamination levels in the immediate vicinity of dump sites in the Kara Sea (136).

With the purpose of establishing the financial and institutional framework needed to solve this problem, the Norwegian government in 1994 approved an action plan to support international collaboration for addressing four major nuclear issues in Russia. Four major contamination sources identified in the plan were: 1) the limited operational safety of Russia's civilian nuclear facilities; 2) the environmentally unsafe management and storage of radioactive materials and wastes; 3) the radioactive waste dumping in the Kara and Barents Seas and inland rivers emptying into the Arctic Ocean; and 4) the hazards from weapons-related activities (123). The government of Norway has committed about $20 million for implementation of this plan.

Consistent with its plan of action, the Norwegian government has proposed the creation of an International Steering Committee to cooperate technically and financially with Russia in the sound removal and cleanup of the *Lepse* and its radioactive cargo. The *Lepse* is a Russian vessel currently storing radioactive wastes, including damaged spent fuel from nuclear-powered icebreakers, in generally unsafe conditions (127). Nearly 90 percent of this radioactive cargo consists of civilian icebreaker fuel (39). Norway is leading the work to gather international support for the proposal.

With the realization that available economic assistance is inadequate to address nuclear safety, Norway's approach is that through cooperation and information exchange, considerable progress could be made in institutionalizing nuclear safety as a priority among Russian decisionmakers and regional governments. Norway, like other Western nations, advocates the closing of the least safe Soviet-designed nuclear reactors still in operation. The Kola Nuclear Power Plant located nearby is one example. Through multilateral channels, including the action plan for Eastern Europe and the Nuclear Safety Account program administered by the European Bank for Reconstruction and Development, Norway provides financial assistance for safety improvements at the Kola Peninsula plant. Through these assistance mechanisms, Norway also encourages field participation by Norwegian technical experts (100).

Despite Norway's participation in a variety of cooperative efforts with Russia, the numerous Russian nuclear military facilities located in the Arctic continue to be among the most dangerous sources of potential radioactive contamination in the region. For this reason, Norway's Ministry of Defense recently initiated discussions with its U.S. and Russian counterparts on areas of cooperation that might be adopted to address this issue. According to information provided at the recent Office of Technical Assessment workshop on spent fuel management, the main objective of this effort would be to sign a trilateral cooperative agreement under which Norway and the United States would, for example, 1) provide technical assistance to the Russian Defense Ministry for addressing and monitoring radioactive contamination problems, and 2) support early notification procedures and information exchanges in the event of accidents at military or civilian nuclear facilities (16,100,123,181).

(continued)

BOX 5-4: Other Relevant Efforts to Improve Russia's Radioactive Waste Management (Cont'd.)

In March 1995, Norwegian and U.S. defense officials held a four-day meeting in Oslo with their Russian counterparts to discuss the feasibility of establishing a framework for cooperation, as well as to identify "potentially unique contributions the respective militaries could make" toward improving the radioactive contamination problem in the Russian Arctic (17,177). The Deputy Undersecretary of Defense for Environmental Security, who is also the head of the Steering Group on Radioactive Contamination in the Arctic, is leading the U.S. effort. On June 30, 1995, the U.S. Secretary of Defense and its Russian counterpart signed a memorandum of agreement to exchange information on the environment, particularly in the areas of environmental protection and cleanup, waste management, and weapons material disposal. Although the agreement lacks a specific timetable or plan of action, this broad accord constitutes a potentially meaningful attempt to address environmental contamination issues associated with the Arctic.

European Union's Radioactive Waste Management System

In 1994, the European Union (EU) started a cooperative program with Russia to identify approaches for improving its radioactive waste management system in the Kola Peninsula region.[a] This project consists of two phases. In phase one, the EU will provide funds for a study of the nature and extent of the problem and identification of alternative solutions. Once this study is completed, the EU will cooperate with Russia in developing the technology and building the storage facility necessary for ensuring proper radioactive waste management in the Kola Peninsula region. The estimated level of funding programmed by the EU for this work is $5.4 million. Little information exists on the funding to be programmed for long-term implementation of the facility once it is built (128).

Department of Energy (DOE) Environmental Management Program

Within the framework of the 1973 Peaceful Uses of Atomic Energy agreement and the 1990 Memorandum of Cooperation with the Ministry of Atomic Energy of the Russian Federation (MINATOM), the (DOE) Environmental Management Program is conducting various pilot projects potentially useful to both countries. The Office of Technology Development (OTD) within the Environmental Management Program is the government branch leading U.S. assistance in the area of radioactive waste management and technology development. Its cooperative projects have included holding technical exchange workshops and initiating pilot-scale projects for demonstrating treatment technologies for high-level radioactive wastes; establishing electronic and computer links with Russian institutions involved in cooperative projects; and instituting an Environmental Management Center to facilitate technology transfer between U.S. and Russian institutions working on environmental cleanup. OTD has also sponsored visits by experts from Russian technical institutes to U.S. nuclear weapons complex sites to exchange information on environmental cleanup experience. To continue the implementation of its Russian assistance projects in FY 1996, the Office of Technology Development has submitted a budget request for $1 million—a 20 percent increase from its FY 1995 budget of $800,000 (163,164).

[a]In addition to waste management, the EU is working with Norwegian experts to identify solutions for remediating the submarines *Komsomolets* and *Elexis* (sunk off the Murmansk coast).

SOURCE: Office of Technology Assessment, 1995.

vent marine pollution caused by dumping and shall harmonize their policies in this regard."[23]

The London Convention requires that each contracting party report to the Inter-Governmen-

[23] Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (including amended Annexes) [in] International Maritime Organization, Office for the London Dumping Convention, *The London Dumping Convention: The First Decade and Beyond* (London, England: International Maritime Organization, 1991).

tal Maritime Consultative Organization, now known as the International Maritime Organization or (IMO), and to other parties where appropriate, about its dumping activities. Since 1975, the IMO has been responsible for executing all secretarial responsibilities associated with the London Convention.[24] Consultation with other members, particularly those that are most likely to be affected, is required in case of emergencies.[25] Member nations must also agree to "*keep records of the nature and quantities of all matter permitted to be dumped and the location, time and method of dumping*" and to monitor in an individual manner or in collaboration with other contracting parties "*the condition of the seas.*" Party states are also responsible for enforcing the provisions of the convention among all vessels and aircraft "*registered in* [their] *territory or flying* [their] *flag.*"[26] These principles, however, are not applicable to internal waters of states.[27]

With its signing, the international community essentially agreed to prohibit the ocean dumping of a variety of "harmful" substances and wastes and to establish a licensing process to regulate disposal of the remaining universe of substances (75). The former Soviet Union became a signatory in January 1976, and after its dissolution, the Russian Federation assumed the rights, responsibilities, and obligations under the convention (21).

The London Convention's efforts regarding radioactive waste have grown from attempts to determine their unsuitability for ocean disposal nearly two decades ago to the actual prohibition of such practices in 1994. In 1978, the London Convention made the International Atomic Energy Agency [28,29] responsible for defining the types of radioactive waste unsuitable for ocean dumping and for making recommendations about regulating the discharge of other types of radioactive waste (136). The first radiation levels issued by IAEA were designed explicitly to control the disposal of all high-level waste, spent nuclear fuel, and wastes from nuclear fuel reprocessing activities.

At its Seventh Consultative Meeting held in London in 1983, the London Convention also made the IAEA responsible for providing scientific guidance on issues relating to the voluntary moratorium on the ocean disposal of low-level radioactive wastes entered into by the contracting parties (68). As a result of this work, the convention authorized the IMO to carry out the following: 1) prohibit the dumping of any highly hazardous or radioactive substances or wastes, and 2) establish permitting and reporting requirements[30] for substances not considered highly hazardous or radioactive that still require special care prior to ocean disposal. Adoption of stricter control measures by contracting parties, for example, banning the disposal of less hazardous substances, is also welcome by the London Convention.[31]

Based on IAEA work that identified areas suitable for ocean dumping, the London Convention limited ocean dumping to that region outside the continental shelf located between latitudes 50° N and 50° S, and to depths of at least 12,000 feet (68). With respect to these boundary limitations, the only bodies of water easily accessible to Russia are located in the North Pacific Ocean. However, according to recent reports by IAEA officials, much of the radioactive waste that was disposed of by the former Soviet Union in the Kara Sea, is considered high level in nature and,

[24] Annex I, paragraph 6 and Annex II, paragraph D of the Convention.

[25] Article V, Paragraph 2 of the Convention.

[26] Article VI of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter at Sea, 1972.

[27] Article III of the Convention

[28] The International Atomic Energy Agency is the international entity with the authority to carry out the convention's recommendations relating to dumping of radioactive wastes in the oceans.

