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The Potential Risks from Russian Nuclear Ships

Povl L. Ølgaard
Risø National Laboratory, Denmark

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Abstract

A review is given of the information available on the Russian nuclear ships including submarines, cruisers and icebreaking ships with special emphasis on the vessels of the Northern Fleet and the Russian icebreakers. A significant part of these ships has today been taken out of active service, and they are in various stages of decommissioning. Information on the decommissioned vessels, their storage sites and the procedures planned for the further decommissioning works is discussed. The handling of spent nuclear fuel is also considered.

The various types of accidents, which might occur with these ships, operational as well as decommissioned, are considered, and examples of actual accidents with operational vessels are presented. The types of accidents considered include criticality accidents, loss-of-coolant accidents, fires/explosions and sinking. Some measures taken by the Russians to avoid such accidents are discussed. The special problems connected to the two decommissioned submarines of the Northern Fleet, which have damaged cores, are mentioned.

In appendices data on the Russian nuclear vessels are presented.

Key words

Nuclear submarines, nuclear icebreakers, naval reactors, Russia, decommissioning, spent fuel, nuclear accidents, damaged reactors

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NKS Secretariat
P.O. Box 30
DK – 4000 Roskilde
Denmark

Phone +45 4677 4045
Fax +45 4677 4046
www.nks.org
e-mail nks@catscience.dk

NKS-SBA-1 Status Report:

The Potential Threats from Russian Nuclear Ships

by

Povl L. Ølgaard
Risø National Laboratory
DK-4000 Roskilde, Denmark

November 2001

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1. INTRODUCTION

During the Soviet era Russia built a nuclear navy larger than that of any other country in the world. The main emphasis was for strategic reasons placed on nuclear submarines, but nuclear propulsion was also used for cruisers, for a missile test ship, and for ice breaking vessels. The Russian construction of nuclear vessels started in the second half of the fifties. Many of the nuclear vessels built have today been decommissioned due to international disarmament agreements, due to technical obsolescence or due to lack of funds to operate them.

The fact that Russia passes through a period with great economic difficulties, has contributed to the problems of the Russian Navy. The resulting lack of resources means that maintenance of the operational part of the Russian Navy is not up to the desirable standard.

Further, the decommissioned ships are not properly handled, but are in most cases kept in floating storage at naval bases for many years with fuel in the reactors and with little maintenance before they are dismantled. In addition the Russian Navy has a special problem because some of its nuclear submarines have damaged cores, which means that the fuel can not be taken out by use of the ordinary defuelling procedure.

To this may be added that the safety culture of the Russian nuclear Navy has not been impressive. A number of accidents has happened (see e.g. ref. 1), and new accidents may happen.

For these reasons it is relevant to look at the potential risks to which the Nordic countries are exposed from the Russian nuclear Navy, in particular from the Northern Fleet

2. THE RUSSIAN NUCLEAR NAVY

In table 2.1 data on the nuclear vessels built and operated by the Soviet/Russian Navy are listed. They are mainly obtained from ref. 2. The table gives the class of vessels (NATO designations have been used), the period during which the vessels were built, the number built, the displacement (for submarines the submerged displacement), the number of reactors per vessel and the thermal power level of the reactors. More complete data on Russian nuclear vessels is given in the appendices. It should be mentioned that data on the Russian nuclear Navy given in different sources do not always agree, but in general the disagreements are not significant.

The Russian submarines may be divided into four types according to their application: 1) Attack submarines, 2) Cruise missile submarines, 3) Ballistic missile submarines and 4) Research submarines. The primary role of the attack submarines is during war to attack naval units of the enemy, in particular other submarines. The primary role of the cruise missile submarines is to attack enemy convoys of supply ships and task forces at the high sea, but they may also be used for attacks on targets on land. It should be mentioned that the difference between attack and cruise missile submarines is gradually disappearing, since cruise missiles that can be launched through torpedo tubes have been developed. The primary role of the ballistic submarines is to launch intercontinental nuclear missile (SLBM) attacks against

Table 2.1. Russian Nuclear Naval Vessels

Attack Submarines

Class	Built	Number built	Submer. displace. (t)	No. of reactors	Reactor power (MWt)
November	1955-63	14	4000	2	70
Victor-1	1967-74	18	6100	2	72
Victor-2	1972-78	7	7200	2	72
Victor-3	1977-87	26	7000	2	72
Alfa	1977-83	7	4300	1	155
Sierra	1983-93	4	7000	1	190
Mike	1983-85	1	7800	1	190
Akula	1983-	14	7900	1	190
Total		91			

Cruise Missile Submarines

Class	Built	Number built	Submer. displace. (t)	No. of reactors	Reactor power (MWt)
Echo-1	1960-65	5	4900	2	70
Echo-2	1961-67	29	5800	2	70
Charlie-1	1967-72	11	5000	1	90
Charlie-2	1973-80	6	5500	2	48
Papa	1963-69	1	7000	2	177
Granay	1993-?	0	8600	1	190
Oscar-1	1978-85	2	17000	2	190
Oscar-2	1990-	8	18000	2	190
Total		62			

Ballistic Missile Submarines

Class	Built	Number built	Submer. displace. (t)	No. of reactors	Reactor power (MWt)
Hotel	1958-1962	8	5000	2	70
Yankee	1967-1972	34	9300	2	90
Delta-1	1972-1977	18	10000	2	90
Delta-2	1973-1975	4	10500	2	90
Delta-3	1975-1981	14	10600	2	90
Delta-4	1981-1992	7	12000	2	90
Typhoon	1977-1989	6	33800	2	190
Total		91			

Table 2.1. Russian Nuclear Naval Vessels (continued)

Research Submarines

Class	Built	Number built	Submer. displace. (t)	No. of reactors	Reactor power (MWt)
X-Ray	1982	1	1000	1	10
Uniform	1982-1989	2	2000	1	
Project 10831		1	2100	1	
Total		4			

Total number of nuclear submarines built: 248

Missile Cruisers

Class	Built	Number built	Displace. (t)	No. of reactors	Reactor power (MWt)
Kirov	1974-1996	4	28000	2	300

Missile Test Ship

Class	Built	Number built	Displace. (t)	No. of reactors	Reactor power (MWt)
SSV 33	1981-1989	1	36000	2	135

strategic targets of the enemy. The development of submarine missiles with steadily increasing range means that the ballistic missile submarines may operate closer to the home base where they are less vulnerable.

Figure 2.1 present curves for the total number of nuclear submarines built by the USSR/Russia versus time and also the number of operational submarines versus time. It is seen that the construction of new submarines has for all practical purposes been stopped and that almost 250 nuclear submarines were built. The number of operational nuclear submarines increased until 1987 when it went through a maximum of slightly more than 200. Since then the number has gradually decreased and today it is about 50. Figure 2.1 is primarily based on data obtained from ref. 3.

It should be mentioned that the degree of utilisation of the Russian submarines, i.e. the average number of cruising hours per year per submarine, has always been considerably less than that of the US Navy. This means that even though the Soviet Navy had more submarines than the US Navy, it had fewer submarines operating at sea (on station) at any given time.

The latest data (ref. 19, Aug. 2001) gives the following strength of the Russian nuclear Navy:

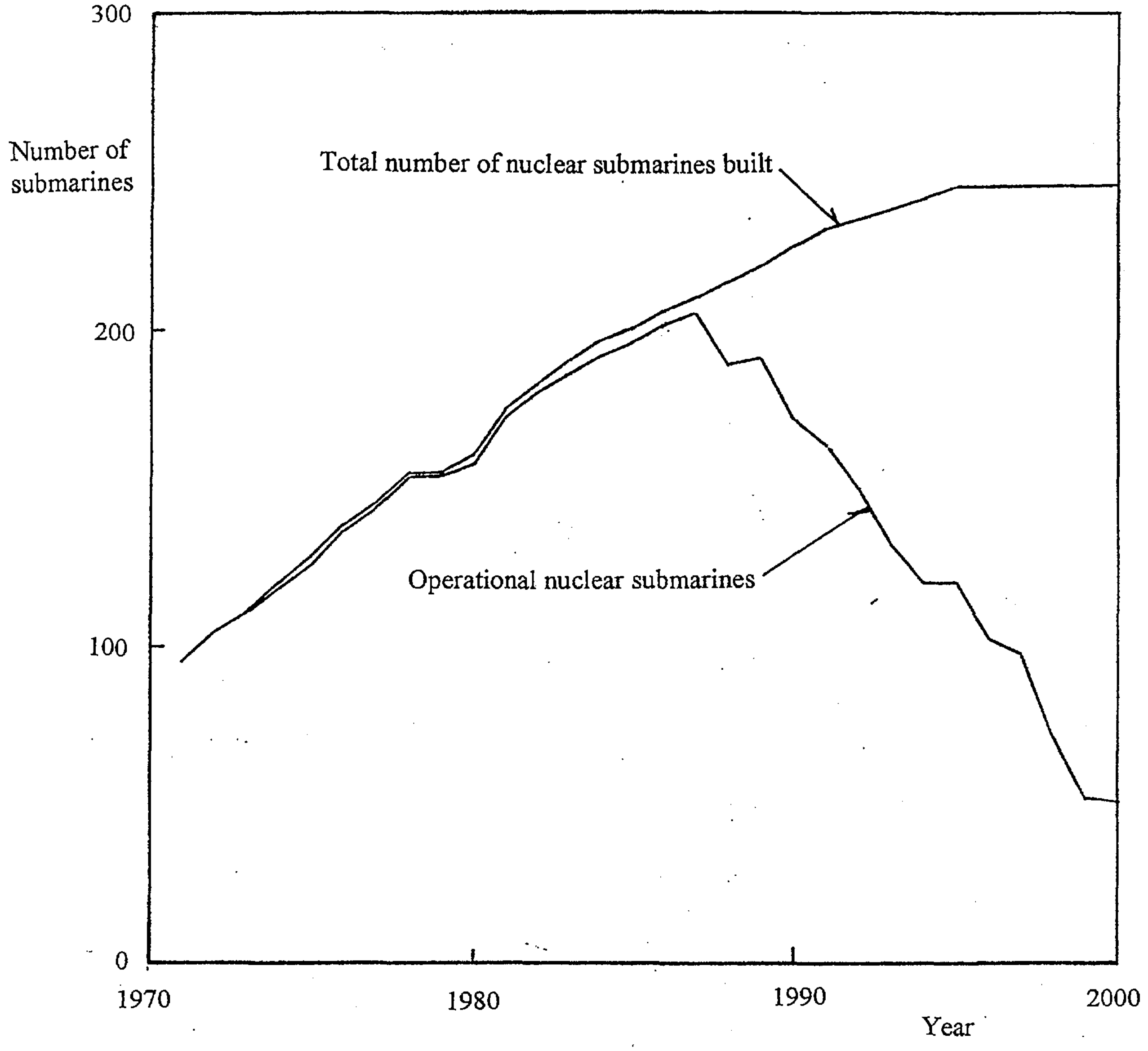


Figure 2.1.Upper curve: Total number of nuclear submarines built by USSR/Russia versus time. Lower curve: Total number of number of operational nuclear submarines in the Soviet/Russian Navy versus time.

3 Typhoon
6 Delta-4
7 Delta-3
1 Delta-1
6 Oscar
8 Akula
1 Sierra
2 Yankee
5 Victor-3
3 Uniform
1 X-ray
2 Kirov

i.e. a total of 45 nuclear powered vessels, down from 51 in 2000.

3. THE NORTHERN FLEET

The potential risks from the Russian nuclear Navy to which the Nordic countries are exposed, come mainly from the Northern Fleet which is based at the Kola peninsula and at Severodvinsk near Archangelsk. Table 3.1 represents an estimate of the Northern Fleet around 1997.

The data of table 3.1 were obtained from ref. 2, ref. 3, ref. 4, ref. 5 and ref. 6. It is seen that the data are not always consistent, but the differences are not of great importance. In addition to the nuclear vessels of the Northern Fleet there is the Russian icebreakers, which all have their home base in the Murmansk area.

According to ref. 19 the number of operational nuclear vessels of the Northern Fleet is as of August 2001

12 ballistic missile submarines (Typhoon and Delta class)
4 cruise missile submarines (Oscar class)
12 attack submarines (Akula, Sierra, Yankee and Victor class)
4 other role submarines (Yankee, Uniform, X-ray)
1 cruiser (Kirov class)

i.e. a total of 33 nuclear powered vessels.

The potential risks of the nuclear vessels of the Russian Northwest come both from the operational vessels and from the decommissioned vessels, which are awaiting dismantling.

4. THE RUSSIAN ICEBREAKER FLEET

The Murmansk Shipping Company is operating the Russian icebreaker fleet. It consists today of six operational icebreakers (Arktika, Rossiya, Sovetskiy Soyus, Yamal, Taymyr, Vaigatch) and one icebreaking freighter or container ship (Sevmorput). They all stationed at the Atomflot's Repair Technical Plant (RTP), located near the city of Murmansk. Two icebreakers have been taken out of service and have been defuelled (Lenin, Sibir). Data on these ships are given in table 4.1.

A new icebreaker, 50 let Pobyedy (50 Years of Victory), is under construction at the Baltiysky Shipyard in Saint Petersburgh. It is of the Arktika-class

To assist the operation of these ships a number of service ships are available. They are designed for repair, refuelling and storage of spent fuel and radioactive waste. These ships include two floating technical bases, Imandra and Lotta, used for refuelling and storage of spent fuel. Imandra stored 1530 spent elements and Lotta 4080 spent elements in 1997 (ref. 33). Earlier a third vessel, Lepse, was also used for storage of spent fuel and contains some 645 fuel elements. About 70% of these elements, some of which originate from the Lenin LOCA accident, have been pressed down in the storage channels and can not be removed. Studies are made of methods to get them out. Volodarsky is used for storage of solid waste and has a storage capacity

Table 3.1. Nuclear Ships of the Northern Fleet 1997

Submarines

Class	Total	In storage Dismant. Sunk	Actually Operational	Difference
November	10	9	0	1
"November"	1	1	0	0
Victor-1	13	13	0	0
Victor-2	7	5	2	0
Victor-3	16	0	16	0
Alfa	7	7	1	1
Sierra	6	0	6	0
Mike	1	1	0	0
Akula	6	0	6	0
Subtotal	67	36	31	0
Echo-2	11	14	0	3
Charlie-2	6	6	3	3
Papa	1	1	0	0
Oscar	9	0	9	0
Subtotal	27	21	12	6
Hotel	6	6	0	0
Yankee	24	24	1	1
Delta-1	9	7	2	0
Delta-2	4	0	4	0
Delta-3	5	0	5	0
Delta-4	7	0	7	0
Typhoon	6	0	6	0
Subtotal	61	37	25	1
Research subs	3	0	3	0
Total	158	94	71	3

Missile Cruisers

Class	Total	In storage	Operational
Kirov	2	1?	1?

of 300 m^3. Serebryanka is a tanker used for storage of liquid waste. It has a capacity of 1000 m^3. Finally there is the Rosta-1 boat, which is used for sanitary treatment of operating personnel and radiation control. None of these ships are nuclear powered.

RTP operates an incineration facility for solid combustible waste, which can reduce the waste volume by a factor of up to 80. Liquid waste is treated in a pilot filter facility.

Information given in this section is taken from ref. 16, 17, 18 and 29.

