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Russian Nuclear Power Plants for Marine Applications

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Abstract

In order to establish a systematic approach for future proliferation and environmental analyses of Russia's marine nuclear reactor systems, this paper summarizes and analyzes the available open-source information on the design properties of reactor systems and nuclear fuels. The most distinctive features of Russian marine reactor development are pointed out, and similarities and differences between Russian military and civilian reactor systems and fuel are discussed. Relevant updated information on all Russian vessels using nuclear propulsion is presented in Annex I. The basic analytic division in this paper follows vessel generations – first to third generation; and reactor types – PWR and LMC technology. Most of the available information is related to nuclear icebreakers. This information is systematically analyzed in order to identify stages in the development of Russia's civilian naval nuclear reactors. Three different reactor models are discussed: OK-150, OK-900 and KLT-40, together with several versions of these. Concerning military reactors, it is not possible to identify characteristics for the individual reactor models, so the basic division follows vessel generations – first to third generation. From the information available, however, it is possible to identify the main lines along which the design of submarines of especially the first and the second generation has been made. The conclusions contain a discussion of possible implications of the results, in addition to suggestions for further work.

Key words

submarines, icebreakers, Russia, design, marine reactors, naval reactors, OK-150, OK-900, KLT-40

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Russian Nuclear Power Plants for Marine Applications

by

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Abstract

In order to establish a systematic approach for future proliferation and environmental analyses of Russia’s marine nuclear reactor systems, this paper summarizes and analyzes the available open-source information on the design properties of reactor systems and nuclear fuels. The most distinctive features of Russian marine reactor development are pointed out, and similarities and differences between Russian military and civilian reactor systems and fuel are discussed. Relevant updated information on all Russian vessels using nuclear propulsion is presented in Annex I. The basic analytic division in this paper follows vessel generations – first to third generation; and reactor types – PWR and LMC technology. Most of the available information is related to nuclear icebreakers. This information is systematically analyzed in order to identify stages in the development of Russia’s civilian naval nuclear reactors. Three different reactor models are discussed: OK-150, OK-900 and KLT-40, together with several versions of these. Concerning military reactors, it is not possible to identify characteristics for the individual reactor models, so the basic division follows vessel generations – first to third generation. From the information available, however, it is possible to identify the main lines along which the design of submarines of especially the first and the second generation has been made. The conclusions contain a discussion of possible implications of the results, in addition to suggestions for further work.

Keywords: Russian marine reactors, reactor design, nuclear fuel, submarines, radioactivity, non-proliferation, impact assessments

Foreword

In 2003, Nordic Nuclear Safety Research (NKS) sponsored a seminar on the safety of Russian nuclear submarines and the risk for releases of radioactivity. The following recommendation was made at the seminar:

> *"The main recommendation made (…) was that there still is a need for analyzing specific elements related to source term analysis of Russian marine reactors and naval fuel when considering possible accidents and consequences for the Nordic countries: if available, evaluating all available design information for marine reactors and fuel, complete studies of release fractions for specific accidents (LOCA, criticality accidents when refueling/defueling) with releases to air and/or sea, examine the possibility for re-criticality in spent fuel configurations on shore (i.e. in storage at former naval bases) for PWR marine reactors and in spent removal blocks from liquid metal reactors."*

On the basis of the seminar, NKS initiated a project aimed at the preparation of two scientific reports:

Report 1:	Russian Nuclear Power Plants for Marine Applications;
Report 2:	Inventory and Source Term Evaluation of Russian Nuclear Power Plants for Marine Applications

The following paper is the first report, a result of collaboration between Risø Laboratories, Denmark, and the Norwegian Radiation Protection Authority, Norway.

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1 Introduction

The scenarios for an accident or diversion of Russian marine reactor fuel or material are numerous, almost as long as the list of actual incidents over the past decade. Major incidents include the sinking of *Komsomolets* and *Kursk*, several thefts of fresh fuel at bases in Northwest Russia, and a Russian sailor's attempt to blow up a submarine after a serious hostage situation. These incidents indicate the importance of in-depth knowledge of the characteristics of Russian marine reactors. However, this information remains a well-kept secret, in Russia as elsewhere. National security considerations have left naval nuclear propulsion activities worldwide in a shroud of secrecy. Overly strict security requirements could, however, be detrimental to sound nuclear safety and non-proliferation practices.

This report has been prepared as part of a project under the framework of the Nordic Nuclear Safety Research (NKS) and the Norwegian Research Council (NFR).

1.1 PAPER: GOAL AND STRUCTURE

This report starts with a discussion of the development and the current state of the vessel classes and generations of the Russian nuclear navy, Russian nuclear icebreaker classes and generations, and Russian nuclear submarine designs. Thereafter, available information on Russian marine reactors is presented. Other information, for example on safety systems, reactivity control systems, protective barriers and containment systems, is discussed below to the extent possible. Special emphasis is given to technical descriptions of the fuel and reactor cores as a basis for further evaluation. In this respect, fuel data occupy a special position as the basis for accidental source terms and material attractiveness in a non-proliferation perspective. The overall approach will be from two distinct different angles: icebreaker and submarine generation vs. reactor technology; and light-water or lead/bismuth coolant.

Unfortunately, obtaining comprehensive information on all these points is practically impossible. Most of the vessels considered here are military vessels, and the relevant national authorities fear that information on such vessels may be used by a potential adversary to prepare countermeasures. All countries with nuclear naval vessels are highly reluctant to make available information on their naval vessels, even in cases where the reasons for such secrecy are not immediately apparent. Fortunately, in many cases it is possible to make a reasonable assessment of the risks connected to these vessels even without full information.

Annex I presents data on the different military reactor systems in submarines and surface vessels together with general information on the vessel. Both NATO and Russian names for vessel classes are included. Annex I is based on recent Russian sources not widely distributed; if otherwise, this is mentioned specifically.

2 The Development of a Russian Nuclear-Propelled Fleet

During the late 1950s, Russia started the development of nuclear-propelled ships for both naval and civilian applications. The naval ships were initially nuclear submarines, later followed by missile cruisers and a command ship. The civilian ships were icebreakers and an icebreaking freighter to assist with shipping along the country's northern Arctic coast.

2.1 MILITARY VESSEL CLASSES AND GENERATIONS

The start was a slow one. As early as 1948 the Russian director for Institute for Problems in Physics, Academician Anatoli Aleksandrov, wanted to see a nuclear-propulsion project established. However, Stalin's right-hand man, Beria, said that nothing was to be done, as described in [Kotcher], until a nuclear bomb had been built. The bomb was finally ready, and on September 9, 1952, work on a submarine using a nuclear-propulsion reactor was officially initiated by the Council of Ministers of the Soviet Union [Demjanovski]. Six years later, the first Russian nuclear submarine was commissioned, and at 10.03 in the morning of July 4, 1958, the November-class attack submarine K-3 *Leninsky Komsomol*, containing two 70 MWt pressurized water reactors (PWR) initiated its first trip as part of the Russian Navy. This event was followed by a rapid build-up of the Russian nuclear fleet, as illustrated in Figure 2.1, which is based on [Pavlov] and [IISS].

Russia's nuclear navy peaked in the late 1980s, as can be seen from Figure 2.1. There were several reasons for the ensuing reduction of the number of nuclear vessels. Some submarines had reached the end of their useful lifetime; disarmament agreements between the USA and Soviet Union/Russia required reductions in the number of ballistic missile submarines; the Cold War was coming to an end and a large nuclear navy was no longer needed; and economic difficulties developed in Russia. Reducing the number of operational nuclear vessels of the Russian Navy automatically created a need for decommissioning and dismantling the vessels no longer needed.

The Russian submarine fleet consists primarily of attack or multi-purpose submarines for attacks on enemy vessels, of cruise missile submarines for attacks on enemy convoys or coastal facilities, and of ballistic missile submarines for deterrence and – if need be – strategic attacks on enemy territory. In addition a few small deep-water nuclear submarines have been built. In the 1980s came the Kirov-class missile cruisers and a fleet command ship. NATO has given its own names to most of the classes of Russian nuclear naval vessels. Since these NATO names are often used also in Russian publications, they will primarily be used here. The first nuclear icebreaker came into operation in the late 1950s, later followed by eight more icebreaking ships.

In this paper, the division between the generations has been made along the following lines, with only a few exceptions: The first generation was built from 1952 to 1968, the second from 1967 to 1992, and the third from 1980 (it remains an active design at Russian naval yards). Additionally, the Russian Navy has built three submarines of different designs of which only one vessel each was made. Therefore, they may be considered experimental submarines. Russia has also constructed three types of small, deep-water nuclear submarines, as well as four nuclear-powered missile cruisers and a nuclear-powered command ship. These vessels are listed in Table 2.2.

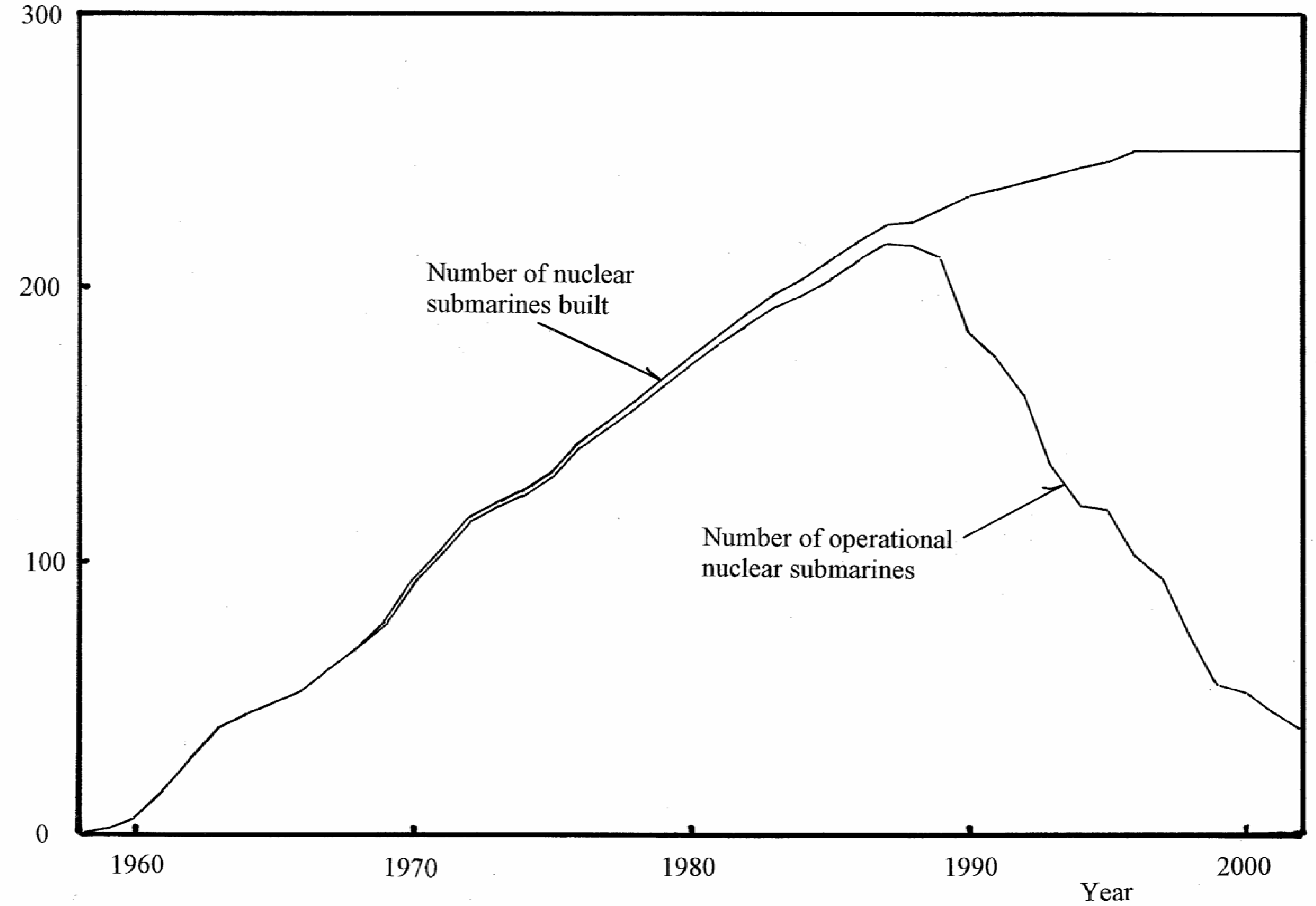

Figure 2.1 Number of Russian submarines built and of Russian nuclear submarines in operation as a function of time

The number of Russian nuclear naval vessels built, sunk and still in operation is listed in Table 2.3. The table gives the Russian project number, the corresponding NATO class name, the number of vessels built, the number of vessels sunk and the number in operation in mid-2003. It should be kept in mind that the figures may not be completely accurate. The information presented in this section is based primarily on [Pavlov], [IISS] and [Apalkov1]. Other technical data on the Russian nuclear naval vessels are given in Annex I of this report.

Table 2.1 Generations and Classes of Russian Nuclear Submarines

	Attack submarine classes	Cruise missile submarine classes	Ballistic missile submarine classes
First generation	**November class** (Project: 627 and 627A (Kit)). Built in Severodvinsk 1955–63.	**Echo-1 and -2 classes** (Project: 659, 659T, 675, 675M and 675MKB). Built in Komsomolsk by Amur 1957–67, Severodvinsk 1961–67 (only Echo-2)	**Hotel class** (Project: 658, 658M and 701). Built in Severodvinsk 1958–62
Second generation	**Victor-1, -2, and -3 class** (Project: 671, 671V, 671K (Ersh), 671RT (Segma), 671RTM and 671RTMK (Shchuka)). Built at the Admiralty Yard in Leningrad, in Gorky and in Komsomolsk 1967–87 **Alfa class** (Project: 705 and 705K (Lira)). Built at the Admiralty Yard in Leningrad, Severodvinsk 1970–83	**Charlie-1 and -2 class** (Project: 670A (Skat) and 670M (Skat-M). Built in Gorky 1967–80	**Yankee class** (Project: 667). Built in Severodvinsk and Komsomolsk 1964–72
Third generation	**Akula class** (Project: 971 (Shchuka-B)). Built in Komsomolsk, Severodvinsk 1982–95 **Sierra class** (Project: 945 (Barracuda) and 945A (Kondor)). Built at the Krasnoye Sormovo yard in Gorky and completed in Severodvinsk 1983–93	**Oscar-1 and -2 class** (Project: 949 (Granit) and 949A (Anteiy)). Built in Severodvinsk 1978–96	**Delta-1, -2, -3 and -4 class** (Project: 667B (Murena), 667BD (Murena-M), 667BDR (Kal'mar) and 667BDRM (Delfin). Built both in Severodvinsk and in Komsomolsk (only Delta-1) 1971–92 **Typhoon class** (Project: 941 (Akula)). Built in Severodvinsk 1977–89

Several systematic features for the development of the Russian military reactor can be noted. Russian nuclear submarines have in most cases a double hull, an outer hull and an inner pressure hull. The room between the two hulls is used for ballast tanks as well as equipment and weapon systems. Western nuclear submarines are in general provided with a pressure hull only. While the pressure hull is in most cases made of steel alloys, a few Russian nuclear submarines have been provided with a titanium pressure hull, as is the case for the Papa, the Mike, the Sierra and the Alfa classes. In addition to the main steam turbines which operate the shafts, the submarines are provided with turbo-generators for electric power supply. Should these generators fail, the submarines are provided with back-up diesel generators and batteries. These power sources can also be used for emergency propulsion. However, the diesel generators can operate only when the submarines are at or close to the sea surface.

Table 2.2 Experimental and deep-water nuclear submarines and nuclear surface vessels

Experimental submarines	Project: 645 (no NATO name). Attack submarine with November-class hull, built between 1958 and 1963 in Severodvinsk	Papa class (Project: 661 (Anchar)). Cruise missile submarine, built between 1963 and 1969 in Severodvinsk.	Mike class (Project: 685 (Plavnik)) Attack submarine, built between 1978 and 1983 in Severodvinsk.
Small, deep-water nuclear submarines	Project: 10831 (no NATO name). Built in Severodvinsk.	X-ray class (Project: 1851). Built around 1982 at the Sudomekh yard in Leningrad.	Uniform class (Project: 1910 (Kashalot)). Built at the Sudomekh yard in Leningrad 1982–93
Nuclear-propelled surface ships	Balcom-1 class (Project: 1144 and 1144.2 (Orlan)) Also known as Kirov class. Missile cruiser. Built at the Baltic yard in Leningrad 1974–96	Kapusta class (Project: 1941 (Titan)). Pacific Fleet command ship, built at the Baltic yard in Leningrad	

Most Russian submarines have two reactors. The exceptions are Charlie, Alfa, Mike, Sierra and Akula classes. For modern attack submarines, the trend is towards a single reactor unit. Western nuclear submarines are in almost all cases provided with one reactor only. The reason for two reactors in all early Russian nuclear submarines was presumably deliberate redundancy: even if one reactor stopped, the other could continue to operate.[1] This might have been a consequence of the lack of time for testing these early versions. The head start enjoyed by the USA goes like a red thread through many Russian publications on submarine warfare and history.

As seen in Annex I, the submerged displacement of the Russian nuclear submarines varies between 4,000 and 48,000 tons. Since vessels have to be able to operate at high speed when submerged, 25–45 knots – attack submarines are the fastest – propulsion power has to be considerable, from 20,000 to 100,000 shaft horsepower. Most of the earlier classes have two shafts, but the newer attack submarines have one shaft only. The early Russian submarines were quite “noisy” and therefore easy to detect – a major concern for Russia’s submarine designers. Much has been done to reduce the noise from the machinery of the submarines so as to avoid detection by passive sonar; in order to prevent detection by active sonar, the outer surface of submarines has been provided with a thick rubber layer.

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[1] Considering Russia’s troublesome experiences with their first-generation nuclear reactors, in addition to the lack of reason for optimizing constructions, redundancy might be a plausible explanation. In addition, the speed of the submarines could be increased. In a forthcoming publication, the first author of this paper analyzes all reported incidents and accidents involving Russian submarines of different generations. Preliminary results indicate that in the two decades from 1960 to 1980, when the Russian fleet was dominated by submarines of the first generation, these vessels experienced over 80 incidents, mostly due to leakages or reactor failures.

Table 2.3 Number of Russian Nuclear Vessels Built

Project No.	NATO name	Submarine generation	Number built	Number in operation, 2003	Constr. period
627, 627A	November	First	13	0	1955–63
659,659T	Echo-1	First	5	0	1956–62
658,658M,658 S, 701	Hotel	First	8	0	1958–62
645	–		1	0	1958–63
675,675K, 675 MK,675MKB	Echo-2	First	29	0	1961–67
661	Papa		1	0	1963–69
667, 667 AO, 667 M, 667 AT,	Yankee	Second	34	1	1964–72
671, 671V,671K	Victor-1	Second	18	0	1965–74
670, 670A	Charlie-1	Second	11	0	1967–72
671RT	Victor-2	Second	7	0	1971–78
670M	Charlie-2	Second	6	0	1973–80
705,705A	Alfa		7	0	1977–83
685	Mike		1	0	1978–83
671RTM,671RTMK	Victor-3	Second	26	5	1978–91
945,945A	Sierra	Third	4	1	1983–93
971	Akula	Third	15	9	1982–
949,949A	Oscar	Third	10 (12?)	6	1978–
667B	Delta-1	Third	18	0	1971–77
667BD	Delta-2	Third	4	0	1973–75
667BDR	Delta-3	Third	14	5	1975–81
667BDRM	Delta-4	Third	7	6	1981–92
941	Typhoon	Third	6	2	1977–89
	Borei	Fourth			
	Granay	Fourth			
	Subtotal		246	36	
10831	–		1	1	
1851	X-ray		1	1	≈1982
1910	Uniform		2	2	1982–93
	Subtotal		250	40	
1144,1144.2	Balcom-1		4	2	1974–96
1941	Kapusta		1	0	
	Subtotal		255	42	
Icebreakers			8	6	
Icebreaker	Freighter		1	1	
	Total		264	49	

According to [Barinov], 191 nuclear submarines had been decommissioned by early 2002: 115 from the Northern Fleet and 76 from the Pacific Fleet.[2] According to Figure 2.1 the total number of nuclear submarines taken out of active service by mid-2003 was 210, with 40 still in active service [IISS].[3] According to [Barinov], of the 115 decommissioned submarines of the Northern Fleet, 67 were in floating storage (51 still with fuel in the reactors), and 48 had had their reactor compartment cut out. Of the Pacific Fleet, 52 submarines were in floating storage (39 still with fuel in the reactors) while 24 had had their reactor compartments cut out. Of the 72 reactor compartments, most are in the form of three-compartment units, but some are single-compartment units or multi-compartment-units. Five three-compartment units have still fuel in their reactors; these units presumably originate from submarines in which the cores have been damaged due to an accident. It should be remembered that the figures given above are constantly changing.