[29] Annex I, paragraph 6 and Annex II, paragraph D of the Convention.

[30] The factors (e.g., characterization of matter to be dumped and of dumping site prior to sea disposal; method of disposal; potential impacts) that must be considered for permit application are contained in Annex III of the London Convention.

[31] Articles VI(3) and VII(5) of the Convention.

therefore, unsuitable for sea disposal and in violation of the London Convention.

Because of the uncertainty about continued adherence by the international community to the convention's voluntary ban on ocean dumping of low-level radioactive wastes, the convention signatories proposed the inclusion of this waste type in the Black List (Annex I). In November 1993, an agreement to voluntarily ban the discharge of all radioactive waste and substances into the marine environment was signed, almost unanimously, at the convention's Sixteenth Consultative Meeting held in London. The Russian Federation was the only party to the convention promising to abide in principle but refraining from formally signing the ban.

In sum, the London Convention has been highly successful in increasing the international community's awareness of the potential global environmental impacts of ocean dumping without appropriate assessment and control. Lamentably for many nations, such as those circumpolar countries neighboring Russia, the guidelines of the convention are voluntary in nature and explicitly applicable to high seas and to the territorial seas of signatory states. As a consequence, these nations view Russia's self-imposed voluntary commitment to the London Convention's official ocean ban of radioactive waste as insufficient to ensure that further dumping does not occur. Of the preventive cooperative efforts under way today, the most relevant is the Murmansk Initiative—described below—because of its attempt to improve Russia's radioactive waste management and "...prevent [the] dumping of liquid radioactive wastes...in accordance with the London Convention" (141).

The Murmansk Initiative

The Murmansk Initiative is a cooperative effort led by the United States and Norway, with Russian participation, to expand the Russian Federation's capacity to store and process low-level radioactive waste (LLW) from the Northern Fleet in the Arctic. The major objective of this effort is to prevent the unsafe management and subsequent dumping of this type of waste into the Arctic Ocean.

The Murmansk Shipping Company, a recently privatized Russian firm, operates the Russian civilian icebreaker fleet and handles LLW. It has also processed, for a fee, some of the low-level radioactive waste produced by the Russian Navy at its Atomflot facility in Murmansk. Most of the space that the Russian Navy uses for the safe storage of liquid LLW is full. In addition, Russia continues to accumulate liquid radioactive waste in the Arctic region, especially at sites (military bases and enterprises) where nuclear reactors from ships, submarines, and icebreakers are operated and repaired and their nuclear fuel is replaced.

The Murmansk Initiative is the direct result of a shared U.S.-Norwegian concern about the need to cooperate in solving Russia's radioactive liquid waste storage and processing problem. Following initial discussion of the Murmansk Initiative concept,[32] the Norwegian and U.S. governments (led by the U.S. Environmental Protection Agency in coordination with the State Department) succeeded in securing Russian participation in the effort. Several technical exchanges, ministerial meetings, and expert site visits were conducted in 1994 and early 1995 to evaluate existing needs and propose possible facility upgrades. A concept paper prepared by the Murmansk Shipping Company claims that, if implemented, the Murmansk Initiative will help improve the regional structure for safe management of radioactive waste from existing sources including Russia's Northern fleet (50).

On September 28, 1994, nearly four months after the initiative was first presented to the Gore-Chernomyrdin Commission, the United States and Russia issued a presidential announcement or formal statement of support. In the state-

[32] Responding to a national concern about the possibility that the Northern fleet's inadequate storage capacity might force the Russians to dispose of their low-level radioactive waste into the Arctic, the Norwegian delegation participating in a 1993 London Convention meeting solicited the cooperation of the United States to help identify a regional-based solution to this potential problem.

ment, both the Russian Federation and the U.S. government claimed to "*. . .confirm their readiness to cooperate in consistently preventing dumping of liquid radioactive wastes, in accordance with the London Convention, and to proceed to a solution of the problem of Arctic Pollution from all sources. To this end, the Russian Federation and the United States of America agree to undertake immediately, in cooperation with other interested countries, a step-by-step expansion and upgrading of a treatment facility for liquid low-level radioactive waste in Murmansk*" (141).

Implementation of this mandate calls for the rapid upgrading and expansion of the Murmansk facility to provide timely storage and processing capacity for the Northern Fleet's LLW. The ultimate goal of the agreement, however, is to serve as "*the focal point of efforts to create the infrastructure for ecologically safe processing and storage of liquid low-level radioactive wastes in the North of Russia*"(141). Information on similar types of preventive initiatives that may be supported by the GCC in the future is scant.

The United States and Norway have signed an agreement with Russia to provide funding for an engineering design report to expand and improve the liquid LLW treatment facility operated by MSC. The design is expected to be completed in 1995. If the recommended design is approved, construction of the project is scheduled to start in 1996. EPA experts anticipate that the Norwegian and U.S. governments will provide funding for construction. Funds (about $750,000) have been committed by EPA, the U.S. AID and DOD for this purpose. Norway has already agreed to provide $750,000 toward the construction of this expanded and upgraded facility (33,39,180).

Initiatives to Improve Nuclear Reactor Safety

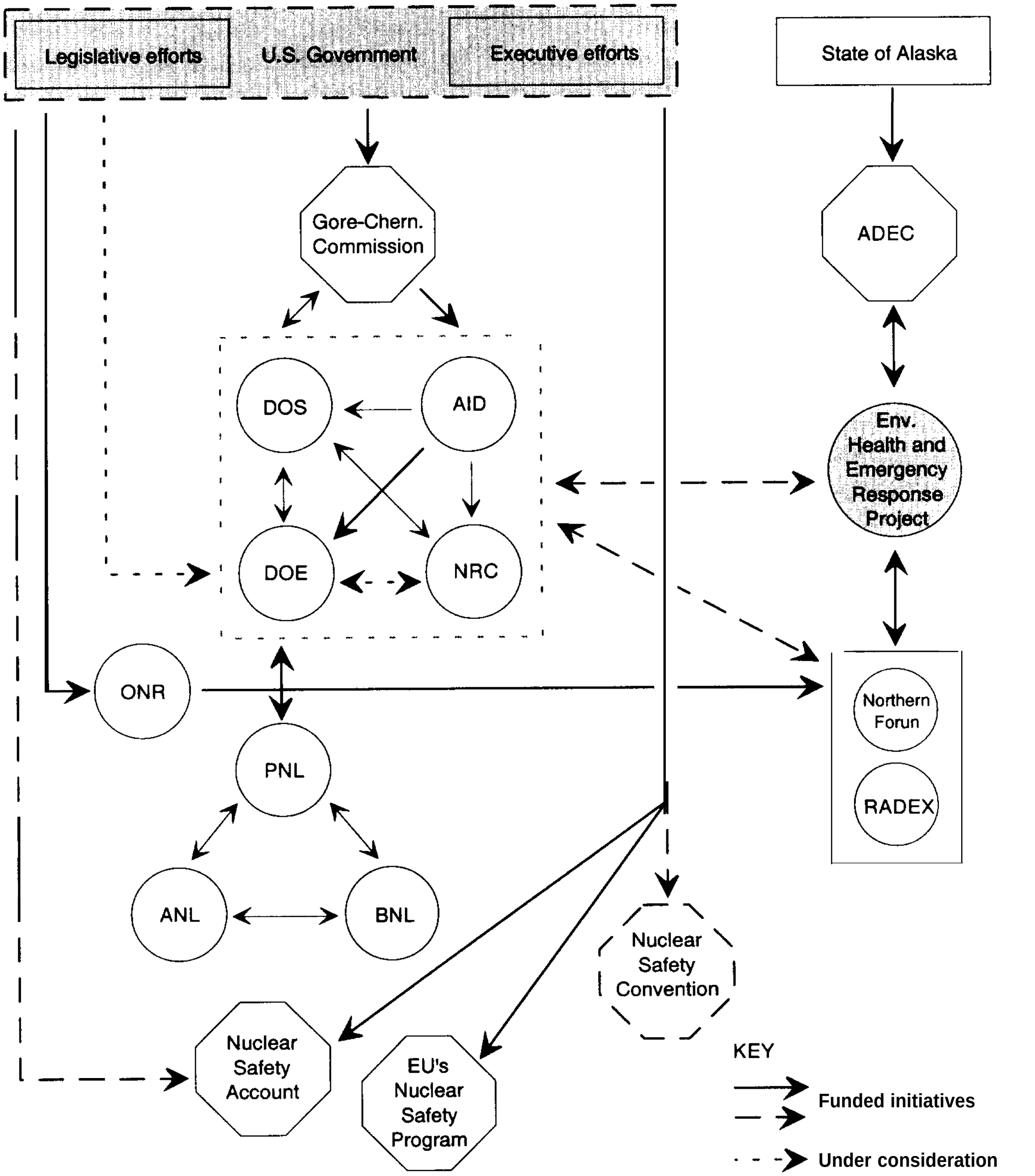
U.S. Bilateral Nuclear Assistance Program

U.S. participation in nuclear safety cooperation with the former Soviet Union (fSU) began in 1986 immediately after the Chernobyl nuclear accident. This cooperation principally involved information exchange efforts by the Nuclear Regulatory Commission and the Department of Energy. Two years after the Chernobyl accident, the U.S. and fSU governments signed a bilateral Memorandum of Cooperation formally supporting these undertakings. Figure 5-5 shows some of the major U.S. efforts underway today to improve nuclear reactor safety in Russia.