Table 4.1 Russian Icebreaking Ships

Name	Displacement (t)	Operational	Reactor power (MW_t)	Horse Power (shp)
Lenin	17 810	1959-89	3×90→2×135	44 000
Arktika	20 905	1974-	2×171	75 000
Sibir	21 120	1977-?	2×171	75 000
Rossiya	22 920	1985-	2×171	75 000
Sovetskiy Soyus	≈22 000	1989-	2×171	75 000
Yamal	≈22 000	1992-	2×171	75 000
50 let Pobyedy	≈22 000	under constr.	2×171	75 000
Taimyr	20 000	1989-	171	50 000
Vaigatch	20 000	1988<	171	50 000
Sevmorput	61 800	1988-	135	40 000

	Length (m)	Beam (m)	Height (m)	Draft (m)	Max. speed (knots)
Lenin	134	27.6	16.1	10.5	19.6
Arktika	147.9	29.9	17.2	11.0	20.8
Sibir	147.9	29.9	17.2	11.0	20.8
Rossiya	150	30	17.2	11.0	20.8
Sovetskiy Soyus					
Yamal	160	33			
50 let Pobyedy					
Taimyr	151.8	29.2	15.2	8.1	18.5
Vaigatch	150	29.4			
Sevmorput	260.1	32.2	18.3	11.8	20.5

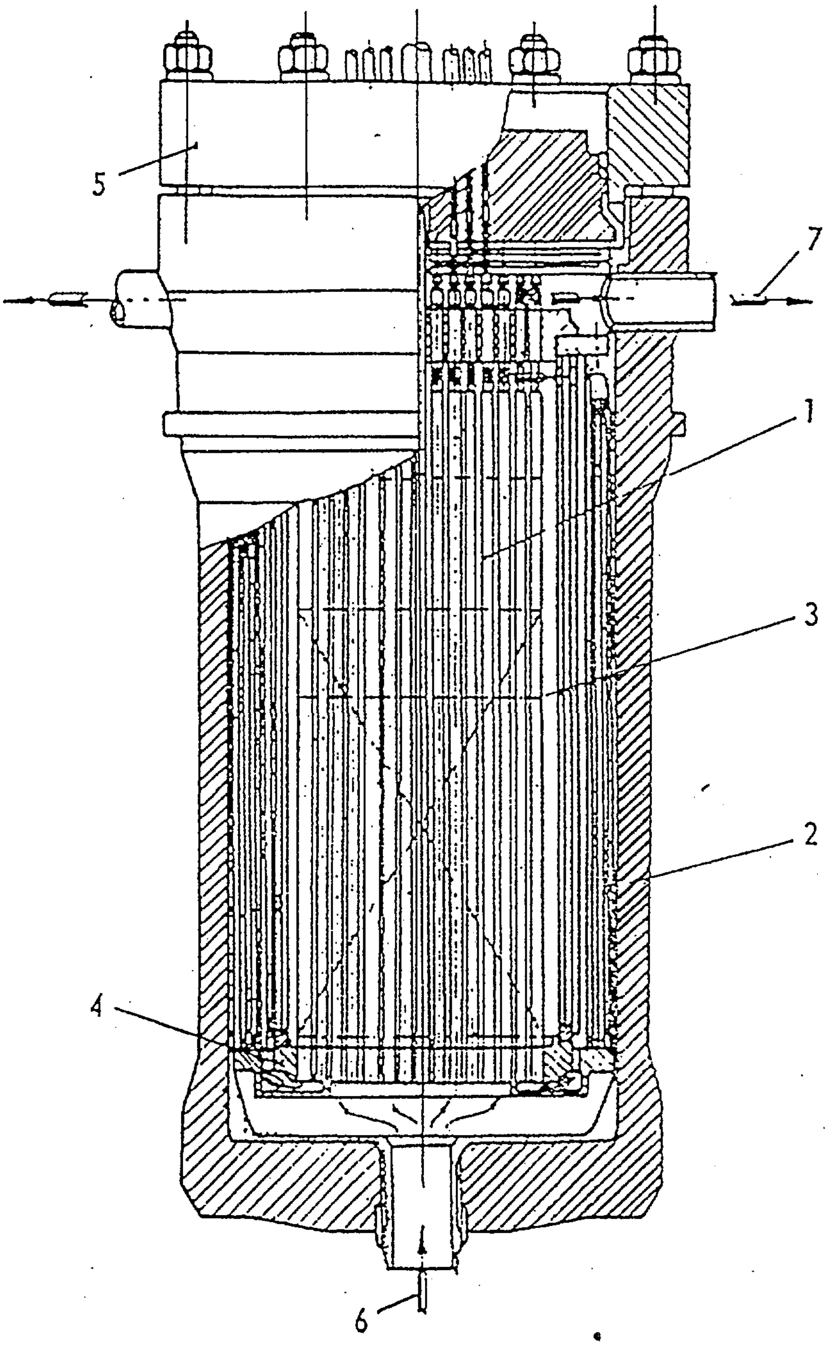
5. RUSSIAN SHIP REACTORS

Little information is for obvious reasons available about the reactors used in Russian naval vessels except that they are primarily pressurised water reactors. However, during the Soviet period a liquid metal cooled reactor was also developed and used by the USSR Navy.

The situation is different for the Russian icebreakers, where a significant amount of information is available on the reactor design. The reactors are all pressurised water reactors. Since the Kurchatov Institute has played an important role in the design of pressurised water reactors for both naval vessels and icebreakers, the general designs are probably similar, though there are differences.

5.1. The OK-150 Design

The initial three OK-150 reactors of the first nuclear icebreaker NS Lenin were pressurised water reactors, each with a power level of 90 MW_t. A vertical cross section of the reactor is shown in figure 5.1 and a horizontal cross section in fig. 5.2. The fuel elements are placed in a removable insert or "basket", which hangs down



1, Channels; 2, pressure vessel; 3, shielding; 4, lower plate; 5, cover; 6, coolant inlet; 7, coolant outlet

Figure 5.1. Vertical cross section of the OK-150 reactor

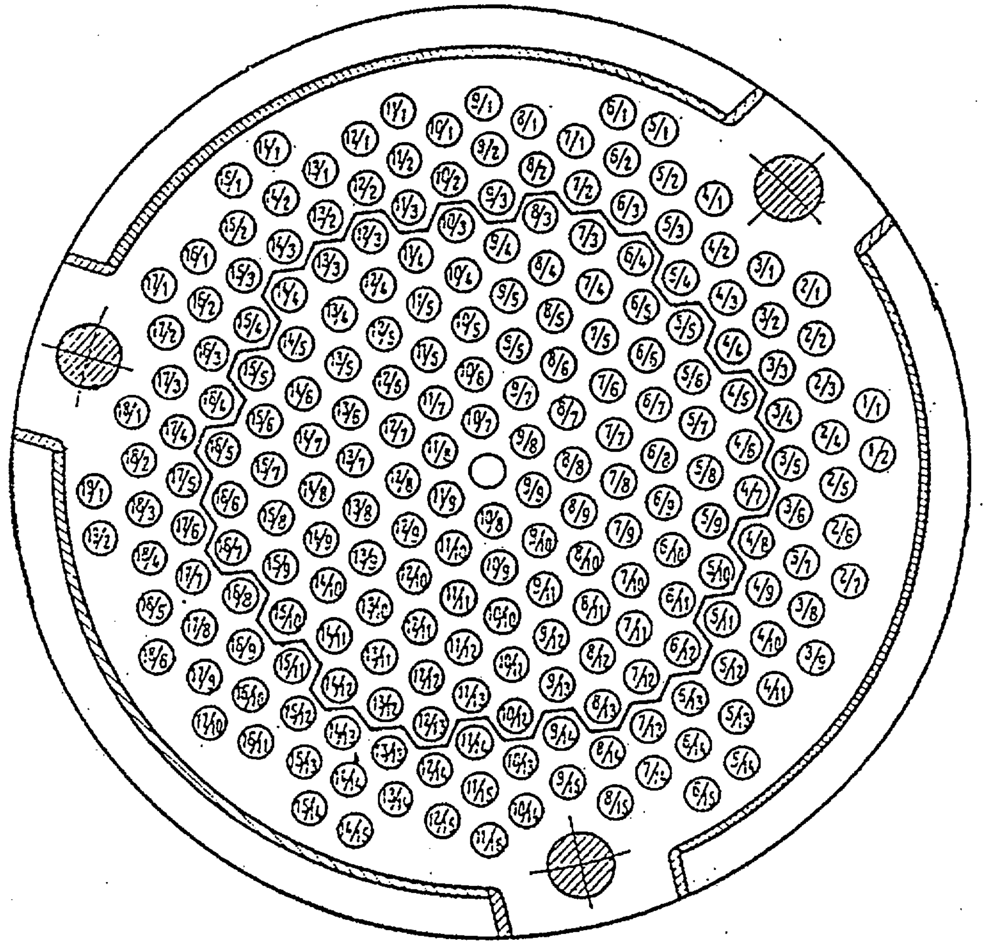


Figure 5.2. Horizontal cross section of the OK-150 reactor.

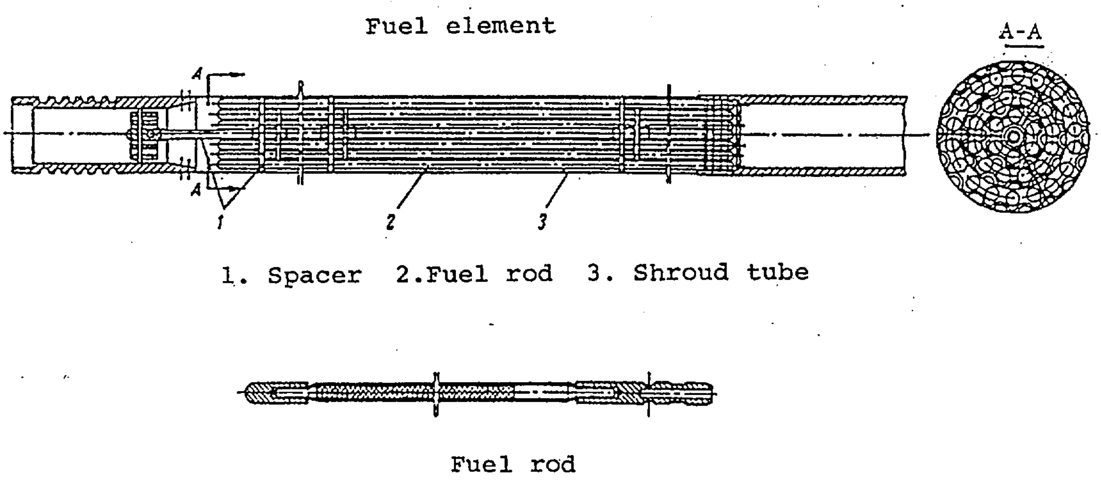


Figure 5.3. Fuel element for the OK-150 reactor

from the top of the tank. The water coolant enters the reactor tank from the bottom and flows up through the central part of the reactor core. At the top of the fuel elements the coolant moves out to the periphery of the tank and down through the thermal shield. At the bottom the coolant flow is again reversed and the coolant flows up through the outer fuel elements and leaves for the steam generators at the top of the reactor tank. The reason for this rather complicated flow pattern is not known, but it played presumably a role in the loss-of-coolant accident, which one of the reactors of NS Lenin suffered in 1966.

At this time the Lenin reactors were undergoing refuelling, and due to an operator error the water was drained from the (central part of the) core and it was left without cooling for some time. Due to the lack of cooling the decay heat caused partial melting and deformation of part of the fuel elements. Only 94 of the 219 fuel elements could be removed by the usual procedure. The rest was taken out by removal of the "basket" with the damaged fuel. After the fuel removal the reactor compartment was cut out of the ship and replaced by a new compartment containing two KLT-40 reactors.

In the West there has been speculations that the initial NS Lenin reactors were identical to those of the early Soviet submarines. According to ref. 6 this is not so, since all early Soviet submarine reactors had no connecting pipes below the upper edge of the core, and thus it is not possible by operator error to drain the coolant from the core or part of it. A model of an early submarine reactor at the town museum of Severodvinsk confirms this design feature since it has both the inlet and outlet pipes above the core.

The core dimensions of the first NS Lenin reactors were quite small, 1.58 m high and 1 m in diameter, thus a compact reactor design. The reactor tank had an outer diameter of about 2 m and a height of about 5 m.

The fuel elements of the OK-150 reactors are shown in fig. 5.3. They were cluster type elements with 36 fuel pins (0.61 cm diam.), arranged in three rings and surrounded by a tubular shroud. The central rod was a steel (?) rod, carrying the weight of the fuel rods. The fuel was UO_2 pellets, enriched to 5%, and the cladding a zirconium alloy. The burn-up was 11.000 to 12.000 MWd/t, corresponding to one year of operation. During refuelling all fuel was replaced.

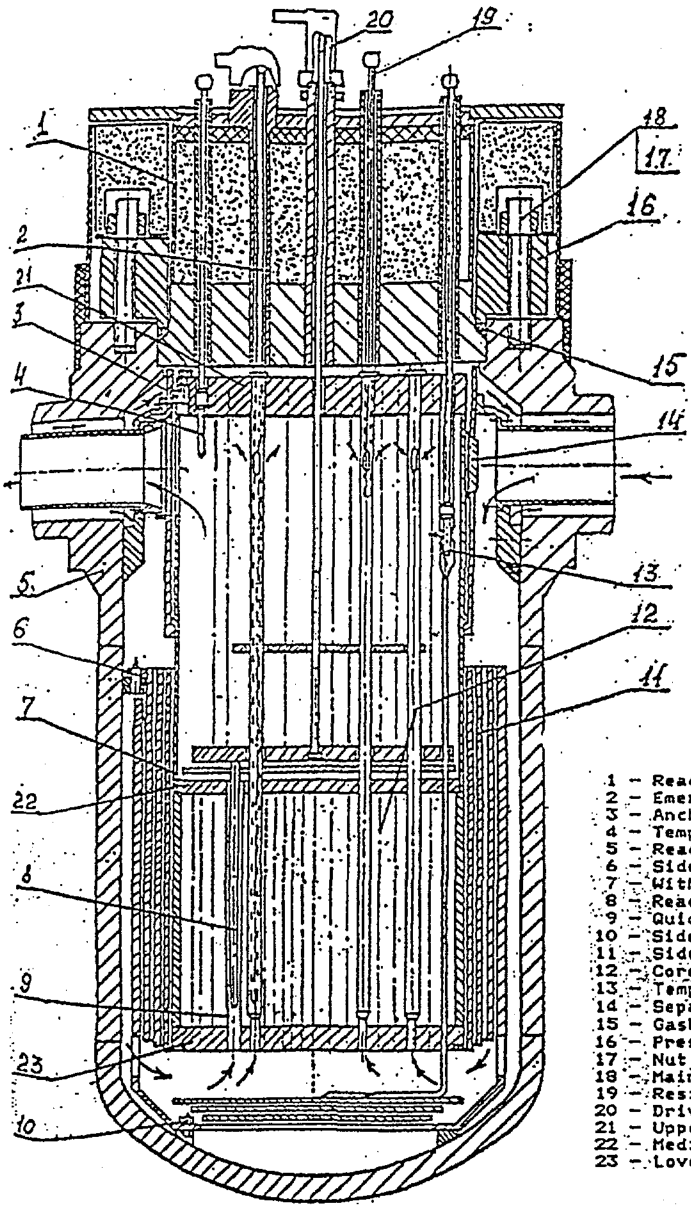
The reactor power was regulated by use three regulation rods and by changing the amount of feed water. The burn-up was controlled by use of burnable poison plates. Burnable poison (^{10}B) was also incorporated in the shrouds of the fuel elements with maximum boron concentration in the inner elements and no boron in the outer. The shutting down of the reactor was accomplished by use of safety rods.

The reactor was provided with two coolant loops. The core inlet temperature was 248 °C and the outlet temperature 278 °C. The operating pressure was 200 bar. There was a pressurizer in each loop. The pressurizers were based on production or condensation of steam to maintain the correct pressure.

Further information on the initial NS Lenin reactors may be obtained from ref. 20, 21 and 17.

