BONN INTERNATIONAL CENTER FOR CONVERSION
B·I·C·C

BONN INTERNATIONAL CENTER FOR CONVERSION · INTERNATIONALES KONVERSIONSZENTRUM BONN

paper 12

Nuclear Submarine Decommissioning and Related Problems

by
Susanne Kopte

August 1997

For many years **Susanne Kopte** was head of the Disarmament Campaign at Greenpeace. She is presently working as a freelance journalist. An earlier version of this paper was prepared as background paper for the Conversion Survey 1997.

Copy editor: **Moira Davidson-Seger**

BICC · AN DER ELISABETHKIRCHE 25 · 53113 BONN · GERMANY · PHONE +49-228-9 11 96-0 · FAX +49-228-24 12 15
E-MAIL: bicc@bicc.uni-bonn.de URL: http://bicc.uni-bonn.de

BONN INTERNATIONAL CENTRE FOR CONVERSION
B·I·C·C

NUCLEAR SUBMARINE DECOMMISSIONING AND RELATED PROBLEMS

CONTENTS

I. INTRODUCTION 1

II. THE MAGNITUDE OF THE PROBLEM 4

III. THE WORLD'S NUCLEAR SUBMARINE FORCES 6

- **1. Nuclear submarines in Russia/Soviet Union** 6
- **2. Nuclear submarines in the United States** 7
- **3. Nuclear submarines in the United Kingdom, France, and China** 8
    - ***3.1 United Kingdom*** 8
    - ***3.2 France*** 8
    - ***3.3 China*** 9
- **4. Other nuclear submarine forces** 10

IV. GENERAL OVERVIEW OF DISMANTLEMENT AND DISPOSAL TECHNOLOGIES FOR NUCLEAR SUBMARINES 11

- **1. The decommissioning process** 12
    - ***1.1 The defueling process*** 12
- **2. Options for reactor compartment disposal** 14
    - ***2.1 Sea disposal*** 14
    - ***2.2 Shallow land burial*** 17
    - ***2.3 Deep land burial*** 19

V. STATUS AND PROBLEMS IN THE DECOMMISSIONING PROCESS OF NUCLEAR SUBMARINES IN RUSSIA 20

1. The Pacific Fleet 22
    1.1 The spent-fuel problem 24
    1.2 Disposition of liquid and solid radioactive waste 26
2. The Northern Fleet 29
    2.1 Shipyard capacities for the decommissioning task in the Northern Fleet 30
    2.2 Problems of spent-fuel management in the Northern Fleet 31
    2.3 Disposition of liquid and solid radioactive waste 34
3. Foreign aid 37

VI. THE US NAVY SCRAPPING AND RECYCLING PROGRAM FOR NUCLEAR-POWERED SUBMARINES 42

VII. THE FRENCH STRATEGY FOR DISPOSAL OF NUCLEAR-POWERED SUBMARINES AND SPENT FUEL 46

VIII. THE UNITED KINGDOM’S PLANS FOR DISPOSAL OF NUCLEAR-POWERED SUBMARINES 48

IX. CONCLUSIONS AND RECOMMENDATIONS 49

X. ACRONYMS 51

XI. REFERENCES 52

ANNEX: CHRONOLOGY OF MAJOR ACCIDENTS ON NUCLEAR SUBMARINES WORLDWIDE 56

TABLES

Table 1: Nuclear Submarines Built and Decommissioning Worldwide 5
Table 2: Soviet Dumpings, 1965-1988 16
Table 3: Estimated Costs of Inactivating and Scrapping Nuclear-Powered Submarines 43
Table 4: Hazardous Vessel Components 44

D

In October 1995, a shocked public learned that a nuclear meltdown of a Russian submarine reactor at a base near Murmansk had been avoided only at the last minute. The story was short and drastic: a dozen nuclear submarines were waiting to be dismantled at the Northern Fleet base. Because of a shortage of storage space their reactors, fuel cells, and nuclear waste had not been removed. The nuclear submarines were in poor condition and, if left without power, their reactors would be in danger of overheating and melting. However, because the military had not paid their bills for months, local authorities decided to cut off heating and electricity to the base. In order to prevent a nuclear catastrophe, soldiers were sent to the power station to force the staff there at gunpoint to restore electricity to the base.

Although this was a very dramatic case, it is only one of the latest incidents and scandals in the field of submarine dismantlement, one of the most severe problems of surplus weapons.

The history of nuclear submarine development is comparatively short. In 1954, the first nuclear-driven vessel, the US submarine *Nautilus*, became operational. Since then, a small number of countries have built or operated nuclear-propelled submarines. The first Soviet nuclear submarine, *Leninsky Komsomol,* became operational in 1959, the first British nuclear submarine, the *Dreadnought,* in 1963, and the first French nuclear submarine, *Le Redoutable,* in 1971. It has been reported that the first Chinese nuclear submarine went into service around 1974. Two others countries (India and Brazil) had, or still have, plans for deploying nuclear submarines. All together, a total of about 500 nuclear-propelled vessels have been constructed since 1954. Of these about 460—that is more than 90 percent—have been submarines.

Nuclear submarines—or nuclear reactors—do not last forever. As they get older, the need for maintenance and repair increases, that is, operation becomes more expensive. Furthermore the technology on which their design was based becomes obsolete and they no longer live up to present day requirements. While there is no set lifespan for nuclear submarines, the general experience is that their service life is between 20 and 30 years. After this time the submarines have to be decommissioned and their spent fuel and reactor plants disposed of. Today—about 40 years after the first nuclear submarine became operational—decommissioning and disposal of these vessels has become an important and urgent topic with unsolved technical and economic problems. An additional reason for taking nuclear submarines out of operation is disarmament agreements (the START Treaties) and this has in particular affected Russian and American ballistic missile submarines.

Besides the restrictions introduced by nuclear arms control and the fact that the normal lifecycle of the first submarines sooner or later comes to an end, there are two more reasons for decommissioning nuclear submarines and these are especially important in the Russian case. Firstly, some submarines have undergone serious accidents and are beyond repair. Secondly, the greatly reduced Russian defense budget precludes maintenance and upgrading of the large Cold War force of nuclear submarines established by the Soviet Union.

The dismantlement of nuclear submarines is different from other fields of weapon disposal. By the time a nuclear submarine is decommissioned, it is no more than a dangerous collection of radioactively contaminated components. Handling and treatment are difficult because of great risk to personnel and the environment. The radioactive waste can be in either solid or liquid form, including spent nuclear fuel and the reactor core itself. While in the United States no or little radiation has been released into the environment as a result of submarine dismantling activities (as far as is publicly known), in Russia, hundreds of square miles of land, sea and air are reportedly believed to be contaminated with radioactivity from submarine deactivation. The Russian Navy has in no way been prepared to deal with the enormous disarmament measures now required. Disposal systems in the past were not even able to keep up with normal lifecycle decommissioning. Now these systems are completely overtaxed by present requirements. Many measures taken so far have been inadequate and often dangerous.

The disposition of nuclear submarines requires an integrated program, supported by adequate funding, special production facilities and infrastructure. The US Navy had been budgeted with additional and sufficient resources for every stage of the decommissioning process. In contrast, the Russian Navy must squeeze its decommissioning and clean-up costs into its operating budget which is overstretched to begin with. Furthermore, decommissioned submarines are in poor shape and manned by unmotivated crews. They may sink at the dockside and cause ecological catastrophes.

This paper provides an overview of the status and problems related to nuclear submarine decommissioning worldwide. After a brief description of the history and development of the world nuclear submarine forces, it discusses the main dismantlement and disposal technologies currently used. Here, it mainly concentrates on defueling procedures and the accompanying risks and on various different options for dealing with reactor compartments. Greatest emphasis is given to the nuclear fleet in Russia and the United States. With regard to the French and British Navies, the decommissioning problem is less extensive due to the comparatively small number of their submarines. As for China, no decommissioning plans currently exist. Russia, however, which has built more nuclear vessels than all other countries together, faces important challenges due to its special problems and the Russian economic situation. A detailed description of the naval support infrastructure, its spent-fuel and radioactive waste management, and the dismantlement problems faced by the Russian Navy has therefore been given. Short explanations about US and French strategies in this field conclude the analysis.

M D M

From open sources, such as Jane’s *Fighting Ships*, *Military Balance* and other publications, it is possible to obtain a reasonably accurate estimate of the total number of nuclear vessels built and of the number of nuclear vessels which are in various stages of decommissioning. Between 1955, when the United States developed the world’s first nuclear-powered submarine, and 1994, 465 nuclear-powered submarines of various kinds had been built at shipyards in five countries: the United States, the Soviet Union, France, Great Britain and China. Brazil had started a program for building a nuclear submarine but stopped due to financial problems in the late 1980s. India is still working on the development of a nuclear submarine. However, it will not be operational before the year 2000.

More than one-half of all nuclear submarines—245—have been built at Russian enterprises: 125 in Severodvinsk, 56 at Komsomolsk-na-Amure, 39 in St. Petersburg, and 25 in Nizhniy Novgorod. However, before 1990, Russian decommissioning programs had not started to any significant extent. At that time a significant number of the nuclear submarines had reached an age of about 30 years. During the first half of the 1990s, all of the older submarines—about 140 vessels—were removed from active service. It can be estimated that, in the year 2000, the total number of Russian nuclear vessels at various stages of decommissioning will be around 180 to 200.

The United States has built 179 nuclear submarines at seven shipyards (86 of them at Groton and 49 a Newport News) over the last 40 years, and of these 71 had been taken out of operation by mid-1996. The first two ships to be removed from operation were USN SSN *Thresher* and *Scorpion* which both sank due to accidents. Planned decommissioning did not start before about 1970, that is, after about 25 years of operation. The total amount of nuclear vessels in the United States which can be expected to be in various stages of decommissioning in the year 2000 will be about 100.

The nuclear fleets of the United Kingdom, France, and China are much smaller than those of the United States and Russia. Britain’s shipbuilders have commissioned a total of 24 nuclear submarines (21 were built at Barrow-in-Furness and three at Birkenhead), of which 11 have been taken out of service. By the year 2000 about 15 nuclear submarines will have been taken out of operation. The French Navy built all their twelve nuclear submarines at Cherbourg. Currently, two of them have been taken out of operation. By the year 2000, the number of submarines to have been decommissioned is not likely to exceed four. China’s five to six nuclear submarines have been built at Hulongdao. All of them are likely to be in active service in the year 2000.

S M S D D MM SS D
D D

	US	*Russia/ Soviet Union*	*France*	*United Kingdom*	*China*	*Total*
Numbers built	179	245	12	24	5–6	465–466
Likely to have been decommissioned by the year 2000	100	180	4	15	0	299

D S S M S

Nuclear submarines in Russia/Soviet Union

The first Soviet nuclear submarine *Leninsky Komsomol* was constructed at Sevmashpredpriyatie (Northern Machine Building Plant or SMP) between 1954 and 1957 and went into service with the Northern Fleet in March 1959 (Marinin, 1995, p. 114). Since then, Soviet and Russian shipyards have produced 245 nuclear submarines, including 91 ballistic missile submarines (SSBNs), 64 cruise missile submarines (SSGNs), 86 attack submarines (SSNs), and four research submarines (Bukharin and Handler, 1995, p. 246). From the Alfa attack submarine—the smallest—with a displacement tonnage of 3,680, to the largest submarine ever, the Typhoon ballistic missile submarine (25,000 tons)—the largest undersea vessel ever produced—the range of Russian submarines offers a great variety in size.

Nuclear submarines are today built by the Northern Machine Building enterprise at Severodvinsk—the world's largest nuclear shipbuilding center—and the Amursky Zavod shipyard at Komsomolsk-on-Amur. Until recently, combatant SSNs were also built at the Krasnoye Sormovo shipyard in Nizhni Novgorod and at the Admiralteyskiye Verfi in St. Petersberg (Marinin, 1995, p. 114).

By 1994, the Amursky Zavod shipyard and the Krasnoye Sormovo shipyard were reported to have already ceased production, while the Admiralteyskiye Verfi yard is currently building only non-nuclear Kilo submarines (Jordan, 1994b, p. 156). In the years to come the entire nuclear submarine-building program is expected to be concentrated at Severodvinsk.

Three nuclear submarines of the Akula class are currently under construction. Three submarines of the new SSN Severodvinsk class are also being built at this shipyard. Construction started in December 1993, and the first of this class was launched in 1995. According to US analysts, the first commissioning of these new boats will take place between 1996 and 1997. Production of a new SSBN is also expected to begin by the end of the decade. This will be a follow-on to the Delta III, Delta IV and Typhon class (Jane's, 1995, p. 6).

Nuclear submarines in the United States

The US Navy began preliminary research into nuclear propulsion for submarines in 1939, even before the so-called Einstein letter to President Roosevelt recommending that the United States should undertake the development of nuclear weapons. Once the Manhattan Project started, all fissionable materials were diverted to that effort and the small Navy program stopped (Polmar, 1983, p. 109). However, in 1949, development work continued, headed by Admiral Rickover. Among others, corporations such as Westinghouse, General Electric, Combustion Engineering, and Babcock & Wilcox were important players in this process. To find the optimal reactor for use on board a submarine, full-scale test models of the different types of reactors were built on land (Eriksen, 1992, p. 45).