Because of the frequent information exchanges conducted under the Memorandum of Cooperation, U.S. government nuclear experts became aware of safety problems at nuclear reactor facilities operating in the former Soviet Union. Some of these problems included one or more of the following: poor or unstable plant design or construction; inadequate operation and maintenance; and limited compliance with regulatory and safety standards such as fire protection.

The U.S. government commitment to cooperate with Russia in the field of nuclear reactor safety was formally announced at the May 1992 Conference on Assistance to the Newly Independent States, held in Lisbon. Known as the Lisbon Initiative, the U.S. announcement consisted of a commitment to provide $25 million in nuclear safety assistance to Russia and other fSU nations. One year later at the Vancouver summit, the U.S. president pledged to expand this assistance by committing an additional $100 million ($80 million in FY 1994 and $10 million in both FY 1995 and in FY 1996) to help Russia with improvements in the operational safety of nuclear power plants, implementation of risk reduction measures, and strengthening of the nuclear regulatory framework (18,116,130). As the implementing body of these U.S. cooperative efforts, the Gore-Chernomyrdin Commission established a Subcommittee on Nuclear Safety. The subcommittee is co-chaired by the heads of the Department of Energy and the Nuclear Regulatory Commission (NRC) for the United States and by the Ministry of Atomic Energy and the nuclear regulatory agency GOSATOMNADZOR for the Russian side (116,122).

FIGURE 5-5: Major U.S.-Supported Initiatives to Improve Nuclear Reactor Safety in Russia



KEY: ADEC: Alaska Department of Environmental Conservation; AID: Agency for International Development; ANL: Argonne National Laboratory; BNL: Brookhaven National Laboratory; DOE: U.S. Department of Energy; DOS: U.S. Department of State; EU: European Union; INSC: International Nuclear Safety Convention; NRC: Nuclear Regulatory Commission; NSA: Nuclear Safety Account: NSP: Nuclear Safety Program; ONR: Office of Naval Research; PNL: Pacific Northwest Laboratory.

SOURCE: Office of Technology Assessment, 1995.

U.S. assistance focuses on improving the safety of nuclear facilities to reduce the risks of another Chernobyl. The United States has committed approximately $205 million for equipment, technical assistance, and training through several bilateral (e.g., Lisbon and Vancouver) and multilateral (e.g., Tokyo and Munich) initiatives (116). Today, the U.S. nuclear assistance program to Russia is multiagency in nature, with AID as the manager; NRC and DOE as executors; and the State Department and the Gore-Chernomyrdin Commission as principal coordinators. The State of Alaska also participates actively in regional and international cooperative nuclear safety and emergency response programs. Box 5-5 describes two of these initiatives

Unlike other agency programs where in-country missions provide the assistance, AID manages the U.S. nuclear safety initiatives from Washington. This departure from agency tradition is attributed largely to the short-term nature of the assistance program and to the U.S. government's coordinating (State Department's Senior Coordinator for Nuclear Safety Assistance) and technical agency (mainly DOE and NRC) missions being located in Washington. The fact that most of the technical expertise required to implement the safety assistance program is found in various U.S. private engineering firms and national laboratories has also contributed to support AID's decision not to manage the assistance program in Russia (174). The following section describes U.S. government programs for implementing the U.S. bilateral nuclear safety initiative.

Department of Energy's nuclear safety program

Cooperative efforts by the Department of Energy to improve operational safety and emergency response at older Soviet-designed reactors began in 1990. DOE activities in nuclear safety are led by its Office of Nuclear Energy and focus primarily on civilian nuclear power plants (140). DOE has also proposed working with Russia on the conversion or replacement of former weapons production plants (104). According to recent congressional testimony by the Secretary of Energy, Hazel O'Leary, DOE's responsibilities under the U.S. nuclear safety initiative include the following:

- Provide the necessary resources for the development of emergency operating procedures by Russian and Ukrainian nuclear plant personnel. The Institute for Nuclear Power Operations and about seven U.S. utilities are the major contributors to this work. Plans to implement the completed procedures are already under way.
- Assist in the establishment of two regional nuclear safety training centers, one in Russia and one in Ukraine. Upon its completion in 1995, the Russian training center is expected to provide operational safety training similar to that employed by U.S. nuclear facilities. (The Ukrainian training center will be completed in 1996.)
- Implement interim risk reduction activities, such as installation of fire detection and emergency equipment and upgrade of confinement systems, at Russia's least safe and oldest nuclear plants to "reduce the safety hazards during their remaining lifetime" (104). Although most conceptual design and feasibility work has been conducted, risk reduction measures await implementation because of difficulties in completing contractor's liability agreements.
- Support the development of a fire safety program that strengthens Russia's capability to detect and mitigate fires at nuclear power plants. U.S. safety equipment is being installed at the Smolensk Nuclear Power Plant; once completed, the fire safety program would then be implemented at other nuclear facilities. Initially, completion of this work was also delayed by the contractor's concern about

Russia's inadequate liability protection[33] (104).

As a means to implement its responsibilities under the U.S. nuclear safety cooperation program, DOE established in 1992 a Nuclear Safety Initiative Office at the Brookhaven National Laboratory (BNL) in New York. This office was to be responsible for administering the various contracts entered into with private firms for the delivery of safety equipment and services to Russian nuclear plants. Although its initial intent was to actively participate in the contracting of technical work, uncertainties about adequate liability protection forced BNL to focus only on projects associated with an "acceptable level of risk" (18). Since transferring its Nuclear Safety Initiative Office work to Pacific Northwest Laboratory on October 1, 1994, BNL functions have been limited to developing accident analysis procedures, improving communications systems, developing an adequate regulatory structure, and training plant personnel in maintenance and operation (38,140).

Today, the technical work supporting DOE's program on international nuclear safety originates at the Pacific Northwest Laboratory (PNL), with both Brookhaven and Argonne National Laboratories as supporting agencies. As part of its management responsibilities, PNL supervises contractors and monitors the quality of the technical work being performed at Russian nuclear facilities. Among the activities supported by this program is training Russian nuclear personnel in the maintenance and operational safety of nuclear power plants. DOE has also supplied fire alarms, hoses, and fire extinguishers to improve the limited fire safety capability at many Russian nuclear power plants. Plans are under way to provide additional safety and training equipment (38,53,174).

Currently, PNL continues to support the contracts entered into by BNL entered with Russian institutions and nuclear power plants in an attempt to reduce unnecessary implementation cost while maintaining a high level of program effectiveness. Because of its efforts to maintain program stability, PNL will continue to: 1) support the Moscow project office established by BNL and staffed by Russians; 2) contract work directly with nuclear power plant personnel to carry out the operational safety measures necessary to reduce risks; and 3) seek engineering support for training and operations from the Russian Research Institute for Nuclear Power Plant Operations (53,81,174).

Since the establishment of the Nuclear Safety Initiative program, DOE has received funds through the Agency for International Development. Of the nearly $205 million earmarked by the U.S. for availability through AID, DOE has obtained $21.9 million (FY 1992), $14 million (FY 1993), $55 million (FY 1994) and $8.5 million for FY 1995. Although in the past DOE received funding through the AID budget, for FY 1996 DOE opted to submit its own request to Congress for nuclear safety assistance projects (116,122).

Nuclear Regulatory Commission's nuclear safety program

The NRC's participation in nuclear safety cooperation projects in the former Soviet Union dates back to 1986 when the "United States tried to ferret out the causes and consequences of the Chernobyl nuclear accident of April 26" of that year (116,130). Two years after the Chernobyl accident and several interchanges with the former Soviet Union, a Memorandum of Cooperation was signed to promote the exchange of information between U.S. and Soviet experts on their nuclear programs—an area previously regarded as secret. Upon signing of the agreement in Washington, D.C., the Joint Coordinating Committee on Civilian Nuclear Reactor Safety (JCCCNRS) was immediately established as the official instrument responsible for implementing the agreement (130).