5.2. The KLT-40 Design

The KLT-40 reactors, two of which replaced the three old OK-150 reactors in NS Lenin after the accident, have been used in all later icebreakers and in the icebreaking cargo carrier NS Sevmorput. They are pressurised water reactors with power levels of 135 or 171 MW_t. Fig. 5.4 shows a vertical cross section of the reactor. The coolant enters the reactor tank at the top, flows downwards through the thermal



1 – Reactor cover
2 – Emergency protection rod
3 – Ancher bolts
4 – Temperature sensor
5 – Reactor vessel
6 – Side screen attachment studs
7 – Withdrawable unit
8 – Reactivity shim rod
9 – Guide pipe of shim rod
10 – Side screen attachment stud
11 – Side screen shell
12 – Core
13 – Temperature sensor
14 – Separating shell with plugs
15 – Gasket
16 – Pressure flange
17 – Nut
18 – Main joint stud
19 – Resistance thermometr
20 – Drive rod of withdrawable unit
21 – Upper plate of withdrawable unit
22 – Medium plate of withdrawable unit
23 – Lover plate of withdrawable unit

Figure 5.4. Vertical cross section of the KLT-40 reactor

shield, up through the reactor core and from the top at the reactor tank to the steam generator. From here the coolant moves through the canned circulation pump back to the reactor. The design is very compact, completely welded with a tube-inside-tube arrangement whereby the length of the piping and number of flanges etc of the primary circuit is kept at a minimum. This reduces the risk of leaks. The reactor can run by natural circulation at 20-25% of full power. A diagram of the primary system is shown in fig. 5.5.

The core height is 1 m and the diameter 121 cm. The fuel elements are of the cluster type with 53 (?) fuel pin (0.7 cm diam.) and surrounded by a shroud. The fuel material is an alloy of 90% enriched uranium and zirconium. The cladding material is a zirconium alloy. The fuel elements are also provided with burnable poison pins containing natural gadolinium. The fuel elements are placed in an removable reactor insert or basket. The reactor may run at full power for 460-500 days before refuelling is needed. Fuel element movements are prevented by fixing the elements both at the bottom and at the top.

The reactor power may be controlled by regulation of the amount of feed water. The reactivity is controlled by use of a scram and shim rod system. The scram system consists of five rod-banks of absorber rods, moving in sleeves in 16 fuel elements. The regulating system consists of four rod-banks. A liquid absorber, cadmium nitrate may be injected into the coolant in the case of emergency.

The reactor has four loops. The core inlet temperature is 278 °C and the outlet temperature 318 °C. The pressure is 130 bar. The pressure is controlled by use of a gas pressurising system, connected to the reactor tank. The pressure may controlled by injection/discharge of gas.

The KLT-40 reactor is provided with a emergency core cooling system. Further, at least in some of the icebreakers the reactors are provided with a containment and various pressure relief systems. Sevmorput is provided with a pressure suppression system.

Information on the KLT-40 may be obtained from ref. 22, 23, 24 and 17.

5.3. Naval Reactors

As mentioned above little information on the Russian naval reactors is available. However, in ref. 2 the designation of some of the pressurised water reactors and their power level is given:

VM-A (70 MW$_t$), VM-4T (72 MW$_t$), VM-4 (75 MW$_t$),
VM-4/2 (89 MW$_t$), VM-4SG (90+ MW$_t$), OK-650 (190 MW$_t$)
KN-3 (300 MW$_t$)

5.4. The VT-1, VM-40B, OK-550 Design

As mentioned above a liquid metal cooled reactor for submarine use was developed at Obninsk. It was first used in a special version of a November class submarine (Project 645, K-27) which used two VT-1 reactors (73 MW$_t$?). Later the same type of reactor was used in the Alfa class submarines. Here the reactors used were VM-40A (two primary loops) or OK-550 (three primary loops) For both types the power level was 155 MW$_t$ (ref. 2).

This reactor type was run on intermediate energy neutrons. The core contained the fuel and the coolant, and was surrounded by a beryllium reflector, which slowed down the neutrons. The fuel had the form of rods containing highly enriched uranium, presumably as an alloy, and clad in stainless steel. The coolant was a lead-bismuth

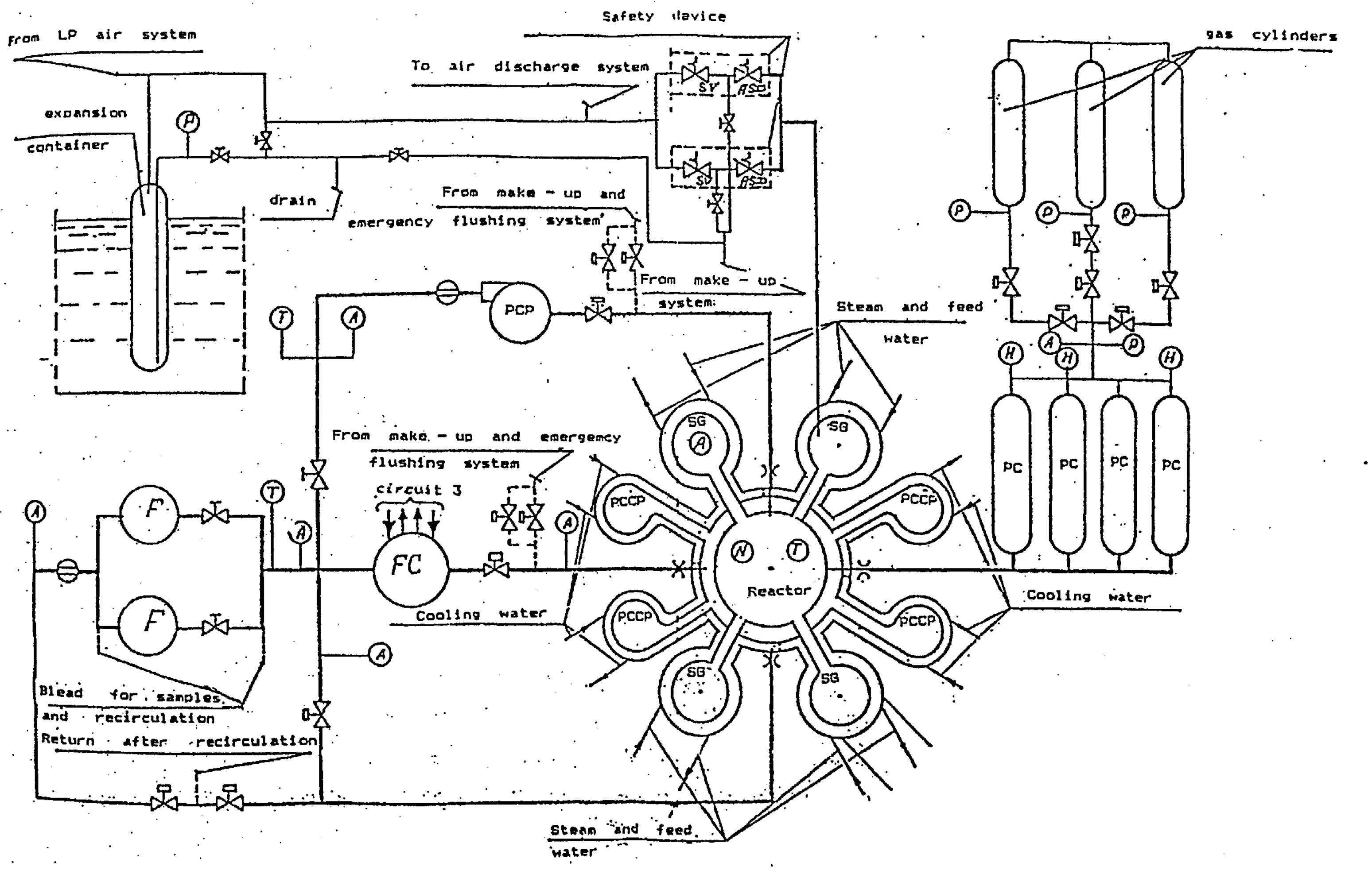


Figure 5.5. Primary circuit of the KLT-40 nuclear plant

alloy with a fairly low melting point. The control rods contain boron and europium (ref. 25).

This reactor type has a number of advantages. It is more compact than pressurised water reactors, since it needs no moderator. Due to the liquid metal coolant it can have a higher operating temperatures and a higher thermal efficiency and it needs no a heavy pressure vessel. Refuelling is faster since all fuel, control rods and reflector is removed in one operation. However, it has also disadvantages since the melting point is above room temperature, so that the primary system has to be heated at all times to remain liquid. If not, the coolant will solidify and the cooling interrupted. It seems also that Mayak can not reprocess this type of fuel.

The K-27 suffered a loss-of-coolant accident in 1968 when it was ordered to participate in a naval exercise at a time when the coolant needed to be cleaned of impurities. These impurities blocked the entrance to the core and thereby caused a LOCA. The submarine was later sunk near Novaya Zemlya (ref. 1).

In 1972 an Alfa class submarine (K-377) suffered a loss-of-coolant accident when the liquid metal coolant solidified. It was not possible to remelt the coolant and get the fuel out. The reactor compartment of the submarine is as a three-compartment-unit in floating storage at a naval base of the Northern Fleet at Severodvinsk (ref. 1).

6. NUMBER OF DECOMMISSIONED NUCLEAR SUBMARINES AT THE NORTHERN FLEET

As can be seen from fig. 2.1 the decommissioning of the Russian nuclear submarines started effectively in the late eighties and has continued at an almost constant rate since then. The decommissioning process is often divided into three phases. Phase one involves submarines that have been taken out of operation and are in floating storage with the nuclear fuel still in the reactors. Phase two involves submarines in floating storage which have had their fuel removed. Phase three involves submarines for which the reactor compartment have been cut out of the submarine and prepared for long storage.

In table 6.1 the number of Russian nuclear submarines that has, as of 2001, been decommissioned are listed. The figures of table 6.1 are based on information presented at the international seminar on "Ecological Problems in Nuclear Submarine" Decommissioning in Severodvinsk in July 2001 (cf. ref. 25). The figures of various presentations at the seminar were not always consistent, so that the figures of table 6.1 are based on an assessment of the data made available at the Severodvinsk seminar and therefore may only be considered approximately correct. Table 6.2 gives the number of submarines that were in floating storage at the Northern Fleet in 1997, with or without fuel (ref. 6).

The decommissioned nuclear submarines of the Northern Fleet are stored at various bases of the Fleet. The sites of these bases are shown in figure 6.1 and 6.2. There are five bases at the Kola Peninsula. The largest is Zapadnaya Litsa which includes four naval facilities: Andreeva Bay, Bolshaya Lopatka, Malaya Lopatka and Nerpicha. The other four bases are Vidyayevo, which consists of the Ara Bay and the Ura Bay facilities, Gadzhieva, which consists of the Saida Bay and Olenia Bay facilities, Severomorsk with the administration center of the Northern Fleet and Gremikha. In addition there is also a base at Severodvinsk, 35 km west of Arkhangelsk (ref. 28).

Table 6.1. Decommissioned Russian Nuclear Submarines (2001)

	Northern Fleet	Pacific Fleet	Total
Submarines with fuel	60	35	95
Submarines without fuel	15	25	40
Cut-out reactor sections	40	15	55
Total	115	75	190

Table 6.2. Stored, Decommissioned Submarines at Northern Fleet (1997)

Class	Operational period	With fuel in core	Defuelled	Total
November	1958-1989	6	2	8
Victor-1	1967-1991	11	1	12
Victor-2	1967-	5	0	5
Alfa	1971-1995	3	4	7
Echo-2	1963-1992	12	2	14
Papa	1970-1988	1	0	1
Charlie-2	1975-1996	5	1	6
Hotel	1960-1989	3	3	6
Yankee	1967-	9	9	18
Delta-1	1972-	7	0	7
Delta-2	1975-	4	0	4
Delta-3	1976-	1	0	1
Total		67	22	89

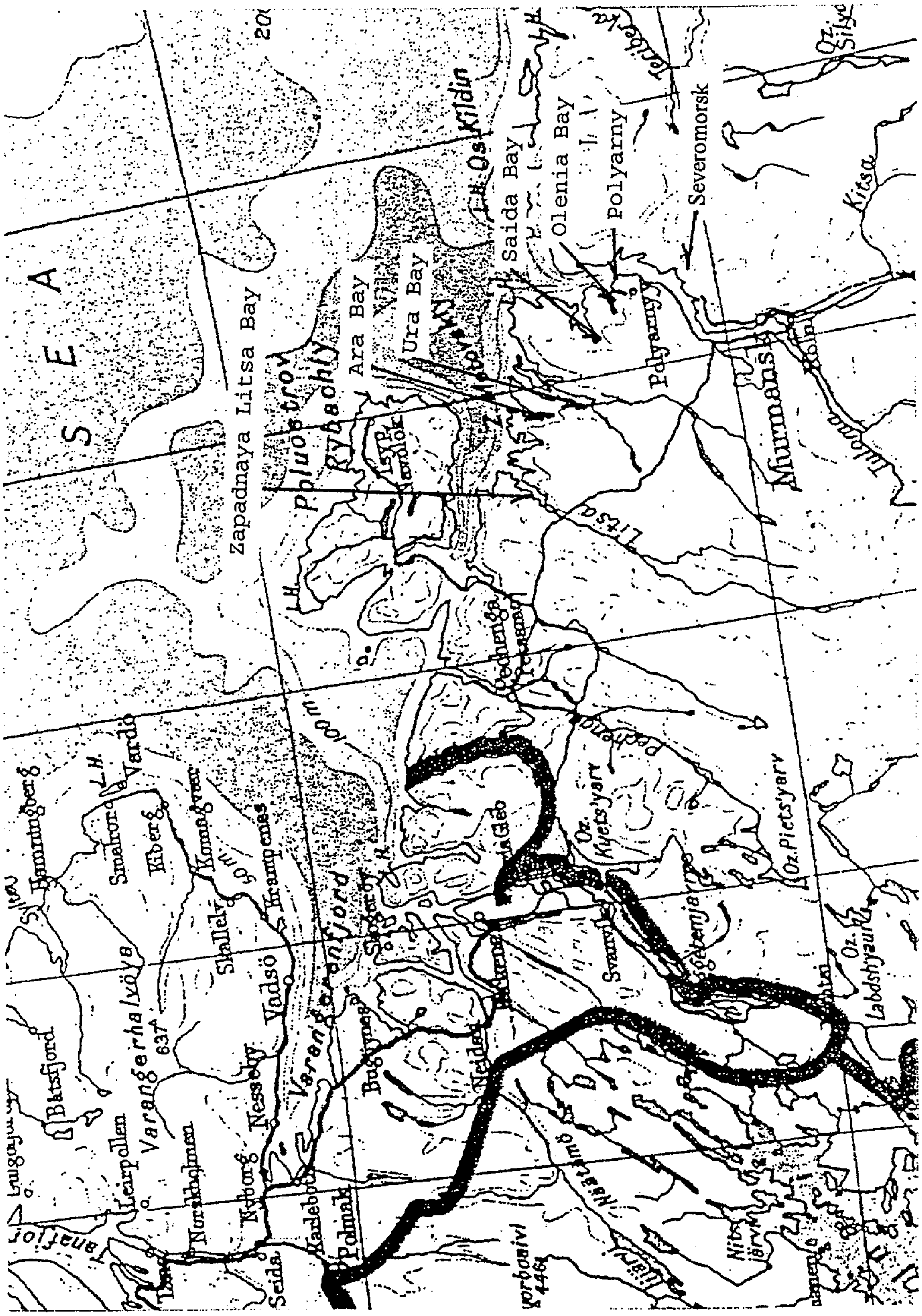


Figure 6.1. Map of the naval bases in the Murmansk area where decommissioned, nuclear submarines are in floating storage.