The construction of the world's first nuclear submarine, *USS Nautilus,* began in the early 1950s. After launching about four years later, it became the first submarine to sail beneath the polar ice in 1957. It was powered by a pressurized-water reactor. The *Nautilus* was followed by a second prototype, the *USS Seawolf* which was initially provided with a beryllium-moderated, sodium-cooled reactor. However, leaks developed in the steam generator between the liquid metal coolant and the water, and the reactor was soon replaced by a pressurized-water reactor. The difficulties with this reactor type led to the decision to develop improved pressurized-water plants for all future US nuclear submarines, each in large part an improvement on the previous one (Olgaard, 1995, p. 4).

Since then, US shipyards have produced 179 nuclear-powered submarines, including ballistic missile submarines (SSBN), nuclear-powered attack submarines (SSN), as well as some research submarines (*Jane's Fighting Ships*, various issues). Today two programs are still continuing: new Seawolf attack submarines and the next generation of SSBN Trident submarines. Both programs have been heavily criticized in the United States and threatened by budget cuts.

Nuclear submarines in the United Kingdom, France and China

3.1 United Kingdom

Development and research of nuclear submarines in the United Kingdom began in 1954. The United Kingdom has cooperated closely with the United States, and the first nuclear submarine of the Royal Navy was equipped with an American-type pressurized-water reactor. This reactor was installed in the submarine *HMS Dreadnought* launched in 1963.

Since then, UK shipyards have built four classes of attack submarines with a total of 18 submarines. Each submarine is propelled by one nuclear reactor. Between 1964 and 1969 Britain produced four Resolution class ballistic missile submarines (SSBN), commonly called Polaris submarines after the missiles they carry. The new Vanguard SSBN class, slated to replace the Resolution class, was expected to enter operational service between 1995 and 2000. Commonly known as the Trident program, it entails the construction of four submarines.

The *HMS Vanguard,* as the first of four Trident-armed SSBNs, began its operational patrol at the end of 1994, eight years after construction had started. The second SSBN of this class, *HMS Victorious,* is continuing sea trials, while *HMS Vigilant* was commissioned in 1995 and *HMS Vengeance* is due in 1997 (Jane's, 1995, p. 32–34).

Currently, the British Royal Navy operates with an all-nuclear submarine Flotilla comprising five Swiftsure-class nuclear attack submarines (SSNs), seven Trafalgar-class SSNs, two Resolution-class Polaris ballistic missile submarines (SSBNs) and *HMS Vanguard,* the first Trident SSBN.

3.2 France

France was the first country to begin its program with plans for a ballistic missile submarine in 1959. Development of a land-based prototype reactor was completed by 1964 and this reactor type was later installed in the first submarine of the Le Redoutable SSBN class. The other four submarines of this class entered service by 1980. In 1985 the SSBN *Inflexible* entered service. The design is more advanced than that used for the Le Redoutable class but not as advanced as the one planned for the new Triomphant class. It is therefore considered as an intermediate class between this two classes. Based on the *Inflexible*, four of the Le Redoutable class were later updated to the same standard as the Inflexible (Norris, Burrows and Fieldhouse, 1994, p. 253).

By the year 2005, France plans to put into service four Triomphant-class nuclear submarines. The lead vessel *Le Triomphant* is to enter service this year. The other three (*Le Téméraire, Le Vigilant* and a fourth) will follow over the next 10 years. The new SSBNs will each carry 16 six-warhead M-45 nuclear weapons (*Jane's Intelligence Review*, Vol. 23, No. 8, 25 February, p. 3).

3.3 China

China began to prepare for the commissioning of nuclear submarines in 1958. Although the first draft design was finished in June 1960, the project was deferred at the time in order to place priority on the development of nuclear devices and because of the lack of enriched uranium fuel for the submarines' reactors. After the first two nuclear tests and the completion of a uranium enrichment plant, the submarine project regained momentum in 1965 (Kong, 1993, p. 322). The plan was now to first construct a nuclear-powered attack submarine to be followed by a nuclear-powered ballistic missile submarine. Relying on extensive published information in the West with regard to water-cooled reactors for submarine use, the Chinese probably devoted five years of intensive research before construction of their first submarine of the Han class began. After the sea trials it was turned over to the Navy in 1974. By 1991, four other submarines of this class had been built (Jordan, 1994b, p. 280).

China's first nuclear-powered ballistic missile submarine, designated the Xia class by the West and called the Daqinyu class in China, was launched in April 1981. In 1986 China declared the submarine operational and as of mid-1993 it was believed that two Xia-class SSBNs had been built and were operational, with perhaps two more under construction (Norris, Burrows and Fieldhouse, 1994, p. 369). However, the exact status of the SSBN class remains unknown.

Other nuclear submarine forces

India is building a nuclear-powered submarine. The work on the nuclear submarine project began around 1991 shortly after India returned a Charlie I-type SSGN it had leased from the former Soviet Union. The submarine is being designed by the Navy and the Defense Research and Development Organization, while scientists from the Bhaba Atomic Research Center at Bombay are designing the reactor unit (Bedi, 1994, p. 3).

Brazil started a program to develop nuclear submarines in the 1970s but it has never been completed. Due to financial and political problems the program was stopped in the late 1980s.

D SM M D D S S S S M S

A nuclear-powered submarine is a complex weapon carrier which, like any other large weapon system, is not easy to dismantle. One problem is the disposal of the weapons, that is, the nuclear and conventional missiles and torpedoes. This task is comparable to the dismantlement of land-based conventional and nuclear weapons. However, the dismantlement of nuclear submarines demands additional attention because of the nuclear reactor which powers the submarine. After several decades of use, not only the nuclear reactor itself but also large parts of the surrounding submarine have been heavily radioactively contaminated. As in the field of civilian nuclear power plants, no solution exists for the dismantlement of nuclear contaminated products and their long-term storage.

Moreover uranium fuel used in submarine reactors is far more highly enriched than that used in civilian reactors, which is only four percent. The majority of nuclear submarines are equipped with pressurized-water reactors (PWR). Depending on the type of reactor, the level of enrichment varies from approximately 20 percent to ‘weapons-grade’ which is usually defined as containing approximately 90 percent uranium 235. In most cases 20–45 percent uranium 235 has been used as fuel in submarine reactors.

More modern generations of submarine reactors, however, probably use even higher enrichment levels so that submarines can go for longer periods between refueling the reactor. For instance, the liquid-metal reactors which propelled Russian Alfa class submarines are almost certainly fueled with weapons-grade uranium (Bukharin and Potter, 1995, p. 46).

The primary circuit of the power plant in a nuclear submarine, which consists of the reactor, the pumps, the steam generators and the connecting piping, is situated in the reactor compartment. This compartment is usually placed aft of, or behind, the center of the submarine.

All but one of the US submarines have been provided with one reactor. The same is true of the British and the French nuclear submarines and, according to available information, also of the Chinese submarines. However, most Russian nuclear submarines have been provided with two reactors, situated in separate rooms, but in the same compartment. Only about 65 of the 245 Russian submarines have been equipped with one reactor.

The cores of these reactors typically hold between 200 and 300 fuel assemblies, each containing up to a few tons of fuel rods. Under normal operating conditions, the PWRs require refueling every seven to ten years (Bukharin and Potter, 1995, p. 47).

The thermal power of nuclear submarine reactors varies from 10 MW used in older submarines to 200 MW for the reactors of the newer classes.

The decommissioning process

There are many steps involved in fully decommissioning a nuclear submarine. Initially, all weapons and explosive devices as well as classified and sensitive materials are removed at its naval base. Next, the submarine sails to the shipyard which has been chosen for the dismantlement process. Upon arrival, the reactor is shut down for a reasonable period to allow the short-lived radioisotopes to decay. During this period expendable materials, technical manuals, tools, spare parts, and loose furnishings are removed.

1.1 The defueling process

At the next step, the submarine is dry-docked and prepared for defueling. This process involves the opening-up of the hull above the reactor plant, the installation of the necessary equipment to allow removal of the spent fuel, the removal of the top shield of the reactor, and the actual removal of the fuel itself. Defueling is accomplished using the same procedures which have been used many times for the necessary reactor refueling during the service life of the nuclear submarine. Although the whole operation has a strictly controlled procedure, errors—large and small—could occur. At minimum, for example, it might be that the refueling personnel lose something in the reactor like a screw which then causes a problem. The lifting of the reactor lid is another highly risky activity which could lead to the maximum danger of a thermal explosion of the reactor. For instance, on 10 August 1985, the reactor on a Victor-class submarine became ‘critical’ during refueling operations at the Chazma Bay naval yard outside Vladivostok. The control rods had been incorrectly removed when the reactor lid was raised. The ensuing explosion led to the release of large amounts of radioactivity. Ten people working on the refueling of the vessel died in the accident. The damaged reactor compartment still contains its nuclear fuel (Hiatt, 1991, p. A 19).

In addition to this Victor-class submarine, the Russian Navy currently has five other nuclear submarines with damaged cores caused by fairly small or major loss-of-coolant accidents. In all these submarines, the fuel or part of it is so damaged that it cannot be removed from the reactor by available techniques. They have therefore been left in a floating condition, while the radioactivity of the fuel gradually decreases. Prior to the 1980s, the Soviet Navy had simply dumped nuclear reactors which had suffered damage preventing the removal of the spent nuclear fuel. Because this procedure is now prohibited by the London Dumping Convention, Russian submarine design bureaus are now developing specialized equipment to remove the damaged nuclear fuel from these submarines (Nilsen, Kudrik and Nikitin, 1996, p. 108).

During the final step of the defueling process, the fuel is placed in a shipping container and later transported to an interim spent-fuel storage facility. Ultimately, the fuel—which contains valuable fissile material—may either be sent to a reprocessing plant or considered as radioactive waste and sent to final disposal.

Defueling removes over 99 percent of the radioactivity associated with the reactor. However, the nuclear power plant still contains a significant quantity of radionuclides in two forms: (1) induced metallic radionuclides, created by neutron bombardment during the reactor’s operation and embedded in the metal of the reactor’s pressure vessel, piping and adjacent bulkhead walls (approximately 99,9 percent of the remaining radioactivity); and (2) radioactive corrosion products (mainly cobalt-60), deposited as film on the internal surfaces of the reactor pressure vessel and piping (approximately 0.1 percent of the radioactivity) (Davis and Van Dyke, 1990, p. 469).

Certain of these radioactive elements will remain toxic for hundreds of thousands of years. This fact should be considered when the final disposal of the reactor compartments is determined.

Options for reactor compartment disposal

Once the fuel has been removed, the further procedure depends on the method chosen for final disposal of the reactor compartment which is so heavily radioactive that a long-term, safe, final disposal is necessary. Since decommissioning programs started, three options have mainly been discussed, or used by the nuclear navies: sea disposal, shallow land burial, and deep land burial.

2.1 Sea disposal

Sea dumping of decommissioned nuclear submarines is an option which has been actively considered by most nuclear nations. Until comparatively recently dumping of liquid and solid radioactive waste was a common practice carried out by many countries possessing a nuclear fleet and a nuclear industry. During the Cold War the problem of handling growing quantities of nuclear waste was not viewed as one of primary importance and the simplest solution was considered to be disposal at sea. This practice was carried out for more than 30 years by the Soviet Union/Russia and for more than 20 years by the other nuclear countries, and it was not until a few years ago that more restrictive international conventions regulating nuclear waste disposal at sea were adopted.

In 1972, the London Dumping Convention (LDC) limited ocean disposal of nuclear waste. Eighty nations agreed to observe the Convention. While it initially prohibited disposal of high-level radioactive waste (which is primarily spent fuel), parties to the Convention more than ten years later also approved moratoriums concerning the ocean-dumping of low- and intermediate-level radioactive waste. It is interesting to note that the Soviet Union abstained and the United States voted against the moratoriums (Escalona, 1993, p. 16). At the Convention’s annual meeting in 1993, a worldwide ban on the dumping of radioactive waste at sea was declared. Thirty-seven countries, including the United States, voted in favor of a permanent ban on nuclear waste dumping at sea. However, Belgium, France, China, the United Kingdom, and Russia abstained (Pitt, 1993, p. 13).

The practice of dumping decommissioned nuclear submarines is not clearly exempted by the LDC. From a legal perspective, for instance, the LDC excludes warships from its regulations by assigning them sovereign immunity. But some questions of interpretation are still open. The main question is how long a warship can be regarded as such, especially after it has been taken out of military service and no longer has a crew or weapons on board.

In 1982, the US Navy carried out an Environmental Impact Study weighing up the advantages either of land disposal of the reactor compartment or of sinking the entire defueled ship in deep water. At that time the US Navy was operating approximately 120 nuclear submarines, most of which were approaching the end of their service life (United States Navy, 1984, p. 1–1). Seven nuclear submarines had already been taken out of service and placed in protective storage. The US Navy calculated at that time that an additional six nuclear submarines per year would have to be decommissioned from 1982 to 2000 (United States Navy, 1984, p. 1–1). In 1959 the US Navy had already disposed of the reactor vessel of the *NSS Seawolf* by dumping it into the Atlantic Ocean at a depth of 2,700 meters, 200 km east of Delaware (Olgaard. 1995, p. 8).