[33] To overcome this obstacle, the Department of Energy signed a bilateral agreement with the Russians in 1993 to provide liability insurance protection to U.S. contractors in Russia (81).

BOX 5-5: Alaskan Initiatives to Prevent Future Arctic Radioactive Contamination

In addition to its involvement in research and monitoring programs to address the Arctic's radioactive contamination problem, the State of Alaska also participates actively in regional and international cooperative programs designed to improve nuclear safety and emergency response in the region. Two of these efforts, the International Radiological Exercise and the Cooperative Information Exchange with Russia's Bilibino Nuclear Power Plant, are discussed here.

International Radiological Exercise (RADEX)

In late June 1994, the eight nations of the Arctic Environmental Protection Strategy and the regional governments of the Northern Forum, with support from the State of Alaska, convened a four-day International Radiological Exercise (RADEX) to discuss possible cooperative approaches that might be adopted to improve notification and response methods among Arctic nations in the event of a nuclear accident in the Arctic. The exercise, one of the results of an information exchange visit to the Bilibino Nuclear Power Plant the previous year, was attended by representatives from Canada, Denmark, Finland, Norway, Russia, Sweden, the United States, the International Atomic Energy Agency, and various Native groups.

In addition to supporting information exchanges on each country's national nuclear emergency programs, the Northern Forum conference also provided participating countries with an opportunity to test their emergency response procedures. This was accomplished by conducting a "tabletop" radiation drill involving a nuclear accident in the fictitious country of "Arcticland." After the radiation drill, participants discussed the types of improvements that were needed in reference to each of the three phases associated with a serious nuclear accident (threat, release, postrelease). Early results appear to indicate the need to conduct similar drills in the future; to develop Arctic-wide emergency response strategies; to improve information exchange; and to improve current methods for anticipating the movement of radioactive plumes through the Arctic air mass (5,149,150,183). The final results of the drill are expected to provide technical data relevant to the Russian Rapid Assessment Project sponsored by the U.S. Environmental Protection Agency and the State Department.

Of greater significance for future international cooperation was the suggestion by participants to establish a "Regional Arctic Response Plan" as a means of improving the current notification system adopted by Arctic nations for responding to nuclear accidents. This plan would be designed to serve as a framework within which all emergency planning and emergency responses carried out by Arctic nations could be more effectively coordinated, consistent with existing applicable international agreements (5). The Alaskan government is currently supporting the drafting of an Arctic emergency response plan (149).

Cooperative Information Exchange with Russia's Bilibino Nuclear Power Plant

In early August 1993, the Northern Forum, at the request of two of its members—the governors of Alaska and of the Chukotka Peninsula—sponsored a visit by U.S. nuclear experts to the Bilibino Nuclear Power Plant in Chukotka. Visiting experts from the U.S. Nuclear Regulatory Commission and the U.S. Environmental Protection Agency discussed with plant personnel possible areas in which safety improvements may be needed. The Office of Naval Research provided funding for the project.

Although no technical assessment was actually conducted, the visit to the Bilibino Nuclear Power Plant appears to have had various positive results. Among others, it helped to 1) improve communications and cooperation between the Chukotka and the Alaskan governments; 2) set the foundation for developing joint cooperative work to identify funds, equipment, and programs to improve safety at the Bilibino plant; and 3) heighten the interest of other northern governments in participating in similar cooperative efforts (5,149). In June 1994, three representatives from the Bilibino plant and one from the Chukotka regional government participated in the International Radiological Exercise, described above.

SOURCE: Office of Technology Assessment, 1995.

NRC engaged in a number of different cooperative activities under the JCCCNRS. These included 1) technical meetings with Soviet experts for the purpose of exchanging information on the technical, legal, and organizational approaches to nuclear safety employed by both countries; and 2) extended exchange of regulatory personnel and safety research experts to broaden their understanding of their counterparts' regulatory structure and improve available options for solving safety problems. The dissolution of the former Soviet Union forced NRC to modify its then-bilateral nuclear safety cooperation program under the JCCCNRS into two joint committees with Russia and Ukraine, and to share the U.S committee chairmanship with DOE.

NRC implements U.S. nuclear safety initiatives by providing the Russians—and Ukrainians—with analytical equipment or training in key regulatory areas of nuclear plant safety. Attempts by NRC experts primarily involve training Russian nuclear power plant personnel in licensing and plant inspection, emergency response, and safety research. With the exception of a few technical seminars held in Russia, most NRC training activities are conducted in the United States at the agency's facilities or at national laboratories.

The Agency for International Development funds NRC activities under the Nuclear Safety Initiative program. To implement NRC's nuclear regulatory and safety programs in Russia, the U.S. Government, through AID, has earmarked since 1992 the following: $3.1 million in FY 1992; $5 million in FY 1993; $6 million in FY 1994; $1.5 million in FY 1995; and about $10 million, for both DOE and NRC, for FY 1996 (116,122). Though delays in disbursing obligated funds in the past have been reported (151), NRC has recently been highly successful in carrying out its responsibilities under the U.S. Nuclear Safety Initiative program.

International Initiatives to Improve Nuclear Reactor Safety

The first official recognition by the international community that the inadequate safety of Soviet-designed nuclear facilities could result in serious environmental and health problems took place at the July 1992 Munich summit of the Group of Seven (G-7) nations. It led to the creation of a multinational nuclear safety program known as the Nuclear Safety Account for the purpose of financing operational and technical safety improvements in Russia. In addition to the Nuclear Safety Account, this section discusses other initiatives being implemented or proposed by the international community (e.g., the European Union and the International Atomic Energy Agency) to prevent future Chernobyl-type nuclear accidents in Russia.

The Nuclear Safety Account (G-7 Munich Initiative)

At their July 1992 Munich summit, the heads of states of the Group of Seven nations identified the inadequate safety of Soviet-designed nuclear power plants operating in Eastern Europe and the former Soviet Union as a major area for assistance by the international community. To help solve this problem, the G-7 leaders attending the summit approved the creation, in coordination with the Group of Twenty-Four (G-24) nations,[34] of a multinational nuclear safety program. As prepared by G-7's Nuclear Safety Working Group, the assistance program known as the Nuclear Safety Account (NSA) was designed to provide funds for the immediate upgrade of high-risk nuclear reactors,[35] in combination with the preparation of plans for their closure (32,130).

[34] The Group of Twenty-Four consists of the 24 member states of the Organization for Economic Cooperation and Development, including the United States and Japan.

[35] These include 15 RBMKs in the former Soviet Union and the 25 VVER 440/230s known to be in operation throughout the former Soviet Union and Eastern Europe (130).

The objective of the Nuclear Safety Account is to finance, through grants projects, immediate operational safety and technical improvements as opposed to the technical assistance and assessments already financed by other international organizations already financed. The European Bank for Reconstruction and Development (EBRD) functions as the NSA Secretariat, providing technical and supporting services and cooperating with the European Community on NSA's behalf (42,43,44,45).

NSA's assistance is intended to secure an agreement from the recipient nation that unsafe nuclear power plants will eventually be closed. Consequently, the account focuses on implementation of immediate measures to improve the safety and operations of nuclear power plants that are considered essential to the energy needs of Eastern Europe and Russia. For example, immediate assistance may include technical safety upgrades and regulatory improvements. The Nuclear Safety Account may also provide long-term assistance for cases involving the replacement of older nuclear facilities for new alternative energy sources or the upgrade of more recent ones. Assistance for upgrades of more modern plants may be provided without any shutdown prerequisite, as long as such upgrading conforms to safety standards enforced by Western nuclear facilities (116,130).

Of the $785 million programmed in assistance at the Munich meeting, nearly $268 million was destined to assist Russia. According to NSA officials, plans are under way to grant Russia $91 million for the implementation of two nuclear safety projects. A total of three facilities will benefit from this program: the Leningrad, Novovoronezh, and Kola[36] Nuclear Power Plants.[37,38] As an essential element for grant approval, the EBRD is currently discussing with Russian officials the terms of an agreement that would include limitations on the future use of unsafe nuclear reactor facilities (80). Based on recently reported estimates (174), the cost of replacing Russia's older reactors with modern alternative energy sources may approach $20 billion and would take at least a decade to complete.

One of NSA's concerns about its participation in Russia is that this might rapidly consume the agency's funds to carry out work in other fSU nations still operating unsafe nuclear facilities. Because requesting additional funds from donor nations could be difficult and time-consuming, NSA officials might opt to assist countries such as Ukraine instead of Russia. The lower implementation costs of nuclear safety projects in other nations of the former Soviet Union, such as preparing safety plans for shutting down Chernobyl, might appear more favorable to NSA than supporting the considerably more expensive upgrading of Russia's nuclear reactors (45,55).