2.2 CIVILIAN VESSEL CLASSES AND GENERATIONS

The first icebreaker built by Russia was *Lenin*, which went in operation in 1959 and was decommissioned in 1989. The second generation of icebreakers consisted of *Arktika* (operational in 1975), *Sibir* (operational in 1977), *Rossia* (operational in 1985), *Sovetskiy Soyus* (operational in 1989) and *Yamal* (operational in 1992). *Rossia*, *Sovetskiy Soyus* and *Yamal* incorporate several improvements as compared to *Arktika* and *Sibir*. *Sibir* was decommissioned in 1992 due to too many pluggings of its steam-generator sections [Makarov]. The last icebreaker of this generation is *Ural*, the construction of which was started, but as far as is known never finished. *Ural* seems later on to have been renamed *50 let Pobedy* (50 years of Victory), which was again renamed "*60 let Pobedy* (60 years of Victory)". According to [Nuclear Europe], the Russian government has decided to provide funds for the completion of *60 let Pobedy*. According to [Makarov], *Arktika* was to have been decommissioned in 2001, but the process has not been initiated yet. The third generation consists of *Taimyr* (operational in 1989) and *Vaigatch* (operational in 1990). Both were built at the Wartsila shipyard in Finland, but provided with nuclear propulsion systems at the Baltiskiy shipyard in Saint Petersburg (Leningrad) in Russia. Finally, there is the icebreaking freighter *Sevmorput*, which became operational in 1988. Available technical data on these ships are given in Annex I of this report.

Several icebreaker projects are under way in Russia. One is a study of *Yamal*-2 to replace *Arktika*. Another is a "super icebreaker" intended to ensure all-year navigation between Europe and Japan along the Russian Arctic coast. A third is the *Pevek* icebreaker with restricted draught, to extend the applicability of the *Taimyr* type to operate in Arctic river estuaries. Finally, Russia has plans for constructing floating power plants, as discussed in chapter 3.4. [Kovalenko]. Due to the country's financial difficulties, the future of these projects and the completion of the icebreakers under construction are uncertain.

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[2] The discrepancy between 210 and 191 may reflect the difference in time; it may indicate that 19 submarines had been taken out of active service but not yet decommissioned; it may reflect the uncertainty of the figures – or a combination of these possibilities.

[3] It should be noted that the division into submarine generations is not always unambiguous. For example, the Yankee class is sometimes placed in the first generation and the Delta-1, -2 and –3 class submarines are placed in the third generation (see e.g. [Elatomtsev]).

3 Russian Civilian Marine Reactor Systems

While only limited information is available about the design of the reactors used in Russian military naval vessels, the situation is different for the country's icebreakers. Here a significant amount of information is available on reactor design.

The reactors are all pressurized water reactors. The development of a Russian marine reactor for civilian purposes started with the OK-150 power plant, which was the first plant used in the NS *Lenin*. Later on came the OK-900 and the KLT-40 plants. The OK-900 and the KLT-40 plants exist in various versions. The plants used in the Russian civilian vessels are listed in Table 3.1.Detailed information is available for only two of these plants, OK-150 and KLT-40, and they will be considered below. A more limited amount of information is presented on OK-900.

Table 3.1 Nuclear Power Plants for Civilian Vessels

Nuclear propulsion system:	**Reactor power:**	**Shaft horse power**	**Vessel names (No. of reactors)**	**Construction and commissioning**
First generation:				
OK-150	90 MWt	44 000 shp	*Lenin* (3)	
Second generation:				
OK-900	159 MWt	44 000 shp	*Lenin* (2)	
OK-900 A	171 MWt	75 000 shp	*Arktika*, *Sibir*, *Rossiya*, *Sovetskiy Soyus*, *Yamal* (2)	
Third generation				
KLT-40	171 MWt	50 000 shp	*Taimyr*, *Vaigatch* (1)	
KLT-40 M	135 MWt	40 000 shp	*Sevmorput* (1)	
KLT-40 S			(To be used in floating power plants and desalination plants)	

3.1 THE OK-150 PLANT

The initial three reactor units of the icebreaker *Lenin* were OK-150 plants, each of which was provided with a pressurized water reactor with a power level of 90 MWt.

3.1.1 Reactor

A vertical cross-section of the reactor is shown in Figure 3.1 and a horizontal cross-section in Figure 3.2. The fuel elements were placed in a removable insert or "basket", which hung from the top of the tank. The water coolant entered the reactor tank from the bottom and flowed up through the central part of the reactor core. At the top of the central fuel elements, the coolant moved out to the periphery of the tank and down through the reflector/thermal shield. At the bottom, the coolant flow was again reversed, and the coolant flowed up through the outer fuel elements and left for the steam generators at the top of the reactor tank. In [Makarov] it is stated that the reason for locating the coolant inlet to the reactor vessel was to reduce the mass of the system. However, this design made repair of the main valves in the primary circuit difficult. The core of the first NS

Lenin reactors was 1.58 m high and had an equivalent diameter of 1 m. This means that the power density was 72 kW/ liter.

3.1.2 Fuel

The core contained 219 technical fuel channels, arranged in a triangular lattice, with a pitch of 64 mm. Out of 219 channels, 189 contained 36 fuel rods, and, according to [IIASAP], 30 contained 30 fuel rods. In total this gives 7,704 fuel rods in each core. The fuel elements of the first loading of the OK-150 reactors are shown in Figure 3.3. They were cluster-type elements with 36 fuel pins or rods (6.1 mm diameter), 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 fuels were UO2 pellets, with a diameter of 4.5mm. The first fuel load consisted of fuel enriched to 5% with a total of 80 kg. U--235 in each reactor, or 1.7 metric tons 5% enriched uranium. The gas gab between the fuel pellet and the cladding, 0.05 mm, was filled with helium. Initially the cladding material was zirconium. Minimum clearance between the fuel pins was 1.5 mm. Fuel density has not been given. Burn-up was 18,000–20,000 MWd for the first loading. In practice this corresponds to a few years of operation. The first fuel loading lasted from 1959 to 1962.

Since several leaks developed in the cladding during the operation of the first core due to fuel-cladding interaction, one of the reactors was at the first re-fueling provided with stainless steel clad fuel and the other two reactors with fuel with an improved zirconium alloy cladding. The fuel was still UO2 pellets. The fuel with stainless steel cladding (and presumably with higher enrichment) achieved an energy production 25% higher than planned. During the re-fueling all fuel was replaced. The core was designed in such a way that the temperature coefficient was moderately negative at operation temperatures. For the second core load, these parameters were changed slightly, with a zirconium-niobium alloy introduced as cladding with a thickness of 0.75 mm. The amounts of fuel in the three reactors were 129 kg. in N1 and 75 kg. in N2 and N3. The density of this fuel has not been given.

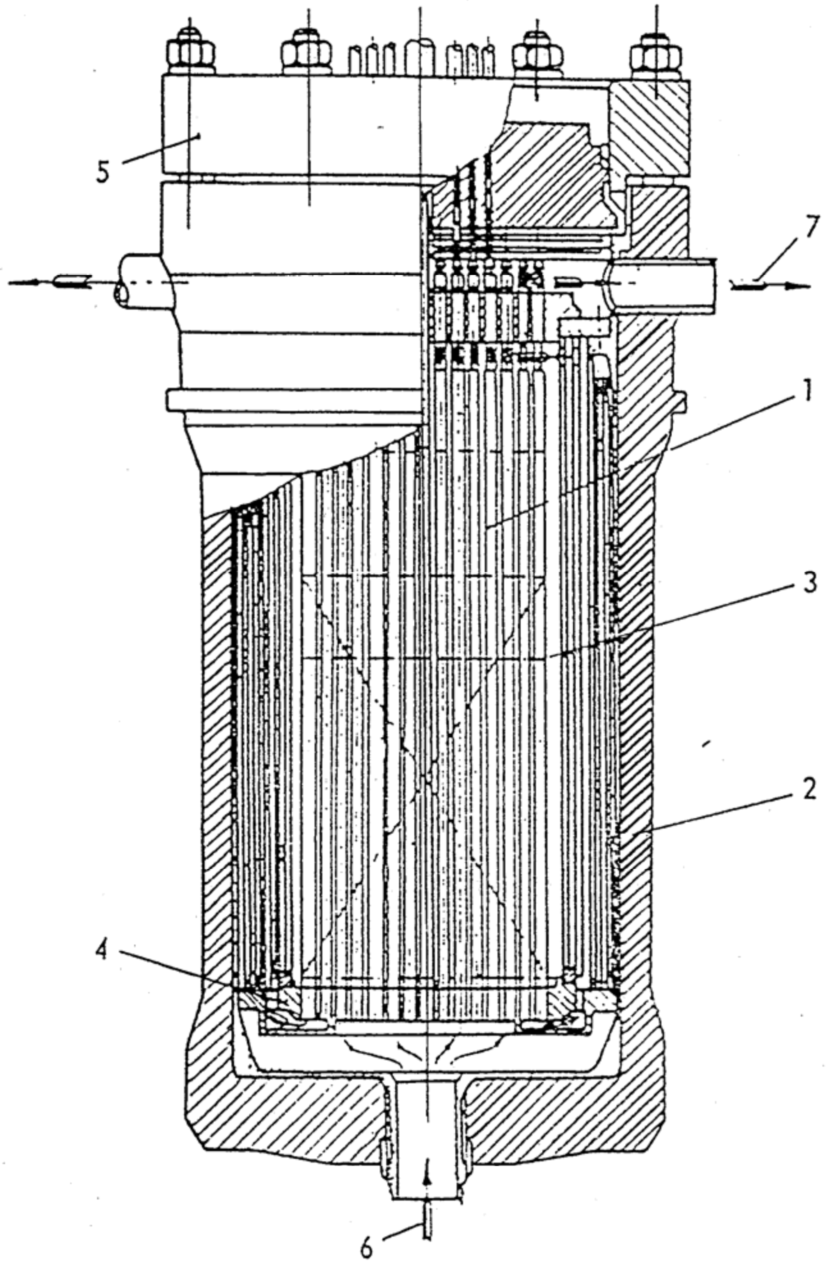
Bellona has claimed that approximately 320 fuel assemblies from the *Lenin* reactors have ended up in *Lepse.* In addition it has been claimed as part of the remediation of Andrejeva Bay that icebreaker fuel is also stored in the bay. It has not been confirmed whether this is fuel from any of the fuel batches from *Lenin*.

3.1.3 Reactivity Control

Reactor power was, thanks to the negative temperature coefficient, regulated by changing the flow rate of the feed-water and by use of three regulation rods (one of them a reserve) with a rack-and-pinion drive. Reactor shutdown was accomplished by use of safety rods. All control rods were inserted from above. Burn-up was increased by the use of burnable poison (B-10). In the first core loading, the boron was situated in the shroud tubes of the central part of the core where it also helped to flatten the power distribution in a radial direction.

3.1.4 Pressure Vessel and Radiation Shield

The pressure vessel had an outer diameter of about 2 m and a height of about 5 m. On the inside it was provided with a stainless steel layer. To protect the reactor vessel against radiation damage a thermal shield consisting of steel plates was placed between the core and the pressure vessel, and was cooled by the primary coolant.



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

Figure 3.1 Vertical cross section of the OK-150 reactor

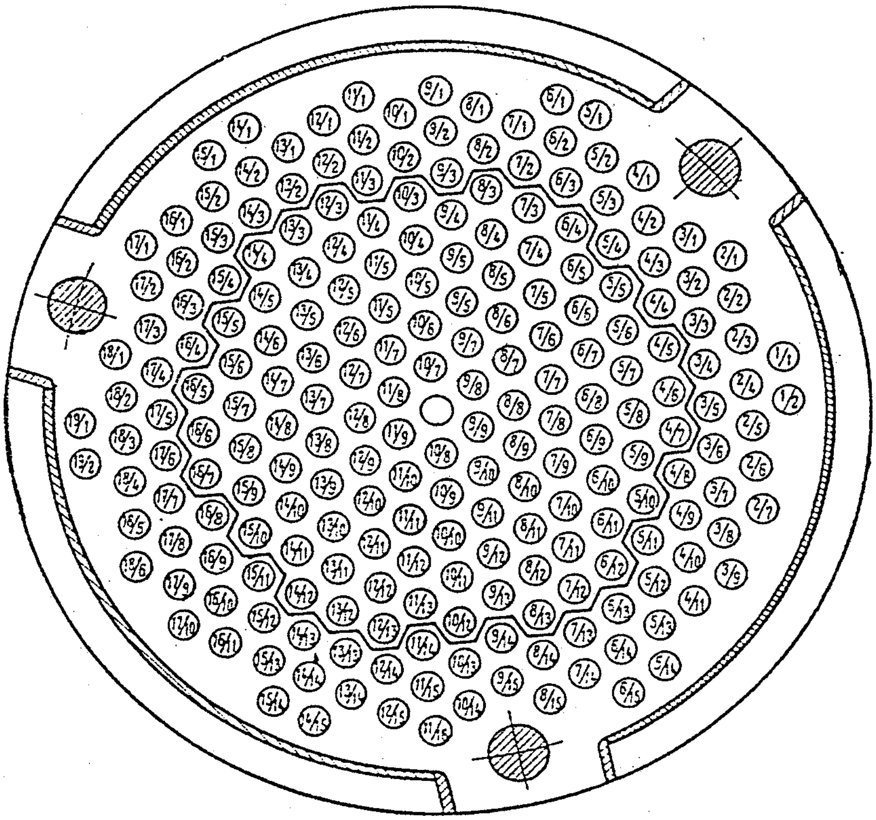


Figure 3.2 Horizontal cross section of the OK-150 reactor

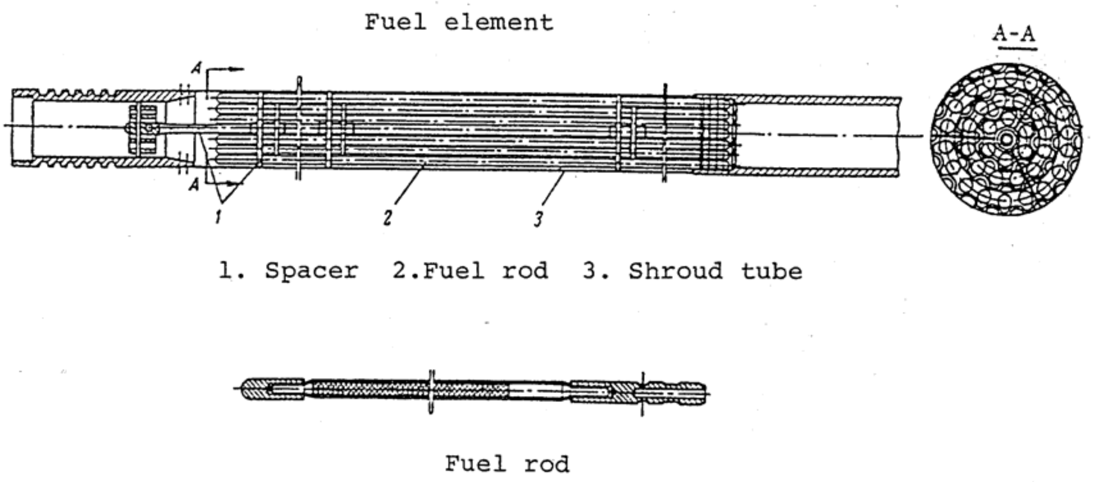


Figure 3.3 Fuel element for the OK-150 reactor

Table 3.2 Core and Fuel Data of OK-150, first core load (all reactors)

Reactor power	90 MWt
Core height	1.58 m
Core diameter	1.0 m
Mass of 235U in core	85 kg
U-enrichment	5%
Number of fuel elements	219
Fuel element lattice pitch	64 mm
Fuel element lattice type	triangular
Shroud, outer diameter	54 mm
Shroud, inner diameter	?
Shroud material	Zr-alloy?
Number of fuel pins per element	36
Fuel pin diameter	6.1 mm
Cladding thickness	0.75 mm
Cladding material	Zr-alloy or SS
He gas gab between cladding and fuel	0.05 mm
Fuel pellet diameter	4.5 mm
Fuel material	UO_2

The reactor vessel was surrounded by a biological shield, primarily iron and water layers. The water was circulated through a heat exchanger, thereby removing the heat produced in the shield. Russian publications often refer to this circuit as the third circuit. At a few places, e.g. at the top of the reactor, heavy concrete shields were used.

3.1.5 Primary Cooling Circuit

The primary cooling system is shown in Figure 3.4. Each reactor had two coolant loops, each provided with a steam generator and two main circulation pumps (one of which was a reserve), an emergency pump and an ion exchange filter with an associated cooler. The primary circuit was provided with four pressurizers, which controlled the pressure of the system (in Russian terminology, pressurizers are called volume compensators). Pressure was increased by heating the water of the pressurizers by electric heating, thereby producing additional steam. Pressure was lowered by condensation of the steam. The pressurizers also accommodated changes in water volume due to temperature changes in the coolant during start-up and shut-down. Figure 3.5 shows the arrangement of the reactor and the primary circuit components.

3.1.6 Thermal Parameters

According to [Alexandrov], core coolant inlet temperature was 248^{o} C, outlet temperature 325^{o} C, operating pressure of the primary circuit was 200 bar, and the coolant flow was 1000 m3/hr. According to [Makarov], inlet temperature was 261^{o} C, outlet temperature 284^{o} C, and operating pressure of the primary circuit 180 bar. According to [Afrikantov], inlet temperature was 260^{o} C, outlet temperature 311 to 313^{o} C, and the coolant flow 435 to 467 tons/hr at a power output at 70–

75%. These differences in thermal parameters probably reflect changes in optimal operating conditions, which may well have changed with time, experience and fuel design.

According to [Alexandrov], steam output of the steam generators was at full power 360 t/hr at a pressure of 29 bar and a temperature of 310° C. According to [Makarov], it was 360 t/hr at a pressure of 31 bar and a temperature of 290° C, whereas according to [Afrikantov], it was 250 tons at a pressure of 29–31 bar and a temperature of 307 to 310° C at 70–75% of full power.

3.1.7 The LOCA in 1966

In 1966 one of *Lenin* reactors suffered a loss-of-coolant accident. At that time the *Lenin* reactors had just been shut down for re-fueling, and due to an operator error the water was drained from the (central part of the) core and was left without cooling for some time. This caused the decay heat to melt or to deform of part of the fuel elements. Only 94 of the 219 technical channels could be removed by the usual procedure. The remainder were taken out by removing the “basket” with the damaged fuel. The reason that the water could be drained from the reactor tank had presumably to do with the coolant inlet at the bottom of the reactor tank. Information on the initial *Lenin* reactors was obtained from [Alexandrov], [Afrikantov] and [Makarov]. The damaged core was partly disposed at sea and partly stored in the service ship *Lepse* now awaiting dismantling in the Murmansk harbor area.