The program of sea disposal was advocated on the grounds that it was cheaper than land-based options. However, largely as a result of the highly uncertain regulatory status of sea disposal in the London Dumping Convention, the US Navy ultimately chose land disposal as the preferred alternative. In 1984 the decision was made in all further cases to cut out the reactor compartment, bury it at the Hanford site in the state of Washington and scrap the remainder of the ship (MacKinnon III and Burritt, 1995, p. 2).

In the Soviet Union/Russia on the other hand, several decommissioned naval reactors have been dumped in shallow waters in the Eastern Arctic since the mid-1960s. In March 1993, a Russian government commission revealed the full extent of the former Soviet Union’s practice of dumping radioactive waste into the seas and oceans surrounding its territories. The commission was led by Aleksei Yablokov, an environmental expert and adviser to President Boris Yeltsin. Other members included the directors of the Ministries of Defense, Atomic Energy, National Security, and Foreign Affairs (Leskov, 1993, p. 13)

The report acknowledges that during the period of 1965 to 1988 the Northern Fleet had dumped four reactor compartments with eight reactors (three containing damaged fuel) in the Abrosimov Gulf in 20 to 40 meters of water. The compartments had been cut out of the submarines and closed at both ends. In the case of reactor compartments still containing reactors with spent fuel, the compartments had been filled with protective material of steel, cement and polyester to prevent radioactivity seeping out into the marine environment. According to Russian reactor constructors, this protection may last for up to 500 years. In addition, the first nuclear power plant of the icebreaker *Lenin,* containing three reactors without fuel, was dropped into the Sivolky Gulf in 1967. The damaged fuel from one of the reactors was also dumped close to this gulf. A barge with a submarine reactor was sunk in the Kara Sea in 1972. A complete submarine, the *K-27,* was jettisoned after an emergency with two fuel-laden reactors in the Stepovov Gulf in 1982. In 1988, a reactor was dumped into the Techeniya Gulf on the east side of Novaya Zemlya.

In 1978, the Pacific Fleet dumped two reactors without fuel. Both dumpings took place in the Pacific Ocean at depths of 3 and 2.5 kilometers (Administration of the President of the Russian Federation, 1993, pp. 12–13).

S D M S

4 compartments (8 reactors)	Northern Fleet - Abrosimov Gulf
1 compartment (3 reactors)	“ - Sivolky Gulf
1 compartment (1 reactor)	“ - Kara Sea
1 compartment (2 reactors)	“ - Stepanov Gulf
1 compartment (1 reactor)	“ - Techeniya Gulf
2 compartments (2 reactors)	“ - Pacific Ocean

After the Yablokov Commission had revealed the secret dumping practice of the Russian Navy, the international public criticism became so scathing that at least for the foreseeable future it is not very likely that Russia will resume any plans to dump deactivated, decommissioned submarines. However, due to lack of financing and the absence of planning, the Russian Navy has not yet developed land-based storage sites, although a number of different possibilities are under discussion. Since the early 1990s, the Navy has begun to separate out the reactor compartments and to prepare them for intermediate storage only. At present, all removed reactor compartments are stored afloat as so-called ‘three-compartment units’ and tied up in sheltered bays in the North and Far East, a few also at shipyards. To achieve the necessary buoyancy of the 1,200 ton pieces, one neighboring compartment with integral bulkhead on each side is cut out together with the reactor compartment and hermetically sealed, hence the name (Kvaerner Moss Technology, 1996, p. 37).

According to Captain Pavel Smirnov of the Pacific Fleet that solution was the lesser of two evils: he argued that the sealed compartments were less likely to sink than a whole submarine, perforated by dozens of outlets for piping and other equipment. However, not only is pier space hardly available, the risk of their sinking or breaking away also remains (Clarke, 1995, p. 37).

2.2 Shallow land burial

In the mid-1980s, the US Navy decided to use shallow land burial of the reactor compartments of nuclear submarines. The process starts at the Puget Sound Naval Shipyard in Bremerton, Washington. This shipyard is the only one which participates in the US Nuclear-Powered Ship and Submarine Recycling Program, launched in the early 90s (Loring-Morison, 1995, p. 47).

The reactor compartment is removed and packaged for disposal when the vessel dismantling process begins. The vessel is dry-docked with the reactor compartment supported by cradles. Tracks and rollers are installed under the cradles to allow the reactor compartment to be slid away once it has been cut free. After it has been slid free of the submarine both ends of the compartment are sealed with bulkheads. In a next step the compartment is loaded onto a barge and transported via the Columbia river to a burial trench at the Hanford site's burial area. Here the reactor compartments are buried at a depth of about five meters of earth. Since 1986, about five reactor compartments per year have been shipped to this site (Olgaard, 1995, p. 9).

According to Malcolm MacKinnon III, a retired Rear Admiral of the United States Navy, and James G. Burritt, a retired Navy Captain, the burial of the reactor compartments at the Hanford site poses no significant risk to the environment. In a paper about nuclear submarine inactivation in the United States they point out "[that] the materials used in construction of the reactor plant and the reactor compartment are resistant to corrosion, and the environment at Hanford is such that corrosion occurs at very slow rates. Radioactivity in the plant will decay naturally, and after 1,000 years only some 140 curies will remain. Studies estimate that the earliest a pinhole would develop allowing lead from the shield to be released is 600 years. The earliest time estimated that lead would reach groundwater is 240,000 years. Even when this happens, the concentrations will be too low to be detected" (MacKinnon III and Buritt, 1995, p. 6).

However, due to startling revelations about radioactive contamination during the last years, the names of nuclear weapons facilities such as Hanford, Rocky Flats and others are to some as synonymous with environmental disaster as Chernobyl and Three Mile Island.

The continued unsafe and impermanent storage of radioactive waste and other deadly by-products of nuclear weapons activities has resulted in numerous accidents, spills and leaks. The likelihood of a disaster is extremely high at the Hanford reservation where, by the early 1990s, 24 underground tanks storing high-level radioactive waste were considered in some danger of exploding (Rothstein, 1995, p. 39). Although the storage of nuclear compartments of submarines in this environment presents no significant danger in itself, it is yet adding to the existing problems.

The Russian Navy is currently exploring the option of putting some reactor compartments into tunnels near submarine bases in the North and Far East. These tunnels were originally intended to conceal and shield strategic nuclear submarines. In 1990, the Ministry of Defense principally approved the option to use one or more of the 400 meter tunnels in the Ara Bay on the Kola Peninsula. According to the proposal, up to 100 reactor compartments could be stored in the tunnels for 70 to 100 years. After this period of time, radiation levels would have been significantly reduced allowing the compartments to be completely dismantled and the resulting scrap metal stored as ordinary solid nuclear waste (Nevzorov, 1995, p. 2). The prospects for the implementation of this project are very low: apart from financial problems, the plans for utilizing the Ara Bay tunnels have met ecological criticism from many Russian agencies. For instance, a precondition for use is that the tunnels are dry. The possibility of flooding in the tunnels resulting in leaks of radioactivity has been the cause of greatest concern. The storage facility would then be in conflict with Russian environmental regulations because current laws prohibit the storage of radioactive waste in locations where there is a significant risk of leakage into the sea (Nilsen, Kudrik and Nikitin, 1996, p. 109).

The storage of reactor compartments in the permafrost of Novaya Zemlya, where the Russian nuclear test site used to be, is another proposal under discussion. There are plans to blast 2–3 km long canals inland from the coast. The reactor compartments would then be towed up the canals.

Once the canals had been filled with compartments, dams would be built and the remaining water pumped out. Finally the reactor compartments, and possibly other types of radioactive waste, would be covered with sand and rock. But again, paperwork has been going around in circles for years and the Russian Government has still not reached a decision (Zhelodkov, 1995, p. 65).

2.3 Deep land burial

The British government is considering a method of deep land burial. At least until the end of the 1980s, the British Navy had recommended the sealing of the submarine hulls and their sinking in the mid-Atlantic as by far the safest and least disruptive means of long-term disposal (House of Commons, 1989). However, since this option seems to be no longer available due to the latest revisions of the London Dumping Convention, UK submarines will probably be disposed of by deep land burial. The reason for choosing this quite expensive option is that in the UK a deep repository is already being planned while a suitable, shallow repository is not be available.

Because of the limited dimensions of the shafts down to the deep repository, submarine compartments which are typically cylinders with a length and diameter of 10 meters and a weight of approximately 850 tons cannot be disposed of in one piece. Deep land burial will therefore require that the reactor compartment and its components are broken up into smaller pieces which will result in a dose burden considerably higher than for sea disposal or shallow land burial. In order to reduce the dose burden, the primary circuit will have to undergo a long cooling off in a interim storage phase and thorough cleaning before break-up commences (Olgaard, 1995, p. 10).

S S D MS D MM SS SS S M S SS

Although the Soviet Union developed the largest nuclear-powered submarine fleet, the Soviet Navy did not make adequate plans for either the disposal of the fleet’s toxic wastes or for the retirement of these vessels. By the end of 1995, Russia had a backlog of about 140 nuclear-powered submarines laid up, awaiting final disposal. By the year 2000 Russia, as the only heir of the nuclear weapons of the former Soviet Union, has to decommission and dispose of 180 to 200 nuclear-powered submarines. According to the Russian Navy, many of the decrepit submarines still have sailors living on them and nuclear fuel in their reactors because of an acute housing shortage and a lack of facilities to remove and store the highly radioactive fuel.

The situation is aggravated by the fact that Russia’s vast international obligations and responsibilities concerning implementation of the treaties and agreements on disarmament overlap the scheduled decommissioning, due to attrition, of the first generation of nuclear-powered submarines, and this involves extra expenditures.

Since the mid-1980s, several decrees and programs have been developed which would specifically deal with or incorporate the decommissioning problem. However, the actual work is far behind schedule. This is partly due to the fact that so many governmental agencies (the Ministry of Defense, the Ministry of Atomic Energy, the Shipbuilding Directorate of the State Committee for Defense Industries, the Nuclear Federal Regulatory Agency, the Ministry of Transport, the Ministry of Railways, regional and local administrations etc.) at the central, regional and local levels are involved in the decommissioning process. Although there is coordination among these agencies there is also considerable confusion and competition, particularly for scarce funds to finance various parts of the decommissioning work (Bukharin and Handler, 1995, pp. 260-261).

Also, the dissolution of the Soviet Union in the mid-1991 to 1992 period complicated the legal implementation of decrees and programs, as agreements signed between agencies under the Soviet Union had to be renegotiated and signed, sometimes with newly appointed officials. However, the main problem boils down to insufficient funding. In 1994, Vice Admiral Victor Topilin, the chief of the Navy’s Main Technical Directorate, stated that it cost more than 5 billion rubles to break up a single submarine. So far, most of the funds for decommissioning and clean-up work have being found by cutting expenditure on maintaining the combat readiness of the Navy's ships (Maryukha, 1994, p. 32). Government funds allocated for the various programs of the decommissioning task have been insufficient, or if allocated in the budget, have not been released or delivered by the government. For example, in 1994, less than a quarter of the funds earmarked for decommissioning nuclear submarines in the state defense order were actually disbursed. In the Pacific Fleet from 1992 to 1994, only 15 percent of the budgeted funds for decommissioning were received (Gromov, 1994, translation 1995, p. 47).

While the government is very reluctant to release ratified sums for the submarine recycling program, it is at the same time against redistributing budget funds. For example, the Ministry for Affairs of Civil Defense, Emergency Situations, and Elimination of Natural Disasters, which would have to help deal with the consequences of any serious nuclear accident and which thus has a vested interest in the issue, was reported to be ready to lend the Navy 10 billion rubles in 1994, but was prohibited from doing so by the Finance Ministry (Maryukha, 1994, p. 32).

If one of the laid-up nuclear submarines were to sink at the dockside, then the money would have to be found, but it would be being used to eliminate the consequences of an accident which could have been avoided.

Official documents and decrees aim at the fact that decommissioning nuclear submarines is self-financing. However, naval yards which have been involved operate at large losses. For example, after cutting up its first submarine in 1993, the Zvezdochka shipyard near Severodvinsk suffered a loss of 311 million rubles. Sixty tons of copper, 100 tons of lead, and 20 tons of aluminum were salvaged from the submarine and sold. But the work turned out to be more expensive than the value of the scrap metal (Filippov, 1995, p. 80).

The Sevmash yards in Severodvinsk, charged with the task of dismantling titanium-hulled submarines, make an even greater loss per unit than the Zvezdochka yard. The shipyard management estimate a loss of one billion rubles for the decommissioning of an Alfa-class submarine. The dismantlement process of titanium-hulled submarines is much more time-consuming and requires advanced equipment. Furthermore, according to F.N. Shukharov, Vice President of the nuclear submarine construction center at Severodvinsk, Sevmash receives no tax relief on its foreign sales of metals. For the moment, the export tax on titanium alloys is set at

1,900 US dollars/ton, while the world market price is about 1,000 US dollars/ton (Nilsen, Kudrik and Nikitin, 1996, p. 105).