Figure 6.2. Map of northwestern Russia with Murmansk, Gremikha and Severodvinsk

According to available information the total number of stored submarines at these bases was 70 in September 1995, and their distribution was the following:

Zapadnaya Litsa Bay:
1 Alfa submarine, defuelled, ready for disposal
1 Alfa submarine, not defuelled

Ara Bay:
5 Echo-2 submarines, not defuelled
1 Charlie-2 submarine, not defuelled

Ura Bay:
6 Echo-2 submarines, not defuelled
1 Charlie-2 submarine, not defuelled

Saida Bay:
1 November submarine, defuelled, prepared for long-term storage
2 Echo-2 submarines, defuelled, prepared for long-term storage
2 Hotel submarines, defuelled, prepared for long-term storage
2 Yankee/Delta submarines, defuelled, prepared for long-term storage
1 Yankee/Delta submarine, not defuelled

Olenia Bay:
1 Victor submarine, defuelled, prepared for long term-storage
1 Echo-2 submarine, not defuelled
1 Charlie-2 submarine, defuelled, prepared for long-term storage
1 Hotel submarine, not defuelled
1 Yankee/Delta submarine, defuelled, prepared for long-term storage

Polyarny:
3 November submarines, not defuelled
3 Victor submarines, not defuelled
1 Echo-2 submarine, not defuelled
1 Hotel submarine, not defuelled

Gremikha:
4 November submarines, not defuelled
8 Victor submarines, not defuelled
1 Hotel submarine, not defuelled

Severodvinsk:
1 Alfa submarine, not defuelled, cut into three-compartment unit, damaged core
3 Alfa submarines, defuelled, ready for disposal
1 Papa submarine, not defuelled
1 Yankee/Delta submarine, defuelled, prepared for long-term storage
2 Yankee/Delta submarines, defuelled, cut into three-compartment-unit
10 Yankee/Delta submarines, not defuelled
2 Yankee/Delta submarines, defuelled, ready for disposal

Murmansk:
1 Hotel submarine, not defuelled

It is not clear how many of the Yankee/Delta submarines, mentioned under Saida, Olenia and Severodvinsk, are Yankee and how many are Delta submarines. However, presumably most of them are of the Yankee class.

Of 70 submarines listed above, 18 were defuelled and the remaining 52 were not.

The difference between "ready for disposal" and "prepared for long-term storage" is not clear, but may be the following. "Ready for disposal" may mean that the reactor compartment of the submarine has been cut out of the hull and prepared for storage. "Prepared for long term disposal" may mean that all armament and all easily removable parts of the submarine has been removed, that the reactor has been defuelled, that all circuits are drained and that the hull prepared for long-term storage. This may include the removal of part of the upper structures of the submarines.

It should be noticed that the fuel in the core of one Alfa and one Echo-2 submarine has been damaged and can not be taken out.

7. DECOMMISSIONING PROCEDURE

The first phase in the decommissioning of nuclear submarines is to remove all weapon systems, fire prone parts, hazardous materials and all easily removable parts, which may be reused. Further many circuits are drained (ref. 6).

The primary coolant pumps are operated until the core temperature can be kept at a sufficiently low level by natural circulation. Later on when the decay heat has decreased sufficiently, electric heating is introduced in the reactor compartment to prevent freezing of the water coolant. Freezing of the seawater at the mooring site could possibly impede the cooling of the reactors. This is unlikely at the bases of the Kola Peninsula with unfreezing waters, but could be a problem at Severodvinsk. For this reason a special service is maintained here to control the ice formation. After three years or more the decay heat has dropped to a level, where the cooling water can be drained from the primary circuit, so that freezing of the coolant can no longer occur. The use of such a measure is being investigated (ref. 6).

The low temperature of the primary system reduces the corrosion, which is further reduced by adding inhibitors to the cooling water. The pressure of the primary circuit is maintained at 10-15 bar by use of the gas-pressurizer system. Maintenance of overpressure in the primary circuit permits control of the tightness of the circuit (ref. 6).

To avoid criticality the power supply to the control rod drive system is cut by the removal of one meter of the electric cables and isolation of the cable ends. Further the movement of the control rods is prevented by use of welding and stoppers with the rods fully inserted. The power supply to the control panel is also cut and the room locked and sealed. To check the state of the submarine a crew of five keeps an all-day watch (ref. 6).

The submarines are left in floating storage at naval bases until economic resources permit further processing. This storage period can last many years, and keeping the submarines floating may therefore be a problem. If leaks develop, the necessary buoyancy may be obtained by pumping out the water, by pumping in low-density plastic balls, or by attaching pontoons to the submarine (ref. 25). It may be mentioned that up to 40% of the decommissioned submarines have been in floating storage without much maintenance for more than 10 years (ref. 7)

The next phase is the removal of the fuel from the reactor. The defuelling is carried out by a team of specially trained people. To avoid criticality accidents during this process the reactor tank and the primary circuit is drained prior to the removal of fuel elements. This means that the defuelling is only carried out three years or more after the final shut down of the reactor. At this time the decay heat is so low that the removal of the coolant will not lead to a loss-of-coolant accident. The drainage of the primary circuit is performed before the removal of the reactor tank lid. The absence of water in the reactor is controlled by use of a suction tube, which is inserted inside an orifice for a liner of a scram rod or of a feeler. To do this one of the scram rods have to be removed. Full removal of water from other circuits and tanks is also checked and so is the closure of all piping through which water can enter the reactor (ref. 6).

The defuelling is started by the removal of the reactor lid. First all the nuts of the lid are loosened 5 to10 cm. Since the lid has been pressed towards the top of the reactor tank for a long time and at high pressure it can not simply be lifted by a crane, so the next step is to "tear" off the lid by use of hydraulic jacks. Then the nuts are removed and the lid lifted 1.5 m up by use of a special crane and the position of the control rods are checked. The lid is replaced by a co-ordinate-positioning refuelling machine, which is provided with the necessary radiation shielding. During the replacement of the lid with the refuelling machine the radiation level above the reactor tank must be very high, since the reactor water, which acts as radiation shield, has been drained. By use of the refuelling machine a fuel transfer container can be placed over any fuel element position and the element removed by use of an expansion gripping device. The operation is monitored through a periscope. It is essential to ensured that the water is fully removed from the reactor before the movement of the control rods (ref. 6).

From available information it seems as if it is not normal Russian procedure to have a neutron source in the reactor and an operating neutron detector close to the core during refuelling or defuelling. This means that the defuelling staff has no measure of how close the reactor is to criticality, when control rods and fuel elements are moved. This increases the risk of unintended criticality (cf. 27).

The removal of the fuel will reduce the amount of activity remaining in the reactor compartment by a factor of 10 to 20.

The number of submarine defuellings per year were earlier limited by the lack of spent fuel storage facilities at the naval bases and the lack of capacity for the transport of the spent fuel to Mayak. During the later years the defuelling rate has been increased significantly. In 1990 four submarines were defuelled, in 1998 nine and in the future it should be possible to defuel 20-25 submarines per year, though about 15 may be a more realistic figure. This increase in the defuelling rate has been helped by the assistance from Norway and the US. Norway has funded four railway cars for transportation of the fuel to Mayak, and the US has funded the construction of defuelling facilities on land. Earlier special ships were used for the defuelling, but they are old and their stores for spent fuel are full. Once the fuel has been removed from the submarines, they represent only a limited risk to the environment (ref. 25).

The third phase has usually been, according to Russian procedures, to cut the reactor compartment and its two neighbouring compartments out of the submarine, while the remaining part of the submarine is dismantled. Next all equipment is removed from the two neighbouring compartments after which they are sealed at the outer ends with steel plates. Before the sealing some waste materials may be deposited in the reactor compartments. In this way the three-compartment unit obtain the necessary buoyancy so it can be stored floating. In some cases only the reactor compartment has been cut out, and the compartment has been given the necessary buoyancy by attachment of pontoons to the compartment. Multi-compartment-units have also been used, probably consisting of more compartments to give the necessary buoyancy. The initial storage of the compartment units has been floating storage at naval bases. However, the present plans call for storage for 50 to 100 years, so that other storage methods may have to be used later. A number of alternative storage methods have been proposed, e.g. underwater storage, sub-soil storage in permafrost areas, and storage in caves or tunnels, but lately it seems that preference is given to storage on land on concrete platforms of one-compartment units. (ref. 25).

The final step is the disposal of the reactor compartments, whether one- or three- or multi-compartment units. In the early days of the nuclear age the Soviet Navy disposed of removed reactor compartments by sinking them in the sea near Novaya Zemlya. Before the sinking the reactors had been filled with the chemical compound furfurol to delay the corrosion of the reactor materials. Some of the early reactors disposed of in the sea contained damaged fuel. However, this procedure is no longer permissible after the USSR joined the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matters (ref. 26).

After a storage period of 50 to 100 years reuse of the materials of the reactor compartment has been suggested, possibly after some decontamination e.g. through re-melting, but it seems that no decision has been taken on how to proceed at this point. In the West the planned approach is to dispose of the reactor compartments in a repository.

A number of Russian shipyards are involved in the decommissioning and dismantling of nuclear submarines. In Russia there are about five shipyards, which can perform submarine dismantling, four in the area of the Northern Fleet and one or two at the Pacific Fleet (ref. 8 and 25):

1) Zvezdotchka Ship Repairing Plant, Severodvinsk near Arkhangelsk (4 subs/yr (ref 8))

2) SevMash Shipyard, Severodvinsk near Arkhangelsk (ref. 25)

3) Nerpa Ship Repairing Plant at Snezhnogorsk near Murmansk (5 subs/yr when renovated (ref. 9))

4) No. 10 Shkval Repair Yard at Pala Bay near Polyarnij (ref. 25)

5) Zvezda Ship Repairing Plant, Bolshoi Kamen Bay, near Vladivostok (2 subs/yr (ref. 10))

There may also be a shipyard, which can perform decommissioning of submarines at Kamchatka.

There is hardly a lack of decommissioning capacity in Russia. The problem is the lack of funding. The decommissioning started in the late eighties (cf. fig. 2.1) and at the beginning of 1997 16 nuclear submarines had their reactor compartment cut out as three compartment units, while 8 submarines were prepared for long term storage (ref. 7). According to ref. 11 Russia planned to dismantle 18 submarines in 2000 and according to ref. 25 the number of dismantled submarines have now reached about 40 at the Northern Fleet and 55 totally at the Russian Navy. So the decommissioning work is progressing.

It may finally be mentioned that the icebreaker Lenin and possibly one more has been decommissioned. Lenin is to serve as a museum ship.

8. SPENT NUCLEAR FUEL

A large amount of spent nuclear fuel has accumulated at the bases of the Russian Navy, including the Northern Fleet. In 1997 the total amount was about 300 reactor cores or 70,000 fuel assemblies. About half of these assemblies are still in the reactors of decommissioned submarines. The rest are stored in various storage facilities at the naval bases. There are several reasons for this large amount of spent fuel at naval bases. The transport capacity for the shipment of spent fuel to the Production Association Mayak where the fuel is to be reprocessed was limited to 10-20 cores per year, and the transport costs had increased. Required lifting equipment and transport facilities were not adequate at the naval bases. This means that all storage facilities, whether on land or on ships, were full and some of the facilities were not designed for long term storage (ref. 7).

In connection with a meeting in February 1996 of a NATO/NACC/CCMS Pilot Study (ref. 31) the Russians published information of the storage of spent fuel at the Northern Fleet (ref. 12 and 13). The documents are not dated, but the figures seem to relate to the situation at the end of 1994.

The spent fuel of the Northern Fleet is store at two shore bases, Andreyev Bay and Gremikha and at 6 support vessels.

At Andreyev Bay in Zapadnaya Litsa Bay spent fuel was initially stored in a in-door storage pool. However, the pool developed a leak and the leaking radioactive water contaminated the surrounding area. Because of this three large liquid waste storage tanks were converted to dry storage facilities for spent fuel, and fuel was transferred from the pool to these facilities. The content of these three facilities was given to be as follows:

Storage facility # 1: 900 canisters or 6300 fuel assemblies
Storage facility # 2: 1021 canisters or 7147 fuel assemblies
Storage facility # 3: 993 canisters or 6951 fuel assemblies

The three facilities are fully loaded.

At the Gremikha base there are 4 spent fuel storage facilities.

Pool # 2 (no longer in operation) contains 95 defect fuel assemblies, which can not be accepted by Mayak, presumably because these elements are deformed and do not fulfil the dimensional requirement of Mayak.

Facility 1V contains 5 cores from liquid metal cooled reactors, probably of the order of 1000 fuel assemblies. Mayak will not accept them due to their design.

An open-air storage area contains 116 Type 6 containers with a total of 812 fuel elements. Mayak will not accept them due to their design.

Another open-air storage area contains 11 Type 11 containers with 77 fuel assemblies, which may be sent to Mayak.

Finally the Northern Fleet has 6 support ships which are used for spent fuel storage:

PM-12: 200 canisters with 1400 assemblies, full
PM-50: 80 canisters with 560 assemblies, full
PM-63: 116 canisters with 812 assemblies, only 60% filled
PM-78: 80 canisters with 560 assemblies, full
PM-124: no figure given, storage not full
PM-128: 80 canisters with 560 assemblies, full

Adding up these figures yields

Andreyev Bay:	20398 fuel assemblies
Gremikha:	≈2000 fuel assemblies
Supply ships	≈4000 fuel assemblies
Total	≈26500 fuel assemblies

It may be noted that the Russian fuel canisters or containers usually contain 7 fuel elements each.

These figures are as mentioned above probably from 1994, and they are presumably not correct today. Any change in the figures depends of what spent fuel has been added and what spent fuel has been removed since then. Since neither of these two amounts is believed to be large, the total figure given above may still give the right order of magnitude. It should also be mentioned that according to Russian information the storage conditions at these facilities are not satisfactory.

The fuel from the liquid metal cooled reactors represents a special problem. The defuelling of these reactors is carried out by lifting the reactor block with all the fuel, the inserted control rods, the beryllium reflector and the top shield and placing the block in a tank with a clean, melted Pb-Bi-alloy. The alloy will gradually solidify, and the tank is then placed in a concrete well in the ground. This storage was only intended to last for three to five years, but it has now become almost permanent. This means that there is the risk that water due to corrosion will enter the tank and permit radionuclides to reach the soil outside the concrete well. The water may also change the reactivity of the reactor block and possibly make it critical, thus causing a criticality accident. Therefore techniques have to be developed to remove and dismantle the reactor block in a safe way (ref. 25). Most, if not all, of these reactor blocks are at the naval base at Gremikha.

As discussed in section 7 the situation has recently improved since Norway has funded the construction of four railroad cars for transport of spent fuel to Mayak and the US has funded the construction of defuelling facilities. However, the storage facilities at Mayak for spent submarine fuel seems to be almost full, and therefore the US and Norway has funded the design and the construction of a limited number of combined storage and transport containers. The idea is to use such containers for dry storage of spent fuel at naval bases and, without reloading, to ship the fuel to reprocessing, once Mayak is ready to receive them. The problem is that with the amount of fuel at the Northern Fleet the use of such containers for storage of all the fuel will cost of the order of one billion $. An alternative is to construct a dry storage facility for the spent fuel similar to the French facility in Cadarache.

9. ACCIDENTS WITH RUSSIAN NUCLEAR SUBMARINES

While civilian nuclear power has suffered few serious nuclear accidents the same can unfortunately not be said for the nuclear navies, in particular the USSR/Russian Navy. The number of accident has been so high that it can actually be used to determine accident probabilities. In ref. 1 a review of naval accidents involving nuclear propelled vessels was presented. A total of 54 accident involving Soviet/Russian vessels are reported. However, 19 of these are dubious and were consequently neglected. Thus only 35 were given further consideration. To this figure may be added the recent Kursk accident (see e.g. ref. 32). The causes of the 36 accidents are presented in table 9.1. All of the accidents involved operational submarines. So far there are no known accidents with decommissioned submarines

"Reactor accidents" are accidents where the information available is too limited to characterise the type of reactor accident. "Propulsion" failure may involve the reactor system, but in most cases this seems not to be the case. "Other reasons" involve one collision and one case of operator error.