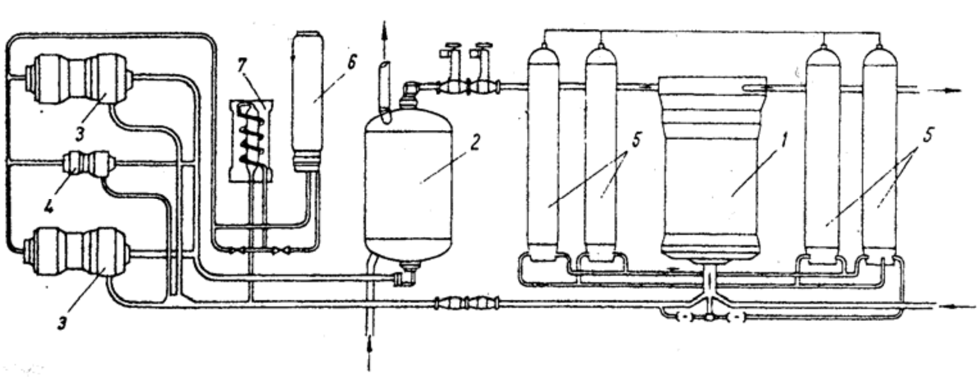


Figure 3.4 Principal diagram of the primary circuit of the OK-150 plant. 1. Reactor. 2. Steam generator. 3. Main circulation pumps. 4. Emergency pump. 5. Pressurizers. 6. Filter. 7. Filter cooler

3.2 THE OK-900 PLANT

From September 1967 to April 1970, the initial reactor compartment with the three OK-150 units, one of which had been damaged by the 1966 LOCA accident, was cut out of *Lenin* and replaced by a new compartment with two OK-900 units, each with a power level of 159 MWt. Later on a modified design, OK-900A with a power level of 171 MWt, was used in the icebreakers *Arktika*, *Sibir*, *Rossia*, *Sovetskiy Soyus* and *Yamal*. Each of these ships was provided with two OK-900A units. However, the plants of the three latter are not identical to those of the two former, since experience obtained from the operation of *Arktika* and *Sibir* was used to improve the plants of the last three. Most, but not necessarily all, of the improvements mentioned below will apply to both the OK-900 and the OK-900A unit.

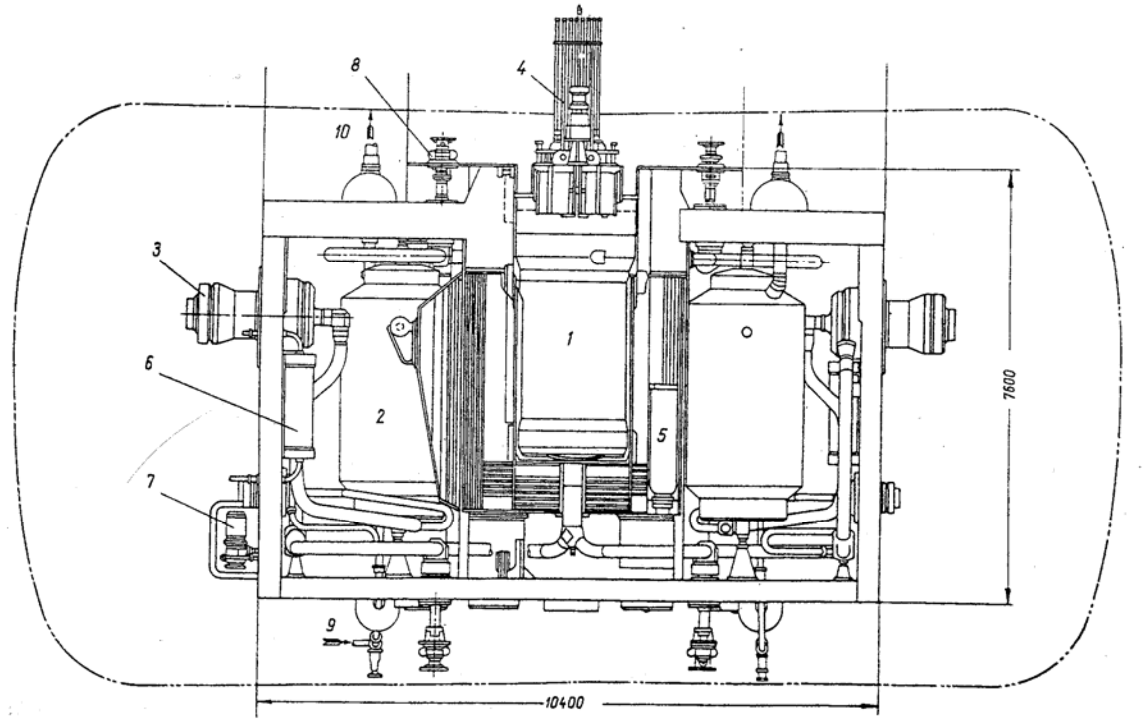


Figure 3.5 General lay-out of the OK-150 plant. 1. Reactor. 2. Steam generators. 3. Main circulation pumps. 4. Control rod drive mechanism. 5. Filter. 6. Cooler. 8. Primary circuit valve. 9. Feed-water inlet. 10. Steam outlet.

During the operation of the *Lenin* reactors, cracks had developed in the primary cooling system due to thermal cycling. Thus, in designing the OK-900, efforts were made to decrease the effect of thermal cycling and thereby increase the lifetime of the system from 25,000 to 50–60,000 hrs.

3.2.1 Reactor

In the OK-900 plant, the number of loops of the primary circuit was increased from two to four. Further the main cooling pumps and steam generators were connected to the reactor tank by a pipe-inside-pipe load-bearing connection, which greatly reduced the length of the pipes in each loop. New pressurizers were introduced in which the reactor pressure was regulated by varying the gas pressure above the water surface of the pressurizer, by use of an external compressed gas source.

Both the inlet tubes to and the outlet tubes from the reactor tank were connected to the tank at the top of the tank, making it impossible for the tank to be drained due to an operator error, as had been the case on NS *Lenin* in 1966.

Since water of the secondary circuit will become contaminated by seawater, stainless steel cannot be used for construction of the steam generator if corrosion leaks are to be avoided. For this reason, the tubing of the steam generators and of the secondary system were made of a corrosion-resistant alloy. This should allow a service life of 50–60,000 hours. Should a rupture occur in the steam generator, the circulation loop is switched off from the secondary circuit, not from the primary one.

3.2.2 Fuel

It was found desirable to develop new fuel elements with a fuel material with much higher specific heat and thermal conductivity than UO_2, e.g. a uranium-zirconium alloy with zirconium cladding. The gas gap between the fuel material and the cladding was removed. The first OK-900 cores had a burn-up of 29–38,000 MWtd, later increased to 88–96,000 MWtd. The use of the new fuel improved the reactor's self-regulation properties. The increased burn-up was possibly a result of increased enrichment levels. The icebreaker fuel at RTP Atomflot in the icebreakers using OK 900 A has been reported to be up to 90%, and this has according to [Mærli] been used as a dimensional factor when establishing physical protection systems for the reactors and the ships themselves. However, representatives from the Murmansk Shipping Company have confirmed that not all icebreakers are using this high enrichment; 55–90% is the range that has been presented earlier.

3.2.3 Reactivity Control

During the operation of the OK-900 plants, the force required to move the control rods increased. This led to the introduction of a new drive mechanism design to ensure "self-propulsion" in the case of power failure, as well as a manual drive system to lower the control rods if need be. In addition, injection into the reactor of a liquid absorber was introduced, in case the control rods should become stuck.

3.2.4 Containment System

The OK-900 plant was provided with a containment system, so that any release of radioactive material from the primary system would remain inside the containment. Should the vessel sink, valves in the wall of the containment would stay open as long as the outside pressure was higher than that inside, thereby flooding the containment and preventing its destruction and the release of radioactivity. The information presented on the OK-900 plant is primarily from [Makarov].

3.3 THE KLT-40 PLANT[4]

The latest version of Russian maritime reactor plants is the KLT-40. It has been installed in the icebreaking freighter *Sevmorput* and in two icebreakers, *Taimyr* and *Vaigatch*, all with one reactor only. Much is known about this plant, because the Russian government submitted the safety report for NS *Sevmorput*, [Information], to the Norwegian safety authorities in 1991 before a visit of *Sevmorput* to Tromsø in 1991. This report has been the basis for many studies of Russian marine reactors. The KLT-40 plant contains a pressurized water reactor with power levels of 135 MWt (*Sevmorput*) and 171 MWt (*Taimyr* and *Vaigatch*). The information given below has been obtained from [Information] and, strictly speaking, applies only to the *Sevmorput* plant. However, data for *Taimyr* and *Vaigatch* are presumably not very different even though the power level of their reactors is somewhat higher. The KLT-40 is in many ways similar to the OK-900.

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[4] The information presented in this chapter is based on [Information], [OKBM] and [Kuznesov1] and [Kuznesov2].

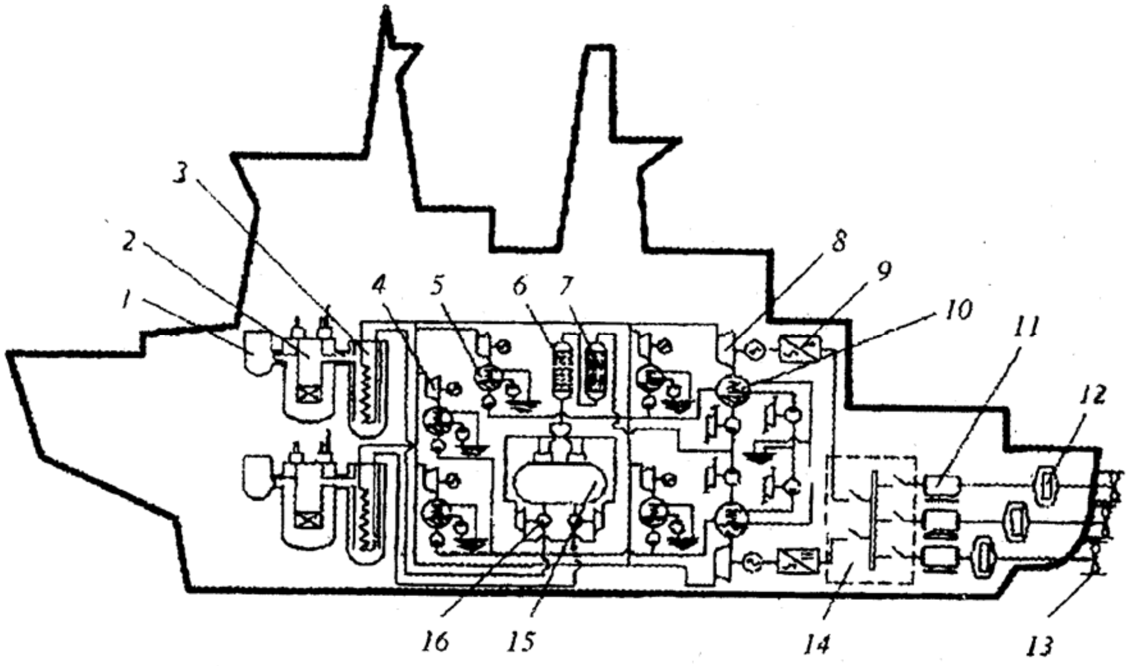

Figure 3.6 Circuits of the nuclear icebreaker “*Arktika*”. 1. Circulation pumps. 2. Reactor. 3. Steam generator. 4. Auxiliary turbo generator. 5. Condenser. 6 Ion-exchange filters. 7. Mechanical filter. 8. Main turbo generator. 9. Converter. 10. Main condenser. 11. Propeller motor (electric). 12. Intermediate bearing. 13. Screw propeller. 14. Circuit breaker for propeller motor. 15. De-aerator. 16. Turbo-feed pump.

3.3.1 Reactor

Figure 3.7 gives a vertical cross-section of the reactor. The coolant enters the reactor tank at the top, flows downwards through the reflector/thermal shield, up through the reactor core and from the top of the reactor tank to the steam generator. From here, the coolant flows 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 to a minimum, reducing the risk of leakage. The reactor tank is on the inside provided with a stainless steel layer. The thermal shield consists, in the radial direction, of steel-water layers and, at the top above the tank lid, of a concrete shield.

The core height is 1 m and the diameter 1.21 m. The 241 fuel elements are arranged in a triangular lattice with a spacing of 72 mm. The fuel elements are placed in a removable insert or basket inside the reactor tank, and movement is prevented by fixing them both at the bottom and at the top.

3.3.2 Fuel

The fuel elements are of the cluster type, with 53 fuel pins with an outer diameter of 5.8 mm. The number of fuel pins is not given in [Information], but since core height, pin diameter, number of pins per fuel element, number of fuel elements in the core and the heat transfer area of the core (233 m2) are all given, the number of fuel pins can be calculated. The spacing of the fuel pins in the element is 7 mm. The cluster of fuel pins is surrounded by a zirconium alloy shroud with an outer diameter of 60 mm. The fuel material is a uranium-zirconium alloy, and the uranium is 90% enriched. The total amount of uranium in the core is 167 kg (150.7 kg U-235). The cladding is a zirconium alloy. The fuel elements are also provided with burnable poison pins containing natural gadolinium.

Table 3.3 Core and fuel data for KLT-40 *(Sevmorput)*

Reactor power	*135 MWt*
Core height	*1 m*
Core diameter	*1.21 m*
Mass of U-235 in core	*150.7 kg*
U-enrichment	*90%*
Number of fuel elements	*241*
Fuel element lattice pitch	*72 mm*
Fuel element lattice type	*triangular*
Shroud, outer diameter	*60 mm*
Shroud, inner diameter	*?*
Shroud material	*Zr-alloy?*
Number of fuel pins	*53*
Fuel pin lattice pitch	*7.2 mm*
Fuel pin diameter	*5.8 mm*
Cladding thickness	*?*
Cladding material	*Zr-alloy*
Fuel material	*U-Zr-alloy*

According to [Information] the operating period for *Sevmorput* is 10,000 effective hours. This presumably means that the achievable burn-up is 56,000 MWd. According to [Kuznesov1] the operation period at full power for OK-900 and KTL-40 reactors is 460–500 days, which for *Sevmorput* yields burn-ups of 62,000 to 68,000 MWd.

3.3.3 Reactivity Control

The power level of the reactor is controlled by regulating the amount of feed-water. This is possible due to the negative temperature coefficient of the reactor, which gives it its self-regulating property. The reactivity is controlled by a system of shim and scram rods. The scram system consists of four banks of scram rods, moving in sleeves in 16 fuel elements. The scram rods are provided with accelerating springs to ensure rapid injection of the rods in case of emergency. The shim system consists of five rod-banks. Further, to ensure reactor shutdown in case of emergency, an aqueous solution of cadmium nitrate may be injected into the coolant.

3.3.4 Radiation Shield

The radial shield consists of consecutive steel-water layers. At the top the reactor tank is provided with a concrete shield.

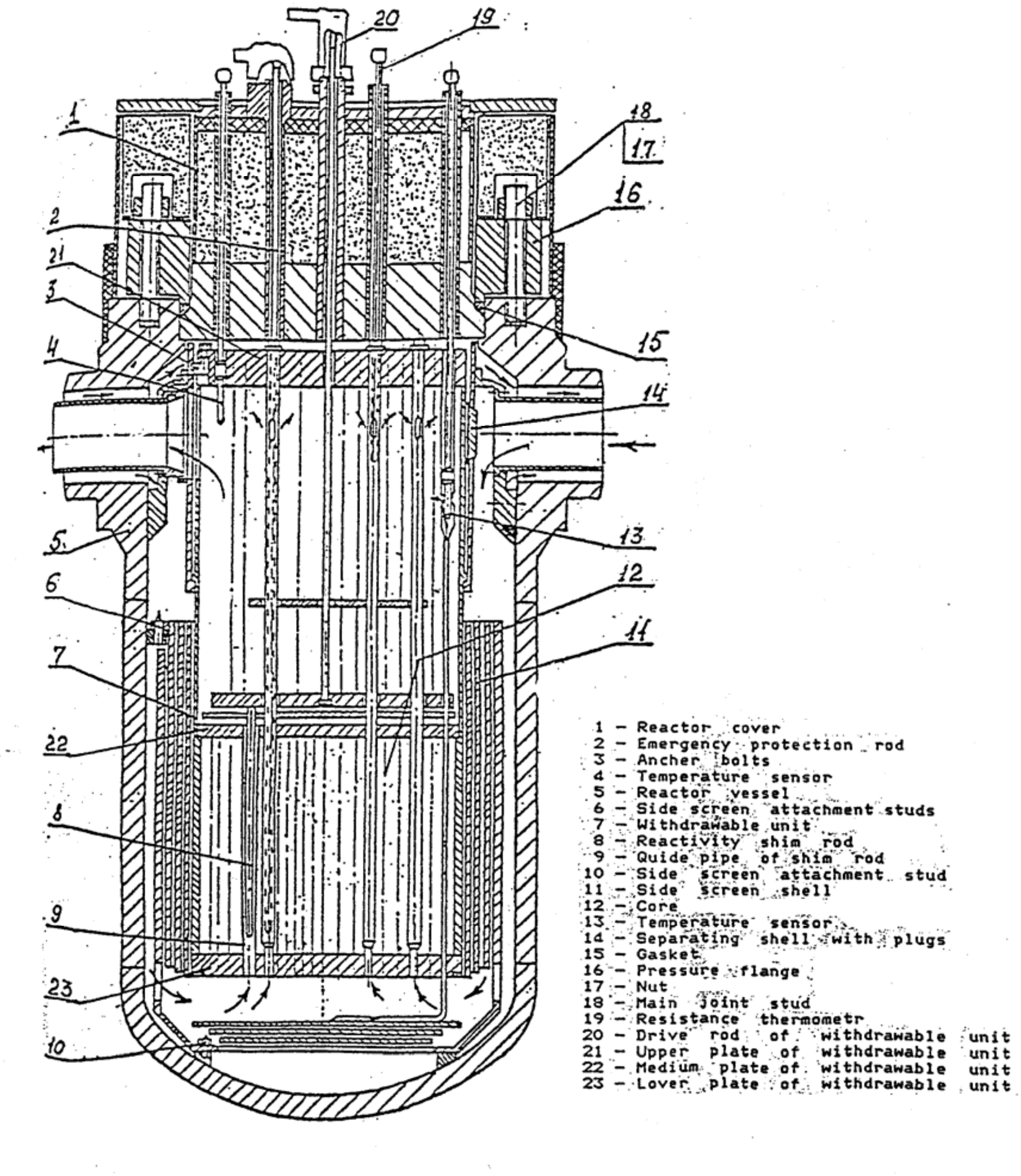

Figure 3.7 Vertical cross-section of the KLT-40 reactor

3.3.5 Primary Cooling Circuit

Figure 3.8 shows the primary system. The reactor is provided with four cooling loops, each of which contains one steam generator and one circulation pump. Pressure in the primary system is controlled by a gas pressurizing system connected to the four pressurizers. This system is based on injection/discharge of gas. According to [Kuznesov1], coolant inlet temperature is 278^{o} C and outlet temperature is 318^{o} C. According to [OKBM] and [Information], inlet temperature is 78^{o} C, outlet temperature 312^{o} C and the pressure of the primary system is 130 bar. The temperature and pressure of the steam leaving the steam generator is 290° C and 40 bar. There is an emergency cooling system, but in addition, the reactor can run by natural circulation at 25–30% full power.

3.3.6 Containment System

Ships using KLT-40 plants are provided with improved versions of the containment system discussed in section 3.2.4, basically a pressure suppression system. With a release of steam inside the containment, pressure will increase. If the pressure rise exceeds about 0.5 bar, a valve will open and the air-steam mixture will be led down through a water pool whereby the steam is condensed and the pressure reduced [Kuznesov2].

3.4 FLOATING NUCLEAR POWER STATIONS

In Russia there is a need for smaller nuclear power stations along the Arctic coast of the country. Some 50 regions have been identified as relevant areas for such facilities, due to the need for electricity. For this reason a modified version of the KLT-40 has been developed, KLT-40S. The concept involves constructing floating power stations, e.g. at Severodvinsk, and towing the plants to where they are needed. Consideration is also being given to using such units for desalination in other areas of the world. The Russian government has no resources available for this kind of investment, however. The current strategy has, according to [Kuznetsov3], been to engage foreign investment in the project in order to enable further development.

The technical data of the KLT 40 S, as described in [Kuznesov3], are presented in Table 3.4.