All indications are that it will prove impossible to finance the decommissioning of nuclear submarines through the sale of scrap metals. Because the world ferrous metal market is already in a difficult situation probably only non-ferrous metals will be of interest to foreign buyers. However, in the case of titanium alloy, it appears that the Russian defense industry prefers to keep this valuable metal itself. Consequently, either the Russian Government or other agencies must be prepared to render large-scale economic assistance to the nuclear submarine shipyards (Nilsen, Kudrik and Nikitin, 1996, p. 105).

e a i i eet

At least 60 nuclear submarines in the Russian Pacific Fleet will be decommissioned by the end of this decade. While, as of 1992, there were 35 decommissioned nuclear submarines in the Pacific Fleet, the number had grown to 53 by late 1994 according to a report from the State Duma (Handler, 1995, p. 21). The number of decommissionings increased more rapidly than anticipated because the service life of the submarines is decreasing due to lack of funds and maintenance (Maryukha, 1994, p. 33).

Mainly two shipyards are involved in scrapping nuclear submarines in the Far East. The Zvezda plant, located on Bolshoi Kamen Bay, 120 kilometers east of Vladivostok, is responsible for the refueling, repairing and decommissioning of nuclear submarines. Under START I, it had been officially declared as a SSBN dismantlement facility. The second plant is the Gornyak shipyard, which is located between the two towns of Primorskiy (Petropavlovsk-50) to the north and Primorskoe (Petropavlovsk-53) to the south. Compared to the Zvezda plant, no full-scale scrapping operations are conducted at Gornyak. Here, workers remove interior equipment, strip down the hull, and so on. These steps are necessary preconditions for the floating storage of submarine sections (Handler, 1994b, p. 166, 170).

The decommissioning process in the Pacific Fleet began in 1987 when the reactor cores were off-loaded from the first submarine, an Echo I SSN. In 1988, two more decommissioned submarines had their cores off-loaded. The second was a November SSN, and the third was a Yankee SSBN.

In 1989 and 1990, three and four submarines respectively had their cores off-loaded. As of mid-1992, 18 submarines had had their fuel removed (Handler, 1993b, p. 16).

Theoretically, the Zvezda plant has the capacity to fully scrap five-to-six submarines a year. However, under the present conditions, it is only operating at a rate of one-to-two submarines a year, which means that it will take 30 to 40 years to dispose of the 60 submarines which the fleet will retire by the year 2000. The threat of an environmental disaster resulting from the failure to take steps to salvage these vessels is growing every year. Lacking permanent land-based storage sites, the Pacific Fleet has had to develop provisional solutions. The submarine's outer shell is stripped away, then the reactor compartment and the two adjoining compartments are hermetically sealed as a single unit. The sealed compartments are towed to a remote base or bay for temporary—but indefinite—floating storage. Sealed reactor compartments are kept, for example, at Pavlovsk, a major nuclear submarine base on the eastern edge of Strelok Bay, some 65 km southeast of Vladivostok. Some are also stored afloat in Razboinik Bay across from the Chazma Bay shipyard (Handler, 1995, p. 22 and 1994, p. 167).

Sealed compartments are also less likely to sink than a whole submarine. The steadily worsening conditions of the laid-up nuclear submarines require a whole set of temporary safety measures to prevent sinking at the dockside, or other problems related to the nuclear reactors. For instance, constant pumping of compressed air into the hulls is needed to keep the vessel afloat. The nuclear reactors on decommissioned submarines are in markedly worse condition than those on operational vessels, for there is more humidity, temperature variation, and the risk of sea water entering the hull. Reactors are therefore treated with self-sealing solutions in order to prevent leaks of radioactivity and to minimize the risk of spontaneous chain reactions in the nuclear fuel through accidental contact with sea water. Also, the reactors of vessels which have not been defueled must be cooled permanently by circulating coolant through the primary circuit. This is achieved by supplying electrical current from a land-based source or from the vessel's own diesel generators or batteries. If all these power sources should fail, the reactors would be in danger of overheating and meltdown (Nilsen, Kudrik and Nikitin, 1996, p. 103).

Furthermore, crew members assigned to laid-up submarines often lack the necessary training or equipment to maintain the vessel in a safe manner. In summer 1994, a commission of the Maritime Kray Administration visited a small nuclear-powered submarine facility near the town of Rakushka at the northern end of the Vladimir Bay. The inspection was ordered after the Navy, implementing cuts in the armed forces, had issued a directive to save funds in the maintenance of the special sub-unit in Rakushka—the very sub-unit which was responsible for providing the submarine base with material and technical support. The commission found seven decommissioned nuclear submarines virtually unattended at their moorings. No one at the 'top-secret' facility had even stopped the inspectors from entering (Barabash, 1994, p. 31).

Excerpts from their report show the extent of the catastrophic state of the base:

> *In facilities capable of producing a catastrophe on the scale of Chernobyl there is no coastal technical backup for security; there is no system of low- and high-pressure air or for draining the compartments, no bilge pumps or compressors; the technical condition of the outer hull and the outboard systems is unsatisfactory, the main ballast cisterns are leaky. … Put more simply, the necessary temperature here is maintained by ordinary, everyday domestic heaters which firemen do not allow to be placed even in student hostels. … There is no light in the majority of compartments. … All the submarine's auxiliary equipment, which might have been able to localize a potential fire, is out of order. The crew does not even have mooring ropes to secure the submarines in the event of a storm* (Barabash, 1994, pp. 31 and 33).

Although the Rakushka case seems to be an extreme example, it is still true of the other facilities that the lack of competent, qualified personnel and maintenance equipment increases the possibility of emergency procedures not being executed correctly in the event of a serious incident.

1.1 The spent-fuel problem

In 1994, decommissioning operations in the Pacific Fleet almost ground to a halt due to lack of financing and lack of storage space for off-loaded spent nuclear fuel and liquid radioactive waste. Explaining the seriousness of the situation, the director of the Zvezda plant stated: "This plant is just like a man without a kidney. The dismantling of nuclear submarines cannot continue without the disposal of nuclear waste" (Polutov, 1994, p. 24).

The off-loading of spent fuel from the submarines at the Zvezda plant is carried out by special service ships. These ships, called 'floating workshops' or 'floating bases,' store spent reactor cores from several submarines and transfer them to a storage site. Only three of the Pacific Fleet's six support ships are currently operational. Five are converted Finnish cargo barges, more than 30 years old. Two have been removed from service because of accidents, while another is in danger of sinking and cannot move under its own power. A fourth ship is said to be in a dangerous condition and in need of repairs (Bukharin and Handler, 1995, p. 257). Service ships bring fresh fuel to active-duty submarines which need to be defueled at the shipyards. The conflict between the tasks of decommissioning on the one hand and supporting submarines on active-duty on the other severely limits the capacity of these ships. There are simply not enough of them available for all the work.

The two land-based facilities for storing, handling and trans-shipping radioactive waste and spent nuclear fuel in the Pacific fleet are also reaching their capacity limits. 1,057 of 1,132 cells for storing spent nuclear fuel at the Shkotovo waste facility are reported to be full (Zakharov, 1995, p. 3). The site is the larger and more complex one, located on the Shkotovo peninsula, near the submarine base at Pavlovsk. The other is located on Kamchatka near the nuclear submarine base at Rybachiy. The fuel is being kept at the facilities for one to two years to allow further radioactive decay and cooling.

The shortage of storage capacity at these facilities has not only been caused by the high rates of submarine decommissioning but also by the slow rate of spent-fuel shipments to the reprocessing plant at the Mayak Chemical Combine in Ozersk, once known as Chelyabinsk-65. The spent-fuel assemblies must be shipped in special casks on special railcars. When, in 1993, the Russian nuclear regulatory agency Gosatomnadzor banned the use of the old shipping casks on safety grounds, shipments of spent fuel from the Pacific Fleet came to a complete halt. The new transport containers, which do meet the required standard of the International Atomic Energy Agency, are too heavy for the existing road and rail systems. The handling of the new containers also requires some technical changes at the bases and at the storage sites which will further delay the spent-fuel shipments (Bukharin and Handler, 1995, p. 258). Even if the Navy were finally successful in upgrading its bases in order to send spent fuel away for reprocessing, the rate of shipments would still be limited by the availability of special railcars. Presently, there is only one four-car train of the special cars for the new containers and this can only carry the spent fuel from one submarine. This train is also required to service the Northern fleet and in 1994 transferred the spent fuel from the training reactors in Paldiski in Estonia (Zheludkov, 1995, p. 66). Reportedly, the Ministry of Nuclear Energy does not want to spend the estimated 800,000 US dollars needed to procure four cars to form a second train (Clarke, 1995, p. 37).

In view of the desperate situation, the Navy has begun to agitate for permission to ship spent fuel in the old containers. Admiral Nikolai Yarasov, the chief of the Navy's nuclear-safety inspectorate, has pointed out that "the risk of transporting nuclear waste in old containers is less than the risk posed by the accumulation of this waste" *(Moscow Interfax,* 10 March 1995). But so far this request has been denied by Russia's federal nuclear-monitoring commission.

However, the risks are real. In 1990, Greenpeace began researching the situation regarding both the Northern and Pacific fleets. It published in detail the appalling conditions found at each fleet's facilities and the inadequate procedures used to deal with increasing environmental problems. Accidents or events which have implied a release or leak of radioactive substances have occurred in virtually all of these facilities. For example, the spent nuclear fuel stored in shallow burial sites at Installation 927 III (Shkotovo nuclear waste storage site) is prone to run off in heavy rains, and cement 'graves' with waste are suspected of leaking into the sea. At the waste facility at Krasheninnikova Bay on the Kamchatka Peninsula, there is no record of what has been placed in one of the three burial trenches used to hold solid radioactive waste. In another trench, water has leaked into approximately 80 percent of the hermetically sealed cells, while cracks have emerged in the outer concrete walls of the third trench, posing a groundwater contamination threat (Handler, 1994a, pp. 3 and 8).

1.2 Disposition of liquid and solid radioactive waste

With little or no place to store liquid or solid radioactive waste, decommissioning operations are further slowed, particularly in the Pacific Fleet. Liquid radioactive waste was gathered at the submarine bases or shipyard facilities aboard special tankers, carrying the Russian designation TNT, before being dumped at sea. In all, there are four to six ships of this TNT class—known in the West as Vala-class radioactive waste tankers—in the Pacific Fleet. Built in the 1960s, they were converted to transport up to 1,000 cubic meters of liquid waste. All of them are now in a very poor state.

In October 1993, the *MV Greenpeace,* one of the environmental organization's ships, followed a Russian tanker toward a site in the Sea of Japan where the Pacific Fleet had disposed of liquid nuclear waste in the past. The tanker TNT-27 was carrying low-level liquid radioactive waste which reportedly came from coolants and cleaning fluids from scrapped nuclear submarines at the Zvezda shipyard (Nerisky, 1993).

Despite strong winds, about 900 to 1,000 cubic meters of liquid nuclear waste were pumped into the sea through a pipe located under the hull, at a point about 105 miles west of Vladivostok and 295 miles from the Japanese island of Hokkaido (Greenpeace, 1993, p. 1). Greenpeace awakened international public interest which lead to the focusing of attention on the severity of the dumping problem. Japan, South Korea, and the United States sent formal protests to Russia.

The Pacific Fleet had planned another dumping operation from the sister ship TNT-5 by November 1993. Reportedly, the TNT-5 was in such a bad condition that shipyard personnel feared it could easily fall apart at the dockside. According to Greenpeace information, the Navy had applied to sink the whole ship together with its cargo of about 800 cubic meters of radioactive waste (Greenpeace, 1993, p.2). However, as a result of the international outcry, permission was not given, and Prime Minister Viktor Chernomyrdin formally ordered the Navy to suspend its plans for a second dumping at the same site (Usui, 1993, p. 4).

In 1994, both tankers were towed from the Zvezda shipyard to the nearby, but more isolated, Pavlosvkii Bay. This was obviously done to calm fears expressed by nearby communities (*Moscow Interfax,* 6 April 1994).

The 900 to 1,000 cubic meters of low-level waste dumped by the Pacific Fleet is relatively small compared to the activities of the former Soviet Union. In March 1993, a Russian Government commission revealed that, since 1959, more than 80,000 tons of low-level liquid waste, more than 5,000 containers of solid low-level waste, 34 ships packed full of waste, and two nuclear reactors (with fuel removed) had all been dumped in the Japan Sea in an area a few hundred kilometers south of the port of Vladivostok (Leskov, 1993, p. 13). Between April and June of the same year, the Japanese Meteorological, Fisheries and Maritime Safety Agencies and the Japan

Marine Science and Technology Center all sent ships to analyze sea water, deep-sea sediments, and fish for various radionuclides in a number of locations. No unusual levels of radioactivity were found and Japan's Science and Technology Agency announced that "the results of the survey so far show that this ocean dumping is not something that has an effect on the health of our people" (Swinbanks, 1993, p. 777).