European Union's nuclear assistance program

For the past two years, the European Union's assistance to Russia in the nuclear field has focused primarily on improving the operational safety of older Soviet-designed reactors in use at the nuclear power plant in the Kola Peninsula. The European Union (EU) established a Program Implementation Unit as the body responsible for overseeing the project and for providing onsite technical assistance and training. At a funding level of $12 million per year, EU assistance has been focused primarily on the purchase of specialized equipment from France and Germany to replace equipment that is obsolete and unsafe. According to a EU official in Brussels, this nuclear safety assistance program might be short-lived, extending for only about two more years (26,128).

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[36] The vicinity of this facility to the Arctic and its radioactive contamination potential makes upgrading the operational safety of this plant crucial to those concerned with protecting the Arctic environment.

[37] The Leningrad facility employs aging nuclear reactors similar in design to those associated with the 1986 Chernobyl accident; the Novovoronezh and the Kola plants use reactors similar in design to Western pressurized-water reactors.

[38] Because of the relative proximity of the Leningrad and Kola Nuclear Power Plants to its territory, the Government of Finland has provided financial assistance (nearly $6 million since 1992) to supported safety upgrades at these plants (102).

International Nuclear Safety Convention

As a result of increasing concern by the international community in preventing a Chernobyl-type nuclear accident, in 1991 the International Atomic Energy Agency proposed to establish an international Nuclear Safety Convention (NSC). A technical working group had been established two years earlier to draft the elements of the convention. Following an invitation by the NSC Secretariat, representatives from 54 nations met informally in Vienna in March 1995 to discuss the range of possible options or approaches on how to implement this international reactor safety effort.

The Nuclear Safety Convention requires that within the first six months it enters into force, contracting parties must hold a "preparatory meeting" for the purpose of adopting the convention's procedural and financial guidelines. Parties attending the March meeting discussed the agenda for the preparatory meeting, including draft guidelines, reporting mechanisms, and the possible types of nuclear facilities that will be subject to the convention. A second meeting might be necessary to give member countries the opportunity to be better prepared for the ratification and implementation phases of the convention.

Although about 30 nations have already approved the text of the convention, IAEA officials do not expect to have the number of ratifications needed to implement it until late 1995 or early 1996. Once ratified, the international Nuclear Safety Convention will be responsible for coordination with countries having unsafe nuclear facilities in an attempt to bring them into compliance with existing internationally acceptable safety standards and practices. One of the current concerns among IAEA officials is the limited information on the level of country assistance that would be required to successfully implement the convention (31,49,74,148).

CURRENT RUSSIAN INSTITUTIONAL STRUCTURE

Environmental Protection Law in Russia

The former Soviet Union maintained a multitude of laws and codes that, in principle, provided for environmental protection and for the conservation and rational use of the country's natural resources. These legislative efforts included statutes designed to regulate air quality (1960), land use (1970), mineral resource development (1976), water quality (1972), and protection of forest resources (1977). Despite these laws, the lack of enforcement—due largely to Soviet economic policies and programs—resulted in inadequate environmental protection.

Considerable legal changes began to occur in the fSU by the late 1980s as a result of *perestroika*. The 1988 Law on State Enterprises, for example, allowed enterprises to become profit-making entities for the first time in the country's history. In principle, this law also made enterprises accountable for the adverse environmental implications of their economic development projects. These changes, although radical for the time, proved insufficient, having only a temporary impact on the environmental management system of the fSU.

The first step in creating a national framework for environmental protection was taken with enactment of the State Law on Environmental Protection in 1991 (124). This broad mandate not only contains the basic principles and institutional authorities for environmental protection at the federal and local levels, but introduces unprecedented concepts of environmental protection (e.g., payment for use of natural resources, pollution fees, environmental quality standards, and environmental assessment of major federal projects). The principal Russian Federation agency responsible for administering this law is the Ministry of Environmental Protection and Natural Resources discussed below.

Although the State Law on Environmental Protection represents an important first step, it does not specify the programs and goals required to ensure the development of a more effective environmental regulatory framework in Russia (110). Effective implementation of this law is further precluded by Russia's current inadequacies with regard to its institutional infrastructure for environmental protection, monitoring, and enforcement. These inadequacies, in the view of experts, are rooted primarily in the country's "severe economic and social upheaval" (86), as well as in the bureaucratic legacy inherited from the Soviet era, which did not favor environmental protection (109). Therefore, Russian efforts to enact additional legislation might result in little actual environmental protection unless Russia first overcomes its current socioeconomic problems, makes all government agencies accountable to environmental laws, and strengthens its environmental regulatory agencies.

Another current trend in Russian environmental management practices is decentralization of responsibility from Moscow to the regions. This strategy attempts to make regional governments responsible for, and aggressive in, implementing environmental protection programs. And even though many regions lack the regulatory and policy capacity to implement effective environmental reform, the slow pace with which democratic reform has progressed in many regions of Russia has adversely impacted regional efforts to improve environmental protection. Furthermore, key institutional concepts, such as property rights and a stable judicial system, have yet to be clearly defined or established and serve as additional limiting factors in the successful implementation of Russian environmental policies.

Ministry of Environmental Protection and Natural Resources

The Ministry of Environmental Protection and Natural Resource (MEPNR) is the primary federal agency responsible for promulgating and enforcing environmental regulations and for reviewing the environmental impacts of major development projects. MEPNR also coordinates national and regional activities relating to environmental protection and natural resource management. The agency's enforcement and environmental impact review functions are carried out through its regional offices.[39] These regional offices are also responsible for conducting environmental reviews of projects and for approving or denying operating permits to activities that might harm the environment (111).

In the area of nuclear safety regulations, MEPNR has little or no enforcement authority. Article 50 of the 1991 State Law on Environmental Protection states that all private and government agencies or activities with nuclear programs are obligated to comply with radiation safety regulations and exposure standards governing the production, management, and disposal of radioactive substances and materials. Article 50 also bans the import of radioactive materials into Russia. However, MEPNR has received little government support in enforcing this law. For example, although the law bans the import of radioactive waste, Russia continues to import spent fuel from Eastern Europe and Finland for reprocessing at its Mayak facility. And in January 1995, President Yeltsin signed a decree to continue construction of the RT-2 plant in Zheleznogorsk (Krasnoyarsk-26) in the hopes of further developing Russia's capability for reprocessing foreign spent fuel (47). Some believe that these steps taken by the highest levels of the Russian government are in contradiction to the state environmental protection law and to the mission of MEPNR. Others in the Russian government claim it is not a contradiction because spent fuel is *not* a waste.

Overall, MEPNR's regulatory effectiveness is questioned both by the general public and by circles within the Russian government (23). Several factors contribute to MEPNR's apparent lack of effectiveness including: 1) its relatively short

[39] There are approximately 90 regional offices and several dozen special offices with limited responsibilities (111).

history; 2) the limited financial support provided by the Russian government; 3) the limited reliability of data available to the agency for making environmental protection decisions; and 4) the poorly defined management and organizational responsibilities among agencies.

MEPNR is a relatively new ministry, with its original predecessor *Goskompriroda* established only in 1988 during *perestroika*. Prior to this, the former Soviet Union lacked a centralized body capable of enforcing environmental protection laws and regulations. MEPNR's lack of extensive institutional experience has limited its ability to influence other more established ministries. Since ministerial and bureaucratic interests remain powerful forces in Russian politics, MEPNR is at a distinct disadvantage in terms of influencing the political process. Furthermore, several internal reorganizations that have occurred in MEPNR's short history have also disrupted its overall continuity and effectiveness.

The inadequate financial support provided by the Russian government is considered another major reason for MEPNR's limited success. Despite the number of ecological protection programs established in Russia since the dissolution of the former Soviet Union, little funding has been provided for actual implementation. The possibility of improving MEPNR's budget appears unlikely at present in light of Russia's difficult economic conditions. The agency's budgetary hardship is also of concern because qualified personnel may seek employment in other areas, thereby depleting the pool of competent workers.

The unreliability of environmental data on which to formulate and oversee environmental programs also affects the limited success of MEPNR. Prior to its dissolution, the Soviet Union supported environmental research activities at more than 1,000 institutions under the auspices of 70 different ministries and agencies (108). In addition to making information gathering and dissemination more difficult, the reluctance of most agencies to adopt uniform nationwide approaches has resulted in the production of an extensive collection of environmental data that is generally inconsistent and, more importantly, of suspect quality and reliability. Furthermore, MEPNR has not gained access to all pertinent information since some valuable environmental data are still controlled by ministries related to the military and nuclear spheres.