Table 3.4 Data for KLT-40 S

Reactor power	148 MWt
Steam production	240 t/h
Effective days of operation with one core	611 d
Period between reloading	2.5–3 yr
Core outlet temperature	317° C
Steam temperature	290° C
Steam pressure	37 bar
Fuel load (U-235)	996 kg
U-235 enrichment	36%
Feed-water temperature	170° C
Power operating range	15–150 MWt
Service life	40 yr

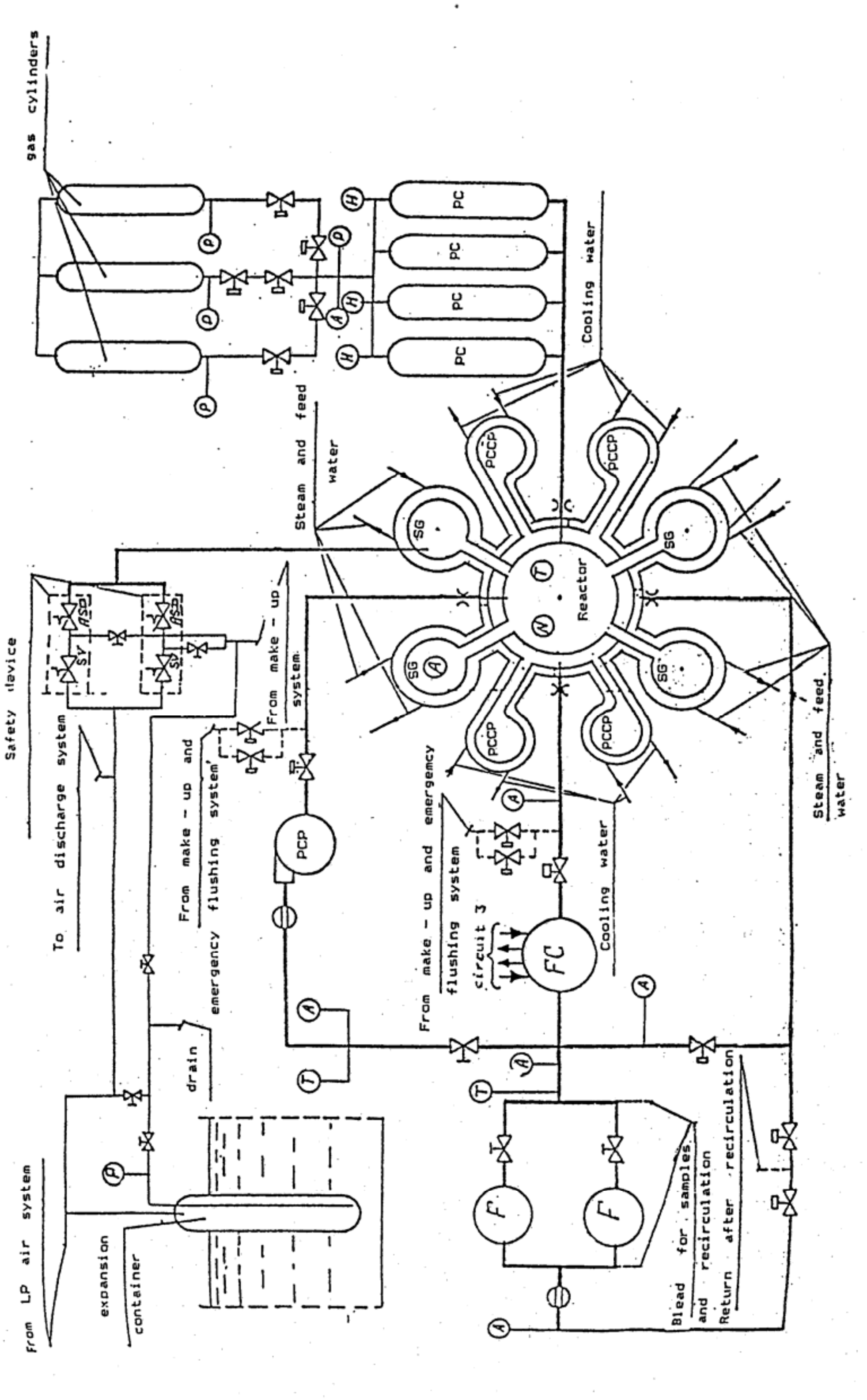

Figure 3.8 Primary circuit of the KLT-40 system

4 Russian Military Marine Reactor Systems

Russian military marine reactor systems may seem as confusing a subject as the submarines itself; several different notations and not very much open-source material.

4.1 VM-A REACTOR SYSTEM – FIRST-GENERATION SUBMARINES[5]

The first generation of Russian submarines is usually understood to include the classes November, Hotel and Echo I and II. They were similar in size, both concerning the vessels themselves and the reactor systems, the latter limited to 70 MWt. A particular designation for the complete steam-generating system has not been registered for the first generation. The operational characteristics of the different vessels are similar, with slightly lower speed for the larger vessel Echo II than the others. The reactor systems are in [Gladkov2] considered to be identical.

According to [Gladkov1], the choice of water-cooled and water-moderated reactor, i.e. reactor with high-purity water as moderator and coolant, marked the breakthrough for this technology in Russia. This reactor type has four interrelated circuits. The first circuit consists of the core which heats up the water in the reactor. In the second circuit, there is a steam turbine using steam with specific properties in its production of power. In order to get the steam with the required parameters in the second circuit, water of the primary circuit should have a temperature exceeding the temperature of the generated steam. In order to avoid boiling in the primary circuit, the pressure is increased considerably compared to normal atmospheric pressure. The equalizers, which regulate the pressure in the primary circuit system, are directly connected to the primary circuit. The third circuit is used to cool equipment in the steam-generating section. An important part of a marine reactor, where weight is a fundamental consideration, is the biological shielding. Consisting of water, steel, lead, concrete and other materials, it protects against the penetration of neutrons and gamma radiation. This biological shielding is heavy: at one point it was approximately 50% of the plant weight.

4.1.1 Reactor

All first-generation vessels seem to have similar reactor systems, VM-A, and propulsion systems using two shafts of 17,500 HP each. The reactors of these submarines of the first generation – and presumably also of the later generations – have no connecting pipes, including tubes of large diameters, below the upper edge of the core, as seen in Figure 4.1. Thus it is not possible to drain part of the core by accident, as happened with the *Lenin* reactor in 1966. A reactor model – presumably of an early submarine reactor – at the town museum of Severodvinsk confirms this design feature, with both the inlet and the outlet pipes above the top of the core. Figure 4.1 shows the VM reactor inside the submarine hull, and the reactor internals. The construction of the reactor system was made on the basis of the properties expected of the vessel and then the necessary operational characteristics for the heat carrier. The vessel should be able to work down to depths of 200–300 meters, achieve an underwater speed of at least 20–25 knots and complete assignments lasting up to 60 days. The resulting heat-carrier properties are given in Table 4.1.

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[5] The notation VM-A should indicate that this was the first water-moderated reactor to be developed.

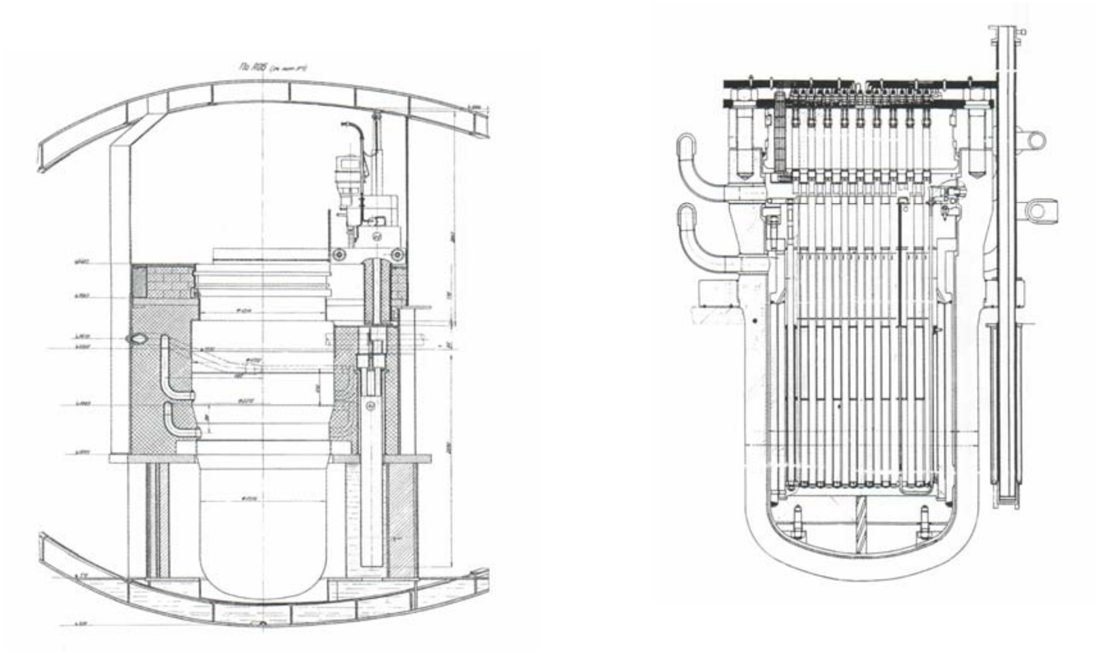

Figure 4.1 Design of first-generation submarine reactor

Figure 2 shows the path of the primary coolant in the reactor: into the reactor and downwards along the central, upwards again along the periphery parts of the reactor. The original plan had the flow in the opposite direction; this was changed when it was realized that the highest temperatures would be in the middle of the reactor [Gladkov1].

Table 4.1 Reactor and coolant characteristics, first PWR submarine reactor [Gladkov1]

Reactor power (MWt)	70
Water pressure in primary circuit (kg/cm^2)	200
Steam pressure (kg/cm^2)	36
Steam temperature (^{0}C)	355[6]

The first generation of Russian submarines operated in limited range from their home bases as described in [Kotcher]. Not until 1966, between February 2 and March 26, did the first Russian nuclear submarine cross the equator in the Atlantic; it then continued south of South America through the Drake Passage to the Pacific Ocean and joined the Russian Pacific Fleet.[7]

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[6] Since water temperatures of the primary circuit should exceed the temperature of the generated steam, this seems not to be correct; in fact, it is the same figure as given for the superheated steam in a LMC – reactor with coolant temperatures at reactor output up to 440^{0}C.

[7] Operating histories will be discussed in greater detail in a forthcoming NKS paper on release fractions for accidents with Russian submarines.

Except for one vessel, a Yankee-class submarine, and a liquid metal reactor, all the reactors dumped in the Kara Sea were reactors of the first generation (November) that had experienced several accidents during the 1960s.

We note that the *Lenin* reactor has been a useful tool for assessing the properties of Russian submarines. Therefore the basic fuel and reactor properties will be presented here and assessed in relation to calculations on the amounts of fuel and assessment of fuel geometry regarding the first-generation submarines as completed below.

4.1.2 Reactivity control

Work on the VM-A started from scratch, and one of the early decisions was to use vertical rods for compensating excess reactivity [Gladkov2]. The control rods used in submarine reactors usually contain europium as the absorbing material. This results in very high activity of the control rods after the final reactor shutdown. In addition the Eu_2O_3 presumably used in the rods has a tendency to swell due to hydration, even if dispersed in a matrix [Kuznesov2].

The control rod system of the early submarines included an unusual design feature: apparently it was not possible or at least not easy to lift the lid of the reactor tank without lifting the control rods as well. This resulted in two criticality accidents with first-generation submarines – one on February 12, 1965, with K-11, a November-class submarine, and one on October 10, 1985, with K-431, an Echo-II-class submarine. Both accidents happened just after re-fueling, i.e. with new core in the reactors. In both cases, the lid had to be lifted slightly with the control rods connected to the lid, presumably due to incorrect alignment. To avoid a criticality accident a beam was placed above the lid to prevent it from being lifted too high up. However, in one case the beam itself had been placed too high up, and in the other the beam had not been fixed properly. In both cases the lid and the control rods were lifted too far up and the reactors went critical. However, this was changed, and reactor design modifications on submarines of the second and third generations should not allow the control rods to be raised when the lid of the reactor vessel is lifted [Elatomtsev]. This element has been emphasized in another article also: *"Electronic and mechanical circuits of higher reliability and with interlocking of failures were developed to greatly reduce the chance of improper lifting of the control members."* [Gladkov1]. The reason for this rather strange arrangement may be that it was difficult to connect the control rods to the drive mechanisms. Once they had been connected, it was tempting for the personnel to avoid a new connection process, even if this meant that the reactor lid had to be lifted a little.

4.1.3 Fuel

A minimum level of reliable information is essential for evaluating the safe and secure handling and protection of excessive stocks of naval fuel – which are often stored under highly unsatisfactory conditions. Among the most important is the enrichment level. The need for self-sufficiency, strong power-outputs and limited reactor sizes may require the use of highly enriched naval nuclear fuel [Gagarinski][8] However, for submarines of the first generation, the enrichment of the uranium of the fuel elements of the pressurized water reactors seems, in general, to have been about 20%, as suggested by Sivintsev in the IASAP report. This is consistent with the Russian prosecutor's article on the stolen HEU in 1994 [Yaderny Kontroll]. The amount of U-235

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[8] An exception is France, which uses LEU in its nuclear-powered submarines.

is here said to be 283.3 grams out of overall uranium content of 1,448.9 grams, enriched to 19. 9% and corresponding to the fuel enrichment in the Russian naval training reactor in Paldiski [Oelgaard2], and data on earlier US submarines [Eriksen].[9]

However, the overall figures presented as part of the IASAP report have been discussed and corrected by other Russian official sources [Rubtsov1]. In the case of a reactor compartment with two reactors (without fuel) dumped near Novaya Zemlya in 1965, the fuel enrichment is presented as being 6%. This was K-3, the first Russian nuclear submarine, which got a new reactor compartment due to several design weaknesses [Oelgaard1]. If this enrichment information is correct, the reactors of the first nuclear submarine, and possibly a few others, may have had a lower enrichment, more like that of the civilian icebreaker *Lenin*. The complete set of data presented by Rubtsov et al., both in the draft paper for the IASAP Source Term Working Group and in the Russian journal *Nuclear Energy,* is given in Table 4.2.

Table 4.2 Fuel data on Russian reactors dumped at Novaya Zemlya, as presented by Rubtsov et al. for the ISAP Source Term Working Group and in the Russian journal *Nuclear Energy*

Project no.										K-140
Plant no. – submarine	285		901		260		538	254		421
NATO class	November									Yankee
Thermal power (MWt)	70		70		70		70	70		90
Fuel com-position	U-Al alloy		U-Al alloy		U-Al alloy		U-Al Alloy	U-Al alloy		U-Al alloy
Enrichment (%)	9	21	20		20		20	6	5.45	21
Left (LB)/ right (RB)	RB	LB	RB	LB			?	RB	LB	LB
Amount of U-235 (kg)	50.4	55	30.6	40.7	40.7	40.7	50	46.3	45.3	116.3

From these data, it seems that the first generation of Russian submarine reactors could accommodate a flexible amount of material. The total amount of uranium in the plant number 254, left board reactor was, according to these data, initially 831.2 kg. At the opposite end we find right board reactor in plan number 901 with only 153 kg of uranium.

Several sources have used the average figures of 50 kg. U-235 enriched to 20% for fuel in the first generation of submarines. However, the additional information set out in Table 4.1 indicates that this is insufficient for calculations regarding criticality, possible releases when considering a certain vessel or reactor. Take, for example, the impact assessment carried out by Norwegian authorities after the sinking of K-159. The Russian government then informed Norway that the submarine in its two reactors contained a total of 400 kg. of spent fuel. However, this was not

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[9] As with the development of the A-bomb, the heavy espionage carried out by the Soviet Union to catch up with the USA in the area of nuclear submarines is a subject of its own. In this context, similar vessel, reactor and fuel properties are of considerable interest.

specified further, which made it difficult to complete a realistic impact assessment. This information also underlined that submarine fuel, especially for this generation, is of less interest in the context of non-proliferation.

Concerning overall fuel density and geometry, very little open-source information has been noted, except from what has been discussed above. However, as part of the IAEA's IASAP effort, the configuration from *Lenin* was used in the source term modeling, indicating certain relevance for this circular tube design. The fuel elements used in early generations of Russian naval vessels may therefore also be of the rod cluster type. We know also that when the design of the first Russian submarine was worked out, each fuel assembly was constructed with *"37, and not 23" [*Gladkov2] fuel elements as originally planned.

The fuel material in the first generation of submarines has been suggested to be a U-Al alloy [IASAP]. This would have been a natural starting point at that time, in the mid-1950s, due to such attractive properties as good thermal conductivity and easy fabrication. Stainless steel was probably the preferred cladding material at that time.[10] The reactor was divided into two groups, the central part and the periphery [Gladkov2]. The central part should, without any more specification in the present sources, have 9 fuel groups, while the periphery should have 14. A similar division between an outer and an inner part of the reactor is seen in the *Lenin* reactor in Figure 3.2

The number of fuel elements – or fuel assemblies in Russian terminology – has been claimed from 180 to 225 for the first generation of Russian military reactors. Together with the given amounts of U-235 above ranging from 30.6 to 55 kg. in one reactor, this yields a range of fissile material pr. fuel assembly of 0.136 to 0.306 kg. Similarly, the amount of uranium pr. fuel assembly has a range of 0.680 to 4.618 kg.

According to the fuel data above for the *Lenin* reactor, overall fuel density in the *Lenin* reactor was 9.7 cm^3, when using 881.74 cm^3 as the volume of one fuel assembly. Using approximately the same fuel density for submarine fuel of first generation, 10 g/cm^3, we see that this equals a total volume pr. fuel assembly in the range of 68–461.8 cm^3, the limits taken from the low and high ends of the possible amount of fuel in the reactor. When considering possible geometries giving this volume pr. fuel assembly based on the *Lenin* fuel geometry, we see that the volume and the fuel density might be reduced and still accommodate the required amount of fuel. This would confirm an assumption that the submarine reactor should be more compact than an icebreaker reactor: a core height of approximately 1 meter has been suggested. However, assuming only small differences between the civilian and the military reactor, the latter should be able to accommodate many different fuel configurations.

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[10] Stainless steel as cladding material has been proposed by Sivintsev in the IASAP report, complete reference given in endnote 54. [Aaagard] claims that also zirconium has been in limited use. We therefore have to assume that also other fuel matrixes beside U-Al alloy have been tried out at an early stage. As discussed later, design alternatives which includes Zr may be the preferred material in more recent fuel materials.

4.2 VM-4/ VM-2 REACTOR SYSTEMS – SECOND-GENERATION SUBMARINES

The second generation comprises in most cases Victor I-III, Yankee, Charlie 1 to 2 and Delta I-IV. By this time, the Cold War and the positive experiences with nuclear propulsion had accelerated the construction of new models with increasing abilities of the submarines as flexible weapons platforms.

4.2.1 Reactor

All Delta submarines have the Yankee vessels as their construction base, and it is reasonable to expect similar propulsion systems in all these 77 submarines. Compared with the first generation, there are overall larger power levels and new propulsion systems, including the use of only one shaft. The use of one shaft and, at least in beginning, reduced displacement, served to improve propulsion by 30% [Screen]. While the hull diameter increased, the second-generation vessel got more compact reactors than had been used in the first generation. The most significant change regarding the propulsion system is the use of one reactor in the Charlie 1-class – a fundamental break with the redundancy found in the all earlier submarine classes, where there were two reactors. This change was possible due to a substantial reorganizing of the reactor system. The emphasis was put on lighter equipment, and, as dryly stated in one source, by giving the submarine the shape of a limo [Kotcher].

The reactor notations change, from VM-A to VM-4, and several different models are registered, possibly due to changes in configuration and continuous improvements. For example, one reactor core is able to accommodate longer and longer journeys, from 750 hours for the core type VM-AB, to 2000 hours for the core type VM-1A used between 1961 and 1963 also in the first generation of submarines. However, the development continues to 2500 hours (VM-1 AM, in 1964 to 4000 hours (VM-2A), and, *"at last, in 1969, core VM-2AG for 5000 hours"* [Gladkov2]. From data presented in Annex I for the reactor systems, it seems as if there is a logical chain of letters in the different notations, starting with the letter "A" or "1" and continuing upwards as different configurations are established.