But the conclusions are of limited value, as none of the surveys was able to collect samples in the *actual* dumping area, which lies within Russia's 200-mile exclusive zone. Investigations have been confined to areas off Japan's coast, tens to hundreds of kilometers distant from the dump site (Swinbanks, 1993, p. 777).

After the dumping in October 1993, naval authorities maintained that they had no choice but to dump the waste into the ocean because all their storage facilities were full. On 10 November 1993, Environment and Natural Resources Minister Viktor Danilov-Danilyan warned the annual meeting of the London Dumping Convention that Russia would have to dump low-level radioactive waste into the sea at least until the end of 1994, and possibly through 1996. Under the condition that the Russian Navy discontinue ocean dumping, the Japanese Government promised support in 1993 for the construction of a liquid radioactive waste processing plant. Japanese plans foresee the installation of a facility on a barge at the Zvezda shipyard in Bolshoi Kamen. Its capacity would be between 5,000 to 7,000 metric tons of waste per year (Dmitriev, 1995). However lengthy business negotiations regarding the facility have continuously delayed construction. Since the situation has become even more acute, the Navy has had to start devoting some additional funds to this problem. Two small facilities were installed by the Navy and these started processing liquid waste on the TNT-tankers in 1994. This stop-gap measure has relieved the crisis for the time being (Grachev, 1995).

After 18 months of negotiating, Russia's State Committee for the Defense Industry finally signed the contract for a floating nuclear waste recycling plant on 11 January 1996. Worth tens of millions of dollars, the business involves a number of Japanese and US companies which have promised to put the plant into operation by the end of 1996 (Clarke, 1996).

There is no near-term solution to the decommissioning problems of the Pacific Fleet. The pace of defueling cannot be accelerated without the special service ships—or 'floating workshops'—

needed to off-load the spent fuel. These service ships, which are constructed at Black Sea shipyards in Ukraine, are no longer being delivered.

Improvements to the technical outfitting of the scrapping yards also cannot be expected. On the basis of an order placed by the former Soviet Defense Ministry, the Kherson shipyard, for example, is building a series of floating docks designed to repair and salvage nuclear submarines. But the construction of the docks specially designed for this purpose is getting nowhere. Although the lead dock ordered by the Northern Fleet is almost complete, it has been financed by Russia at only a rate of 67 percent of requirement (the job will cost about US dollars 8 million more), and the shipyard management will not turn the dock over to the fleet until the money is received (Borisov, 1995, p. 3). The fate of a similar structure for the Pacific Fleet is no less lamentable. This dock is only 30 percent complete, and its construction has been completely halted due to the lack of financing.

Without more money, other shipyards cannot be enticed into the scrapping process. The close navy–shipyard relationship has been fractured because the shipyards are now free to contract profitable commercial work at the expense of naval orders. There are also environmental considerations (Handler, 1993a, p. 8).

A land-based storage site will not be built until at least the year 2000. In addition, a transport system to carry reactor vessels will have to be devised and constructed. This will occur only if there are enough funds.

The Northern Fleet

A total of about 88 nuclear submarines have been taken out of service from the Northern Fleet and are at present laid-up in the Kola/Severodvinsk area. The nuclear fuel, which is the item causing most concern, still remains in 52 of these submarines. Another 55 nuclear submarines are planned to be decommissioned by the year 2010 (Kvaerner Moss Technology, 1996, p. 6).

Inactive Northern Fleet submarines are laid up at Gremikha, Severodvinsk, Vidyayevo (Olenya Bay, Sayda Bay and the Nerpa yards), Polyarny, Sevmorput, Gadzhievo (Ara and Ura Bays) and Zapadnaya Litsa (Nilsen, Kudrik and Nikitin, 1996, p. 101).

2.1 Shipyard capacities for the decommissioning task in the Northern Fleet

Five shipyards in the Northern Fleet are involved in the decommissioning process. Two facilities are located in the northern part of Severodvinsk: the Production Association Severnoe Mashinostroitelnoe Predpriyatie (or Sevmash, as the name is abbreviated) which began building nuclear submarines in 1952 and the Production Association Sever (PO Sever or Zvezdochka) which was established in 1973 to repair and refit nuclear submarines. Covering an area of about 15 square kilometers, the two yards are to be the leading ones for the disposal work. The Nerpa, and the Pala Guba and Rosta shipyards on the Kola peninsula are the other three facilities involved in the scrapping program.

At three locations, the full dismantlement process is carried out, namely at the Severodvinsk shipyards, Sevmash and Zvezdochka, and at the Nerpa plant. The other two shipyards, Pala Guba and Rosta, apparently only carry out preparatory operations which involve stripping down and separating parts of the hull for floating storage (Bukharin and Handler, 1995, p. 256).

The Zvezdochka yard is working on dismantling Yankee-class as well as some first generation Echo-II-class submarines. These submarines were designed by the Rubin Central Design Bureau and it is thus this office which has been assigned the task of coordinating their dismantling. By mid-1994, the plant had managed to process at least six submarines. Four were scrapped down to a three-compartment configuration, while the other two were partially stripped down to a so-called eight-compartment configuration. In this process most of the submarine hull is kept together, and only some parts of the sail and superstructure are removed (Bukharin and Handler, 1995, p. 256).

These steel ‘barrels’ still contain nuclear reactors whose safety requires special storage procedures. Pipelines and cables through which steam, electricity, and compressed air travel from the shore are linked to the moored submarines. The ballast tanks must be pumped full of compressed air, otherwise the submarine would sink, and its life-support system must be kept in working order. The annual expenditure on keeping one submarine in port is 2 billion rubles (Filippov 1995, p. 80).

According to Mr. Goryledzyan from the Rubin Central Design Bureau, the dismantlement of a Yankee-class submarine takes some 630,000 man hours. This includes the complete cutting up of the hull and preparation of the reactor compartment for transport. The cost in 1995 terms was 22 billion rubles (Nilsen, Kudrik and Nikitin, 1996, p. 106).

The dismantlement of titanium-hulled submarines takes place at the Sevmash yard where most of them had originally been built at the end of the Seventies. As of mid-1994, three Alfa-class submarines had been scrapped. In the autumn of 1994, the shipyard started with the dismantlement process on the K-316 Alfa-class submarine. At present, work is still going on. The reactor core had been removed at Gremikha where it is now being stored. Two other submarines of the Alfa class are ready to be processed. A Papa-class submarine, also titanium-hulled, is currently moored in Severodvinsk waiting to be dismantled at SMP (Nilsen, Kudrik and Nikitin, 1996, p. 59, 107).

As for the Nerpa plant, in 1992 two submarines—a Charlie- and a Viktor-class submarine—were assigned to the plant for scrapping, but work there seems to be proceeding slowly. A new land-based dry-dock with special equipment for the dismantling of submarines is under construction at the shipyard, and will be equipped with machinery manufactured in the United States, including a Hughes Aircraft Systems International plasma torch for cutting tempered steel hull plates. The construction began in 1993, and was scheduled to be completed by 1996. However, due to economic problems, the work has been delayed by a few years. Building costs are estimated at 270 billion rubles (Litovkin, 1995, p. 32).

2.2 Problems of spent-fuel management in the Northern Fleet

The use of nuclear reactors creates radioactive waste which needs to be processed, transported and stored. Most of this waste stems from replacement of fuel assemblies from the reactors. A Russian nuclear-powered submarine is usually equipped with two reactors, and these reactors are normally refueled twice during the service life of the submarine. Assuming that a naval reactor typically contains approximately 280 fuel assemblies, the six core loads consumed by each submarine generate a total of almost 1,700 spent nuclear fuel assemblies. Spent nuclear fuel is highly radioactive, much more so than any other item on board. The Soviet/Russian system for nuclear fuel management assumes a closed fuel cycle in which spent nuclear fuel is transported to a reprocessing facility where uranium and plutonium are extracted and later reused. Under this system, it is only necessary to store the spent nuclear fuel for about three years after its removal from the submarine so as to allow the most intense radioactivity to decay.

However, the naval infrastructure for fuel management had already been in difficulties prior to the massive ‘write-off’ of submarines. It is now stressed to the limits. Defueling of the currently retired submarines will roughly double the amount of spent fuel and, despite the reduction of fueling requirements to support active-duty submarines, is not feasible in the near term (Bukharin and Handler, 1995, p 257).

Existing storage facilities are filled more or less to capacity. Although there are no exact figures available on the overall storage capacity of the Navy, the Yablokov Report stated in 1993 that the Northern and Pacific Fleet have jointly accumulated approximately 30,000 spent-fuel assemblies, corresponding to the contents of about 140 nuclear submarine reactor cores. There is apparently only spare room left for another three cores (Administration of the President of the Russian Federation, 1993, p. 28).

The Northern Fleet operates one main land-based storage facility at Andreeva Bay in the Zapadnaya Litsa fjord. This facility is technically obsolete and filled to capacity. Reportedly, it contains about 70 reactor cores, the equivalent of almost 20,000 spent-fuel assemblies. The fuel assemblies are stored in stainless-steel containers in two large concrete tanks (Kvaerner Moss Technology, 1996, p. 22). A report recently released by the Norwegian environmental protection organization Bellona confirms the rather unsatisfactory conditions at this facility (Nilsen, Kudrik and Nikitin, 1995, p. 1–5)

Russian plans advising the immediate unloading of the Andreeva Bay storage facility and the construction of a new one already exist. According to these, the new facility is to be built in the permafrost regions of the Novaya Zemlya archipelago (Zheludkov, 1995, p. 67). Running out of space in the land-based storage sites, the Navy has had to switch over to service ships as interim storage places for their spent fuel.

At Severodvinsk, for instance, spent fuel is currently stored in three 25-year-old corroding 362M lighters moored at Sevmash. Between them, they have 240 containers which hold a total of 1,680 fuel assemblies. These are full, and a 2020 service ship has been brought into use with a capacity for 1,400 assemblies. However, transfer operations ceased in 1993 after a special loading facility built in 1979 to handle the spent fuel was closed following a fire (Pereira 1995, p. 44).

Submarine spent fuel is eventually sent to Mayak in the Urals for processing and storage, but as with the Pacific Fleet the infrastructure needed for a timely removal is far from adequate. As described above, there is only one four-car train available which can carry 12 of the new transport containers. A round trip from the Northern Fleet to Mayak takes up to 45 days, so theoretically, the maximum transport capacity is about eight submarines per year. Taking only the decommissioning program of the Northern Fleet up to year 2010 into account, this would probably be about the required transportation capacity. However, apart from the need to transport the spent fuel from the Pacific Fleet, there is also a strong requirement to empty the Andreeva Bay storage facilities as well as other interim facilities. Additionally, the operative units of the Navy and the nuclear icebreaker fleet based in Murmansk are in need of transport capacity, and may be given priority by the Russian Authorities.

There are numerous other factors obstructing the removal of spent fuel. For instance, the rail link to Severodvinsk has deteriorated to such an extent that between 1973 and 1992 spent fuel had to be shipped by a 2020 service ship to Murmansk for loading onto the special train. This was stopped in 1992 when, on safety grounds, the Murmansk authorities withdrew permission to continue (Nilsen and Bohmer, 1994, p. 46).

Meanwhile the Northern Fleet and the Murmansk Shipping Company have carried out some upgrades which permitted the carrying out of two trial shipments of spent fuel between 1994 and 1995 from Severodvinsk (May 1994) and Murmansk (1995) (Bukharin and Handler, 1995, p. 258).

Another reason for the drop in the rate at which spent nuclear fuel is removed and reprocessed is that the Navy lacks funds to pay for the services of the Mayak Chemical Combine. Transportation and reprocessing of one train-load presently cost about seven billion rubles. The Mayak Chemical plant also changed its billing policy and now only organizes a special train after having received payment in advance from the customer, regardless of who the customer is (Kvaerner Moss, 1996, p. 20).

As the financial situation is not expected to improve in the near future the amount of spent nuclear fuel at the naval bases will continue to pile up. Specialists and the commanders of the fleet are all greatly concerned about this situation, for in theory it will be impossible to transport all this fuel to Mayak over the course of the next 30 to 40 years. Parts of the naval spent fuel cannot be reprocessed using today's techniques. This includes:

- All spent nuclear fuel from liquid metal reactors
- Defective fuel assemblies, that is, parts which are bent or whose shells have been broken due to improper storage
- Damaged fuel assemblies.

In total, experts estimate that about 10 percent of the fuel assemblies accumulating at Northern Fleet bases cannot be reprocessed (Nilsen, Kudrik and Nikitin, 1996, p. 116).

Additionally, as mentioned above, there are the 52 nuclear submarines which have been taken out of operation, but from which the spent fuel has not yet been removed. Fifty of these have two reactors each, so that the total number of reactors with fuel-elements is 102. Instead of adopting urgent and cardinal measures, the departments involved in the salvaging of the submarines have recently reached a joint decision to extend the term of the 'secure storage' of spent fuel in a reactor from 10 to 30 years (Filippov, 1995, p. 81). Many of the submarines have been laid up for several years now. Because of the lack of possibilities to control the status of the fuel elements, it is impossible to calculate how many of these are damaged. The amount of fuel which cannot be reprocessed in a standard way could therefore be much higher than 10 percent (Nilsen, Kudrik and Nikitin, 1996, p. 116).