It is seen from table 9.1 that fires and explosions are the most dangerous accidents for the crews. However, in no case did they involve the reactors. Loss-of-coolant, criticality and reactor accidents all involve the reactors and propulsion failures may in some cases have involved the reactors.

In ref. 1 it has been estimated that the total number of ship-reactor-years (sry) of Russia was around 7700 at the end of 1996. From this it may be estimated that the probability of a submarine accident is

Table 9.1. Accidents in the USSR/Russian Navy

Cause	Number of accidents	Number of subs sunk	Number of fatalities
Fire	10	2	194
Explosion	2	2	122
Loss-of-cooling	9	0	17
Criticality	5	0	10
Reactor accident	3	0	5
Propulsion failure	5	0	1
Other reasons	2	0	29
Total	36	4	378

$$36/7700 = 5\ 10^{-3} \text{ per sry}$$

The probability of a reactor accident is

$$17/7700 = 2\ 10^{-3} \text{ per sry}$$

In ref. 14 it as estimated that the USSR/Russian Navy has carried out about 1200 refuellings. Since there has been at least 2 serious refuelling accidents as reported in ref. 1, the probability of a refuelling accident has been

$$2/1200 = 2\ 10^{-3} \text{ per refuelling}$$

It is interesting to notice that in ref. 15 the probability of a criticality accident during refuelling was estimated to be

$$10^{-7} \text{ per refuelling}$$

but this probability was in ref. 6 increased to

$$2\ 10^{-3} \text{ per refuelling}$$

in full agreement with that predicted by ref. 14.

Should this probability apply to the defuelling of the hundred decommissioned Russian submarines with fuel, the risk of a criticality accident during the defuelling of decommissioning becomes unacceptably high.

However, with the additional safety precautions taken by the Russian Navy in connection with the defuelling of decommissioned submarines, especially the drainage of water from the reactor before defuelling, the risk should be significantly less, provided it is ensured that the water is in fact removed from the reactors.

It should also be noted, as mentioned above, that while the Russian criticality accidents with submarines have so far happened with fresh fuel in the cores, a criticality accident during defuelling of a decommissioned submarine reactor will always involve spent fuel containing a large amount of fission products. In this case the release of radioactive nuclides will be significantly larger than in the case of a reactor with fresh fuel.

10. SUBMARINES WITH DAMAGED CORES

The Russian Navy has a special problem because five of its decommissioned nuclear submarines have reactors with damaged cores from which fuel can not be removed. All of these submarines have suffered reactor accidents. Two of the submarines belong to the Northern Fleet and three to the Pacific Fleet. Until the seventies the reactor compartment of submarines with damaged cores was cut out of the submarine, transported to Novaya Zemlya and sunk in the sea off the island. This is not permissible after the USSR became party to the London Dumping Convention.

A number of solutions to this problem have been studied. It has been suggested to cut out the reactor compartments of the damaged submarines and to put them into empty compartments of larger missile submarines. However, this approach will result in large doses to the personnel involved. Further it does not solve the problem. It only postpones it.

Another possibility, which has recently been suggested, is to excavate a short channel at an isolate coastline, to tow the submarines into this channel and to bury it there under concrete and soil. However, it is questionable whether the London convention will permit this approach. A third possibility is to haul the submarines on land and bury them there under concrete and soil (ref. 25).

Other questions connected to the these submarines are:

Should the tanks of the damaged reactors be filled with a metallic alloy to reduce the radiation level?

Should it be attempted to defuel the undamaged reactor of the submarine (most Russian submarines have two reactors)?

The design bureau Rubin in St. Petersburg, which has designed most of the Russian missile submarines, is making a study of what should be done with these submarines (ref. 25).

11. TYPES OF ACCIDENTS RELEVANT TO THE NORDIC COUNTRIES

The potential nuclear risks to the Nordic countries from Russian naval activities are connected to the risk that these activities result in the release of significant amounts of radioactive nuclides. Such release can happen suddenly, e.g. in connection with a criticality accident, or it can happen slowly, e.g. due to corrosion of the fuel or other radioactive reactor materials of a sunken nuclear submarine. Both types of releases need to be considered. In the following a number of types of accidents which has actually occurred will be discussed.

Firstly reactor accidents will be considered. Significant release of radioactive nuclides, i.e. fission products, from the reactor fuel can only occur if the fuel has been severely damaged, i.e. at least partly melted. This may happen in two ways: In a criticality accident and in a loss-of-coolant accident.

11.1. Criticality Accidents

A criticality accident occurs if for some reason the reactor becomes prompt supercritical since this results in a run-away chain reaction. The fuel will melt, will be scattered around, and the reactor will be destroyed. The whole accident takes only a few seconds. Thus the release of radioactivity will be very fast, and little can be done to stop it. If the containment around the reactor is not effective, large amounts of radionuclides may be released to the environment.

While criticality accidents in principle may occur at any time in a reactor, experience shows they occur in practice when the reactor system is not in normal operation. During normal operation the reactor is provided with monitoring and safety systems which will react if for some reason the reactor starts to become supercritical, and the systems will close the chain reaction down. All five criticality accidents in Russian submarine reactors occurred either during refuelling (2) or when the reactor control system was operated at shipyards (3), i.e. under abnormal conditions.

The refuelling accidents are in particular dangerous because before refuelling can take place, the submarine hull above the reactor compartment is opened. This means that there is a direct pathway from the reactor to the environment, i.e. no containment. This means that the power excursion of a criticality accident will send fission products and pieces of fuel – even whole fuel elements - out of the reactor to the environment. The release height will probably be up to 50-100m so a radioactive cloud will be formed which will move with wind.

The amount of radionuclides released in submarine criticality accidents, the so-called source term, depends on the content of radionuclides in the reactor, which again depends on the reactor power level and whether the reactor contain new or spent fuel. Since the power level of nuclear submarines is of the order of 100-200 MW_t, while modern nuclear power plants have power levels of 3000 MW_t, the release of radionuclides from power reactor will be much smaller for submarine reactors than for nuclear power plants. However, western nuclear power plants are provided with a containment that will prevent the radionuclides in getting out to the environment. If the fuel is new, only radionuclides produced during the power excursion can contribute to the release. However, if the reactor contains spent fuel, the radionuclides produced during the earlier power generation will also contribute to the release. Therefore criticality accidents during defuelling are more dangerous than criticality accidents in reactors with new fuel.

An important parameter in the assessment of a criticality accident is the amount of radionuclides released to the environment during the accident. This amount depends on the total activity of the reactor at the time of the accident and on the fraction of the activity released. This fraction depends on the reactor type.

In the case of the Tjernobyl accident the daily release of activity was fairly constant during the first ten days after which it stopped almost completely. It was highest on the first day, 0.45 EBq/d. On the second day it had been reduced to 0.15 EBq/d, and the decrease continued until the fifth and sixth day, when it was 0.08 EBq/d. Then it increased again until the tenth day when it was 0.3 EBq/d. After that it was practically zero. The reason was that at the start of the accident the graphite moderator caught fire and this fire lasted for ten days, at which time all graphite had burned so the fire stopped. This fire heated the damaged fuel and thereby increased the release of activity. The hot gas from the fire also lifted the radionuclides up to significant heights. The fact that the Tjernobyl reactor had no effective containment helped the release to the environment (ref. 30).

In a water moderated reactor there are no inflammable materials and therefore a fire can not be sustained. This means that the damaged fuel will be cooled down fairly rapidly, in particular if water can be made available to cool it, and that the release of activity will be correspondingly reduced. Since there is no fire, large amounts of hot gas will not be available to lift the radionuclides up to high altitudes and therefore smaller areas will be affected by the accident.

Due to the modest power levels of submarine reactors, due to the short release period of water reactors and due to the limited release height of the radionuclides, even criticality accidents are not likely to have severe consequences at distances of more than about 50 km from the site of the accident. The radioactivity will be measurable at much larger distances, but the protective measures to be taken in areas further away than 50 km will be limited, if any at all. However, people close to the accident may be killed and the area around the reactor may be significantly contaminated.

As discussed in section 7 a number of measures have been introduced at the Russian Navy in order to reduce the risk of criticality accidents in decommissioned, non-defuelled submarines.

11.2. Loss-of-Coolant Accidents (LOCA)

A different type of reactor accident is loss-of-coolant accidents or LOCA's. This type of accident is caused by the fact that while the fission processes of the chain reaction are stopped immediately when a reactor is shut down, the heat production in the reactor is not. The fission product and other radionuclides produced during reactor operation will continue to decay and hereby to produce heat. Immediately after shut-down the power production will be 5 to 7% of the power level before shut-down. After 24 hours it will be of the order of 0.5%. If the decay heat is not removed, the fuel may melt and fission products may be released. A LOCA will proceed much slower than a criticality accident, say hours rather than seconds, so there is more time for counter measures. But if they are not taken the result will again be significant release of fission products and other radionuclides.

LOCA's usually occur during normal operation, e.g. when a major leak in the cooling system develops while the primary circuit is at full pressure and the decay heat after shut down is significant. The control system should immediately shut down the reactor. But if an efficient emergency core cooling system is not available, the decay heat may damage the fuel and cause a fuel melt-down. If the reactor is provided with an effective containment, the radionuclides will not get out to the environment, but the reactor will of course be destroyed. Experience show that the hull of the Russian submarines act as a rather efficient containment system, i.e. only very small amounts of radioactive materials will be released to the environment. However, LOCA's may well give rise to high radiation levels in parts of the submarine, and to exposure of the crew.

The early Soviet submarines were not provided with efficient emergency cooling system. This situation seems to have changed, but of course an emergency cooling system will only work if it is properly maintained.

For decommissioned submarines LOCA's may happen for a short period after reactor shut down if the cooling of the reactor for some reason fails. But soon natural circulation should provide the necessary removal of the decay heat. This heat production will as discussed above gradually decrease and after two to three years the cooling water may be drained from the reactor without an overheating of the fuel.

11.3. Fires and Explosions

Based on past experience fires and explosions are not likely to affect the reactor system directly. Weapons are not situated close to the reactor compartment and the same is true for inflammable materials. However, fires and explosions can cause the submarine to sink. The reason for the sinking of the four Soviet/Russian submarines now at the bottom of the oceans was fires or explosions. The problems of the sunken submarines are considered in section 11.4.

11.4. Sinking of Submarines

Submarines may sink for a number of reasons. But of the 6 submarines, which are today at the bottom of the sea, three are there due to explosions (one American and two Russian), two (two Russian) are there due to fires and one (one American) is there due to a leakage in the hull of the submarine after a maintenance period. There is no indication that the reactor system was involved in any of these accidents.

If a nuclear submarine sinks, the corrosion of the seawater will after a number of years start to corrode the fuel and ultimately fission products will be released to the sea. However, the corrosion process will be very slow because the materials used in submarine reactors (pressurised water reactors) have to stand up to the corrosion of the hot cooling water. So the release will be very slow and it will be carried away from the submarine by the sea currents. Thus the contamination level of the seawater affected will be very low, taking into account the enormous volume of seawater involved. At the same time the activity of the radionuclides will all the time decrease due to radioactive decay.

Measurements of the activity of seawater samples collected close to sunken submarines confirm very low levels of contamination.

11.5. Spent Fuel Accidents

Spent fuel may give rise to radiation accidents if not properly shielded. Such an accident could happen if the fuel is stored in a water pool and the water for some reason drains out of the pool. However, due to the amounts of water involved and provided an alarm system of the water level exists, ample time should be available for counter measures, before the radiation level becomes too high. While the consequences of such an accident may be severe for people close to the pool, if proper counter measures are not taken, it will be of no importance for people situated say 10 km away.

If the pool water is not properly cleaned, it may be contaminated. If a leak develops contaminated water will enter the environment and contaminate soil and water of the surroundings. If the pool water is properly cleaned the contamination will be limited.

Another possibility is criticality accidents with spent fuel during handling of this fuel in a pool or during flooding of a dry storage of spent fuel. Nuclear fuel, whether new or spent, should always be placed in so-called safe-geometry arrangements, and for such geometry accidents can not occur. Fuel elements are handled one at a time in a pool, and the excess reactivity achievable in such cases will be small and the consequences of the accident limited. As far as is known there has been no criticality accidents involving stored spent fuel from nuclear vessels.

12. CONCLUSIONS

Experience shows that the potential risk to the Nordic countries from Russian nuclear ships is quite small.

The most important type of accident is undoubtedly criticality accidents during refuelling or defuelling with spent fuel in the reactor. These accidents may occur both for operational and for decommissioned submarines. However, such accidents are likely to occur more than 50 km from the territory of the Nordic countries and will therefore have little effect on these countries. Three criticality accidents have occurred at the Northern Fleet, all at Severodvinsk 450 km from Finland, and none of these were detected in the Nordic countries.

LOCA's have primarily occurred in operational submarines, but with little effect on the environment. In 1989 an Echo-II submarine suffered a LOCA 110 km from Sørøya in Northern Norway. The Norwegian Authorities took water samples close to the submarine, and they contained only minute amounts of radioactivity, which might have originated from the submarine.

Fires and explosions have resulted in the sinking of nuclear submarines, e.g. the Komsomolets in 1989 and the Kursk in 2000. In none of the cases have any significant contamination of the seawater around the vessel been detected. The same applies to the two sunken US nuclear submarines, Thresher and Scorpion. The Kursk accident has also demonstrated that if a submarine sinks at depth of at least down to 100 m it can if necessary be recovered.

There have been no serious accidents with spent fuel, but the pool of a spent fuel storage facility in Andrejev Bay at Zapadnaya Litsa developed a leak which caused contamination of the surrounding area. However, this contamination was too small to be measured outside the Zapadnaya Litsa Bay.

It can not be excluded that in the future accidents may happen at the Northern Fleet and give rise to release of radioactive materials, which may have serious consequences for the people nearby. However, both experience and theoretical considerations confirm, that such accidents will not have significant consequences for the Nordic countries, even though it may well be possible in these countries to measure radioactive nuclides released by such accidents.

Therefore the potential threat to the Nordic countries from Russian nuclear ships is quite small.