A new surface vessel, project 1941, with an atomic energy plant, was put into active service in the Navy in 1985; it had a steam-generating unit OK-900B that provided a shaft power of 2x23000 HP [3bok]. The steam-generating unit of the surface vessel consisted of two self-contained sections, each with a water-cooled and water-moderated reactor with all the supporting systems and installations, and situated in the reactor compartment. The steam-turbine plant was divided into two self-contained parts located towards the stern and the bow directions from the steam-generating unit, as in the icebreaker *Lenin*. Each main turbo-gear assembly, with a power of 70,000 HP, functioned along its own line of shafting. Alongside with the main turbo-gear assemblies there was one standby boiler with a steam capacity of 115 tons per hour in each steam-turbine compartment. Besides this vessel, this steam-generating system has been registered (as seen in Annex I) only in civilian icebreakers, and the properties of this reactor type will therefore be discussed at the end of this chapter.

4.2.2 Reactivity control

An unusual control system feature became apparent during an accident involving a Yankee-class submarine. Due to fire, the submarine was endangered and the reactors were shut down with the submarine at the sea surface. However, the control rods could not be fully inserted due to a short circuit in the electric system. To achieve full insertion, it was necessary to send two crewmembers into the reactor compartment to carry out a manual operation. One of the staff members perished during the operation [Giltsov].

Here the reason that the control rod could not be fully inserted was the short circuit of the electric system. But another reason for the manual system may possibly be that, as mentioned above, the control rods have a tendency to swell near the end of their lifetime, and at that time the electric drive mechanisms may not have power enough to drive the swollen control rods into the core. A third possibility is that if a submarine sinks it may not end up in its normal position. A significant deviation from that position may mean that the control rods are moved out of the core, and manual insertion could ensure that this does not happen.

A third feature heavily discussed, due to later accidents, is the mechanism for locking the control rods in case the submarine rolls over and remains in an upside-down position. During the investigations of possible accident scenarios for the raising the submarine *Kursk* in 2001, it were never confirmed that such a mechanism was in place to prevent the control rods from falling out of the reactor during the lifting operation.

According to [Gladkov1], “the redistribution of the regulating members made it possible to reduce the non-uniformity of energy liberation in the core by a factor of 1.2 – 1.3.”. As a result of further improvements, the core-life was improved more than threefold, and absorbers distributed heterogeneously in the fuel channels.

4.2.3 Fuel

In Table 4.2, data on the fuel of the Yankee vessel N-421 are presented; 116.3 kg of U-235 and 21% enrichment, which corresponds an overall amount of 553.8 kg. uranium. These figures represent a significant change compared to first generation of Russian submarines, at the same time the second generation submarines are said to have more compact reactors. These figures point towards an important breakthrough in the design and operation of naval reactors. In [Sarkisov1], enrichment is claimed to be around 40% for the second generation. This seems to be the case with the fuel in the third generation, as will be seen later, and this is not supported of other sources.

The number of assemblies in the second generation has been specified to approximately 280, but it must be kept in mind that the number of assemblies is linked with the submarine project in question [Aaagard]. [Watson] and [Sarkisov2] have suggested 225 to 270 per reactor, and for second-generation submarines about 250 cluster type fuel elements with 350 kg 20% enriched uranium, each element containing 54 fuel pins and each fuel pin containing 25.9 g 20% enriched uranium [Bakin]. This might be, however, an indication that the increased amount of fuel in reactors of the second generation has been achieved through a greater number of fuel assemblies in the reactor using the same level of enrichment, probably without increasing the size of the reactor. From the figures given for N421 and the number of fuel assemblies given in [Aagaard], each fuel assembly then contains 1.97 kg uranium or 0.42 kg U-235.

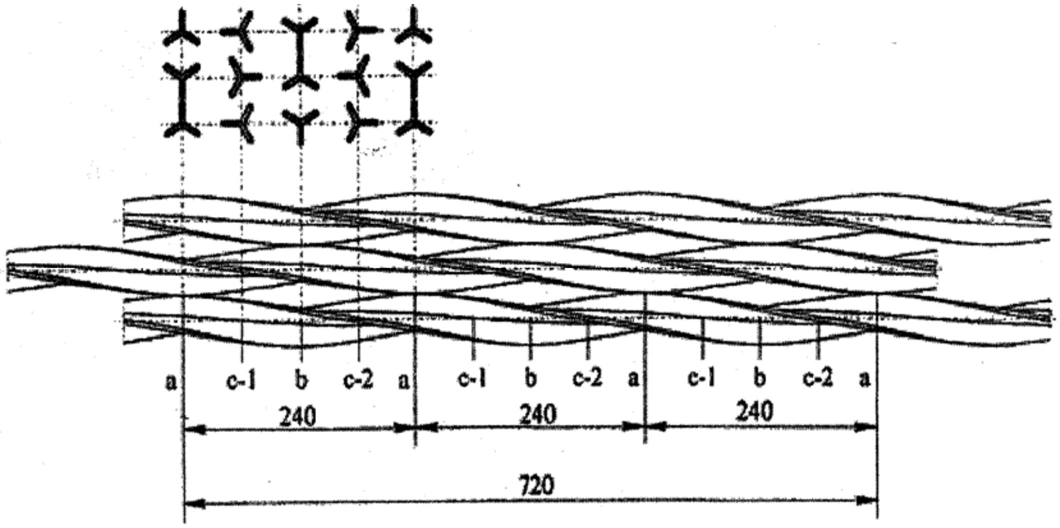

Figure 4.2 Alternative Russian submarine fuel-assembly configurations

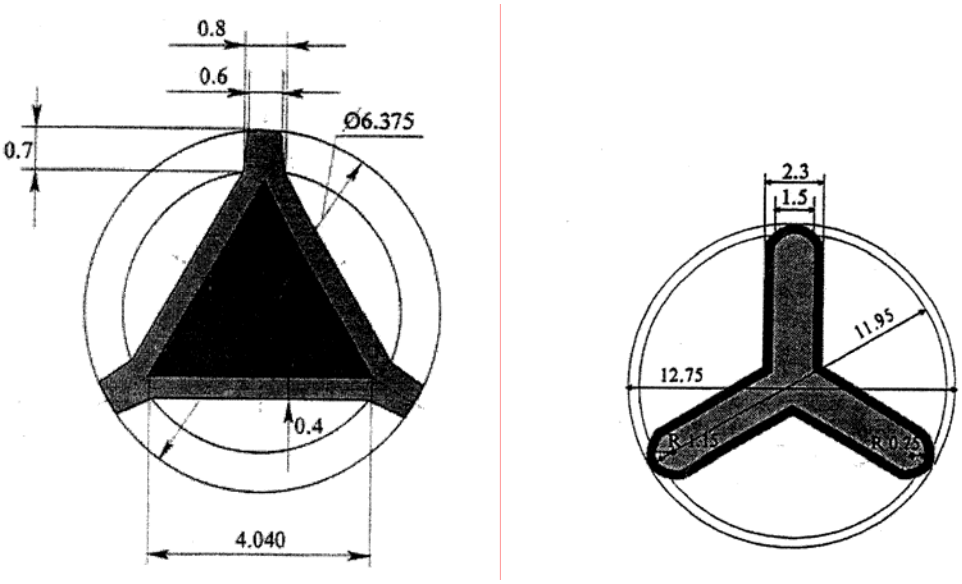

Figure 4.3 Alternative Russian submarine fuel-element geometry

Another article suggests *“the quantity of uranium per assembly is similar to that known to be used in the VM-4-AM core”*, later specified to *“1.4 kg of 20% enriched uranium”* [Bukharin]. As seen in Annex I, this notation corresponds a second-generation reactor model. Considering the overall amount of fuel reported above, the number of fuel assemblies might be even higher. In that case this would be consistent with the figures in the recently worked out Pre-Draft Interim

Report of the Strategic Master Plan for the Northern Dimension Environmental Fund (NDEP). Here 31 PWR reactors cores contain 12,188 fuel assemblies. If we assume that 10 cores come from first-generation submarines with 225 fuel assemblies, as assumed above, this yields an average figure of 473 for the rest of the vessels. Using 1.4 kg as the figure for one assembly, as given above, this means an overall amount of 662.5 kg uranium in one core.[11] This is in line with the figures above. It suggests both the number of fuel assemblies in the second generation of Russian submarine reactors was considerably higher than in the first, and that the amount of fissionable material was increased by increasing the overall fuel mass, and not the fuel enrichment.

In assessing the risk for spontaneous fission reactions in transportations casks, calculations have been performed at one occasion under the assumption that a second generation submarines core has about 250 cluster type fuel elements with 350 kg 20% enriched uranium, each element containing 54 fuel pins [Bakin]. Without specifying the basis for these speculations, this seems founded on a core configuration similar to that specified for the IASAP report, possibly using the confirmed data from the civilian icebreaker *Sevmorput* on number of assemblies.

Alternative fuel geometries

Due to the noise problems inherent in using circular fuel rods (and hence the increased turbulence in the reactor coolant), second- and later generations of submarines have presumably used other fuel types of different, less noisy, geometries. The USA today uses plate fuel, presumably also to reduce noise, but virtually no information has been published on possible fuel geometries in modern Russian military nuclear vessels.

When considering the need for less noise, for improved thermal properties and for accommodating more fuel material, we might assume a radical change in the submarine fuel geometry. The expected direction, considering the discussions above, would be a more compact design that would facilitate a higher power density, improved thermal characteristics and increased fuel mass in the reactor as a whole. If assuming circular fuel rods in the VM-A reactor type, Figure 4.2 and 4.3, which has been said to be Russian submarine fuel design [Glaser], might represent one version of “second generation” submarine fuel. Figure 4.3 is a sketch of two types of fuel pins; in Figure 4.2 we see a tentative fuel assembly configuration using one of the possibilities given in Figure 4.3

4.3 OK 650/ KN-3 REACTOR SYSTEMS – THIRD-GENERATION SUBMARINES/ OTHER VESSELS

The third generation was constructed due to the growing concern for Soviet capabilities of retaliation in case of a Western nuclear attack. Most of these vessels are still in active service, except those dismantled as part of the START treaties, and are therefore not the subject of the same broad international interest as the older vessels for cooperation on the dismantling of the vessels. A special feature of the Typhoon class is that it is provided with two parallel pressure hulls, each with a reactor and a shaft, with the missile launching tubes placed between the two hulls. The Sierra and Akula classes were provided with titanium hulls, with considerable effect on displacement.

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[11] Such considerations might be accompanied by simulations, and this will be the next part of the project that has generated this paper.

4.3.1 Reactor

From 1952, the starting point of the first submarine project, until 40 years later with the construction of the third generation of Russian submarines, the development of the reactor systems involved more than a doubling of the energy density in the reactor [3bok]. The increase in nominal power is apparent: from 90 MWt to 190 MWt in submarines, while a separate reactor system for the surface vessels, KN-3, seems to have developed. The relevant submarine classes are Typhoon, Sierra, Akula and Oscar, in addition to Mike. Extremely limited open-source information is available concerning third-generation reactor systems. However, OK-650 seems to be the reactor system in the vessels with titanium hull, hence only one reactor, four steam generators and one shaft with a little less than 50,000 HP. In the Typhoon and Oscar classes, two similar reactor systems were installed, however, using two shafts of 50,000 HP each.[12]

4.3.2 Fuel

The increased power levels should be reflected in the amount of fissile material in the reactor. According to [Sarkisov1], for the subsequent generations, enrichment was later increased to around 40%. A similar figure, 36%, for third-generation submarine fuel has been put forward to a US Senate Committee [Potter]. Also 21–45% has been proposed earlier [Bukharin]. This increase in enrichment should provide space for additional fissile material, and the total amount of U-235 has been claimed to be as high as 200 kg. If correct, this is in line with the amount in modern US submarines using 90% enriched fuel, however, with a lower enrichment. *Komsomolets* was of the Russian side said to have "modestly enriched fuel", however no specification of the actual level of enrichment has ever been given in the literature. Compared with the low enrichment levels in the first generation, 'modest' might very well be in the area around 20% or more.

Another discussion concerns the fuel material. While the starting point in 1958 was presumably U-Al alloy with stainless steel cladding as seen above, at some point the disadvantages of this technology compared to other fuel and cladding materials would have become obvious. As seen in the civilian program, the change from ceramic fuel to metal fuel was completed with the OK-900, however, then using U-Zr in Zr-cladding. This development continued into the third generation of civilian marine reactors, building the KLT-40, so this model will be briefly discussed below.

4.4 RM-1 AND VM- 40 A REACTOR SYSTEMS – PROJECT 645 AND ALFA-CLASS SUBMARINES[13]

During the construction of the first November-class submarine, Russia also initiated a program in 1954 for building liquid-metal cooled submarine propulsion systems. As mentioned above, liquid-metal cooled submarine reactors have been used by the Russian Navy. The technology was developed at the Institute of Physics and Power Engineering (IPPE) in Obninsk and used in two submarine classes: Project 645, a class in itself, and the Alfa class.

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[12] Several different notations are registered here without any indications what they possibly might represent (OK 650 6, OK 650 A and B, OK 650.01, OK 650.02). [Sutyagin] suggest in his article the reactor type to be VM-5: "Project 941 subs are powered by two pressurized water reactors (supposedly of the VM-5 type) with OK-650 core". [Handler] refers to variants of this reactor as OK-650b and OK 650 B-3.

[13] The No. numbers given above are not the K-numbers but the Order Numbers.

Using liquid metal coolant was considered to have several advantages. It is more compact than pressurized water reactors, since it needs no moderator. No heavy pressure vessel is needed; it operates at higher temperatures and has therefore a higher thermal efficiency. The use of an intermediate reactor makes xenon poisoning less important. Refueling is faster, since the core is removed in a single operation. However, there are disadvantages: the melting point of the coolant is above room temperature, so the primary system must be kept heated at all times for the coolant to remain liquid. If not, the coolant will solidify and the cooling will be interrupted. The liquid metal coolant will gradually oxidize and the oxides must be removed regularly, to avoid blockage of the coolant flow through the core. [14]

The LMC reactor was first used in 1962 in a special version of a November-class submarine (Project 645, K-27), which used two RM-1 reactors with capacity of 73 MWt each.[15] The K-27 was re-fueled in 1967. However, it suffered a loss-of-coolant accident in 1968 in port when it was ordered to participate in a naval exercise at a time when the coolant needed to be cleaned of oxide impurities. During the exercise, these impurities blocked the entrance to the core of the port-side reactor and caused a LOCA, after which the submarine was laid up. In 1981 the free volume in the reactor and in the reactor compartment was filled with a conserving material and the submarine was sunk off Novaya Zemlya at 50 m.[Giltsov], [Pankratov], [Oelgaard].

The first Alfa-class submarine (K-377 or No. 900) became operational in 1970, but suffered a loss-of-coolant accident in 1972 when a leak developed between the secondary water-steam circuit and the primary liquid metal circuit, exposing the primary circuit to a pressure of 70 atm. As the pressure relief system failed to function, the high pressure caused a rupture of the piping of the primary circuit. Two tons of liquid metal coolant flowed out into the reactor compartment, where it solidified. Leakage of the coolant of the reactor tank was prevented by closing the isolation valves. The coolant in the tank later solidified. At the time of the accident, the reactor had been in operation for only 10% of its lifetime. It was not possible to re-melt the coolant and remove the fuel. In 1986, the reactor compartment was cut out of the submarine, the reactor room was filled with furfural, the upper deck above the reactor was covered with bitumen and the compartment was prepared as a three-compartment unit, now in floating storage at Saida Bay of the Northern Fleet. It is not the intention to de-fuel this reactor.

The first 705K Alfa submarine (No. 105) operated from 1977 to 1982, when it suffered a LOCA and leakage of coolant into the reactor compartment. The reactor compartment with fuel in the reactor and the coolant frozen was cut out, and is now in floating storage. A new reactor compartment was inserted into the submarine (still No. 105), which was put in operation again from 1992 to 1996. The Alfa submarines were withdrawn from active service during the 1990s and were never re-fueled, since at the time of decommissioning maximum fuel burn-up had not been reached. Current burn-up of the reactor fuel varies between 10 and 100% of the design value.[16]

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[14] Another issue of more recent concern has now come up as the Mayak reprocessing facility may not have the possibility for reprocessing this type of fuel.

[15] The designation VT-1 has been used for this reactor type; however, this report follows the notation given in [Kotcher] using ‘RM-1’ for this reactor type.

[16] At present the decay heat is about 2 kW and the coolant is frozen. This form of storage was not intended for long-term use, and it might be, in the case of extended storage, that water will penetrate through the

The Alfa submarines were based at Gremikha on the Kola Peninsula. Fueling and de-fueling operations were performed by loading and unloading the whole core, including the control rods, the reflector (for Project 705K) and the upper biological shield, as one unit. Upon de-fueling, this unit was placed in a steel tank containing non-radioactive Pb-Bi coolant at 150–160^{o} C. The steel tank was later transferred to a concrete well, to be cooled by natural circulation of air. As the decay heat gradually decreased, the liquid metal solidified. At present the decay heat is about 2 kW and the coolant is frozen. This form of storage was not intended for long-term use; it might be, in case of extended storage, that water will penetrate through the steel tank and into the core through porosity formed during the solidification of the Pb-Bi coolant. This might make the core critical. Six unloaded cores are currently stored in such wells in Gremikha. Three of the cores remain in the submarines.

Two of the 705 Alfa submarines (No. 905, in operation from 1978 to 1986, and No. 915, in operation 1981–89) were de-fueled in 1989 and 1990. Two of the 705K Alfa submarines (No. 106, in operation 1978–90 with core burn-up of 96%, and No. 107, in operation 1981–90 with core burn-up of 87%) were de-fueled in 1991 and 1992. These four core units are stored in the storage facility at Gremikha. This facility has room for eight core units, of which six are in use, since it contains also the two cores from the de-fueling of Project 645. This means that, while the facility can take the core unit from No. 910 (burn-up 80%) and the second core unit of No. 105 (burn-up 15%), there is no room for the first core unit of No. 105 (burn-up 50%). Since the coolant is frozen in these three reactors, it will have to be re-melted before de-fueling can be performed ([Pankrakov], [Ignatiev], [Sazonov]).

The de-fueling of submarine No. 910 will present a special problem, since the top of the reactor has become contaminated with Eu-152 and Eu-154. This occurred when water condensate penetrated the control-rod gas system, resulting in boiling of the water and ejection of europium from the control rods into the drive mechanisms of the rods.

4.4.1 Reactor

Two land prototypes of this type of reactor plant have been made, one at Obninsk (27/ VT) and one at Sosnovy Bor (KM-1) near Saint Petersburg. Work on the 27/ VT facility started, as mentioned above, in 1953, the year after the beginning of the PWR submarine project. Technical specifications of the ground prototype 27/ VT facility are given in Table 5.1 [Sullivan]. Several problems were noted concerning the operation of this reactor, such as coolant freezing problems in sections of the lead-bismuth circuits and leaks. However, work on a submarine reactor was initiated in 1957 at the Malakit Design Bureau (SKB-143) in Leningrad.

Table 5.1 Technical data for the VT/ 27 test reactor

Power:	*70 MWt*
Core diameter	*769 mm*
Core height	*853 mm*
Content of U in U-Be alloy	*7–16 %*
Diameter of U-Be core	*11 mm*
Triangular lattice pitch	*13.6 mm*

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steel tank and into the core through porosity formed during the solidification of the Pb-Bi coolant. This might make the core critical. At present, six unloaded cores are stored in such wells in Gremikha on the Kola Peninsula. Three of the cores remain in the submarines.