2.3 Disposition of liquid and solid radioactive waste

In the course of the maintenance process of nuclear submarines, solid radioactive waste (SRW) is generated during fuel assembly replacement, repairs in the reactor section, and replacement of cooling water filters or further reactor equipment. In addition, filters from the destruction plant for liquid radioactive waste and from the incineration plant for solid radioactive waste have to be stored.

Once a nuclear submarine is decommissioned, the most heavily contaminated SRW generally stems from the reactor system—excluding the spent nuclear fuel. Liquid radioactive waste

(LRW) typically originates from the primary circuit of a nuclear reactor, from decontamination work, or from special laundry, that is, from the cleaning of radiological contaminated work clothes and tools. Depending on the origin, the activity and the chemical properties of LRW may therefore vary significantly.

Overall, the Northern Fleet generated about 3,000–4,000 cubic meters of solid radioactive waste a year from 1981–1993. The annual volume increased 2 to 2,5 times during this period and is expected to grow further due to the decommissioning program. As for liquid radioactive waste, from 1981–1993, the Northern Fleet generated about 8,000–12,000 cubic meters a year (Bukharin and Handler, 1995, p. 269).

Since—until the beginning of this decade—radioactive waste was routinely dumped into the sea, only modest-sized intermediate storage facilities were required. For example, the Sevmash and Zvezdochka shipyards at the Severodvinsk Center generate 520 cubic meters of solid radioactive waste per year. This waste, including contaminated equipment, is packed and collected in temporary storage grounds at the Center. There are two disposal sites, both very limited. The Norwegian delegation which recently visited the Zvezdochka shipyard was shown a large open-air collection of one-cubic meter containers—about 100 in all—outside the shipyard’s solid radioactive waste storage building. These containers held low-activity SRW, while the higher activity SRW was stored in other containers inside the storage building. A new SRW storage facility is now under construction adjacent to the old facility (Kvaerner Moss Technology, 1996, p. 23).

Reportedly, the total capacity of the facility is 1,200 cubic meters. As of December 1993, the store contained 972 cubic meters and is probably full by now. Most of the containers deposited in the depot had been punctured in order to facilitate the planned dumping and are thus susceptible to leakage (Nilsen and Bohmer, 1994, p. 55). As the systems for protection or safeguarding against drainage are insufficient, radioactive leakage might already have occurred.

The disposal site of the Sevmash shipyard, located about 12 kilometers southwest of the city near Mirovna Mountain, was already filled in the 1970s. Improved temporary storage sites and processing facilities for reducing the volume of waste by incineration, compression or melting are therefore urgently needed. At present, there is one incineration plant at the Zvezdochka shipyard with a capacity of 40 kilos of waste per hour. Mostly, contaminated clothes, rags and other inflammable materials are burnt. The waste gases from the plant are monitored and led through special filters. When the radioactivity of the waste gases exceeds certain fixed limits, the plant is shut down. However, as filter cleansing is very inefficient, this happens so frequently that the plant is running at an average of only one month a year (Nilsen and Bohmer, 1994, p. 56).

The current situation of liquid waste is very similar. It used to be dumped until 1991, and present storage facilities are essentially filled to capacity. Liquid waste is stored aboard cargo boats, lighters, floating tanks, tank lorries, and at land-based tank facilities. The Zvezdochka shipyard has four 500 cubic meter tanks on shore, only two of which are usable, and four 4 cubic meter lorry tanks. It also has a large lighter-type ship, the *Osetiya* which holds 1,033 cubic meters and a TN-25 tanker with a capacity of 870 cubic meters, both of which are full (Pereira, 1995, p. 43).

The Sevmash shipyard, which has five 19–24 cubic meter floating tanks, only two of which are useable, and a 3 cubic meter lorry tank, sends most of its liquid waste to Zvezdochka (Nilsen and Bohmer, 1994, p. 57).

Each facil1ity had a liquid waste processing plant built in the 1960s but they were never used as it was easier to release the waste, and now they are too old to be renovated. With the growing number of retired nuclear submarines, the amount of liquid waste is rapidly increasing. The decommissioning of one nuclear submarine initially leads to the generation of about 200 cubic meters of LRW. Usually about 20 cubic meters originate from the primary circuit of the reactors, about four cubic meters from various filters and about 170 cubic meters from the biological protection tanks. During the scrapping process, various cleaning procedures generate another 800 cubic meters of LRW (Kvaerner Moss Technology, 1996, p. 23).

Today, the emphasis for LRW is not so much on storage, but rather on processing. However, the only operational LRW facility in the region is at Atomflot, the base for the civilian nuclear icebreaker fleet. With a capacity of only about 1,200 cubic meters per year, it has already processed some 1,000 cubic meters LRW from the Northern Fleet over the last years. A trilateral Norwegian–American–Russian project to upgrade and expand this facility to about 5,000 cubic meters per year is currently underway. For the design and construction costs of about US dollars 1.7 million, the Russian Government has allocated approximately US dollars 620,000. The Norwegian share will be about US dollars 830,000. The project has on several occasions been subject to the favorable attention of the Gore–Chernomyrdin Commission and it has been adopted as an important project under the Russian–American environmental cooperation program. Construction was planned to start during 1996 (Norwegian Assistance Programme for Nuclear Safety, 1996, p. 2).

According to Russian authorities the construction of other new coastal complexes for processing liquid radioactive waste is planned, but not expected to start until 1997. The program’s cost for a total capacity of about 10,000 cubic meters a year is estimated at one billion rubles (Leskov, 1993, p. 55).

oreign aid

The international community is worried that Russian nuclear naval facilities will increasingly threaten the environmental integrity of neighboring regions. Given the tense financial situation of the Russian Government and the complexity of the problems it must manage, there is concern that Russia will not be able to deal with this particular crisis. Since decommissioning costs deplete the operating costs of the active-duty fleet, security problems could arise. Internationally, there could be consequences regarding the implementation of the START Treaties if Russia cannot keep up with the demanding disarmament process.

A first important step would be to conduct open and complete radiation surveys of the Russian nuclear submarine bases, shipyards and waste sites. However, not surprisingly, there are obstacles to international monitoring of the Russian efforts to address the decommissioning problem. In the hope that the international community would help find a solution to this problem, individual Russian Navy officers, who have waited months for their salaries, have publicly admitted that mistakes and inadequate practices have occurred. But the military as an institution is still secretive and appears to want to avoid close scrutiny, especially in the field of nuclear submarines. To complicate matters, the secret-mongering of the Russian Navy is not only restricted to international monitoring. President Yeltsin declared in 1994 that the State Committee for Nuclear and Radiation Safety (Gosatomnadzor) should control radiation safety for all nuclear facilities, including those of the military. The Navy’s resistance was very strong. It denied entrance to inspectors and lobbied so strongly against Yeltsin’s decree that the President was forced to cancel his plan (Meek, 1995, p. 2).

More recently, a Russian newspaper covered extensively the arrest of Alexander Nikitin, a former Soviet Navy officer, accused of espionage while gathering data for a report on environmental conditions in the Russian North (Pushkarev, 1996, p. 32). This report, compiled by the Norwegian environmental foundation Bellona, describes nuclear safety status for the nuclear submarines of the Northern Fleet, paying particular attention to those 88 submarines which are no longer in service. The report also gives detailed coverage to the storage of spent nuclear fuel and other radioactive waste at the various different bases and yards. The Russian security service, which had arrested Mr. Nikitin early in February 1996, declared that, during the search of the Murmansk and St. Petersburg Bellona offices, some material was found containing state secrets regarding the Russian Navy. However, according to Frederic Hauge the managing director of the Bellona Foundation, the information contained in the report had been collected from open sources, both Russian and international over a period of several years (Hauge, 1996). Again, this incident shows that there is still massive interest inside the Russian Navy to prevent information about the deplorable status of their bases and shipyards from being widely circulated.

There has, however, been some modest progress in other areas. The close proximity of Russian nuclear submarine naval bases, shipyards and waste sites to neighboring countries has led to offers of assistance, especially by Norway, Japan and the United States.

In 1995, the Norwegian government presented a Plan of Action focusing largely on radiation protection and radioactive waste management in Russia. A total of US dollars 35 million has been appropriated to cover activities under this Plan of Action. As of March 1996 approximately US dollars 15 million have been spent or allocated. Among the main activities listed in the Plan of Action, are three projects which are directly devoted to supporting the nuclear submarine decommissioning program (Norwegian Assistance Programme for Nuclear Safety, 1996, pp. 1–3). These are:

- The project to expand the capacity of the liquid radioactive waste treatment facility at the Murmansk Atomflot icebreaker base. Project costs are estimated to be US dollars 1.7 million. The Norwegian share will be about US dollars 830,000.

- A feasibility study of the program for disposal of Russian nuclear submarines under the technical organization of Kvaerner Moss Technology and the Russian company RSC

Energia. The feasibility study has been completed, and Kvaerner Moss Technology and Energia presented their reports in January 1996. Their recommendation was to proceed with four parallel projects: Design, construction, and commissioning of a container vessel for spent nuclear fuel; construction and commissioning of special railway wagons for transporting nuclear fuel; design, construction, and commissioning of a temporary storage facility for liquid radioactive waste at the Zvezdochka yard in Severodvinsk; and establishment of a mobile facility for concentrating liquid radioactive waste. The total cost was estimated at US dollars 23 million with an expected construction period of two to three years. Norway and Russia also agreed to encourage and facilitate possible financial and technical participation from third parties.

- One of Norway's greatest concerns has been the dumping of nuclear waste in the Arctic seas. As a result, the Norwegian government has approved a plan to address this problem and Norway has participated in several marine expeditions to assess radioactive contamination in the Kara and Barents seas. Also, the carrying out of a joint survey of the risk of radioactive contamination from the Majak facility in the Urals has been approved.

Japan's assistance includes efforts to avoid further dumping in the Sea of Japan. As recently as 1993, Russia dumped a large volume of liquid radioactive waste into the Sea of Japan from its fleet of nuclear-powered submarines based near Vladivostok. In response to the dumping of this waste, the Japanese Government agreed to provide a liquid radioactive waste treatment facility to the Zvezda plant at Bolshoi Kamen (see section IV.1.)

Environmental concerns resulting from Russia's nuclear fleets have also received the increased attention of the United States in recent years. As of August 1995, the United States had committed about US dollars 55 million to support various programs which primarily focus on the environmental and health effects of the long-term operation of the former Soviet Union's nuclear weapons production complex. Of that amount, about US dollars 9 million have been spent on studying the Russian nuclear contamination of the Arctic region (GAO, 1995, p. 15). In coordination with Norway, the US Environmental Protection Agency (EPA) and the State Department have assessed the feasibility of the conceptual design to expand the waste processing facility operated by the Murmansk Shipping Company. This expansion includes handling the waste associated with decommissioning nuclear submarines. If the facility is constructed, the United States and Norway plan to share the cost equally (GAO, 1995, p. 35). Under the Cooperative Threat Reduction program, the United States also delivered equipment to assist with the dismantlement of SSBN missile launchers. The shipments started in late 1994. The project provides US dollars 25 million worth of equipment and services. This includes shears, cable cutters, and other shipbreaking equipment. Thus, the equipment may also help to increase the overall rate of submarine scrapping (Bukharin and Handler, 1995, p. 262).

Attempts to get the problem of the Russian Navy's decommissioning project sorted out have also been made from a different direction. In June 1995, NATO sponsored a workshop in Moscow on improving the technology used to defuel, dismantle, and dispose of retired submarines. It was the first time that scientists and practical workers from Russia, the United States, Germany, Denmark, Norway, Sweden, France, Canada, and Estonia had shared their technical experience in solving this problem and had reached agreement on mutual aid. For example, a US Government representative promised that his country would supply American technological equipment to Russian ship-building plants which were becoming available as a result of the closure of a number of shipyards and would allocate US dollars 130 million for carrying out salvaging work (Litovkin, 1995, p. 32).

Since the US Navy is also facing the problem of safely decommissioning nuclear submarines on a large scale and storing their waste, a natural area of cooperation exists. However, the US Navy has mostly been opposed to such cooperation, curtailing efforts to broaden assistance programs for decommissioning submarines and to bring Russian specialists to the Puget Sound Naval Shipyard, the US Navy's primary submarine dismantlement site in Bremerton, Washington (Huchthausen, 1993, p. 80). US Navy critics point to the continued construction of new classes of Russian nuclear submarines and suggest that the money involved here should be spent on disposing of the derelict fleet. Others are concerned that the United States might be held liable for Russian environmental problems (Bukharin and Handler, 1995, p. 262).