The last major contributing factor in MEPNR's limited success to date relates to its poorly defined management and organizational responsibilities. There is a great deal of overlap and redundancy in the mission and responsibility of the different Russian organizations involved in environmental protection. MEPNR is responsible for coordinating environmental protection programs among a variety of government agencies, but thus far, interagency coordination has been inadequate. Historically, Soviet institutions were primarily linked vertically to Moscow, and there were few horizontal links between individual institutions, which would have enabled them to better coordinate efforts. This Soviet legacy has yet to be effectively overcome as the institutional arrangements between the various ministries and organizations are being developed and refined. Therefore, intraministerial and organizational conflicts exist today not only concerning jurisdiction but also for an extremely limited pool of federal funding. Furthermore, the devolution of authority from the center to the regions has not necessarily streamlined MEPNR's activities due in part to the fluid and often idiosyncratic dynamics involved in center-periphery politics.

Ministry of Atomic Power

The Ministry for Atomic Power (MINATOM) is a key player in Russia's nuclear activities relating to operation of nuclear reactors and sources of Arctic radioactive contamination. The mission of MINATOM involves a variety of functions. The most relevant are to: 1) oversee the functioning of enterprises and organizations within the nuclear complex; 2) conduct national scientific-technical investigations; 3) coordinate programs in the areas of nuclear arms and radioactive waste management; and 4) ensure nuclear and radiation safety at its nuclear facilities (23).

MINATOM is a large government agency with functions somewhat analogous to both the commercial nuclear industry and the Department of Energy of the United States (e.g., nuclear energy research and production, high energy physics, lasers, and other civilian programs).

MINATOM was established in its present form by presidential decree in January 1992. It succeeded the former Ministry of Atomic Power and Industry (MAPI), which was responsible for all aspects of the nuclear industry, from uranium mining and processing to research, development and the design and manufacture of nuclear bombs, warheads, and other devices (28). MAPI, in turn, had been formed in mid-1989 by merging the Ministry for Medium Machine Building,[40] previously responsible for nuclear weapons, with the Ministry for Nuclear Power, which regulated the country's civilian nuclear power plants. As a result, MINATOM now has management and oversight responsibilities for activities at civilian nuclear power plants as well as the Russian military nuclear complex.

In addition to its military[41] and civilian[42] operational departments, MINATOM also contains a number of highly specialized research institutes and production associations. The Khlopin Radium Institute in St. Petersburg and the Research Institute of Inorganic Materials (VNIINM) in Moscow are among the best known. There are also nearly 20 "quasi-private companies" affiliated with MINATOM. Examples of these include *Rosenergoatom*, which is responsible for the design, reconstruction, and operation of nuclear power stations, and *Atomstroy*, the Russian group responsible for building nuclear power stations (125).

Overall, MINATOM is an extremely large and powerful ministry. MINATOM garners support not only in Moscow but in many of the regions where it maintains operations. Entire towns and cities such as Chelyabinsk-65 and Arzamas-16 are basically dedicated to serving the nuclear-military complex and the interests of MINATOM. Furthermore, in July 1995, Viktor Mikhailov, Minister of MINATOM, was appointed to the Russian Federation Security Council, thereby increasing his role in national politics. It is still unclear how this translates in terms of MINATOM's future, but the past several years have shown that Russian politics is increasingly shaped by the individual tendencies of its leaders, which suggests that Mikhailov's appointment may have strengthened MINATOM's position relative to other ministries and organizations.

State Committee for Oversight of Nuclear and Radiation Safety

The Russian State Committee for Oversight of Nuclear and Radiation Safety (GOSATOMNADZOR or GAN) was organized in its present form at the end of 1991 by presidential decree.[43] GAN reports directly to the President and operates independently of the Russian Council of Ministers. GAN's responsibilities include: 1) establishing criteria and promulgating regulations for nuclear radiation safety; 2) overseeing and licensing all nuclear activities performed by government, nongovernment, and private institutions in Russia; 3) organizing and overseeing the training of workers at nuclear facilities; and 4) reporting to the government and general public about safety practices at nuclear facilities (106).

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[40] The Ministry for Medium Machine Building (MMB) was the highly secretive ministry that controlled the nuclear-military complex in the Soviet Union. MMB operated a network of secret cities across the country that was, until recently, unknown to foreigners as well as citizens of the Soviet Union. MMB was thought to be a primary claimant of economic resources and exercised a good deal of autonomy within the rigid political structure of the Soviet Union.

[41] The military branch contains primarily the Departments of Fuel Cycle and Nuclear Weapons Production; Security; International Relations; and Design and Testing of Nuclear Weapons.

[42] The civilian branch is composed, among others, of the Departments of Radioactive Waste; Nuclear Power Plants; Operation/Maintenance/Safety; and Construction and Development.

[43] President Yeltsin issued decree No. 249 of the RSFSR "On the reorganization of the state committee on oversight of nuclear and radiation in safety of the RSFSR" on December 3, 1991. GAN's institutional predecessor, Gospromatomnadzor, was by and large an ineffective regulatory agency whose authority extended only to civilian industries, not to the military or to enterprises of the military-industrial complex.

GAN's responsibilities vary between the national and regional levels. GAN headquarters is responsible for the organization and implementation of national policy on nuclear and radiation safety (19). Its regional offices are entrusted with the actual monitoring and oversight of nuclear installations and facilities. The regional offices are intended to ensure that the planning, construction, operation, and decommissioning of installations and facilities do not violate established norms and to oversee safety requirements for the treatment, storage, and disposition of radioactive wastes and radioactive materials, as well as the management of licensing activities as established by its headquarters.

Although GAN has the legal authority to regulate and inspect all types of nuclear activities, it has not gained full and complete access to certain military-nuclear sites (31,138,148). The agency's authority originates principally from a number of presidential decrees and executive orders. A decree introduced into law on January 18, 1993, for example, gives GAN the authority to license and inspect military nuclear operations (113). A presidential directive enacted in December 1993 calls for GAN to oversee safety practices at MINATOM's nuclear fuel cycle enterprises (114). After the accident at Tomsk-7 in April 1993, the Russian President issued presidential directive 224 granting GAN the authority to inspect all nuclear installations regardless of affiliation. Despite these directives, GAN's access to nuclear facilities managed by MINATOM and the Ministry of Defense is reported to be limited (138).

Overall, GAN's activities to date have focused primarily on establishing a set of rules and regulations for ensuring operational safety at nuclear facilities. The actual implementation of inspection and monitoring by its regional offices has been unsuccessful in some cases because the Ministry of Atomic Energy and the Ministry of Defense continue to limit GAN's access to certain nuclear facilities.

Other Ministries and Organizations

Several other institutional structures in Russia are involved in the regulation of nuclear power. The Department of Radiation Safety of the Russian Navy is chiefly responsible for regulating the use of nuclear reactors within the Russian Navy. During the Soviet period, the Navy was essentially self-regulatory in its nuclear activities, with its Department of Radiation Safety carrying out regulatory functions. Presently, it appears that the Russian Navy prefers to maintain its self-regulatory nature as evidenced by its continual refusal to allow GAN access to some of its nuclear facilities.

Two other Russian institutions that play a role in the development of rules and regulations for nuclear-related matters are the Ministry of Health and the State Committee for Hydro-Meteorology (Rosgidromet). These two organizations do not regulate nuclear activities directly, but they do maintain some independent responsibilities in terms of the drafting of regulations that relate to the nuclear industry.

Proposed Radioactive Waste Management Legislation

Russia today lacks a comprehensive set of laws needed to effectively regulate the use of nuclear materials and manage radioactive waste. Currently, three pieces of legislation (On the State Policy of Radioactive Waste Management, On the Use of Nuclear Energy, and On the Population's Radiation Safety) are being drafted in the Russian State Duma (Parliament) that would, in principle, help regulate the use of nuclear energy and waste.

If enacted, these legislative proposals would provide a legal framework under which all Russian nuclear energy users, including MINATOM, the Ministry of Defense, and numerous nuclear research institutes, would be accountable. Passage of these laws, however, faces considerable opposition. The draft law On the State Policy of Radioactive Waste Management, for example, is a potentially important piece of legislation because it attempts to build the environmental legislative framework first laid out by the 1991 Law on Environmental Protection. According to its stated objectives, the proposed legislation seeks to: 1) define the concept of radioactive waste; 2) establish national and international policy and agency responsibilities regarding radioactive waste management and treatment; and 3) develop liability guidelines to compensate for risk and damage to health and property from radioactive contamination. In addition to establishing that radioactive waste is "exclusively federal property," proponents of the legislation call for creation of an independent federal agency to manage all radioactive wastes. However, this piece of legislation has failed repeatedly in hearings before the State Duma and most recently in the Federation Council in June 1995.[44] Legislators have cited as weaknesses of the bill its incompleteness in the technological policies for handling radioactive waste and the lack of specified funding sources to finance envisioned programs (46).