Number of fuel rod elements	*2735*
Number of control and safety system rods (absorber is natural boron carbide)	*16*
Reactor thermal power	*70*
Coolant flow rate (m3/h)	*850*
Eutectic temperature at reactor inlet	*235*
Eutectic temperature at reactor outlet	*440*
Pressure	*38*

KM-1 was a prototype for the Alfa-class submarine with OK-550 steam supply system. The operation of the KM-1 started in 1978 and lasted until 1987. Then the core was unloaded and stored in the same type of storage block as at Gremikha. The experience gained with KM-1 is said to be used to solve the unloading problems at Gremikha.

The main propulsion plant of the project 645 submarine consisted of a double reactor steam-generating unit with two RM-1 reactors and heat power of 2 x 73.5 MWt and a two-shaft steam turbine plant. Coolant pressure in reactor was 20 kg/cm^2. The generated steam had the following parameters: pressure 36 kg/cm^2, temperature 355^{0}C. Some overall technical data on the RM-1 are given in IASAP; among the dimensions – core diameter approx. 800 mm and core diameter 780 mm [Yefimov]. The radial reflector consisted of "*from the core surface on outward, 10 mm thick ss, 65 mm BeO, and 8 mm thick SS*" [IASAP].

Two different models of the LMC-type reactor were developed for the Alfa-class submarines, VM-40 A reactor with two separate steam loops and circulating pumps, and the OK-550 steam system with branched first-loop lines and triple circulating loops and pumps [Sullivan]. VM-40 A was used in the three Alfa-class submarines (Project 705). They had two primary loops and a fixed beryllium reflector. The remaining four submarines (Project 705K) were each provided with one OK-550 reactor with three primary loops and a beryllium reflector that was fixed to the core and removed together with the fuel. For both types, the power level was 155 MW$_t$. These reactors were built by EDO "Gidropress" and OKBM under supervision of IPPE. This reactor type was run on intermediate energy neutrons. The core consisted of the fuel and the coolant, and was, as for RM-1, surrounded by a radial reflector of beryllium. The core had a diameter of 85 cm and a height of 77 cm. The fuel pins had a diameter of 1.1 cm and were arranged in a triangular lattice with a pitch of 1.36 cm. The number of fuel rods was 2,735 and the number of control rods 16.

4.4.2 Reactivity control

The emergency protection rods (EPR), control rods (CCR) and emergency cooling tubes (ECT) passed through a special shield plug on the top of the core for the RM-1 reactor. The ten CCRs were approx. 17 mm in inside diameter and arranged with one at the center, three evenly spaced at a radius of 97.5 mm and six spaced within radii of 97.5 and 292.5 mm. Both EPRs and CCRs were made of europium hexaboride (EuB_6). The content of europium has resulted in very high activity of the control rods. As described in [IASAP], the 24 ECTs were 70 mm inside and 80 mm outside diameter and evenly spaced on a radius of 641.5 mm. total amount of U-235 in the RM-1 core was 90 kg at an enrichment of 90%. The fuel rod pellets were approximately 10 mm in diameter. According to [IASAP], the pellets were covered with a 0.1 mm thick layer of MG and clad in SS with 0.5 mm thickness, yielding an outside diameter of 11 mm. These were subsequently arranged in a 13 mm triangular pitch, as shown in the IASAP report. In total, there were approximately 3,000 fuel rods in each LMR core. For the larger VM-40A m reactor, the total amount of U-235 was about 200 kg. For both reactor types, the coolant was a eutectic lead-bismuth alloy (44.5 wt% lead, 55.5 wt% bismuth) with a fairly low melting point (around 125^{o} C).

4.4.3 Fuel

The fuel for both the RM-1 and the VM-40A m had the form of rods containing an intermetallic compound of 90% enriched uranium and beryllium ($U\text{-}Be_{13}$), dispersed in a beryllium matrix. The total amount of ^{235}U in the RM-1 core was 90 kg at an enrichment of 90%. The fuel rod pellets were approximately 10 mm in diameter. The pellets were covered with a 0,1 mm thick layer of MG and clad in SS with 0,5 mm thickness, as a result the fuel rods were 11 mm outside diameter. These were subsequently arranged in a 13 mm triangular pitch as shown in the IASAP-report. In total, there were approximately 3000 fuel rods in each LMR core. For the larger VM-40A m reactor, the total amount of 235U is about 200 kg. For both reactor types, the coolant was a eutectic lead-bismuth alloy (44.5 wt% lead, 55.5 wt% bismuth) with a fairly low melting point (around 125 ^{o}C).

5 Summary and conclusions

This report should not be seen as forming the basis for firm conclusions. Rather, it should encourage for further work in the area of Russian marine nuclear systems. Available information has remained scarce, while updated knowledge is important for nations, interest groups and individuals engaged in areas where such reactor systems are operated.

5.1 MAIN DIRECTIONS IN THE DEVELOPMENT OF RUSSIAN MARINE NUCLEAR SYSTEMS

In the development of Russian marine reactor systems, two specific avenues have been pursued: (1) civilian reactor systems with conventional designs and materials, (2) military reactor systems, much less transparent, but with more advanced technologies and materials. The development of military naval reactors soon branched into two separate tracks: water-cooled and water-moderated reactors vs. liquid-metal-cooled reactors (without moderations using intermediate neutrons)

From the very beginning, the main feature of both civilian and the military systems was the use of two identical reactors in each vessel – in contrast to US nuclear submarines, where one reactor was considered sufficient. Given the limited operation of the first generation of Russian submarines outside Russian coastal waters, the use of two reactors seems to be a measure of deliberate operational redundancy. This is a logical consequence when one recalls the many failures experienced in the first decades of submarine reactor operation, as also stated in Russian scientific sources. This in turn might have been a consequence of the lack of testing of these early versions of the military reactors.

Since the Kurchatov Institute has played an important role in the design of pressurized water reactors for both naval and icebreaking vessels, it seems reasonable to assume that the general designs were probably quite similar. On this basis the assumption was made that the design of fuel assemblies in the first generation of submarine reactors was similar in naval vessels and in icebreakers: however, the validity of this is hard to judge. However, the overall tendencies for the civilian program should apply to the military realm as well, even if there are distinct differences between important elements in the civilian and military technology.

5.1.1 Civilian Russian Marine Reactors

The first civilian marine propulsion system installed in the icebreaker *Lenin* was based on low-enriched ceramic fuel, uranium dioxide, in Zr-cladding. Apparently, there was a need to improve the cladding, as several other types of cladding were introduced as part of the second fuel load for the reactor, at least stainless steel and Zr-Nb alloy. After the accident with *Lenin* in 1967, important developments were identified, and today the icebreakers use a uranium-zirconium alloy as fuel in Zr-cladding. The precise amount of fuel is not known except for the freighter *Sevmorput*, where the safety report specifies 150.7 kg. enriched to 90% as one fuel load. The changes can be summarized as follows:

- increased amount of fuel in the core (from 80 kg to 150.7 kg. U-235) and increased enrichment levels (from 5% to 90%);
- increased number of fuel pins pr. assembly (36 to 54) and increased number of assemblies in the core (219 to 241);

- improved heat-transfer characteristics (from ceramic – UO-2 – to metal fuel – U-Zr alloy);

In total, this accounts for improved output with regard to reactor power, 90 to 171 MWt, and optimalization of the operational characteristics, as the number of reactors was reduced from two to one, thereby removing the redundancy. As seen, safety provisions were also dramatically increased from OK-150 to OK-900.

5.1.2 Military Russian Marine Reactors

Russia started developing submarine reactors in 1952, about the same time as the civilian marine reactor program was initiated. For the PWR platform, an aluminia-based metal fuel was developed. The use of two reactors compensated for the low-enriched uranium used in the fuel. Changes here can be summarized in the same way as for the civilian sphere:

- increased amount of fuel in the core (from 30 kg to possibly 200 kg. U-235) and increased enrichment levels (6% to 45%);
- increased number of fuel pins pr. assembly and increased number of assemblies in the core (180–280 – presumably even higher for third-generation submarines);
- different fuel compositions and cladding materials (U-Al with stainless steel cladding, unknown matrix with zirconium cladding)

As the composition and geometry of the submarine fuel are rarely made public, it is hard to evaluate whether and how the heat-transfer characteristics of submarine fuel have been improved. It is reasonable to assume, however, that considerable scientific effort has been devoted to this. The strategies have possibly been to improve heat production capabilities by increasing the amount of metal and the heat-producing area in the fuel matrix and . The latter implies employing other fuel shapes than rods, for example plate fuel as used in US submarines or advanced geometries based on the rod shape, e.g. hollow pins, extremely small pins, use of fins, etc.

A pertinent question when considering enrichment levels in Russian submarines is why higher levels have not been used in order to boost the operational properties of the submarines – improving overall economy by reducing re-fueling operations to zero, as the US Navy has achieved, and reducing the time the submarine is not operational at sea. The explanation might lie in the inherent inertia in the Russian military-industrial complex and the absence of financial constraints in military spending until fairly recently. Under conditions of the same societal laws as in the West, one might expect to see future Russian submarines consisting of one single reactor with highly enriched fuel.

Regarding the reactor systems, leaks in the reactor circuits seem to have been a major problem, and one that has limited the operation of submarines.

5.2 PROPOSAL FOR FURTHER WORK

Most studies focusing on Russian marine reactors have used the *Sevmorput* safety report as the basis for their models of other marine reactors. As mentioned, this report constitutes the most comprehensive report on the details of Russian marine reactors to date. However, the characteristics of Russian marine reactors, as shown in the present report, represent a wide array of properties, and this should be reflected in future Russian marine reactor modeling. This report has thereby established the foundations for further design considerations and modeling of Russian marine reactors as a basis for, for example, a set of reactor and fuel models and reference levels for various scenarios for releases (accidents, sabotage etc.) involving Russian marine reactors and fuel, as a basis for environmental risk assessments, and for analyses of material attractiveness (amount and quality of fissile material, barrier evaluation, radiological emissivity) as a basis for proliferation risk assessments.

6 Acknowledgements

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ANNEX I: DATA FOR RUSSIAN VESSELS WITH NUCLEAR PROPULSION SYSTEMS

ANNEX I.A SUBMARINES

Annex I is based mainly on [Kotcher], [Apalkov1], [Apalkov2], [Apalkov3], [Apalkov4], [Demjanovski] and [Gladkov2]; all being recent Russian sources. If other sources are used. the reference is given in the endnotes. The meaning of the various terms employed in the Annex below is as follows:

Type/ project no.	Submarines are traditionally divided into groups describing their main function. In this annex, the following functions have been used: attack, cruise-missile, ballistic missile and research. One submarine might of course fill several of these functions, in which case the most typical one has been chosen.
NATO/ Russian Class:	NATO designation, always a name. / Russian designation of the class: usually a project number, sometimes also a name.
Displacement:	Surface displacement/submerged displacement (metric tons).
Speed:	Surface speed/submerged speed (knots).
Diving depth:	Design depth/max. depth (meters).
Dimensions:	Length×beam×height (not including the sail or conning tower).
Reactor model:	In most sources, a name or abbreviation is used for the specific type of reactor in the submarine.
# of reactors:	Russian submarines use one or two (left and right board) reactors in their submarines.
Steam generator unit:[17]	The steam-producing part of the submarine often has a separate designation from the reactor model.
Power:	Maximum thermal power output of one reactor.
Total shaft power:	Number of shafts and each shaft horse power.
Number built:	Total number of submarines built.
No. op. 2003:	Number in operation in the beginning of 2003.
Design:	Name of design bureau and chief designer(s). In the former Soviet Union and Russia, nuclear submarines are designed by special design bureaus: the TsKB-16 Malakhit and the TsKB-18 Rubin in Saint Petersburg and the TsKB-112 Lazurit Central Design Bureau in Nizhniy Novgorod (earlier Gorkiy).
Construction period:	Period during which construction took place.

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[17] Russia uses several notations for their submarines, reactors systems and parts thereof. Russian nuclear submarines are numbered by use of a letter (earlier K, but for the Typhoon class a TK, after the establishment of the Russian Navy 'B') followed by a number, e.g. K-3 or TK-20. The numbers are not issued according to the age or the class of the submarine, but quite randomly distributed. Once in a while the numbers may be changed, for example after upgrading or modernization of the vessel itself or of the different operational or military systems onboard. The submarines are also given a name. Some times other numbers are used to refer to specific nuclear submarines. The steam-generating system as such, including the reactor, has been given as designation consisting of \`OK\` and a number, without giving any specific explanations about how these notations being established. The nuclear reactors themselves, or the core and core configuration, are given a designation which seems to be based on the moderated medium. All registered notations are included in Annex 1 for further study.

Shipyard:	Yard where the submarine was built.
Comments:	Number of compartments, if data available, also the use of the compartments. Total number of crew members. Other information relevant to the presentation in the text.

Type/ project no. NATO/ Russian notation	Displacement surface/ submerged (metric tons) Speed (submerged/ surface) (knots) Diving depth/ max depth (meters) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ construction period/ shipyard	Comments (# of crew, description of compartments, status of certain vessels etc.)

Submarines with water-moderated and water-cooled reactors – first generation[18]

Attack submarine/ 627, 627A[19] NOVEMBER/ KIT	627: 3,101/ 4,069 627 A: 3,087/ 3,986 15.5/ 28 300/240 107.4 × 7.96 × 6.42	VM-A/ 2 NA 70 2 x 17,500	13/ 0	SKB-143[20] (G. Svetaev)/ 1955–63/ Severodvinsk	9 compartments: (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, crew – 110 men
Cruise missile submarine, later attack submarines/ 659, 659T ECHO-1	3,731/ 4,920 15.1/ ca. 26 300/ 240 111.2 × 9.2 × 7.6 m	VM-A/ 2 NA 70 2 x 17,500	5/ 0	TsKB-18 Rubin[21] (A. Klimov)/ 1956–62/ Komsomolsk-by Amur and Severodvinsk	10 compartments: (1) torpedo room, (2) quarters, 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, crew – 120 men

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[18] The main source regarding Russian submarines of first generation [Apalkov1], [Kotcher] and [Gladkov2].

[19] 627A had a torpedo system with larger caliber.

[20] SKB is a Russian abbreviation for “special construction bureau”. SKB-143 in St. Petersburg was later merged into TsKB -16 Malakhit. Malakhit built the first Soviet nuclear submarine, the *Leninsky Komsomol*. The Malakhit Design Bureau was created in 1948 for developing submarines with energy sources independent of atmospheric oxygen. Such a submarine (Design Project 617) was created and tested. In the late 1950s, when the nuclear-powered submarine program had been expanded substantially, a portion of the work was transferred to the Rubin Central Design Bureau. In 1974, TsKB-18 and SKB-143 merged to form the present St. Petersburg Malachite Marine

[21] TsKB is a Russian abbreviation for “central construction bureau”. Rubin has for many years been the central construction bureau for Ocean Technology; Malakhit is another one

Ballistic missile submarine/ 658, 658M[22], 658 S[23], 701[24] HOTEL	4,030/ 5,000 15/ 26 300/ 240 658: 114.1 × 9.2 × 7.31 701: 127 × 9.2 × 7.1	VM-A/ 2 NA 70 2 x 17,500	8/ 0	TsKB-18 Rubin (S. Kovalev)/ 1958–62/ Severodvinsk	10 compartments: (1) torpedo room, (2) quarters, 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, crew – 128 men
Cruise missile submarine/ 675, 675K [25] ECHO-II/ (not found)	4,450/ 5,650 14/23 300/ 240 115.4 × 9.3 × 7.9	VM-A/ 2 NA 70 2 x 17,500	29/ 0	TsKB-18 Rubin (P. Pustyntsev)/ 1961–67/ Komsomolsk by Amur and Severodvinsk	10 compartments: (1) torpedo room, (2) batteries, quarters and officers mess, (3) radar transmitter and missile fire control, (4) command center, (5) diesel generator and condensers, (6) reactors, (7) turbines, (8) electric motors, (9) quarters, galley, sick bay, refrigerators, (10) torpedo room, provisions, steering gear , crew – 137 man
675MK ECHO-II/ NA	5,090/ 6,500 14/ 23 300/ 240 115.4 × 9.3 × 7.9	VM-A/ 2 NA 70 2 x 17,500	9 out of 29		675MK represented replacement of cruise missile system with faster missiles (“Basalt”).
675MKB ECHO-II/ NA	5,375/ 6,810 14/ 22 300/ 240 115.4 × 9.3 × 7.9 m	VM-A/ 2 NA 70 2 x 17,500	4 out of 29		675MK represented replacement of cruise missile system (“Vulkan”).Total crew were 112 man.

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[22] 658M was identical in construction to 658, but was equipped with missiles which could be launched while submerged.

[23] 658S was a modernization of 658, as for example K-19 experienced 1978–79.

[24] K-145 was called project 701 after the steam generators were changed in December 1965.

[25] 675K was a modification for using submarines for launching satellites into space.

Type/ project no. NATO/ Russian notation	Displacement surface/ submerged (metric tons) Speed (submerged/ surface) (knots) Diving depth/ max depth (meters) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ construction period/ shipyard	Comments (# of crew, description of compartments, status of certain vessels etc.)
Submarines with water-moderated and water-cooled reactors – second generation[26]					
Ballistic missile submarine/ 667A, 667 AO YANKEE/ NAVAGA, NALIM, MURENA (667 AO)	7,850 / 10,100 16.5/ 27 450/ 380 129.8 × 11.7 × 8.7	VM-2 – 4/ 2 OK-700 90 2 x 20,000	34/ 0	TsKB-18 Rubin (A. Kassatsier/ S. Kovalev))/ 1964–72/ Severodvinsk (NAVAGA) and Komsomolsk-by Amur (NALIM)	10 compartments: (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) turbines, (10) electrical compartment , crew – 114 man. 667 AO had a different missile complex than 667A.
Research submarine/ 667 AN YANKEE/ 09774	8 900/ ? 16,5/ 27 400/ 320 162,5 × 11,7 × 8,3	VM – 2 – 4/ 2 OK – 700 90 2 x 20 000	1 out of 34	TsKB-18 Rubin (A. Kassatsier/ S. Kovalev), 1964-72, Severodvinsk	1 modified 667 to become a midget-submarine carrier (Project 09780 or Yankee-Stretch).

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[26] The main sources regarding Russian submarines of second generation are [Apalkov1], [Apalkov2] and [Demjanovski].