Finally, the Russian Navy has been able to get some help from qualified US nuclear energy service companies. A number of these firms employ ex-Navy engineers experienced in naval reactor dismantling. In 1993, the Jersey-based company, Newcon Inc., entered into a partnership with A/O Compass Corp., a company formed by officials of the Russian Navy. The partnership has submitted a proposal to the Clinton administration requesting US dollars 100 million to develop equipment for spent-fuel removal and for dismantling procedures, and another US dollars 150 million to begin building US-style prefabricated housing for retiring Russian naval officers. Proceeds from selling the scrap of the submarines—which contain a considerable amount of valuable metals including copper, titanium and special high-strength steels—should eventually cover the cost of the decommissioning equipment (Fialka, 1993, p. A4F). Other companies have also begun to explore this possibility, lured by the hope for a cut of the Cooperative Threat Reduction program which the US Congress authorized to pay for dismantling former Soviet nuclear weapons and their launch platforms (Handler 1993, p.9).

However, in view of the enormous problems faced by the Russian Navy, these measures do not add up to much. National and international institutions must be tapped to a much higher degree in order to cope with this immense task. International financial institutions like the World Bank, the European Bank for Reconstruction and Development, the European Investment Bank. and so on, have already turned their attention to the state of nuclear power in the former Soviet Union in general, but none of the projects has so far addressed the serious situation of the naval reactors. Likewise the Group of seven largest global economies have also addressed the Russian nuclear safety issue several times during the last years but—again—naval reactors were not on the agenda.

S S D M - D S M S

The US Navy has been operating nuclear-powered submarines since 1955, when the *USS Nautilus* first went to sea. Since then, many of the nuclear submarines have reached the end of their useful lives, which is defined as the time when their military capability does not justify the cost of continued operation. Arms control treaties have also forced the US Navy to take a significant number of nuclear submarines out of service. By the year 2000, the US Navy is to decommission about 100 nuclear submarines.

Initial planning for the inactivation and disposal of nuclear-powered ships and submarines began in the late 1970s. The first ships decommissioned were defueled and prepared for waterborne storage. Ballistic missile submarines had the missile compartment cut out and the hull joined up again. Some of the submarines had their reactor compartment cut out and the hull sections rejoined (United States Department of the Navy, 1993. p. 3). In 1982, the US Navy performed an Environmental Impact Study considering either land disposal of the reactor compartment or sinking in deep water of the entire defueled ship. Both methods were determined to be safe. In 1984 the decision was made to cut out the reactor compartment and bury it at the Hanford site in the state of Washington (United States Navy, 1984, p. 1-1).

With adequate funding, production facilities, and infrastructure, the United States was able to initiate an integrated program for the disposal of nuclear-powered vessels in the early 1990s. Under the Nuclear-Powered Ship and Submarine Recycling Program, all decommissioned nuclear-powered submarines (SSNs/SSBNs) and cruisers (CGNs) are dismantled at the Puget Sound Naval Shipyard in Bremerton, Washington. This shipyard is the only one which participates in the recycling program (Loring-Morison, 1995, p. 47). To dispose of the more than 100 nuclear submarines, US dollars 2.7 billion have been provided for the program (Handler, 1993a, p. 9). The estimated cost of inactivating and scrapping nuclear-powered submarines is as follows:

S M D S S D S
- D S M S

Type	Inactivation cost	Scrapping cost
SSBN	US $ 29.6 million	US $ 9.2 million
SSN	US $ 29.6 million	US $ 6.9 million

Source: MacKinnon III and Burrit, 1995, p. 1

For the inactivation process—the first step in the program—the submarine is placed in a dry-dock. Inactivation involves defueling the submarine, removing classified and sensitive military equipment, and generally preparing the submarine for extended waterborne storage or scrapping. Upon completion, the bare hull is formally decommissioned and struck off the Naval Vessel Register. The current Navy drawdown and the workload at Puget Sound have necessitated the inactivation of nuclear submarines at other naval shipyards after which they are towed to Puget Sound for dismantling (Loring-Morison, 1995, p. 47).

After the removal of the reactor compartments (see section 3.1.), the hull is cut into large sections for removal from the dry-dock. Hulls cuts are made using oxygen-gas or plasma torches. The majority of hull cuts are made with an oxygen-gas mixture called MAPP (methyl acetylene propadiene). The advantage is that it can achieve high cutting rates and has proven to be the most cost-effective method of cutting (MacKinnon III and Burritt, 1995, p. 14). It is a well-known but rather polluting method. At the NATO-sponsored workshop about submarine dismantling in Moscow last year, the participants discussed a number of alternative methods (hydro-jets, laser cutting, etc.) and pointed out that there is a need for further research to determine the best method for cutting up submarines (Popkov, 1995, p. 4).

Removed scrap is segregated into recyclable and waste material with further segregation of the waste material into hazardous and non-hazardous waste. The recyclable metallic material (various types of steel and non-ferrous components: aluminum, bronze, copper, zinc, lead) is sold and shipped to various consumers for melting down or reuse in other forms.

The toxic wastes have to be treated very carefully during the scrapping process and removal requires protective measures for the workers. For example, full protective clothing which can be discarded, and air-fed respirator hoods are needed when working with, or in the vicinity of, certain hazardous materials such as polychlorinated biphenyls (PCBs) or asbestos.

Most of the toxic wastes are various types of insulating material. But there are also oil and oil-related products. One significant type of toxic waste is the sulfuric acid from the vessel’s lead batteries which could amount to more than 20 tons (Kvaerner Moss Technology, 1996, p. 42). Some of these materials, and where they might be found on board ship, are listed in the following table:

D S SS M S

Hazard	**Source on submarine**
Polychlorinated biphenyls (PCBs)	Electrical cables; ventilation gaskets; transformers; foam and other insulation; hydraulic oils; greases; machinery mounts and other rubber products
Asbestos	Pipe and ventilation lagging; valve packing; electrical cable coverings; heat shields; sound dampening; deck tiles
Lead	Ballast; paint; batteries; cable; plumbing systems
Mercury	Instruments; fluorescent light tubes
Cadmium	Plated fasteners
Ethylene glycol	Antifreeze; air conditioning and refrigeration systems
Halogenated fluorocarbons	Refrigeration and air conditioning systems; aerosol cans

Source: MacKinnon and Burritt, 1995, p. 17

Apparently, toxic waste materials are disposed of in accordance with existing environmental regulations. At least, no literature has been found to prove the contrary. After the hazardous waste has been segregated, bagged, identified and inventoried, it is sent to designated waste-receiving sites.

By mid-1996 the US Navy had decommissioned 71 nuclear-powered submarines, of which 32 had been completely dismantled and 39 inactivated; the latter—at various stages in the dismantling process—are awaiting final disposal.

Compared to the Russian Navy, the technologies involved in the decommissioning and disposal of nuclear submarines in the US Navy are well known and—apparently—give no rise to significant risks. However, when handling significant amounts of strongly radioactive and fissile materials, the risk of an accident always exists.

One possibility is a criticality accident in connection with the defueling of a reactor or in connection with the interim storage of spent fuel. Another possibility is a loss-of-coolant accident which could occur if the reactor coolant of a recently decommissioned submarine suddenly fails.

S D S S - D S M S D S

The French Navy had commissioned twelve nuclear propulsion submarines. Until now the Navy has decommissioned two SSBNs: *Le Redoutable* in 1991 and *Le Terrible* in 1996. While for the first one there are plans to transform it into a museum, the second is to be scrapped following the removal of the reactor. Future decommissions include *Le Foudroyant* in 1998, *L'Indomptable* in 2001, *L'Inflexible* in 2003 and *Le Tonnant* in 2007 (*Jane's Defence Weekly,* 29. May 1996, p. 10).

There are two companies performing the dismantling of the nuclear submarines: Technicatome, the 'on-board' reactor designer, and DNC Cherbourg, which is responsible for planning the actual dismantling of the reactor and the rest of the ship. The long-term storage of all radioactive waste is handled by the National Radioactive Waste Agency (ANDRA) which is also responsible for civilian nuclear waste.

The process of dismantlement is in many steps similar to those described above. After unloading the fuel, the reactor compartment, forming a section of the ship, is isolated and separated from the rest. The compartment is emptied of all removable equipment and sealed off. After this the section is dry-stored at DNC Cherbourg for 15–20 years. A location protected from inclement water and large enough to store other submarine sections, as dismantling progresses, has been provided at the Cherbourg arsenal (Masurel, 1995, p. 3).

The reactor is dismantled separately and resulting waste is stored on the surface by ANDRA. After 15–20 years of interim storage, the circuits and components of the reactor can be dismantled and cut into transportable packages. This is necessary because France does not have a long-term storage site capable of accepting a 'package' with the volume and mass of a reactor compartment.

The fuel disposal strategy plans to have two phases of interim storage: first for 5 to 20 years in a pool until the radioactivity level has decreased sufficiently to allow dry storage. And then, second, dry storage for another 10 to 50 years before reprocessing or terminal storage by ANDRA. For this last step no decisions have been made so far. Problems with this strategy based mainly on medium-term storage will increase as more nuclear submarines are taken out of service.

D K D M S S D S S - D S M S

With the decommissioning of the *HMS Repulse* on 28 August 1996, the British Navy now has 11 nuclear submarines moored and awaiting final disposition. From theses submarines, only the spent nuclear fuel has been removed. All the remaining reactor components are still inside the hulls and have been sealed in after removal of the fuel elements. The entire hulls are currently being kept afloat in the naval dockyards at Devonport and Rosyth (*Financial Times*, 13 June 1996, p. 7).

As mentioned above, at least until the end of the 1980s the British Navy had recommended the sealing of the submarine hulls and their sinking in the mid-Atlantic as by far the safest and least disruptive means of long-term disposal (House of Commons, 1989). However, since this option does not seem available any longer due to the latest revisions of the London Dumping Convention, UK submarines will probably be disposed of by deep land burial. The reason for choosing this quite expensive option is that, in the United Kingdom, a deep repository is already being planned at Sellafield in northern England while a suitable, shallow repository will not be available. In all probability, the permanent nuclear waste store at Sellafield will be available in 2012. The number of decommissioned nuclear submarines is expected to have doubled by that time.

S S D MM D S

Decommissioning of nuclear submarines will cause costs to grow continuously and will cause environmental problems for the years to come. The magnitude of the problem is not really known to the broader public. The decommissioning, dismantling and long-term storage of radioactive contaminated waste from almost 300 nuclear submarines with as many as 400 nuclear reactors will cost billions of dollars and for the long-term storage, no technically feasible and ecologically safe method is known so far. The time horizon of radioactive decay is far beyond the human ability to plan. Today no one can forecast the ecological risks of land burial on ground water—and it is only a weak hope that the consequences of past Russian dumping will not greatly affect the ecological stability of whole areas of the Northern Sea.

There are problems to be solved in the short- and the long-term. Obviously the short-term security problems in Russia deserve special and rapid attention. They cannot be handled without increased funding and better technology. Additionally, the Russian government and the Russian military have to define clearer responsibilities, increase ecological control, and provide the public with more information. Among those steps immediately required are:

- Increased storage capacity for spent nuclear fuel in the Northern and Pacific Fleets
- Safer interim harbor places for decommissioned submarines awaiting defueling and scrapping
- Upgrading and enlarging the LRW processing capacities and SRW storage areas in the fleets
- Better training for naval personnel
- Continuous ecological monitoring and an open information policy
- Increase of scrapping capacities at shipyards
- Finding long-term land-based storage sites for reactor components.

The obvious inability of Russia to resolve its disarmament problems at acceptable ecological costs has consequences for Russia’s geographical neighbors. Japan, Norway, the United States and other countries have to deal with the nuclear waste dumped in the oceans and the constant danger of an accidental nuclear catastrophe involving a submarine. These countries should therefore be interested in serious cooperation to address the issues of submarine scrapping and interim and long-term storage of spent nuclear fuel. Here more technical help and more money is needed to solve the most important problems.

In the United States, France and Great Britain, the decommissioning process seems to be progressing less chaotically. But in these countries as well the problems of long-term storage of military and civilian nuclear waste are completely unsolved. This is all the more pressing, as the build-up of nuclear-powered submarines enters the next round. New generations of submarines have been ordered or planned in several nations; in fact, nuclear submarines are becoming increasingly important in future nuclear deterrence strategies. However, there now exists a unique chance to stop a new arms build-up in this field of military technology. A plan is needed for downsizing the nuclear fleets in Russia and the United States much more drastically—a plan which at the same time offers a mid-term perspective for a minimum deterrence policy. The ecological costs of the nuclear arms build-up and the long-term subsequent cost of nuclear submarines should be a sufficient incentive for further radical disarmament.

MS

ANDRA	National Radioactive Waste Agency (France)
CGN	Nuclear-powered guided-missile cruiser
EPA	Environmental Protection Agency (United States)
LDR	London Dumping Convention (1972)
LRW	Liquid radioactive waste
MAPP	Methyl acetylene propadiene
PCB	Polychlorinated biphenyls
PWR	Pressurized-water reactor
SRW	Solid radioactive waste
SSBN	Ballistic missile submarine
SSGN	Cruise missile submarine
SSN	Attack submarine

S

Administration of the President of the Russian Federation. 1993. *Facts and Problems Related to the Dumping of Radioactive Waste in the Seas Surrounding the Territory of the Russian Federation.* Moscow. Translation by Greenpeace, Washington DC.