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APPENDIX I. DATA FOR RUSSIAN NUCLEAR NAVAL VESSELS

This appendix contains tables of data for Soviet/Russian nuclear naval vessels. The data are primarily obtained from:

(1) A.S.Pavlov: Warships of the USSR and Russia 1945-1995. Chatham Publishing, 1997

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The meaning of the entrances given below is as follows:

Russian Class: Russian designation of the class. Usually a project number, sometimes also a name
NATO Class: NATO designation, always a name
Role: Attack, guided missile, ballistic missile or research submarine
Displacement: Surface displacement/submerged displacement
Dimensions: Length×beam×height (not including the sail or conning tower)
No. of comp.: Number of compartments. If available, also the use of the compartments
Diving Depth: Design depth/max. depth?
Armament: Number of missiles and torpedo tubes. At the early submarines the torpedo tubes were designed for firing torpedoes only. Later on they may also be used to fire cruise missiles. This means that the difference between attack and cruise missile submarines became less distinct
Machinery: Number of reactors, designation and power level, number of shafts, and shaft horse power. All reactors used are pressurised power reactors, except for Project 645 and the Alfa class, which used a liquid metal (a Pb-Bi eutectic alloy) cooled, intermediate neutron energy reactor
Speed: Surface speed/submerged speed in knots
Crew: Total number of crew members
Design: Name of design bureau and chief designer(s)
Shipyard: Yard where the submarines were built
Built during: Period during which construction took place
Number built: Total number of submarines built

No. op. 2000: Number in operation in 2000

SUBMARINE DATA

Russian Class: Project 627 and 627A (KIT)
NATO Class: **November**
Role: Attack submarine
Displacement: 627: 3101/4069 t; 627A: 3087/3986 t
Dimensions: 107.4×7.96×6.42 m
No. of comp.: 9
(1) torpedo room and quarters
(2) officers mess and quarters, sonar, batteries
(3) command center
(4) diesel generator, refrigerators, compressors, evaporators
(5) reactors
(6) turbines
(7) electrical motors, reactor control and quarters
(8) quarters, galley, sick bay
(9) quarters, steering gear, provisions
Diving Depth: 300/240 m
Armament: Eigth 533 mm torpedo tubes (bow)
Machinery: Two reactors (VM-A, 70 MWt each), two shaft, 35 000 HP
Speed: 15.5/28 kts
Crew: 110 man
Design: SKB-143, later merged into TsKB-16 Malakhit, V.Peregudov and A.Shmadov
Shipyard: Severodvinsk
Built during: 1955 -1963
Number built: 14
No. op. 2000: 0

Russian Class: Project 659 and 659T
NATO Class: **Echo-1**
Role: Cruise missile submarine, later attack submarines
Displacement: 3731/4920 t
Dimensions: 111.2×9.2×7.6 m
No. of comp.: 10?
Diving Depth: 300/240 m
Armament: Six cruise missiles; four 533mm bow and four 406mm stern torpedo tubes
Machinery: Two reactors (VM-A, 70 MWt each), two shafts, 35 000 HP
Speed: 21-29 kts
Crew: 120 man
Design: TsKB-18 Rubin, P.P.Pustyntsev and N.A.Klimov
Shipyard: Komsomolsk
Built during: 1957 -1962
Number built: 5
No. op. 2000: 0

Russian Class: Project 658, 658M, 701
NATO Class: **Hotel**
Role: Ballistic missile submarine
Displacement: 4030/5000 t
Dimensions: 658: 114.1×9.2×7.31 m; 701: 127×9.2×7.1 m
No. of comp.: 10
(1) Torpedo room
(2) Quaters, batteries?
(3) Command center?
(4) Missile compartment?
(5) Diesel generators, reactor control room, quarters
(6) Reactor room
(7) Turbine room
(8) Electric generators
(9)Auxiliary installations, galley, quarters
(10) Quarters, torpedo room
Diving Depth: 300/250 m
Armament: 658: three ballistic missiles; 701: six missiles; four 533mm and two 406mm stern torpedo tubes
Machinery: Two reactors (VM-A, 140 MWt each), 2 shafts, 39 200 HP
Speed: 21-26 kts
Crew: 128 man
Design: TsKB-18 Rubin, S.N.Kovalyov
Shipyard: Severodvinsk
Built during: 1958 -1962
Number built: 8
No. op. 2000: 0

Russian Class: Project 645
NATO Class: - (November class hull)
Role: Attack submarine
Displacement: 3420/4380 t
Dimensions: 109.8×8.3×5.85 m
No. of comp.: 9
(1) torpedo room
(2) batteries and quarters
(3) command centre
(4) reactors
(5) turbogenerators, diesel generators, refrigerators, auxiliaries
(6) turbines, engine control room
(7) electric motors
(8) quarters and refrigerators
(9) quarters, steering gear
Diving Depth: 300/270 m
Armament: Eight 533mm torpedo tubes
Machinery: Two reactors (VT-1, 146 MWt total?), two shafts, 35 000 HP, Pb-Bi coolant
Speed: 14.7/30.2 kts
Crew: 105 man
Design: V.N.Peregudov+ A.K.Nazarov

Shipyard: Severodvinsk
Built during: 1958 -1963
Number built: 1
No. op. 2000: 0

Russian Class: Project 675, 657M (675M?), 675MKB
NATO Class: **Echo-2**
Role: Cruise missile submarine
Displacement: 4500/5760 t
Dimensions: 115.4×9.3×7.1 m
No. of comp.: 10
(1) torpedo room
(2) batteries, quaters and officers mess
(3) radar transmitter and missile fire control
(4) command centre
(5) diesel generator and condensors
(6) reactors
(7) turbines
(8) electric motors
(9) quarters, galley, sick bay, refrigerators
(10) torpedo room, provisions, steering gear.
Diving Depth: 300/240 m
Armament: Eight cruise missiles, four 533mm bow and two 406mm stern torpedo tubes
Machinery: Two reactors (VM-A, 70 MWt each), two shafts, 39 000 HP
Speed: 15/23 kts
Crew: 137 man
Design: TsKB-18 Rubin, P.P.Pustyntsev
Shipyard: Komsomolsk and Severodvinsk
Built during: 1961 -1967
Number built: 29
No. op. 2000: 0

Russian Class: Project 661 (ANCHAR)
NATO Class: **Papa**
Role: Cruise missile submarine, titanium pressure hull
Displacement: 5197/7000 t
Dimensions: 106.92×11.5×8.2 m
No. of comp.: 9
(1) torpedo roomand battery
(2) torpedo room and battery
(3) quarters and batteries
(4) command center and quaters
(5) reactors
(6) turbines
(7) turbogenerators, main switchboard
(8) auxiliaries (refrigerators, compressors)
(9) electric motors and steering equipment
Diving Depth: 550/400 m
Armament: 10 missiles; four 533mm torpedo tubes

Machinery: Two reactors (177.4 MWt each), two shafts, 80 000 HP
Speed: 25/45 kts
Crew: 82 man
Design: TsKB-16 Malakit, N.N.Isanin + N.F.Shul'zhenko
Shipyard: Severodvinsk
Built during: 1963 -1969
Number built: 1
No. op. 2000: 0

Russian Class: Project 667
NATO Class: **Yankee**
Role: Ballistic missile submarine. Some later modified to cruise missile submarines (Project 667AT (GRUCHA) or Yankee-Notch). Two were rebuilt for special duties (Project 09774 Akson or Yankee- Pod) and one was modified to become a midget-submarine carrier (Project 09780 or Yankee-Stretch).
Displacement: 7766/9300 t
Dimensions: 129.8×11.7×8.7 m
No. of comp.: 10
(1) Torpedo room
(2) Officers quarters, batteries
(3) Command center
(4) Missile room
(5) Mess, quarters
(6) Reactor control room, diesel generator, quarters
(7) Reactor room
(8) Main turbine
(9)
(10)
Diving Depth: 450/380 m
Armament: 16 ballistic missiles; four 533mm and two 406mm torpedo tubes
Machinery: Two reactors (VM4/2, 89.2 MWt each), two shafts, 52 000 HP
Speed: 16/26 kts
Crew: 120 man
Design: TsKB-18 Rubin, S.N.Kovalyov
Shipyard: Severodvinsk (Project NAVAGA) and Komsomolsk (Project NALIM)
Built during: 1964 -1972
Number built: 34
No. op. 2000: 2 (1 Yankee Notch, 1 Yankee (other roles))

Russian Class: Project 671,671V, 6712K (ERSH)
NATO Class: **Victor-1**
Role: Attack submarine
Displacement: 4108/6085 t
Dimensions: 92.5×10.6×7.3 m
No. of comp.: 7
(1) torpedo room, quaters, batteries
(2) command center
(3) reactors
(4) turbines

(5) quaters and diesel generators
(6) auxiliary equipment
(7) electric motors
Diving Depth: 400/320 m
Armament: Six 533mm torpedo tubes
Machinery: Two reactors (VM-4T, 72 MWt each), one shaft?, 31 000 HP
Speed: 12/32 kts
Crew: 76 man
Design: TsKB-16 Malakhit, G.N.Tchyernyshov
Shipyard: Admirality Yard, Leningrad
Built during: 1965 -1974
Number built: 18
No. op. 2000: 0

Russian Class: Project 670A (SKAT)
NATO Class: **Charlie-1**
Role: Cruise missile submarine
Displacement: 3574/4980 t
Dimensions: 94.3×9.9×7.5 m
No. of comp.: ?
Diving Depth: 350/270 m
Armament: Eight cruise missiles; four 533mm and two 406mm torpedo tubes
Machinery: One reactor (VM-4, 89.2 MWt), one shaft, 18 800 HP
Speed: 12/26 kts
Crew: 100 man
Design: TsKB-112 Lazurit, V.P.Vorob'ev
Shipyard: Gorkiy
Built during: 1967 -1972
Number built: 11
No. op. 2000: 0

Russian Class: Project 671RT (SEGMA)
NATO Class: **Victor-2**
Role: Attack submarine
Displacement: 4675/7190 t
Dimensions: 101.8×10.78×7.3 m
No. of comp.: 8
(1) torpedo room, battery
(2) quarters, sick bay, falley, officers mess
(3) command center, navigation, sonar
(4) reactors
(5) turbines
(6) turbogenerators, auxiliary equipment, refrigerators
(7) quarters, dieselgenerators
(8) steering gear, creep motors
Diving Depth: 400/320 m
Armament: four 533mm and two 650mm torpedo tubes
Machinery: two reactors (MWt), one shaft, 31 000 HP
Speed: 12/31.7 kts
Crew: 96 man

Design: TsKB-16 Malakhit (?), G.N.Tchyernyshov
Shipyard: Admirality Yard, Leningrad, and Gorkiy
Built during: 1971 -1978
Number built: 7
No. op. 2000: 0

Russian Class: Project 667B (MURENA)
NATO Class: **Delta-1**
Role: Ballistic missile submarine
Displacement: 7800/10 000 t
Dimensions: 139×11.7×8.4 m
No. of comp.: 10?
Diving Depth: 550/390 m
Armament: 12 ballistic missiles; four 533mm and two 406mm torpedo tubes
Machinery: Two reactors (VM-4 type, ? MWt), two shafts, 52 000 HP
Speed: 16/26 kts
Crew: 120 man
Design: TsKB-18 Rubin, S.N.Kovalyov
Shipyard: Severodvinsk and Komsomolsk
Built during: 1971 -1978
Number built: 18
No. op. 2000: 2

Russian Class: Project 667BD (MURENA-M)
NATO Class: **Delta-2**
Role: Ballistic missile submarine
Displacement: 9350/10.500 t
Dimensions: 155×11.7×8.6 m
No. of comp.: 10
  (1) torpedo
  (2) batteries and officers quaters
  (3) central command post
  (4) missiles
  (5) missiles
  (6) diesel gernerators
  (7) reactors
  (8) turbines
  (9) turbines
  (10) electrical compartment
Diving Depth: 550/390 m
Armament: 16 ballistic missiles; four 533mm and two 406mm torpedo tubes
Machinery: Two reactors (VM type, ? MWt), two shafts, 55 000 HP
Speed: 14/25 kts
Crew: 126 man
Design: TsKB-18 Rubin, S.N.Kovalyov
Shipyard: Severodvinsk
Built during: 1973 -1975
Number built: 4
No. op. 2000: 0

Russian Class: Project 670M (SKAT-M)
NATO Class: **Charlie-2**
Role: Cruise missile submarine
Displacement: 4372/5500 t
Dimensions: 104.9×9.9×7.8 m
No. of comp.: One compartment more than Charlie-1
Diving Depth: 320/250 m
Armament: Eight missiles; four 533mm and two 406mm torpedo tubes
Machinery: Two reactors (VM-4, 47.5 MWt each), one shaft, 18 800 HP
Speed: 15/24 kts
Crew: 98 man
Design: TsKB-112 Lazurit
Shipyard: Gorkiy
Built during: 1973 -1980
Number built: 6
No. op. 2000: 0

Russian Class: Project 667BDR (KAL'MAR)
NATO Class: **Delta-3**
Role: Ballistic missile submarine
Displacement: 8940/10 600 t
Dimensions: 155×11.7×8.7 m
No. of comp.: 11
Diving Depth: ?
Armament: 16 ballistic missiles; four 533mm and two 406mm torpedo tubes
Machinery: Two reactor (? MWt), two shafts, 80 000 HP
Speed: 14/25 kts
Crew: 130 man
Design: Tskb-18 rubin, S.M.Koralyov
Shipyard: Severodvinsk
Built during: 1975 -1982
Number built: 14
No. op. 2000: 7

Russian Class: Project 705 and 705K (LIRA)
NATO Class: **Alfa**
Role: Attack submarine, titanium alloy hull, highly automated
Displacement: 2310/4320 t
Dimensions: 79.5×9.5×6.9 m
No. of comp.: Six, only two manned
Diving Depth: 350/420 m
Armament: Six 533mm bow torpedo tubes
Machinery: One reactor (705: OK-550; 705K: BM-40A, 155 MWt), one shaft, 38 000 HP
Speed: 14/43 kts
Crew: 30 man
Design: TsKB-16 Malakhit, A.B.Petrov, M.G.Rusanov
SKB-143 Volna, V.A.Romin
Shipyard: Admirality Yard, Leningrad, and Severodvinsk
Built during: 1977 -1983

Number built: 7
No. op. 2000: 0

Russian Class: Project 941 (AKULA)
NATO Class: **Typhoon**
Role: Ballistic missile submarine
Displacement: 24 500/33 800 t
Dimensions: 175×22.8×11.5 m
No. of comp.: 19 sections in two separate pressure hulls. Three separate sections: torpedo, central and steering. Missile launchers between pressure hulls
Diving Depth: ?
Armament: 20 ballistic missiles; four 533mm and two 650mm torpedo tubes
Machinery: Two reactor (OK-650, 190 MWt each), two shafts, 100 000 HP
Speed: 16/27 kts
Crew: 150 man
Design: TsKB-18 Rubin, S.N.Kovalev
Shipyard: Severodvinsk
Built during: 1977 -1989
Number built: 6
No. op. 2000: 3

Russian Class: Project 685 (PLAVNIK)
NATO Class: **Mike**
Role: Attack submarine, titanium hull
Displacement: 5750/7810 t
Dimensions: 117.5×10.7×8 m
No. of comp.: 7
(1) torpedo room, batteries, special underwatere communications
(2) quarters, officers mess, provisions, galley
(3) command center, computer complex, diesel generators
(4) reactors
(5) main switchboard, pumps
(6) geared turbine
(7) electric motors, steering gear, pumps
Diving Depth: 1000/1250 m
Armament: six 533mm bow torpedo tubes
Machinery: One reactor (OK-650B-5, 190 MWt), one shaft, 43 000 HP
Speed: 14/30.6 kts
Crew: 57 man
Design: Tskb-18 Rubin, N.A.Klimov + Yu.N.Kormilitsyn
Shipyard: Severodvinsk
Built during: 1978 -1983
Number built: 1
No. op. 2000: 0

Russian Class: Project 671RTM, 671RTMK (SHCHUKA)
NATO Class: **Victor-3**
Role: Attack submarine
Displacement: 4950/6990 t
Dimensions: 107.2×10.8×7.4 m

No. of comp.: 8
(1) Torpedo room and batteries
(2) Accomodations and mess
(3) Control room and steering
(4) Reactor compartment
(5) Turbines
(6) Turbo generators
(7) Accomodations and diesel generators
(8) Steering and electric motor
Diving Depth: 400/350 m
Armament: four 533mm and two 650mm torpedo tubes
Machinery: Two reactors (? MWt), one shaft, 31 000 HP
Speed: 18/30 kts
Crew: 100 man
Design: TsKB-16 Malakhit, G.N Tchyernyshov
Shipyard: Komsomolsk and Admirality Yard, Leningrad
Built during: 1978 -1991
Number built: 26
No. op. 2000: 7