667M YANKEE/ ANDROMEDA	10 500/ 13 600 16,5/ 27 400/ 320 152 × 14,7 × 8,7	VM – 2 – 4/ 2 OK – 700 90 2 x 20 000	1 out of 34	TsKB-18 Rubin (A. Kassatsier/ S. Kovalev), 1964-72, Severodvinsk	1 modified 667 to become a midget-submarine carrier (Project 09780 or Yankee-Stretch). Crew – 120 men.
667AT YANKEE/ GROSHA	8 880/ 11 400 16,5/ 27 400/ 320 141,7 × 12,8 × 7,8	VM – 2 – 4/ 2 OK – 700 90 2 x 20 000	3 out of 34/ 1	TsKB-18 Rubin (A. Kassatsier/ S. Kovalev)), 1964-72, Severodvinsk	3 later modified to cruise missile submarines (Project 667AT (GROSHA) or Yankee-Notch). Operational base in Saida Bay, Northwest-Russia.
Ballistic missile submarine/ 667B DELTA-I/ MURENA	8,900/ 11,000 17.5/ 25 400 /320 139 × 11.7 × 8.4	VM-4 B/ 2 OK- 700 290 2 x 20,000	18/ 2	TsKB-18 Rubin, (S. Kovalev), 1971-77, Severodvinsk and Komsomolsk- by Amur	10 compartments – built on the basis of 667A (Yankee) -(1) torpedo, (2) batteries and officers quarters, (3) central command post, (4) missiles, (5) missiles, (6) diesel generators, (7) reactors, (8) turbines, (9) turbines, (10) electrical compartment, crew – 120 man. Operational base: Saida Bay, Northwest-Russia.
Ballistic missile submarine/ 667BD DELTA-II/ MURENA-M	10,500/ 13,600 15/ 25 400 /320 155 × 11.7 × 8.6	NA/ 2 NA 90 2 x 20,000	4/ 0	TsKB-18 Rubin, (S. Kovalev), 1973-75 Severodvinsk	10 compartments built on the basis of 667 B (Delta-I): (1) torpedo, (2) batteries and officers quarters, (3) central command post, (4) missiles, (5) missiles, (6) diesel generators, (7) reactors, (8) turbines, (9) turbines, (10) electrical compartment, crew – 126 man

Ballistic missile submarine 667BDR DELTA-III/ KAL'MAR	10,600/ 13,700 14/ 24 400/ 320 155 × 11.7 × 8.7	VM- 4 S/ 2 OK-700 A 90 2 x 20,000	14/ 12	Tskb-18 Rubin, (S. Kovalev), 1975–81 Severodvinsk	11 compartments, crew – 130 man. Operational base: Saida Bay, Northwest-Russia and Tarya bay, Pacific coast. 7 vessels operational as part of ordinary service, in addition one vessel, K-129, is expected to be converted to research vessel.[27]
Ballistic missile submarine/ 667BDRM DELTA-IV/ DELFIN	11,700/ 18,200 14/ 24 400/ 320 167 × 11.7 × 8.8	VM-4 SG/ 2 OK -700 A 90 2 x 20,000	7/ 6	TsKB-18 Rubin, (S. Kovalev), 1981–90, Severodvinsk	11 compartments, crew – 135 men
Cruise missile submarine/ 670, 670A CHARLIE-1/ SKAT	3,574/ 4,560 12/ 26 300/ 240 95.5 × 9.9 × 7.5	VM-4 – 1/ 1 OK-350 89 1 x 18,800	11/ 0	TsKB-112 Lazurit, (V. Vorob'ev)/ 1967–72/ Gorkiy	7 compartments: (1) torpedo room, accumulators, (2) quarters, (3) central post for accumulators , (4) electromechnical room, (5) reactor, (6) turbines, (7) electromechnical room, crew –100 men
Cruise missile submarine/ 670M CHARLIE-2/ SKAT M (TCHAIKA)	4 ,00/ 5,350 12/ 24 300/ 240 m 104.5 × 10.0 × 6.9	VM-4 – 1/ 1 OK-350 89 1 x 18,800	6/ 0	TsKB-112 Lazurit, (V. Vorob'ev)/ 1967–72/ Gorkiy	One compartment more than Charlie-1, crew – 98 men.

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[27] [Jane’s], p. 586.

Attack submarine/ 671, 671V, VICTOR-I[28]/ ERSH	3,570/ 4,870 10/11.5/ 14 – 30/31 400/ 320 92.5 × 10.6 × 7.3	VM-4/ 2 OK-300 72 1 x 31,000	11/ 0	TsKB-16 Malakhit, (G.N.Tchnishov)/ 1965–74/ Admiralty Yard, Leningrad	7 compartments: (1) torpedo room, quarters, batteries, (2) command center, (3) reactors, (4) turbines, (5) quarters and diesel generators, (6) auxiliary equipment, (7) electric motors – 68/ 76/ 94 men (various sources)
Attack submarine/ 671RT VICTOR-II/ SEMGA	4,245/ 5,670 10–11.7/ up to 30 400/320 101.8×10.78×7.3	VM-4 P/ 4T/ 2, OK-300 (2) 72 1 x 31,000	7/ 0	TsKB- 16 Malakhit, (G.N.Tchyernyshov)/ 1971–78/ Admiralty Yard, Leningrad and Gorkiy	8 compartments: (1) torpedo room, battery, (2) quarters, sick bay, galley, officers mess, (3) command center, navigation, sonar, (4) reactors, (5) turbines, (6) turbo-generators, auxiliary equipment, refrigerators, (7) quarters, diesel generators, (8) steering gear, creep motors, crew – 98 men
Attack submarine/ 671RTM, 671RTMK VICTOR-III/ SHCHUKA	4,750/ 6,990 11/less than 30 knots 400/ 350 107.2 × 10.8 × 7.4	VM- 4A/ 2 NA 72 1 x 31,000	26/ 12	TsKB-16 Malakhit, (G.N Tchyernyshov),/ 1978–91/ Komsomolsk-by Amur and Admiralty Yard, Leningrad	8 compartments: (1) torpedo room and batteries, (2) accommodations and mess, (3) control room and steering, (4) reactor compartment, (5) turbines, (6) turbo generators, (7) accommodations and diesel generators, (8) steering and electric motor, crew – 100 men. Operational base: Litsa and Saida bay

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[28] [Handler] discusses a general type Viktor with the properties of VM-4/ OK-300A, 69-70 MWt 4 pumps and steam generators, Handler (1995) One variant is, as seen in this annex, VM-4 AM, a two-reactor configuration, same fuel type as that stolen in Andreeva Bay in 1993.

Type/ project no. NATO/ Russian notation	Displacement surface/ submerged (metric tons) Speed (submerged/ surface) (knots) Diving depth/ max depth (meters) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ construction period/ shipyard	Comments (# of crew, description of compartments, status of certain vessels etc.)
Submarines with water-moderated and water-cooled reactors – third generation[29]					
Cruise missile submarine/ 949 OSCAR/ GRANIT	13,400/ 22,500 15/ 30 450/ 400 144×18.2×9,2 m;	VM-5/2 OK-650M.02, OK-650M.01 190 2 x 50,000	2/ 0	Tskb-18 Rubin, (P. Pustyntsev and E. Bazanov)/ 1974–80/ Severodvinsk	10 compartments, crew – 107 men
Cruise missile submarine/ 949A OSCAR II / ANTEIY	15,000/ 25,650 14.6/ 33.4 800–600/ 520 154.7 × 18.2 × 9,5	VM-5/ 2 OK-650M.02, OK-650M.01 190 2 x 50,000	11/ 6		10 compartments, crew – 106 men. Operational base: Litsa bay, Northwest-Russia (2), Tarya Bay, Pacific coast. One vessel under construction which is likely to never be finished.[30]

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[29] The main sources regarding Russian submarines of third generation are [Apalkov1], [Apalkov2] and [Demjanovski].

[30] [Jane’s], p. 580.

Ballistic missile submarine/ 941 TYPHOON/ AKULA	23,200/ 48,000 12/ 25 400/ NA 172.8 × 23.3 × 11	VM-5/ 2 OK-650 190 2 x 50,000	6/ 3	TsKB-18 Rubin, (S. Kovalev)/ 1977–89/ Severodvinsk	19 sections in two separate pressure hulls. Three separate sections: torpedo, central and steering. Missile launchers between pressure hulls, crew – 160 man. One vessel never completed, scrapped in 1990 (not included in the 6). Operational base: Litsa bay, Northwest-Russia.
Attack submarine, 945 SIERRA/ BARRACUDA	6,300/8,200 12./ 35.15 600/ 520 107×11.2×8.5	VM-5/ 1 OK-650 A 190 1 x 50,000	2/ 1	TsKB-112 Lazurit/ TsKB-16 (N. E. Kvasha)/ 1983–93/ Gorkiy and Severodvinsk	6 compartments, crew – 61 men. Operational base: Ara Bay, Northwest-Russia.
Attack submarine, 945 SIERRA II/ KONDOR	6,470/8,500 14/ 32.8 600/ 520 112.7×11.2×8.5	VM-5/ 1 OK-650 B 190 1 x 50,000	2/ 1	TsKB-112 Lazurit/ TsKB-16 (N. E. Kvasha)/ 1983–93/ Gorkiy and Severodvinsk and	7 compartments, crew – 70 men. Operational base: Ara Bay, Northwest-Russia.
Attack submarine/ 971 AKULA/ BARS	8,140/ 10,500 10/ 33 600/ 480 110.3×13.6×9.68	VM-5/ 1 OK-9VM or OK-650M.01 190 1 x 50,000	18/ 10	TsKB-16 Malakhit (G.N.Tchernyshov)/ 82-/ Komsomolsk by Amur and Severodvinsk	8 compartments, crew – 73 men. Operational base: Saida Bay, Northwest-Russia and Tarya Bay, Pacific coast. Two vessels under construction in Komsomolsk-na-Amur.

Type/ project no. NATO/ Russian notation	Displacement surface/ submerged (metric tons) Speed (submerged/ surface) (knots) Diving depth/ max depth (meters) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ construction period/ shipyard	Comments (# of crew, description of compartments, status of certain vessels etc.)
Submarines with water-moderated and water-cooled reactors – fourth generation					
Ballistic missile submarine/ 885[31] GRANAY/ YASEN	NA 19/ 31 NA 111 × 12 × 8.4	NA OK-650 195 1x 43,000	0/ 0	TsKB-18 (Rubin), (J. Kormilitsin)/ 1993-/ Severodvinsk	8 compartments, crew – 50 man. One vessel (*Severodvinsk)* under construction.
Ballistic missile submarine/ 955 ---/ BOREI	NA / 19,400 NA NA NA	(OK-650 B)/ 2 NA 195 2x 98,000	0/ 0	TsKB-18 (Rubin) PO/ 1996-/ Sevmash-predpriyatiye, Severodvinsk	Two vessels under construction, *Yuriy Dolgoruky* (planned to be finished in 2006) and *Alexander Nevsky* (hull reported completed in 2004).[32]

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[31] These data are taken from the www.fas.org website August 1, 2004.

[32] These data are taken from the www.bellona.org website August 20, 2004.

Type/ project no. NATO/ Russian notation	Displacement surface/ submerged (metric tons) Speed (submerged/ surface) (knots) Diving depth/ max depth (meters) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ construction period/ shipyard	Comments (# of crew, description of compartments, status of certain vessels etc.)
Other submarines with water-moderated and water-cooled reactors					
Cruise missile submarine, 661 Papa/ ANCHAR	5,197/ 7,000 25/ 45 550/ 400 106.92 × 11.5 × 8.2	NA/ 1 177. 4[33] 2 x 40,000	1/ 0	TsKB-16 Malakit, (N.N.Isanin and N.F.Shul'zhenko)/ 1963–69/ Severodvinsk	9 compartments: (1) torpedo room and battery, (2) torpedo room and battery, (3) quarters and batteries, (4) command center and quarters, (5) reactors, (6) turbines, (7) turbo-generators, main switchboard, (8) auxiliaries (refrigerators, compressors), (9) electric motors and steering equipment, crew – 82 men.
Attack submarine, 685 Mike/ PLAVNIK	5,750/ 7,810 14/ 30.6 1000/ 1250 117.5 × 10.7 × 8	NA/ 1 OK 650 B-3/ OK-650B 190 1 x 43,000	1/ 0	Tskb-18 Rubin (N.A.Klimov and Yu.N.Kormilitsyn)/ 1978–83/ Severodvinsk	7 compartments: (1) torpedo room, batteries, special underwater, 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, crew – 57 men
Research submarine/ 10831 (A-23) X-RAY	1,600/ 2,100 6 1,000 60 × 7 × 5.1	NA/ 1 1 x 15,000	1/ 1	NA/ NA/ Severodvinsk	Small, deep-water nuclear submarines, crew – 25 men. Operational base: Yagri Island, Northwest-Russia.

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[33] [Handler], p. 1.

Research submarine/ 1851 PALTUS/ NEHLMA	550/ 1,000 NA 1,000/ NA 53 × 53,8 × 5	NA/ 1 NA 10 1 x NA	2/ 2	NA/ 1982/ Sudomekh, Leningrad	A third vessel was started but never completed.[34] Operational base: Olenya Bay, Northwest-Russia.
Research submarine/ 1910 UNIFORM/ KASHALOT	1,390/ 2,000 10/ 30 1,000/ NA 69 × 7 × 5.2	10/ 1 NA 10 1 x 10,000	3 /3	NA/ 1982–95/ Sudamekh, Leningrad	Crew 36 men. Operational base: Olenya Bay, Northwest-Russia.

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[34] [Jane's], p. 587.

Type/ project no. NATO/ Russian notation	Displacement surface/ submerged (metric tons) Speed (submerged/ surface) (knots) Diving depth/ max depth (meters) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ construction period/ shipyard	Comments (# of crew, description of compartments, status of certain vessels etc.)
Liquid-metal-cooled submarines Russian military marine reactors					
Attack submarine/ 645 (November class hull)/ ZhMT	3,414/ 4,370 14.9/30.2 300/ 270 109.8 × 8.3 × 6.28	RM-1/ 2 NA 73 2 × 17,500	1/ 0	V.N.Peregudov and A.K.Nazarov/ 1958–63/ Severodvinsk	9 compartments: (1) torpedo room, (2) batteries and quarters, (3) command center, (4) reactors, (5) turbo-generators, diesel generators, refrigerators, auxiliaries, (6) turbines, engine control room, (7) electric motors, (8) quarters and refrigerators, (9) quarters, steering gear, crew – 105 men
Attack submarine/ 705 ALFA/ LIRA	2,300/ 3,180 14.0 / 41 350/ 420 84.1 × 10 × 7.6	VM-40 / 1 OK-550 155/ 1 x 40,000	4/ 0	TsKB-16 Malakhit (A. Petrov, M. Rusanov), SKB-143 Volna, (V. Romin)/ 1977–83/ Adm. Yard, Leningrad, and Severodvinsk 1970 –1983	Six, only two manned – 30 men. Titanium alloy hull, highly automated
Attack submarine/ 705K ALFA/ LIRA	2,280/ 3,180 14.0 / 41 350/ 420 79.6 × 10 × 7.6	VM-40A/ 1 OK-550 155/ 1 x 40,000	3/ 0	TsKB-16 Malakhit, A. Petrov, M. Rusanov SKB-143 Volna, V. Romin 77–83 Admiralty Yard, Leningrad, and Severodvinsk 1970 –1983	Six, only two manned – 30 men. Titanium alloy hull, highly automated

ANNEX I.B MILITARY AND CIVILIAN SURFACE SHIPS

The meaning of the different terms employed in Annex I.B below is as follows:

Type/ project no.	Surface vessels are traditionally divided into groups describing their main function (missile cruiser, command ship, icebreakers)
NATO/ Russian Class:	NATO designation, always a name./ Russian designation; always a project number, sometimes also a name
Displacement:	Standard displacement/ loaded displacement (metric tons).
Speed:	Standard/ using reserve propulsion (knots).
Diving depth:	Design depth/max. Depth (meters).
Dimensions:	Length × beam × height (meters).
Reactor model:	In most sources, a name or abbreviation is used for the specific type of reactor in the submarine. All reactors used are pressurized power reactors
# of reactors:	Russian surface vessels use one or two reactors.
Steam generator unit:	The steam-producing part of the vessel often has a separate designation compared to the reactor model.
Power:	Maximum thermal power output of one reactor.
Total shaft power	Number of shafts and each shaft horse power.
Number built:	Total number of vessels built.
No. op. 2003:	Number in operation in mid-2003.
Design:	Name of design bureau and chief designer(s).
Construction period:	Period during which construction took place.
Shipyard:	Yard where the submarines were built.
Comments:	Number of compartments, if data available, also the use of the compartments. Total number of crew members. Other information relevant to the presentation in the text.

Type/ project no. NATO/ Russian notation	Displacement standard/ loaded (metric tons) Speed (standard/ reserve) (knot) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ constr. period/ shipyard	Comments (# of crew, status of certain vessels etc.)
Water-moderated and water-cooled Russian military marine reactors – surface ships[35]					
Missile cruiser 1144 BALCOM-1/ ORLAN (ALSO KNOWN AS THE KIROV CLASS)	24,300/ 28,000 31/ 14 251.2 × 28.5 × 9.1	KN-3/ 2 NA 300 2 x 70,000	1/ 0	Nevskii PKB (B. Kupyenskiy and V. Perevalov)/ 1974–96/ Baltic Yard, Leningrad	Crew – 610 man, one vessel (Kirov, renamed Adm Ushakov)
Missile cruiser 1144.2	24,300/ 28,000 31/ 14 251.2 × 28.5 × 9.1	KN-3/ 2 NA 300 2 x 140,000	4/ 4	Nevskii PKB (B. Kupyenskiy and V. Perevalov)/ 1974–96/ Baltic Yard, Leningrad	Crew – 610 man, four vessels (Frunze, renamed Adm Lazarev; Kalinin, renamed Adm Nakhimov; Yuri Andropov, renamed Petr Velikiy; Admiral of the Soviet Fleet Kuznetsov)

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[35] The main sources regarding Russian surface vessels are [Apalkov3], [Apalkov4] and [Jane's].

Aircraft carrier 11437	65,800/ 75,000 30 knots 321.2 × 42 × 83.9	KN-3–43/ 4 NA 305 4 × 50,000	0/ 0	Nevskii PKB (L. Belov and Y. Varfalameev)/ Nikolaev/ 1988–92/ NA	Crew – 3,400 men. The ship was completed 20%, then in October 1992 completely stopped.
Pacific Fleet command ship (missile tests) 1941[36] KAPUSTA/ TITAN	32,780 /34,640 265 × 29.9 × 7.81	VM-16/ KN-3/ 2 OK-900 B 171 ? × 66,500	1/ 1	Baltic Yard, Leningrad	Crew – 923 men. Kapusta class (Project: 1941 (Titan)). Pacific Fleet command ship

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[36] The information here is based on the Bellona website (www.bellona.no) accessed August 10, 2004.

Type/ project no. NATO/ Russian notation	Displacement (metric tons) standard/ loaded Speed (standard/ reserve) (knots) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ constr. period/ shipyard	Comments (# of crew, status of certain vessels etc.)
Civilian icebreakers – first generation					
Icebreaker *LENIN* 1958–1966	15,940/ 17,810 19.6 knots in open sea, 3–4 knots in 2.4 m ice 134×27.6×16.1 m	OK-150/ 3 NA 90 44,000	1/0	1955–59/ Admiralty Yard, Leningrad	Reconstructed with two reactors in 1970
Civilian icebreakers – second generation					
Icebreaker *LENIN* 1970–1989	15,940/ 17,810 t NA 134×27.6×16.1 m	OK-900/ 2 NA 159 44,000		1966–70/ Admiralty Yard, Leningrad	Crew – 230, withdrawn from service in 1989

Icebreaker	21,000/23,400	OK-900 A	2/2	Central Design Office “Aisberg”/ 1971–77/ Baltijskij Shipyard, Leningrad	Crew – 183, *Arktika* and *Sibir* built, *Arktika* still in active service, *Sibir* withdrawn
ARKTIKA	20.8 knots in open sea	NA			
		171			
	47.9 × 29.9 × 17.2	75,000			
Icebreaker	22,920	OK-900 A	3/3	1981–92/ Baltijskij Shipyard,Leningrad	Crew – 171. *Rossija, Sovetsky Soyus* and *Yamal*. All in active service.
ROSSIJA	20.8 knots in open sea	NA			
		171			
	50 × 30 × 17.2	75,000			

Civilian icebreakers – third generation

Icebreaker	20,000	KLT-40	2/2	1984–89/ Wartsila Marine Shipyard, Finland – Baltiskij Shipyard, Leningrad/	*Taimyr* and *Vaigach* in active service.
TAIMYR	18.5 knots in open sea	NA			
		171			
	151.8×29.2×15.2 m	50,000			
Icebreaker (freighter)	33,900/61,800	KLT-40 M	1/1	1984–88/ Baltic Shipyard, Leningrad,	In active service
	20.5 knots in open sea	NA			
SEVMORPUT		135			
	260.3 × 32.2 × 18.3	40,000			

ANNEX II:
RUSSIAN NUCLEAR MARINE BASES AND SHIPYARDS

ANNEX II.A NAVAL BASES OF THE NORTHERN FLEET

Existing and former naval bases and other nuclear facilities of the Northern Fleet:

Andreeva Bay, Murmansk Region. Undergoing decommissioning. Storage of spent fuel and radioactive waste

Ara Bay, Murmansk Region. Naval base, Akula, Sierra, and Oscar-II subs (?),
storage of decommissioned submarines

Berpich’ya Bay, Murmansk Region. Storage of decommissioned submarines

Belomorskaya Navy base. Murmansk Region. Storage of decommissioned submarines and compartment units

Bolshaya Lopatka, Zapadnaya Litsa Bay, Murmansk Region. Naval base, Oscar-II and Victor-III, storage of decommissioned submarines

Gadzhievo, Murmansk Region. Name of main base (Olenaya Bay, Skalisty).