In its present form, the draft law prohibits the disposal of any radioactive material or waste, including contaminated equipment, in soils, rivers, and oceans. In the past, MINATOM used Lake Karachai and the Techa River as dumping sites for radioactive waste. If passed, the proposed legislation would also place regulatory controls on, and possibly eliminate, MINATOM's spent fuel reprocessing activities. Another objective considered adverse to MINATOM's plans is the proposed creation of a independent Russian agency for management of radioactive waste. If created, this new agency could end MINATOM's decades-long self-regulation in this area. Currently, in the absence of comprehensive nuclear legislation, MINATOM exercises coordinating and executive authority for radioactive waste handling.[45] However, even if the law is passed, there are no guarantees that its implementation and enforcement would be successful.

Summary of Russia's Institutional Efforts and Programs

The overall institutional framework guiding the use of nuclear power and nuclear and radiation safety is complex and involves elements from the Soviet past as well as emerging trends in Russia today. Since the disintegration of the Soviet Union, Russia finds itself in the midst of a difficult transition having neither fully shed itself of its Soviet legacy nor fully transformed itself into a market-based economy.

In the past, the use of nuclear power, especially in the military sector, was shrouded in secrecy. Secret cities, which designed and manufactured nuclear weapons, were dotted across the Soviet Union unknown to the outside world. These facilities (enterprises and installations affiliated with the Ministry of Medium Machine Building, which was responsible for the design and production of nuclear weapons) received priority funding within the Soviet command economy. Production targets served as the primary goal, and environmental concerns were given little to no attention throughout most of the Soviet period. Not until *perestroika* in the late 1980s, and public opinion's increased role in national politics, did environmental issues finally make their way onto the Russian government's agenda. Since then, both the public and the government have increasingly recognized the need to support environmental protection efforts.

Since the disintegration of the Soviet Union, the Russian government has made official its intent to improve environmental protection and nuclear safety on a number of occasions. In 1991, Russia adopted the Law of the Environment establishing, for the first time, a comprehensive framework for environmental management (124). In 1993, Article 42 of the

[44] A Russian draft law must pass both hearings in the State Duma and a hearing in the Federation Council before it is signed into law by the President.

[45] A situation that appears to be legitimized further by the Council of Ministers' decree "On the Primary Measures in the Field of Handling Radioactive Wastes and Spent Nuclear Materials" of August 1993.

newly adopted Russian Constitution stipulated that every citizen in Russia has the right to a favorable environment, reliable information about its state, and compensation in case of body and property losses inflicted by environmental polluting activities (27). And in 1991, GAN was created by President Yeltsin to oversee the control of nuclear safety and radioactive waste management. GAN is an independent executive agency empowered with the authority to inspect every nuclear facility in Russia, including military sites.

However, the management of radioactive waste and spent nuclear materials is a complex problem requiring many ministries and agencies.[46] Despite the Russian government's approval of decrees to ensure interagency coordination, MINATOM and the Russian military continue to make key decisions concerning radioactive waste management without coordinating with regulatory agencies such as GAN. As a result, the implementation of approaches to solving radioactive waste contamination problems in the Arctic region continues to be determined by the military and MINATOM with little regulatory oversight. Although considerable progress has been made in the environmental regulatory sector, many aspects of the old system have yet to be fully dismantled and replaced by more effective approaches.

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Appendix B: Acronyms and Glossary B

ACRONYMS

ACOPS: Advisory Committee for Protection of the Sea (International)

AEPS: Arctic Environmental Protection Strategy

AID: U.S. Agency for International Development

ALARA: As low as reasonably achievable

AMAP: Arctic Monitoring and Assessment Program (International)

ANWAP: U.S. Arctic Nuclear Waste Assessment Program

ARCORA: U.S. Arctic Contamination Research and Assessment Program

ARPA: U.S. Arctic Research Policy Act

BEIR: U.S. National Research Council's Committee on Biological Effects of Ionizing Radiations

BNL: U.S. Brookhaven National Laboratory

CAFF: Conservation of Arctic Flora and Fauna

CEPNR: Committee of Environmental Protection and Natural Resources (International)

CF: Concentration factors

CIFAR: Cooperative Institute for Arctic Research (International)

CRESP: Coordinated Research and Surveillance Program (International)

DNA: Deoxyribonucleic acid

DOD: U.S. Department of Defense

DOE: U.S. Department of Energy

EBRD: European Bank for Reconstruction and Development

EMAP: Environmental Monitoring and Assessment Program (International)

EOI: Emergency operating instructions

EPA: U.S. Environmental Protection Agency

EPP&R: Emergency Prevention, Preparedness and Response

EU: European Union

FBR: Fast breeder reactor

fSU: former Soviet Union

G-24: Group of Twenty-four nations

G-7: Group of Seven nations

GAN (Gosatomnadzor) State Committee for Nuclear and Radiation Safety (Russian)

GCC: Gore-Chernomyrdin Commission (U.S.-Russian)

GESAMP: Group of Experts on the Scientific Aspects of Marine Pollution (International)

GIS: Geographical information system

GOSKOMGIDROMET: State Committee for Hydrometerology (Russian)

GOSKOMOBORONPROM: State Committee for the Defense Industry (Russian)

HEU: Highly enriched uranium

IAEA: International Atomic Energy Agency

IARPC: U.S. Interagency Arctic Research Policy Committee
IASAP: International Arctic Seas Assessment Program
ICRP: International Commission on Radiological Protection
IEA: International Energy Agency
IGPRAD: Inter-governmental Panel of Radioactive Waste Disposal at Sea
INSP: International Nuclear Safety Program
JCCCNRS: Joint Coordinating Committee for Civilian Nuclear Reactor Safety
JCCRER: Joint Coordinating Committee on Radiation Effects Research
LET: Linear energy transfer
LMR: Liquid metal reactor
LRW: Liquid radioactive waste
MAPI: Ministry of Atomic Power and Industry (Soviet)
MINATOM: Ministry of Atomic Energy (Russian)
MSC: Murmansk Shipping Company (Russian)
NATO: North Atlantic Treaty Organization
NEA: Nuclear Energy Agency
NGO: Non-governmental organization
NIS: Newly Independent States
NOAA: U.S. National Oceanic and Atmospheric Administration
NPP: Nuclear power plants
NRC: U.S. Nuclear Regulatory Commission
NRL: U.S. Naval Research Laboratory
NSA: Nuclear Safety Account
NSC: Nuclear Safety Convention
NSF: U.S. National Science Foundation
OECD: Organization for Economic Cooperation and Development
OMB: U.S. Office of Management and Budget
ONR: U.S. Office of Naval Research
OTA: Office of Technology Assessment
PAME: Protection of the Arctic Marine Environment
PCB: Polychlorinated biphenyls
PNL: U.S. Pacific Northwest Laboratory
PUAEA: Peaceful Uses of Atomic Energy Agreement
PWR: Pressurized water reactor
RADEX: Radiological Exercises
SRW: Solid radioactive waste
SSAN: Nuclear-powered auxiliary submarine
SSBN: Nuclear-powered ballistic missile submarine
SSGN: Nuclear-powered guided missile submarine
SSN: Nuclear-powered attack submarine
START: Strategic Arms Reduction Treaty
THORP: Thermal Oxide Reprocessing Plant
TTC: Technical training center
USGS: U.S. Geological Survey
VNIINM: All-Russian Scientific Research Institute of Inorganic Materials

GLOSSARY

Actinides. Radioactive elements with atomic number larger than 88.

Alpha particle. Two neutrons and two protons bound as a single particle emitted from the nucleus of certain radioactive isotopes in the process of decay or disintegration.

Bathymetry. The measurement of depths of water.

Benthic. Dwelling at the bottom of a body of water.

Beta emitter. A charged particle emitted from the nucleus of certain unstable atomic nuclei (radioactive elements), having the charge and mass of an electron.

BN-600. A type of Soviet designed breeder reactor.

Curie. A unit of radioactivity equal to that emitted by 1 gram of pure radium.

Damaged nuclear fuel. Nuclear fuel (normally in the shape of rods) that has been corroded, eroded, cracked, or has had its casing opened.

Defueling. The process of removing nuclear fuel from a reactor after the fuel has been used for some period of time.

Demilitarization. The process of eliminating or reducing military weapons, materials, other hardware and organizational structures.

Dismantlement. The process of taking apart and disposing of submarines, ships or other military systems and equipment.

Dry storage (of spent nuclear fuel). Refers to the use of special storage containers that do not require water or other cooling liquids.

Effective dose. Radiation dose which takes into account the type and energy of radiation as well as the different tissues or organs irradiated.

EPG-6. A type of Soviet designed graphite moderated and boiling water cooled nuclear reactor.