Barabash, Natalya. 1994. “Will ‘Trestles’ Save the Nuclear Fleet?” *Komsomolskaya Pravda.* 15 December 1994, p. 3, translated in FBIS-SOV-94-242, 16 December, pp. 31–33.

Bedi, Rahul. 1994. “Nuclear Submarine Is Being Built in India.” *Jane’s Defence Weekly.* Vol. 22, No. 24, 17 December, p. 3.

Borisov, Yuriy. 1995. “Russia’s Nuclear Viability in Jeopardy: Future of Russian Nuclear Submarine Fleet To Be Cut Up With Acetylene Torches at Kherson Shipyard.” *FBIS Daily Report.* FBIS-UMA-95-206-S, 29 September, p. 3.

Bukharin, Oleg and Joshua Handler. 1995. “Russian Nuclear-Powered Submarine Decommissioning.” *Science & Global Security.* Vol. 5, pp. 245–271.

Bukharin, Oleg and William Potter. 1995. “Potatoes Were Guarded Better.” *The Bulletin of the Atomic Scientists.* May/June 1995, pp. 46–50.

Clarke, Doug. 1996. “Contract Signed for Nuclear Waste Disposal Plant.” *OMRI Daily Digest.* No. 10, 15 January.

Clarke, Douglas L. 1995. “Naval Nuclear Waste Poses Immense Risk.” *Transition*. 17 November, pp. 34–38.

Davis, Jackson W. and Jon M. Van Dyke. 1990. “Dumping of Decommissioned Nuclear Submarines at Sea.” *Marine Policy.* November, pp. 467–476.

Dmitriev, Constantine. 1995. “Russia, Japan Agree to Build Nuclear Waste Plant.” *OMRI Daily Digest.* No. 219, 9 November 1995.

Eriksen, Viking Olver. 1992. “Sunken Nuclear Submarines.” Oslo.

Escalona, Carolina. 1993. “Russia’s Far Eastern and Northern Waters: Nuclear Waste Bins?” *CIS Environmental Watch.* No. 5, Fall, pp. 16–39.

Fialka, John. 1993. “US Is Studying Ways to Help Russia Dispose of Aging Nuclear Submarines.” *Wall Street Journal.* 2 April, p. A4F.

Filippov, Viktor. 1995. “Nuclear Submarines Call for Help.” *Izvestiya*. 24 May 1995, translated in JPRS-TEN-95-OO8, 15 June, pp. 80–81.

GAO: See United States General Accounting Office.

Grachev, Yuriy. 1995. “The Pacific Fleet Has Begun to Dispose of Radioactive Waste.” *Itar-Tass.* 20 March.

Greenpeace, 1993. *Die atomare Entsorgungsmisere der Russischen Marine*. [The catastrophic atomic disposal by the Russian Navy]. Background information. Hamburg, 12 October.

Gromov, F. 1994. “The Navy Last Year.” *Morskoy Sbornik.* No. 12, December, translated in JPRS-UMA-95-007, 21 February 1995, p. 47.

Handler, Joshua. 1993a. “No Sleep in the Deep for Russian Subs.” *The Bulletin of the Atomic Scientists*. April, pp. 7–9.

________1993b. *Russian Navy Nuclear Submarine Safety, Construction, Defense Conversion, Decommissioning, and Nuclear Waste Problems.* Trip Report: Greenpeace Visit to Moscow and Russian Far East, July–November 1992. Washington D C, 15 February.

________ 1994a. *Radioactive Waste Situation in the Russian Pacific Fleet, Nuclear Waste Disposal Problems, Submarine Decommissioning, Submarine Safety, and Security of Naval Fuel.* Greenpeace Trip Report. Washington, October.

________ 1994b. “Russia’s Pacific Fleet—Submarine Bases and Facilities.” *Jane’s Intelligence Review.* Vol. 6, No. 4, April, pp. 166–171.

________ 1995. “Russia’s Pacific Fleet—Problems with Nuclear Waste.” *Jane’s Intelligence Review.* March, pp. 17–22.

Hauge, Frederic. 1996. “Can This Information Be Kept Secret?” In Thomas Nilsen, Igor Kudrik and Alexander Nikitin, 1996. *The Russian Northern Fleet. Sources Of Radioactive Contamination.* Bellona Report, No 1, 19 April, Preface.

Hiatt, Fred. 1991. “Soviet A-Sub Blast Killed 10.” *Washington Post.* 25 October, pp. A19, A20.

House of Commons. 1989. *Decommissioning of Nuclear Submarines.* Her Majesty’s Stationary Office, London.

Huchthausen, Peter. 1993. “Russian Navy in Distress.” Proceedings, May, pp. 77–80.

Jane. 1995. *Jane’s World of Defence ’95.* Coldstone, United Kingdom.

Jordan, John. 1994a. “The People’s Liberation Army Navy (PLAN).” *Jane’s Intelligence Review.* June, pp. 275–282.

________. 1994b. “The Russian Navy in Transition.” *Jane’s Intelligence Review*. April, pp. 154–159.

Kong, Yan. 1993. “China’s Nuclear Bureaucracy.” *Jane’s Intelligence Review.* July, pp. 320–326.

Kvaerner Moss Technology A.S. 1996. *Disposal of Russian Nuclear Submarines.* A Report Presented to the Ministry of Foreign Affairs. Oslo, January.

Leskov, Sergei. 1993. “Lies and Incompetence.” *The Bulletin of the Atomic Scientists.* June, pp. 13, 55.

Litovkin, Dimitry. 1995. “Decommissioned Nuclear Submarines Are Still Awaiting a State Salvage Program. But They Are Already Threatening To Cause a Disaster.” *Krasnaya Zvezda*. 13 July 1995, translated in FBIS-SOV-95-135, 15 July, pp. 31–33.

Loring-Morison, Samuel. 1995. “US Naval Battle Force Changes: 1 January 1994–31 May 1995.” Naval Proceedings. US Naval Institute, Vol. 121/6/1108, p. 47.

MacKinnon III, Malcolm and James G. Burritt. 1995. “Overview of Nuclear Submarine Inactivation and Scrapping/Recycling in the United States.” Paper presented at the NATO Advanced Research Workshop on Decommissioning of Nuclear Submarines, Moscow, 19–22 June.

Marinin, Valery. 1995. “Nuclear Submarine Construction in Russia.” *Military Parade.* March/April, pp. 114–119.

Maryukha, Vladimir. 1994. “Obsolete Nuclear Vessels Leave Us No Choice—Either We Bury Them or They Will Bury Us.” *Krasnaya Zvezda.* 14 September, translated in JPRS-TEN-94-023, 28 September, pp. 32–33.

Masurel, A. 1995. “French Strategy For Disposal Of Nuclear Powered Ships and Spent Fuel.” Paper presented at the NATO Advanced Research Workshop on Decommissioning of Nuclear Submarines, Moscow, June 19–22.

Meek, James. 1995. “Russia Hides Nuclear Waste.” *Guardian Weekly.* 10 December, p. 2.

Nerisky, Martin. 1993. “Russia May be Buckling under Atom Dump Protests.” *Reuters.* 20 October.

Nevzorov, B. 1995. “Alternative Concept of Nuclear Powered Submarine Decommissioning.” Paper presented at the NATO Advanced Research Workshop on Decommissioning of Nuclear Submarines, Moscow, June 19–22.

Nilsen, Thomas, and Nils Bohmer. 1994. *Sources to Radioactive Contamination in Murmansk and Arkhangel’sk County*. Bellona Report. Vol. 1, Oslo.

Nilsen, Thomas, Igor Kudrik and Alexander Nikitin. 1995. “Zapadnaya Litsa.” Working Paper No. 5. Bellona Foundation, Oslo.

Nilsen, Thomas, Igor Kudrik and Alexander Nikitin. 1996. *The Russian Northern Fleet. Sources of Radioactive Contamination.* Bellona Report No. 1. Moscow, 19 April.

Norris, Robert S., Andrew S. Burrows and Richard W. Fieldhouse. 1994. *British, French, and Chinese Nuclear Weapons. Nuclear Weapons Databook. Volume V.* San Fransisco/Oxford: Westview Press, Boulder.

Norwegian Assistance Programme for Nuclear Safety. 1996. *Russia. Programme Area 2: Management and Storage of Spent Nuclear Fuel and Radioactive Waste.* Ministry of Foreign Affairs, Oslo, March.

Olgaard, Povl L. 1995. *Worldwide Overview of Nuclear Submarine Decommissioning Plans and Issues.* Technical University of Denmark, Lyngby.

Pereira, Judith. 1995. “Submarine Purgatory.” *Nuclear Engineering International.* December, pp. 43–44.

Pitt, David E. 1993. “Russia is Pressed on Nuclear Waste Accord.” *New York Times.* 5 December, p. 13.

Polmar, Norman. 1983. *The American Submarine.* Annapolis, Maryland: Nautical and Aviation Publishing Company.

Polutov, A. 1994 “Paper Reports on Submarine Dismantling Plant in Vladivostok.” *Tokyo Shimbun.* 11 March, translated in JPRS-TEN-94-008, 25 March, pp. 24–25.

Popkov, K. 1995. “Comparative Ecological Analysis of Existing and Perspective Technologies for Nuclear Submarine Dismantlement.” Paper presented at the NATO Advanced Research Workshop, Moscow, 19–22 June.

Pushkarev, Sergei. 1996. “Nuclear Contamination: A Secret Worth Keeping?” *Monitor*. Vol. 2, No. 1–2, Winter/Spring 1996, The Center for International Trade and Security, University of Georgia, pp. 32–33.

Rothstein, Linda. 1995. “Nothing Clean about ‘Cleanup’ ”. *The Bulletin of the Atomic Scientists*. May/June, pp. 34–41.

Swinbanks, David. 1993. “Japan To Study Damage From Russian Dumping.” *Nature*. Vol. 365, 28 October, p. 777

United States General Accounting Office. 1995. *Nuclear Safety. Concerns With Nuclear Facilities And Other Sources Of Radiation in the Former Soviet Union.* GAO/RCED-96-4, Washington DC, November

United States Department of the Navy. 1993. *US Naval Nuclear Powered Submarine Inactivation, Disposal, and Recycling.* September.

United States Navy. 1984. *Final Environmental Impact Statement on the Disposal of Decommissioned, Defueled Naval Submarine Reactor Plants.* Vol. 1, Washington DC: Department of the Navy.

Usui, Naoaki. 1993. “Russian Radwaste Dumping in Sea of Japan Mars Bilateral Entente.” *Nucleonics Week.* 21 October, pp. 4–5.

Zakharov, Viktor. 1995. “The Status of and Solutions to the Problem of Handling Radioactive Waste at the Pacific Fleet.” Presentation made at the Conference Japan–Russia–United States Group on dumped Nuclear Waste in the Sea of Japan, Sea of Okhotsk, and the North Pacific Ocean, organized by the Mississippi State University, Vanderbilt University, and the US Geological Service, Biloxi, Mississippi, 12–13 January.

Zhelodkov, Arkadiy. 1995. “Northern Nuclear Waste Disposal Problem Eyed.” *Izvestiya*. 14 March, translated in JPRS-TEN-95-OO8, 15 June, pp. 65–67.

M D S S M S D D

u

During exercises in the North Atlantic, a leak developed in an inaccessible part of a Soviet Hotel-class submarine (K-19) primary cooling circuit. The leak caused a sudden drop in pressure, setting off the reactor emergency systems. All of the crew were exposed to substantial doses of radiation, and eight men died of acute radiation sickness. The two damaged reactors with their fuel on board were dumped in Abrosimova Bay in the Kara Sea in 1965.

pri

The nuclear-powered *USS* Thresher imploded and sank 100 miles east of Cape Cod, Massachusetts, in approximately 8,500 feet of water, killing all 129 aboard, including 17 civilian observers.

Ma

The Soviet nuclear submarine (K-27) suffered a major reactor accident. Nine people died of radiation injuries. Attempts to repair the reactor were futile. The entire submarine—including two liquid metal cooled reactors—was scuttled at a depth of 50 meters in Stepovogo Bay at Novaya Zemlya in 1981.

Ma

The *USS Scorpion* sank 400 miles southwest of the Azores in more than 10,000 feet of water, killing 99 crewmen. Aboard: two nuclear torpedoes and one reactor.

pri

A Soviet November-class submarine (K-8) experienced a nuclear propulsion casualty and sank while operating in heavy seas, approximately 300 nautical miles northwest of Spain. Two reactors and at least two nuclear torpedoes were on board. 52 people died.

to er

A Soviet Yankee-class submarine (K-219) with 16 SS-N-6 missiles and probably two nuclear torpedoes caught fire in one of the missile tubes, sinking 600 miles northeast of Bermuda. The submarine had been powered by two nuclear reactors. Four people died.

pri

A Soviet Mike-class submarine (Komsomolets Litvy, K-278), with at least two warheads and one reactor on board, sank 300 miles off the coast of Norway, 150 miles south/southwest of Bear Island. 42 people died.