Russian Class: Project 949 (GRANIT), 949A (ANTEIY)
NATO Class: **Oscar-1, Oscar-2**
Role: Cruise missile submarine
Displacement: 949: 12 500/17 000 t; 949A: 13 400/18 000 t
Dimensions: 949: 143×18.2×9 m; 949A: 154×18.2×9 m
No. of comp.: 10
Diving Depth: ?
Armament: 24 missiles; four 533mm and two 650mm torpedo tubes
Machinery: Two reactors (OK-650, 190 MWt each), two shafts, 98 000 HP
Speed: 949: 30 kts, 949A: 28 kst
Crew: 130 man
Design: Tskb-18 Rubin, P.P.Pustyntsev + E.L.Bazanov
Shipyard: Severodvinsk
Built during: 1978 -
Number built: 2+8 or 11
No. op. 2000: 8

Russian Class: Project 667BDRM (DELFIN)
NATO Class: **Delta-4**
Role: Ballistic missile submarine
Displacement: 10 210/12 000 t
Dimensions: 167×12.2×8.8 m
No. of comp.: 11?
Diving Depth: ?
Armament: 16 ballistic missiles; four 533mm torpedo tubes
Machinery: Two reactors (VM-4SG, ? MWt), two shafts, 60 000 HP
Speed: 14/24 kts
Crew: 130 man
Design: TsKB-18 Rubin, S.N.Kovalyov

Shipyard: Severodvinsk
Built during: 1981 -1992?
Number built: 7
No. op. 2000: 7

Russian Class: Project 945 (Barracuda), 945A (KONDOR)
NATO Class: **Sierra**
Role: Attack submarine, titanium hull
Displacement: 945: 5300/7100 t; 945A: 5200/6800 t;
Dimensions: 945: 107×11.2×8.5 m; 945A: 112.7×11.2×8.5 m
No. of comp.: 945: Six; 945A: Seven
Diving Depth: 800/700(?) m
Armament: Four 533mm and four 650mm torpedo tubes
Machinery: One reactor (OK-650B?, 190 MWt?), one shaft, 43 000 HP
Speed: 18/35 kts
Crew: 60 man
Design: TsKB-112 Lazurit, N.E.Kvasha
Shipyard: Gorkiy+Severodvinsk
Built during: 1983 -1993
Number built: 4
No. op. 2000: 3

Russian Class: Project 971 (SHCHUKA-B)
NATO Class: **Akula**
Role: Attack submarine
Displacement: 5700/7900 t
Dimensions: 108×13.5×9.6 m
No. of comp.: Eight
Diving Depth: 550/450 m
Armament: Four 533mm and four 650 torpedo tubes
Machinery: One reactor (OK-650B, 190 MWt?), one shaft, 43 000 HP
Speed: 20/35 kts
Crew: 62 man
Design: TsKB-16 Malakhit, G.N.Tchernyshov
Shipyard: Komsomolsk and Severodvinsk
Built during: 1982 -
Number built: 14-15
No. op. 2000: 8

Russian Class: Project 885 (YASEN)
NATO Class: **Granay**
Role: Cruise missile submarine
Displacement: 5900/8600 t
Dimensions: 111×12×8.4 m
No. of comp.: 8?
Diving Depth: ?
Armament: Four 533mm and 20(?) 650mm missile tubes
Machinery: One reactor (? MWt), one shaft, 43 000 HP
Speed: 19/31 kts

Crew: 50 man
Design: TsKB-18 Rubin
Shipyard: Severodvinsk
Built during: 1993 -
Number built: 0

Russian Class: Project 885 (Severodvinsk)
NATO Class: -
Role: Ballistic missile submarine; only one missile?
Displacement: 5800/8200 t
Dimensions: 111×12×8.4 m
No. of comp.: ?
Diving depth: ?
Armament: One SS-N-17 missile?
Machinery: One reactor (200 MWt), one shaft?, 43 000 HP
Speed: 31 kts
Crew: 50 man
Design: SKB-18 (Rubin?), J.N.Kormilitsin
Shipyard: Severodvinsk
Built during: 1993-
Number built: 0

Russian class: Project Borei
NATO Class: -
Role: Ballistic missile submarine
Displacement: ?
Dimensions: ?
No. of comp.: ?
Diving depth: ?
Armament: Ballistic missiles, torpedoes
Machinery: ?
Speed: ?
Crew: ?
Design: TsKB-18 Rubin
Shipyard: PO "Sevmashpredpriyatiye", Severodvinsk
Built during: 1996-
Number built: 0

Russian Class: Project 10831
NATO Class: -
Role: Research submarine
Displacement: 1600/2100 t
Dimensions: 60×7×5.1 m
No. of comp.: ?
Diving Depth: 1000 m
Armament: None
Machinery: One reactor (? MWt), one shaft, 15 000 HP
Speed: 30 kts
Crew: 25 man
Design: ?

Shipyard: Severodvinsk
Built during: ?
Number built: 1
No. op. 2000: 1?

Russian Class: Project 1851
NATO Class: **X-Ray**
Role: Research submarine
Displacement: 550/1000
Dimensions: 40×5.3×5
No. of comp.: ?
Diving Depth: ?
Armament: None
Machinery: One reactor (10 MWt), one shaft, HP
Speed: ?
Crew: ?
Design: ?
Shipyard: Sudomekh, Leningrad
Built during: 1982
Number built: 1
No. op. 2000: 1

Russian Class: Project 1910 (Kashalot)
NATO Class: **Uniform**
Role: Research submarine
Displacement: 1390/2000
Dimensions: 69×7×5.2 m
No. of comp.: ?
Diving Depth: ?
Armament: None
Machinery: One reactor (? MWt), one shaft?, 10 000 HP
Speed: 10/30 kst
Crew: 36 man
Design: ?
Shipyard: Sudamekh, Leningrad
Built during: 1982-1993
Number built: 3
No. op. 2000: 3

Next surface vessels are considered. They include missile cruisers, command ships and ice-breaking vessels. The meaning of the entrances of the tables is as follows:

Russian Class: Russian designation of the class. For naval vessels always a number, sometimes also a name
NATO Class: NATO designation only for naval vessels, always a name
Role: Missile cruiser, command ship, icebreakers
Displacement: displacement/ displacement
Dimensions: Length×beam×height
Armament: Torpedoes, missiles, guns

Machinery: Number of reactors, (designation and power level), number of shafts, and shaft horse power. All reactors used are pressurised power reactors
Speed: Speed in knots
Crew: Total number of crew members
Design: Name of design bureau and chief designer(s)
Shipyard: Yard where the ships were built
Built during: Period during which construction took place
Number built: Total number of submarines built

SURFACE VESSEL DATA

Russian Class: Project 1144, 1144.2 (ORLAN)
NATO Class: **Balcom-1 (earlier Kirov-class)**
Role: Missile cruiser
Displacement: 24 300/28 000 t
Dimensions: 251.2×28.5×9.1 m
Armament: Missiles, torpedoes, guns
Machinery: Two reactors (KN-3, 300 MWt each), two shaft, 140 000 HP
Speed: 31 kts
Crew: 610 man
Design: Northern PKB(?), B.I.Kupyenskiy + V.A.Perevalov
Shipyard: Baltic Yard, Leningrad
Built during: 1974 -1996
Number built: 4
No. op. 2000: 2
Names: Kirov, renamed Adm Ushakov
Frunze, renamed Adm Lazarev
Kalinin, renamed Adm Nakhimov
Yuri Andropov, renamed Petr Velikiy Admiral Flota Sovetskogo
Soyuza Kuzneyzov (Dzerzhinskiy?)

Russian Class: Project 1941 (TITAN)
NATO Class: **Kapusta**
Role: Pacific fleet command ship (missile tests)
Displacement: 32 780/34 640 t
Dimensions: 265×29.9×7.81 m
Armament: Missiles, guns
Machinery: Two reactors (171 MWt each?), two shafts, 54 000 HP?
Speed: ?
Crew: 923
Design: ?
Shipyard: Baltic Yard, Leningrad
Built during: ?
Number built: 1
No. op. 2000: ?
Name: SSV-33

APPENDIX II. SOVIET/RUSSIAN SUBMARINES ACCORDING TO DESIGNATION

The data of the table given below have primarily been obtained from

A.S.Pavlov: Warships of the USSR and Russia 1945-1995. Chatham Publishing 1997,

but also from

T.Nilsen, I.Kudrik, A.Nikitin: The Russian Northern Fleet. Bellona !996

The table lists the designation of Soviet/Russian submarines, the corresponding class, the fleet to which they belong/belonged and the name, if available and other relevant information. The following supplementary information should also be given:

Information is not available on the bases of the 15 Victor-1 submarines. However, 13 served at the Northern Fleet and two at the Pacific Fleet. The same is the case for the 14 Delta-3 submarines. Five of this class submarines were stationed at the Northern Fleet, nine at the Pacific Fleet.

There is a difference in the numbering of the Echo-1 submarines between Pavlov and Bellona. Pavlov lists a K-151 while Bellona lists a K-259, but the total number of Echo-1 submarines is the same in the two cases, five. Presumably there is a misprint. Also for Echo-2 there is a disagreement. Pavlov lists K-131 and K-199, while Bellona lists K-189 and K-192. The total number of Echo-2 submarines is the same in both cases, 29.

In the case of Victor-2 Pavlov lists K-467 while Bellona lists K-476. Presumably. one of the designations involve a misprint. The total number of Victor-2 submarines is the same in the two cases, seven. For Victor-3 Pavlov lists K-414 and K-527, while Bellona lists K-114 and K-327. Presumably Pavlov is correct on K-414, since, if Bellona was correct, there would be two K-414 submarines. Therefore only K-114 Victor-3 class is listed in the table. The total number of Victor-3 submarines is the same in the two cases, 26.

Disagreement also exists between Pavlov and Bellona on the Delta-1 class. Here Pavlov lists K-366, 453 and 475, while Bellona lists K-336 and 465. Pavlov is presumably correct for K-366, since else there would be two K-336 submarines. Therefore, only K-336 Sierra class is listed in the table. Pavlov and Bellona agree on the total number of Delta-1 submarines built, 18, but Pavlov identifies 18, while Bellona only 17.

With respect to the Oscar-2-class there is also differences. Pavlov gives numbers for eight submarines, while Bellona states that 11 have been built, but identifies only 10. Bellona lists K-119 Vorone and K-148 Krasnodar, which are not mentioned in Pavlov. Further the name of K-173 is by Pavlov given to be Tambov, while it is given to be Chelyabinsk by Bellona. According to Bellona K-442, finished in 1991, has the name Tomsk, while according to Pavlov Tomsk was finished in 1996 but is given no K-number. In Pavlov K-442, finished in 1991, is given no name.

In the cases where there is disagreement between Pavlov and Bellona on the designations, the last colums of the table below is started with a ?.

Designation	Class	Fleet	Name and other information
K-1	Echo-2	Northern Fleet	
K-3	November	Northern Fleet	Leninskiy Komsomolets
K-5	November	Northern Fleet	
K-7	Echo-2	Pacific Fleet	renamed K-127 in 1968
K-8	November	Northern Fleet	
K-10	Echo-2	Pacific Fleet	
K-11	November	Northern Fleet	
AS-11	X-ray	Northern Fleet	
TK-12	Typhoon	Northern Fleet	
AS-12	Project:10831	Northern Fleet	
TK-13	Typhoon	Northern Fleet	
K-14	November	Pacific Fleet	
AS-15	Uniform	Northern Fleet	
K-16	Hotel	Northern Fleet	
AS-16	Uniform	Northern Fleet	
TK-17	Typhoon	Northern Fleet	
K-18	Delta-4	Northern Fleet	
K-19	Hotel	Northern Fleet	
AS-19(?)	Uniform	Northern Fleet	
TK-20	Typhoon	Northern Fleet	
K-21	November	Northern Fleet	
K-22	Echo-2	Northern Fleet	Krasnogvardeets
K-23	Echo-2	Pacific Fleet	
K-25	Charlie-1	Pacific Fleet	
K-26	Yankee	Northern Fleet	
K-27	"November"	Northern Fleet	Pb-Bi cooled reactors
K-28	Echo-2	Northern Fleet	renamed K-428
K-31	Echo-2	Pacific Fleet	renamed K-431 in 1969
K-32	Yankee	Northern Fleet	
K-33	Hotel	Northern Fleet	
K-34	Echo-2	Pacific Fleet	Kefal, renamed K-134
K-35	Echo-2	Northern Fleet	
K-38	Victor-1		
K-40	Hotel	Northern Fleet	
K-42	November	Pacific Fleet	Rostovskiy Komsomolets
K-43	Charlie-1	Pacific Fleet	leased to India 1988-91
K-44	Delta-3		

K-45	Echo-1	Pacific Fleet	
K-47	Echo-2	Northern Fleet	
K-48	Echo-2	Pacific Fleet	
K-50	November	Northern Fleet	renamed K-60
K-51	Delta-4	Northern Fleet	
K-52	November	Northern Fleet	
K-53	Victor-1		
K-55	Hotel	Pacific Fleet	
K-56	Echo-2	Pacific Fleet	
K-57	Echo-2	Pacific Fleet	renamed K-557
K-59	Echo-1	Pacific Fleet	
K-60	November	Northern Fleet	earlier K-50
K-64	Delta-4	Northern Fleet	
K-66	Echo-1	Pacific Fleet	
K-69	Victor-1		renamed K(B?)-369
K-71	Echo-2	Northern Fleet	renamed K166
K-74	Echo-2	Northern Fleet	
K-84	Delta-4	Northern Fleet	
K-86	Echo-2	Northern Fleet	
K-87	Charlie-1	Pacific Fleet	renamed K-212 in 1972
K-90	Echo-2	Pacific Fleet	
K-92	Delta-2	Northern Fleet	
K-94	Echo-2	Pacific Fleet	
K-104	Echo-2	Northern Fleet	renamed K-144
K-108	Echo-2	Pacific Fleet	
K-114	Delta-4	Northern Fleet	
K-115	November	Pacific Fleet	
K-116	Echo-2	Pacific Fleet	
K-117	Delta-4	Northern Fleet	
K-119	Oscar-2	Northern Fleet	? Vorone(sh?)
K-121	Charlie-1	Pacific Fleet	
K-122	Echo-1	Pacific Fleet	
K-123	Alfa	Northern Fleet	Pb-Bi-cooled reactor
K-125	Echo-2	Northern Fleet	
K-127	Echo-2	Pacific Fleet	until 1968 K-7
K-128	Echo-2	Pacific Fleet	
K-129	Delta-3		
K-131	Echo-2		?
K-132	Oscar-2	Pacific Fleet	? Belgorod
K-133	November	Pacific Fleet	
K-134	Echo-2	Pacific Fleet	until 1968 K-34 Kefal
K-135	Echo-2	Pacific Fleet	
K-137	Yankee	Northern Fleet	Leninets
K-138	Victor-3	Northern Fleet	
K-140	Yankee	Northern Fleet	
K-141	Oscar-2	Northern Fleet	Kursk
K-144	Echo-2	Northern Fleet	earlier K-104
K-145	Hotel	Northern Fleet	
K-147	Victor-1		
K-148	Oscar-2	Northern Fleet	? Krasnodar