Fallout. Radioactive particles that are deposited on the earth's surface.

Fission products. Atoms created by the splitting of other heavier atoms—usually in a nuclear reactor and usually resulting in radioactive isotopes.

Fuel assemblies. A number of individual nuclear fuel rods grouped together with structural support.

Furfural. A resin based compound used in Russia to solidify dumped nuclear materials in containers.

Gamma radiation. Similar to x-rays, short-wavelength electromagnetic radiation of nuclear origin.

Half life. The time required for a radioactive substance to lose fifty percent of its activity by decay.

Ionizing radiation. Any electromagnetic or particulate radiation capable of producing ions as it passes through matter.

LGR. A type of Soviet designed light water cooled, graphite moderated reactor.

Non-standard nuclear fuel. Nuclear fuel of a special design or containing special materials for which special manufacturing, handling, storage, or processing systems are required.

Nuclear fuel cycle. From mining uranium to manufacturing fuel to use in a reactor to reprocessing for future use again.

Plutonium. Man-made element produced when uranium is irradiated in a reactor. Plutonium-239 is the most suitable isotope for constructing nuclear weapons.

Rad. Radiation absorbed dose, a basic unit of absorbed dose of ionizing radiation representing an amount of energy absorbed per unit of absorbing material such as body tissue.

Radionuclide. Certain natural and man-made atomic species with unstable nuclei that can undergo spontaneous breakup or decay and, in the process, emit alpha, beta, or gamma radiation.

RBMK. A type of Soviet designed graphite-moderated and light water cooled nuclear reactor.

Reactor core. The center and energy-producing section of a nuclear reactor containing the nuclear fuel and associated structural components.

Rem (Rad Equivalent Man). Unit of dose equivalent. The dose equivalent in "rem" is numerically equal to the absorbed dose in "rad" multiplied by necessary modifying factors.

Remediation. The process of taking actions to remove, stabilize, contain, or make benign hazardous or radioactive materials that have been dumped, discharged or otherwise released into the environment.

Reprocessing. Taking spent nuclear fuel and separating out the specific nuclear and non-nuclear materials for re-use or disposal using mechanical and chemical processes.

RT-1. A nuclear fuel reprocessing plant located at Mayak.

RT-2. A nuclear fuel reprocessing plant currently being built at Krasnoyarsk-26.

Sedimentation rate. The rate of deposition of sediment at the bottom of a body of water.

Semipalatinsk. A former Soviet nuclear weapons testing site located in Kazakhstan.

Source term. The quantities and types of released radionuclides and their physical and chemical conditions.

Spent nuclear fuel. Nuclear fuel that has been irradiated in a reactor for some period of time and thus "used-up."

Stochastic. A process that is random and results involve chance.

Tritium. A radioactive gas, an isotope of hydrogen, that serves as a booster for the fusion reaction in the secondary component of a nuclear weapon.

Vitrification. Process of immobilizing radioactive material, mixing it with molten glass, and encapsulating it into a glasslike solid.

VVER. A type of Soviet designed pressurized water nuclear reactor.

Weapons grade. Nuclear materials such as plutonium and highly-enriched uranium that are of a type and purity suitable for use in nuclear weapons.

Appendix C: Excerpts from DoD Appropriations Acts for FY1993, 1994 & 1995 Providing Funding and Authority for the Arctic Nuclear Waste Assessment Program (ANWAP)

C

PUBLIC LAW 103-335—SEPT. 30, 1994

103D CONGRESS

An Act making appropriations for the Department of Defense for the fiscal year ending September 30, 1995, and for other purposes.

TITLE II OPERATION AND MAINTENANCE

Former Soviet Union Threat Reduction

For assistance to the republics of the former Soviet Union, including assistance provided by contract or by grants, for facilitating the elimination and the safe and secure transportation and storage of nuclear, chemical and other weapons; for providing incentives for demilitarization; for establishing programs to prevent the proliferation of weapons, weapons components, and weapon-related technology and expertise; for programs relating to the training and support of defense and military personnel for demilitarization and protection of weapons, weapons components and weapons technology and expertise; for supporting the demilitarization of military technologies and production infrastructure; $400,000,000 to remain available until expended: *Provided*, That of the funds appropriated under this heading, $10,000,000 shall be made available only for the continuing study, assessment, and identification of nuclear waste disposal by the former Soviet Union in the Arctic and North Pacific regions.

PUBLIC LAW 103-139—NOV. 11, 1993

103D CONGRESS

DEPARTMENT OF DEFENSE APPROPRIATIONS ACT, 1994

TITLE II OPERATION AND MAINTENANCE

Former Soviet Union Threat Reduction

For assistance to the republics of the former Soviet Union, including assistance provided by contract or by grants, for facilitating the elimination and the safe and secure transportation and storage of nuclear, chemical and other weapons; for providing incentives for demilitarization; for establishing programs to prevent the proliferation of weapons, weapons components, and weapons-related technology and expertise; for expansion of military-to-military contacts; for supporting the conversion of military technologies and capabilities into civilian activities; and for retraining military personnel of the former Soviet Union; $400,000,000, to remain available until expended: *Provided,* That of the funds appropriated under this heading, $10,000,000 shall be made available only for the continuing study, assessment, and identification of nuclear waste disposal by the former Soviet Union in the Arctic region: *Provided further,* That the transfer authority provided in section 9110(a) of the Department of Defense Appropriations Act, 1993, shall continue to be in effect during fiscal year 1994: *Provided further,* That any transfer made under the foregoing proviso in this paragraph shall be subject to the limitations and the reporting requirements stipulated in section 8006 of this Act: *Provided further,* That the Director of Central Intelligence shall report to the President and the Congressional defense, foreign affairs, and intelligence committees on the current status of intercontinental ballistic missile development and production in states eligible for assistance under this heading: *Provided further,* That none of the funds appropriated under this heading may be expended or transferred to an otherwise eligible recipient state if the President concludes, and notifies the Congressional defense, foreign affairs, and intelligence committees in a written report, that the potential recipient is currently engaged in the production of a new road mobile or fixed-site land based intercontinental ballistic missile armed with multiple nuclear re-entry vehicles.

PUBLIC LAW 102-396—OCT. 6, 1992
102D CONGRESS

DEPARTMENT OF DEFENSE APPROPRIATIONS ACT, 1993

TITLE IX GENERAL PROVISIONS

Sec. 9110 (a) The Secretary of Defense may transfer to appropriate appropriation accounts for the Department of Defense, out of funds appropriated to the Department of Defense for fiscal year 1993, up to $400,000,000 to be available for the purposes authorized in the Former Soviet Union Demilitarization Act of 1992: *Provided,* That amounts so transferred shall be in addition to amounts transferred pursuant to the authority provided in section 108 of Public Law 102-229 (105 Stat. 1708).

(b) Of the funds transferred pursuant to subsection (a):

(1) not less than $10,000,000 shall be available only for the study, assessment, and identification of nuclear waste disposal by the former Soviet Union in the Arctic region;

(2) not less than $25,000,000 shall be available only for Project PEACE;

(3) not more than $50,000,000 may be made available for the Multilateral Nuclear Safety Initiative announced in Lisbon, Portugal on May 23, 1992;

(4) not more than $40,000,000 may be made available for demilitarization of defense industries;

(5) not more than $15,000,000 may be made available for military-to-military contacts;

(6) not more than $25,000,000 may be made available for joint research and development programs; and

(7) not more than $10,000,000 may be made available for the Volunteers Investing in Peace and Security (VIPS) program.

(c) The Secretary of Defense may transfer from amounts appropriated to the Department of Defense for fiscal year 1993 or from balances in working capital funds not to exceed $15,000,000 to the appropriate accounts within the Department of Defense for the purposes authorized in section 109 of Public Law 102-229.

(d) The authority provided in sections 108 and 109 of Public Law 102-229 (105 Stat. 1708) to transfer amounts appropriated for fiscal year 1992 shall continue to be in effect during fiscal year 1993.

(e) The Secretary of Defense may transfer to appropriate appropriation accounts for the Department of Defense, out of funds available to the Department of Defense for fiscal year 1993, up to $40,000,000 to be available for international nonproliferation activities authorized in the Weapons of Mass Destruction Control Act of 1992: *Provided,* That such transfer authority shall not be available for payments either to the "Contributions to International Organizations" account of the Department of State or to activities carried out by the International Atomic Energy Agency which have traditionally been the responsibilities of the Departments of State or Energy: *Provided further,* That up to $20,000,000 of the transfer authority provided in this section may be used for the activities of the On-Site Inspection Agency in support of the United Nations Special Commission on Iraq.

(f) The transfer authority provided in this section shall be in addition to any other transfer authority contained in this Act.