K-149	Hotel	Northern Fleet	Ukrainskiy Komsomolets
K-151	Echo-1	Pacific Fleet	?
K-157	Akula	Northern Fleet	Tigr
K-159	November	Northern Fleet	
K-162	Papa	Northern Fleet	renamed K-222?
K-166	Echo-2	Northern Fleet	earlier K-71
K-171	Delta-1	Pacific Fleet	
K-172	Echo-2	Pacific Fleet	
K-173	Oscar-2	Pacific Fleet	Tambov? Chelyabinsk?
K-175	Echo-2	Pacific Fleet	
K-178	Hotel	Pacific Fleet	
K-180	Delta-3		
K-181	November	Northern Fleet	
K-182	Delta-2	Northern Fleet	Shestidesyatiletie Velikogo Oktyabrya
K-184	Echo-2	Pacific Fleet	
K-186	Oscar-2	Northern Fleet	Omsk
K-189	Echo-2	Pacific Fleet	?
K-192	Echo-2	Northern Fleet	?
K-193	Delta-2	Northern Fleet	
K-199	Echo-2		?
K-201	Charlie-1	Pacific Fleet	
TK-202	Typhoon	Northern Fleet	
K-206	Oscar-1	Northern Fleet	Murmansk
K-207	Yankee	Northern Fleet	
TK-208	Typhoon	Northern Fleet	
K-209	Charlie-2	Northern Fleet	
K-210	Yankee	Northern Fleet	
K-211	Delta-3		
K-212	Charlie-1	Pacific Fleet	earlier K-87
K-214	Yankee	Northern Fleet	
K-216	Yankee	Northern Fleet	
K-218	Victor-3	Northern Fleet	
K-219	Yankee	Northern Fleet	
K-222	Papa	Northern Fleet	earlier K-162?
K-223	Delta-3		
K-228	Yankee	Northern Fleet	
K-236	Yankee	Pacific Fleet	
K-239	Sierra	Northern Fleet	Karp
K-241	Yankee	Northern Fleet	
K-242	Victor-3	Pacific Fleet	50 Let Komsomolsk-na-Amur
K-244	Victor-3	Northern Fleet	
K-245	Yankee	Northern Fleet	
K-247	Victor-3	Pacific Fleet	
K-249	Yankee	Northern Fleet	
K-251	Victor-3	Pacific Fleet	
K-252	Yankee	Pacific Fleet	
K-253	Yankee	Northern Fleet	
K-254	Victor-3	Northern Fleet	
K-255	Victor-3	Northern Fleet	

K-258	Yankee	Pacific Fleet	
K-259	Echo-1	Pacific Fleet	?
K-263	Akula	Pacific Fleet	Delfin
K-264	Victor-3	Pacific Fleet	
K-266	Oscar-2	Northern Fleet	Orel, earlier Severodvinsk
K-267	Akula	Pacific Fleet	Drakon
K-276	Sierra	Northern Fleet	Krab
K-278	Mike	Northern Fleet	Komsomolets
K-279	Delta-1	Northern Fleet	
K-284	Akula	Pacific Fleet	
K-292	Victor-3	Northern Fleet	
K-298	Victor-3	Northern Fleet	
K-299	Victor-3	Northern Fleet	
K-303	Charlie-1	Pacific Fleet	K-302?
K-305	Victor-3	Pacific Fleet	
K-306	Victor-1		
K-308	Charlie-1	Pacific Fleet	
K-313	Charlie-1	Pacific Fleet	
K-314	Victor-1		
K-316	Alfa	Northern Fleet	Pb-Bi-cooled reactor
K-317	Akula	Northern Fleet	Pantera
K-320	Charlie-1	Pacific Fleet	
K-322	Akula	Pacific Fleet	Kashalot
K-323	Victor-1		50 Let SSSR
K-324	Victor-3	Northern Fleet	
K-325	Charlie-1	Pacific Fleet	
K-327	Victor-3	Northern Fleet	?
K-328	Akula	Northern Fleet	Leopard
K-331	Akula	Pacific Fleet	Narval
K-336	Sierra	Northern Fleet	Okun
K-355	Victor-3	Pacific Fleet	
K-358	Victor-3	Northern Fleet	
K-360	Victor-3	Pacific Fleet	
K-366	Delta-1	Pacific Fleet	
K-367	Victor-1		
K(B?)-369	Victor-1		earlier K-69
K-370	Victor-1		
K-371	Victor-2	Northern Fleet	
K-373	Alfa	Northern Fleet	Pb-Bi-cooled reactor
K-377	Alfa	Northern Fleet	Pb-Bi-cooled reactor
K-385	Delta-1	Northern Fleet	Murmanskiy Komsomolets
K-387	Victor-2	Northern Fleet	
K-388	Victor-3	Northern Fleet	
K-389	Yankee	Pacific Fleet	
K-391	Akula	Pacific Fleet	Kit
K-395	Yankee	Northern Fleet	
K-398	Victor-1		
K-399	Yankee	Pacific Fleet	
K-403	Yankee	Northern Fleet	
K-407	Delta-4	Northern Fleet	

K-408	Yankee	Northern Fleet	
K-410	Oscar-2	Northern Fleet	Smolensk
K-411	Yankee	Northern Fleet	
K-412	Victor-3	Pacific Fleet	
K-414	Victor-3	Northern Fleet	?
K-415	Yankee	Northern Fleet	
K-417	Delta-1	Pacific Fleet	
K-418	Yankee	Northern Fleet	
K-419	Akula	Pacific Fleet	Morzh
K-420	Yankee	Northern Fleet	
K-421	Delta-2	Northern Fleet	
K-423	Yankee	Northern Fleet	
K-424	Delta-3		
K-426	Yankee	Northern Fleet	
K-428	Echo-2	Northern Fleet	earlier K-28
K-429	Charlie-1	Pacific Fleet	
K-430	Yankee	Pacific Fleet	
K-431	Echo-2	Pacific Fleet	earlier K-31
K-432	Alfa	Northern Fleet	Pb-Bi-cooled reactor
K-433	Delta-3		
K-434	Yankee	Pacific Fleet	
K-436	Yankee	Pacific Fleet	
K-438	Victor-1		
K-441	Delta-3		
K-442	Oscar-2	Pacific Fleet	? Tomsk?
K-444	Yankee	Northern Fleet	
K-446	Yankee	Pacific Fleet	
K-447	Delta-1	Northern Fleet	
K-448	Victor-3	Northern Fleet	
K-449	Delta-3		
K-450	Delta-1	Northern Fleet	
K-451	Yankee	Pacific Fleet	
K-452	Charlie-2	Northern Fleet	Berkut
K-453	Delta-1	Northern Fleet	?
K-454	Victor-1		
K-455	Delta-3		
K-456	Oscar-2	Pacific Fleet	Kasatka
K-457	Delta-1	Northern Fleet	
K-458	Charlie-2	Northern Fleet	
K-460	Delta-1	Northern Fleet	
K-461	Akula	Northern Fleet	Volk
K-462	Victor-1		
K-463	Alfa	Northern Fleet	Pb-Bi-cooled reactor
K-465	Delta-1	Northern Fleet	?
K-467	Victor-2	Northern Fleet	?
K-469	Victor-1		
K-472	Delta-1	Northern Fleet	
K-475	Delta-1	Northern Fleet	?
K-476	Victor-2	Northern Fleet	?
K-477	Delta-1	Pacific Fleet	

K-479	Charlie-2	Northern Fleet	
K-480	Akula	Northern Fleet	Bars
K-481	Victor-1		
K-487	Delta-3		
K-488	Victor-2	Northern Fleet	
K-490	Delta-3		
K-492	Victor-3	Pacific Fleet	
K-493	Alfa	Northern Fleet	Pb-Bi-cooled reactor
K-495	Victor-2	Northern Fleet	
K-496	Delta-3		
K-497	Delta-1	Pacific Fleet	
K-500	Delta-1	Pacific Fleet	
K-502	Victor-3	Northern Fleet	
K-503	Charlie-2	Northern Fleet	
K-506	Delta-3		
K-507	Victor-3	Pacific Fleet	
K-508	Charlie-2	Northern Fleet	
K-512	Delta-1	Pacific Fleet	70 Ley Viksm
K-513	Victor-2	Northern Fleet	
K-517	Victor-2	Northern Fleet	
K-523	Delta-1	Pacific Fleet	
K-524	Victor-3	Northern Fleet	60 Let Shefstva Vlksm
K-525	Oscar-1	Northern Fleet	? Arkhangelsk, earlier Minskiy
Komsomolets			
K-527	Victor-3	Northern Fleet	?
K-530	Delta-1	Pacific Fleet	
K-534	Sierra	Northern Fleet	Zubatka
K-557	Echo-2	Pacific Fleet	earlier K-57
K-?	Oscar-2	Northern Fleet	? Tomsk?
K-?	Sierra	Northern Fleet	? Barracuda
K-?	Sierra	Northern Fleet	? Condor
K-?	Akula	Northern Fleet	Gepard
K-?	Akula	Northern Fleet	Vepr'
K-?	Akula	Pacific Fleet	? Nerpa

APPENDIX III. CROSS SECTIONS OF RUSSIAN NUCLEAR SUBMARINES

In this appendix available cross sections of Russian nuclear submarines are shown. They have been obtained from ref. 2 and 6.

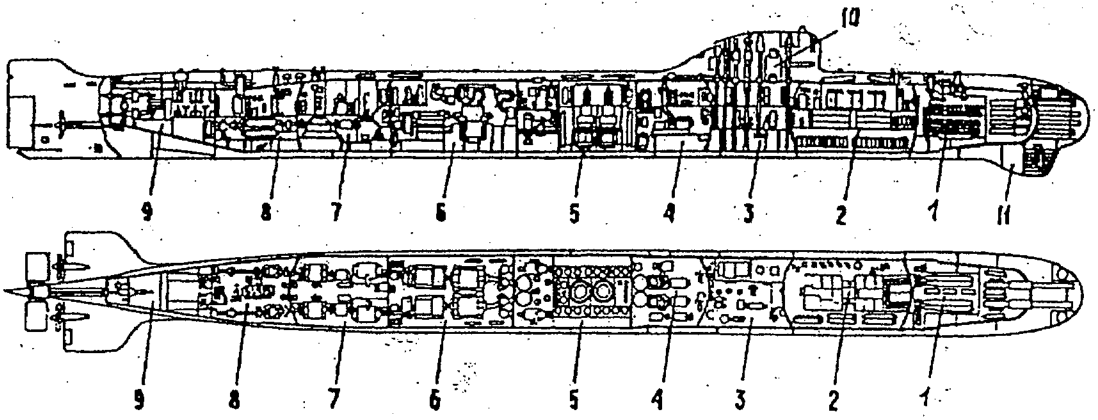
The November class (Project 627) submarine is an attack submarine.

The Project 645 class submarine had a November class hull, but was provided with two liquid metal cooled reactors and was more an experimental than an attack submarine.

The Charlie (Project 670M) and Granay (Project 885) class submarines are cruise missile submarines. Construction of the first Granay class submarine was started, but as far as is known never finished.

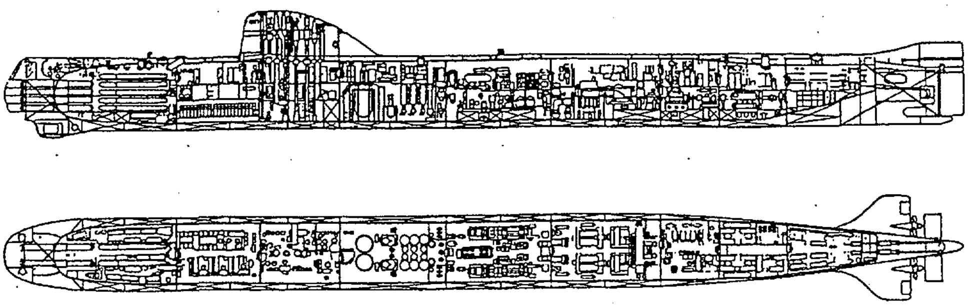
The Delta-3 (Project 667BDR) and Typhoon (Project 941) class submarines are both ballistic missile submarines.

November Class, Project 627

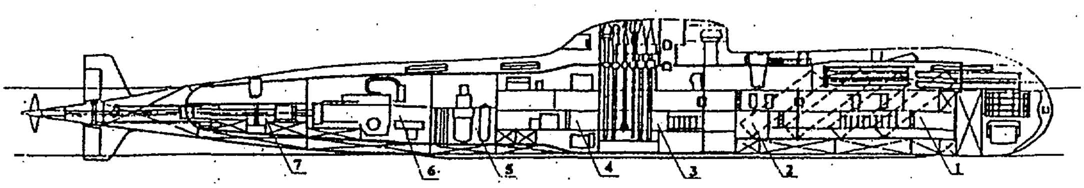


1 - torpedo compartment; 2 – accumulatorbattery compartment; 3 - central control posi 4 diesel compartment; 5 reor compartment; 6 - main machinery compartment;7- electric motors compartment; 8 - accommdation compartment; 9 - aft mpartment; 10- conning tower, 11 - antenna of a hydrolocaor.

Project 645 (November Class Hull)

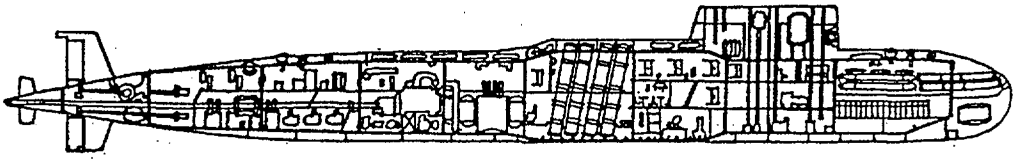


Charlie-2, Project 670M

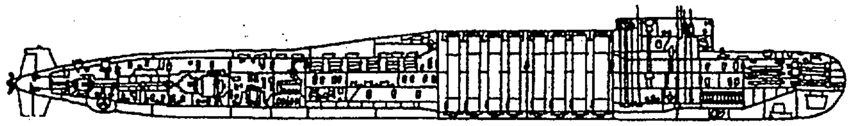


1 - torpedo compartment; 2 - accommodations and battery compartment; 3 - central operation control room; 4 - auxiliary equipment room; 5 - reactor compartment; 6 - main machinery room; 7 - propulsion plant auxiliary mechanisms room/

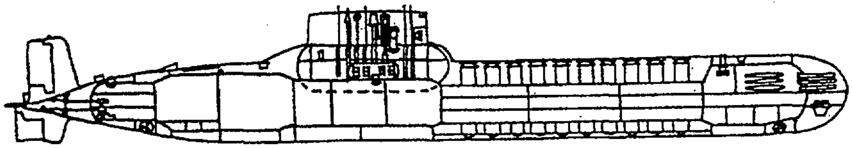
Granay, Project 885



Delta-3, Project 667BDR



Typhoon, Project 941



Bibliographic Data Sheet NKS-57

Title	The Potential Risks from Russian Nuclear Ships. NKS-SBA-1 Status Report
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Affiliation(s)	Risoe National Laboratory, Denmark
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Date	November 2001
Project	NKS/SBA-1
No. of pages	58
No. of tables	6
No. of illustrations	14
No. of references	33
Abstract	A review is given of the information available on the Russian nuclear ships including submarines, cruisers and icebreaking ships with special emphasis on the vessels of the Northern Fleet and the Russian icebreakers. A significant part of these ships has today been taken out of active service, and they are in various stages of decommissioning. Information on the decommissioned vessels, their storage sites and the procedures planned for the further decommissioning works is discussed. The handling of spent nuclear fuel is also considered. The various types of accidents, which might occur with these ships, operational as well as decommissioned, are considered, and examples of actual accidents with operational vessels are presented. The types of accidents considered include criticality accidents, loss-of-coolant accidents, fires/explosions and sinking. Some measures taken by the Russians to avoid such accidents are discussed. The special problems connected to the two decommissioned submarines of the Northern Fleet, which have damaged cores, are mentioned. In appendices data on the Russian nuclear vessels are presented.
Key words	Nuclear submarines, nuclear icebreakers, naval reactors, Russia, decommissioning, spent fuel, nuclear accidents, damaged reactors

Available on request from the NKS Secretariat, P.O.Box 30, DK-4000 Roskilde, Denmark.
Phone (+45) 4677 4045, fax (+45) 4677 4046, e-mail nks@catscience.dk, www.nks.org