Gremikha, Murmansk Region. Undergoing decommissioning. Earlier Alfa submarines, storage of decommissioned submarines and one-compartment units, storage of fuel.

Nerpichya, Zapadnaya Litsa Bay, Murmansk Region. Naval base, Typhoon submarines

Oleniya Bay, Murmansk Region. Naval base, Delta-4 and Delta-3 submarines, storage of decommissioned submarines

Ostrovnoy, , Murmansk Region (Gremikha?). Naval base, Delta-1 submarines

Saida (Sayda) Bay, Murmansk Region. Long-term storage of compartment units planned

Severomorsk. Home base for the Northern Fleet, Balcom-1 cruisers.

Skalisty, Murmansk Region. Naval base, Delta-III, Delta IV and Yankee submarines.

Snezhnogorsk, Murmansk Region. Naval Town.

Ura Bay, Murmansk Region. Naval base, Akula, Sierra, and Oscar-II subs (?), storage of decommissioned submarines

Vidiaevo, Murmansk Region. Naval town and name of main base (Ara Bay, Ura Bay)

Yag(y)elnaya Cove, Murmansk Region. Delta-3, Delta-2, earlier Yankee submarines

Zaozersk, Murmansk Region. Naval Town

Zapadnaya Litsa Bay, Murmansk Region. Name of main base (Andreeva Bay, Nerpichya, Bolshaya Lopatka, Malaya Lopatka)

Naval bases of the Pacific Fleet:

Abrek Bay, Primorsky Krai Region?

Konyushkova Bay, Primorsky Krai Region

Krasheninnikova Bay, Kamchatska region. Undergoing decommissioning

Palovskiy Primorsky Krai Region. Delta-I submarine

Pavlovskogo Bay, Primorsky Krai Region. Storage of decommissioned submarines

Razboinik Bay, Primorsky Krai Region. Long-term storage of compartment units planned

Rybachiy. Delta-3, Delta-1 and Yankee submarines

Severnaya Bay, Primorsky Region

Sysoyeva Bay, Primorsky Krai Region. Undergoing decommissioning. Construction of site for storage of spent fuel containers

Ust-Kut Bay, Primorsky Krai Region?

Ustrichnyi (Oyster) Cape between Chazhma Bay and Razboinik Bay, Primorsky Bay

Postovaya Bay, Khabarovsk Region. Storage of decommissioned submarines Soviet Gavan, Khabarovsk Region

Krasheninnikova Bay, Kamchatska Region. Undergoing decommissioning. Storage of decommissioned submarines

Petropavlovsk-Kamchatski, Kamchatska Region

Ribachly, Kamchatska Region

Gorbusheja, Pacific

Some of the bases listed above are given by the name of the bays where they are situated, some by a name. Therefore, it may well be that some of the bases are listed twice, both by their name and by the bay where they are situated.

ANNEX II.B NAVAL SHIPYARDS

Russia has shipyards for construction of new naval vessels, for maintenance and repair, and for decommissioning. Shipyards for construction of new vessels are:

Northwest Russia
Admiralty Yard, Leningrad
Baltijskij Shipyard (Baltic Yard), Leningrad (surface ships only)
Krasnoye Sormovo Shipyard, Gorkiy
SevMash Shipyard, Severodvinsk, Arkhangelsk Region. The main shipyard for
new units. Participates also in decommissioning work.
Sudomekh, Leningrad

Pacific
Komsomolsk-by Amur

Over the past decade SevMash seems to have been the only Russian shipyard involved in construction of new naval vessels.

Maintenance and repair shipyards for nuclear vessels are:

Northwest Russia
Malaya Lopatka, Zapadnaya Litsa Bay, Murmansk Region. Repair shipyard
Murmansk, Murmansk Region. Shipyard, storage of spent fuel and radioactive waste.
Nerpa repair and decommissioning shipyard, Snezhnogorsk, Murmansk Region
Polyarninsky repair and decommissioning shipyard, Polyarniy, Murmansk Region (The 10th shipyard or Shkval Polyarniy ?)
Roslyakovo, Murmansk Region. Repair shipyard.
Sevmorput shipyard, Murmansk Region
Service and Repair Enterprise “Atomflot”, Sevmorput, Murmansk Region.
Construction of site for storage of spent fuel containers
Zvezdochka repair and decommissioning shipyard, Severodvinsk, Arkhangelsk Region. Construction of on-shore de-fueling facility and site for storage of spent fuel containers

Pacific
Zvezda, Bolshoi Kamen, Primorsky Krai Region (near Vladivostok). Construction of on-shore de-fueling facility and site for storage of spent fuel containers
Chazhminsky Ship Repair Plant, Primorsky Krai Region (near Vladivostok)
SVRTs MOD RF, Federal State Unitary Enterprise, Kamchatka
Vilyuchinskiy Ship Repair Plant, Kamchatka

The maintenance and repair yards are also where most of the decommissioning and dismantling of old naval vessels take place.

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ANNEX I: DATA FOR RUSSIAN VESSELS WITH NUCLEAR PROPULSION SYSTEMS

ANNEX I.A SUBMARINES

Annex I is based mainly on [Kotcher], [Apalkov1], [Apalkov2], [Apalkov3], [Apalkov4], [Demjanovski] and [Gladkov2]; all being recent Russian sources. If other sources are used. the reference is given in the endnotes. The meaning of the various terms employed in the Annex below is as follows:

Type/ project no.	Submarines are traditionally divided into groups describing their main function. In this annex, the following functions have been used: attack, cruise-missile, ballistic missile and research. One submarine might of course fill several of these functions, in which case the most typical one has been chosen.
NATO/ Russian Class:	NATO designation, always a name. / Russian designation of the class: usually a project number, sometimes also a name.
Displacement:	Surface displacement/submerged displacement (metric tons).
Speed:	Surface speed/submerged speed (knots).
Diving depth:	Design depth/max. depth (meters).
Dimensions:	Length×beam×height (not including the sail or conning tower).
Reactor model:	In most sources, a name or abbreviation is used for the specific type of reactor in the submarine.
# of reactors:	Russian submarines use one or two (left and right board) reactors in their submarines.
Steam generator unit:[1]	The steam-producing part of the submarine often has a separate designation from the reactor model.
Power:	Maximum thermal power output of one reactor.
Total shaft power:	Number of shafts and each shaft horse power.
Number built:	Total number of submarines built.
No. op. 2003:	Number in operation in the beginning of 2003.
Design:	Name of design bureau and chief designer(s). In the former Soviet Union and Russia, nuclear submarines are designed by special design bureaus: the TsKB-16 Malakhit and the TsKB-18 Rubin in Saint Petersburg and the TsKB-112 Lazurit Central Design Bureau in Nizhniy Novgorod (earlier Gorkiy).
Construction period	Period during which construction took place.
Shipyard:	Yard where the submarine was built.
Comments:	Number of compartments, if data available, also the use of the compartments. Total number of crew members. Other information relevant to the presentation in the text.

Submarines with water-moderated and water-cooled reactors – first generation[2]

Type/ project no. NATO/ Russian notation	Displacement surface/ submerged (metric tons) Speed (submerged/ surface) (knots) Diving depth/ max depth (meters) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ construction period/ shipyard	Comments (# of crew, description of compartments, status of certain vessels etc.)
Attack submarine/ 627, 627A[3] NOVEMBER/ KIT	627: 3,101/ 4,069 627 A: 3,087/ 3,986 15.5/ 28 300/240 107.4 × 7.96 × 6.42	VM-A/ 2 NA 70 2 x 17,500	13/ 0	SKB-143[4] (G. Svetaev)/ 1955–63/ Severodvinsk	9 compartments: (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, crew – 110 men
Cruise missile submarine, later attack submarines/ 659, 659T ECHO-1	3,731/ 4,920 15.1/ ca. 26 300/ 240 111.2 × 9.2 × 7.6 m	VM-A/ 2 NA 70 2 x 17,500	5/ 0	TsKB-18 Rubin[5] (A. Klimov)/ 1956–62/ Komsomolsk-by Amur and Severodvinsk	10 compartments: (1) torpedo room, (2) quarters, 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, crew – 120 men
Ballistic missile submarine/ 658, 658M[6], 658 S[7], 701[8] HOTEL	4,030/ 5,000 15/ 26 300/ 240 658: 114.1 × 9.2 × 7.31 701: 127 × 9.2 × 7.1	VM-A/ 2 NA 70 2 x 17,500	8/ 0	TsKB-18 Rubin (S. Kovalev)/ 1958–62/ Severodvinsk	10 compartments: (1) torpedo room, (2) quarters, 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, crew – 128 men

Cruise missile submarine/ 675, 675K [9] ECHO-II/ (not found)	4,450/ 5,650 14/23 300/ 240 115.4 × 9.3 × 7.9	VM-A/ 2 NA 70 2 x 17,500	29/ 0	TsKB-18 Rubin (P. Pustyntsev)/ 1961–67/ Komsomolsk by Amur and Severodvinsk	10 compartments: (1) torpedo room, (2) batteries, quarters and officers mess, (3) radar transmitter and missile fire control, (4) command center, (5) diesel generator and condensers, (6) reactors, (7) turbines, (8) electric motors, (9) quarters, galley, sick bay, refrigerators, (10) torpedo room, provisions, steering gear , crew – 137 man
675MK ECHO-II/ NA	5,090/ 6,500 14/ 23 300/ 240 115.4 × 9.3 × 7.9	VM-A/ 2 NA 70 2 x 17,500	9 out of 29		675MK represented replacement of cruise missile system with faster missiles (“Basalt”).
675MKB ECHO-II/ NA	5,375/ 6,810 14/ 22 300/ 240 115.4 × 9.3 × 7.9 m	VM-A/ 2 NA 70 2 x 17,500	4 out of 29		675MK represented replacement of cruise missile system (“Vulkan”).Total crew were 112 man.

Type/ project no. NATO/ Russian notation	Displacement surface/ submerged (metric tons) Speed (submerged/ surface) (knots) Diving depth/ max depth (meters) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ construction period/ shipyard	Comments (# of crew, description of compartments, status of certain vessels etc.)
Submarines with water-moderated and water-cooled reactors – second generation[10]					
Ballistic missile submarine/ 667A, 667 AO YANKEE/ NAVAGA, NALIM, MURENA (667 AO)	7,850 / 10,100 16.5/ 27 450/ 380 129.8 × 11.7 × 8.7	VM-2 – 4/ 2 OK-700 90 2 x 20,000	34/ 0	TsKB-18 Rubin (A. Kassatsier/ S. Kovalev))/ 1964–72/ Severodvinsk (NAVAGA) and Komsomolsk-by Amur (NALIM)	10 compartments: (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) turbines, (10) electrical compartment , crew – 114 man. 667 AO had a different missile complex than 667A.
Research submarine/ 667 AN YANKEE/ 09774	8 900/ ? 16,5/ 27 400/ 320 162,5 × 11,7 × 8,3	VM – 2 – 4/ 2 OK – 700 90 2 x 20 000	1 out of 34	TsKB-18 Rubin (A. Kassatsier/ S. Kovalev), 1964-72, Severodvinsk	1 modified 667 to become a midget-submarine carrier (Project 09780 or Yankee-Stretch).
667M YANKEE/ ANDROMEDA	10 500/ 13 600 16,5/ 27 400/ 320 152 × 14,7 × 8,7	VM – 2 – 4/ 2 OK – 700 90 2 x 20 000	1 out of 34	TsKB-18 Rubin (A. Kassatsier/ S. Kovalev), 1964-72, Severodvinsk	1 modified 667 to become a midget-submarine carrier (Project 09780 or Yankee-Stretch). Crew – 120 men.

667AT YANKEE/ GROSHA	8 880/ 11 400 16,5/ 27 400/ 320 141,7 × 12,8 × 7,8	VM – 2 – 4/ 2 OK – 700 90 2 x 20 000	3 out of 34/ 1	TsKB-18 Rubin (A. Kassatsier/ S. Kovalev)), 1964-72, Severodvinsk	3 later modified to cruise missile submarines (Project 667AT (GROSHA) or Yankee-Notch). Operational base in Saida Bay, Northwest-Russia.
Ballistic missile submarine/ 667B DELTA-I/ MURENA	8,900/ 11,000 17.5/ 25 400 /320 139 × 11.7 × 8.4	VM-4 B/ 2 OK- 700 290 2 x 20,000	18/ 2	TsKB-18 Rubin, (S. Kovalev), 1971-77, Severodvinsk and Komsomolsk- by Amur	10 compartments – built on the basis of 667A (Yankee) -(1) torpedo, (2) batteries and officers quarters, (3) central command post, (4) missiles, (5) missiles, (6) diesel generators, (7) reactors, (8) turbines, (9) turbines, (10) electrical compartment, crew – 120 man. Operational base: Saida Bay, Northwest-Russia.
Ballistic missile submarine/ 667BD DELTA-II/ MURENA-M	10,500/ 13,600 15/ 25 400 /320 155 × 11.7 × 8.6	NA/ 2 NA 90 2 x 20,000	4/ 0	TsKB-18 Rubin, (S. Kovalev), 1973-75 Severodvinsk	10 compartments built on the basis of 667 B (Delta-I): (1) torpedo, (2) batteries and officers quarters, (3) central command post, (4) missiles, (5) missiles, (6) diesel generators, (7) reactors, (8) turbines, (9) turbines, (10) electrical compartment, crew – 126 man
Ballistic missile submarine 667BDR DELTA-III/ KAL'MAR	10,600/ 13,700 14/ 24 400/ 320 155 × 11.7 × 8.7	VM- 4 S/ 2 OK-700 A 90 2 x 20,000	14/ 12	Tskb-18 Rubin, (S. Kovalev), 1975–81 Severodvinsk	11 compartments, crew – 130 man. Operational base: Saida Bay, Northwest-Russia and Tarya bay, Pacific coast. 7 vessels operational as part of ordinary service, in addition one vessel, K-129, is expected to be converted to research vessel.[11]

Ballistic missile submarine/ 667BDRM DELTA-IV/ DELFIN	11,700/ 18,200 14/ 24 400/ 320 167 × 11.7 × 8.8	VM-4 SG/ 2 OK -700 A 90 2 x 20,000	7/ 6	TsKB-18 Rubin, (S. Kovalev), 1981–90, Severodvinsk	11 compartments, crew – 135 men
Cruise missile submarine/ 670, 670A CHARLIE-1/ SKAT	3,574/ 4,560 12/ 26 300/ 240 95.5 × 9.9 × 7.5	VM-4 – 1/ 1 OK-350 89 1 x 18,800	11/ 0	TsKB-112 Lazurit, (V. Vorob'ev)/ 1967–72/ Gorkiy	7 compartments: (1) torpedo room, accumulators, (2) quarters, (3) central post for accumulators , (4) electromechnical room, (5) reactor, (6) turbines, (7) electromechnical room, crew –100 men
Cruise missile submarine/ 670M CHARLIE-2/ SKAT M (TCHAIKA)	4 ,00/ 5,350 12/ 24 300/ 240 m 104.5 × 10.0 × 6.9	VM-4 – 1/ 1 OK-350 89 1 x 18,800	6/ 0	TsKB-112 Lazurit, (V. Vorob'ev)/ 1967–72/ Gorkiy	One compartment more than Charlie-1, crew – 98 men.
Attack submarine/ 671, 671V, VICTOR-I[12]/ ERSH	3,570/ 4,870 10/11.5/ 14 – 30/31 400/ 320 92.5 × 10.6 × 7.3	VM-4/ 2 OK-300 72 1 x 31,000	11/ 0	TsKB-16 Malakhit, (G.N.Tchnishov)/ 1965–74/ Admiralty Yard, Leningrad	7 compartments: (1) torpedo room, quarters, batteries, (2) command center, (3) reactors, (4) turbines, (5) quarters and diesel generators, (6) auxiliary equipment, (7) electric motors – 68/ 76/ 94 men (various sources)

Attack submarine/ 671RT VICTOR-II/ SEMGA	4,245/ 5,670 10–11.7/ up to 30 400/320 101.8×10.78×7.3	VM-4 P/ 4T/ 2, OK-300 (2) 72 1 x 31,000	7/ 0	TsKB- 16 Malakhit, (G.N.Tchyernyshov)/ 1971–78/ Admiralty Yard, Leningrad and Gorkiy	8 compartments: (1) torpedo room, battery, (2) quarters, sick bay, galley, officers mess, (3) command center, navigation, sonar, (4) reactors, (5) turbines, (6) turbo-generators, auxiliary equipment, refrigerators, (7) quarters, diesel generators, (8) steering gear, creep motors, crew – 98 men
Attack submarine/ 671RTM, 671RTMK VICTOR-III/ SHCHUKA	4,750/ 6,990 11/less than 30 knots 400/ 350 107.2 × 10.8 × 7.4	VM- 4A/ 2 NA 72 1 x 31,000	26/ 12	TsKB-16 Malakhit, (G.N Tchyernyshov),/ 1978–91/ Komsomolsk-by Amur and Admiralty Yard, Leningrad	8 compartments: (1) torpedo room and batteries, (2) accommodations and mess, (3) control room and steering, (4) reactor compartment, (5) turbines, (6) turbo generators, (7) accommodations and diesel generators, (8) steering and electric motor, crew – 100 men. Operational base: Litsa and Saida bay

Type/ project no. NATO/ Russian notation	Displacement surface/ submerged (metric tons) Speed (submerged/ surface) (knots) Diving depth/ max depth (meters) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ construction period/ shipyard	Comments (# of crew, description of compartments, status of certain vessels etc.)
Submarines with water-moderated and water-cooled reactors – third generation[13]					
Cruise missile submarine/ 949 OSCAR/ GRANIT	13,400/ 22,500 15/ 30 450/ 400 144×18.2×9,2 m;	VM-5/2 OK-650M.02, OK-650M.01 190 2 x 50,000	2/ 0	Tskb-18 Rubin, (P. Pustyntsev and E. Bazanov)/ 1974–80/ Severodvinsk	10 compartments, crew – 107 men
Cruise missile submarine/ 949A OSCAR II / ANTEIY	15,000/ 25,650 14.6/ 33.4 800–600/ 520 154.7 × 18.2 × 9,5	VM-5/ 2 OK-650M.02, OK-650M.01 190 2 x 50,000	11/ 6		10 compartments, crew – 106 men. Operational base: Litsa bay, Northwest-Russia (2), Tarya Bay, Pacific coast. One vessel under construction which is likely to never be finished.[14]
Ballistic missile submarine/ 941 TYPHOON/ AKULA	23,200/ 48,000 12/ 25 400/ NA 172.8 × 23.3 × 11	VM-5/ 2 OK-650 190 2 x 50,000	6/ 3	TsKB-18 Rubin, (S. Kovalev)/ 1977–89/ Severodvinsk	19 sections in two separate pressure hulls. Three separate sections: torpedo, central and steering. Missile launchers between pressure hulls, crew – 160 man. One vessel never completed, scrapped in 1990 (not included in the 6). Operational base: Litsa bay, Northwest-Russia.

Attack submarine, 945 SIERRA/ BARRACUDA	6,300/8,200 12./ 35.15 600/ 520 107×11.2×8.5	VM-5/ 1 OK-650 A 190 1 x 50,000	2/ 1	TsKB-112 Lazurit/ TsKB-16 (N. E. Kvasha)/ 1983–93/ Gorkiy and Severodvinsk	6 compartments, crew – 61 men. Operational base: Ara Bay, Northwest-Russia.
Attack submarine, 945 SIERRA II/ KONDOR	6,470/8,500 14/ 32.8 600/ 520 112.7×11.2×8.5	VM-5/ 1 OK-650 B 190 1 x 50,000	2/ 1	TsKB-112 Lazurit/ TsKB-16 (N. E. Kvasha)/ 1983–93/ Gorkiy and Severodvinsk and	7 compartments, crew – 70 men. Operational base: Ara Bay, Northwest-Russia.
Attack submarine/ 971 AKULA/ BARS	8,140/ 10,500 10/ 33 600/ 480 110.3×13.6×9.68	VM-5/ 1 OK-9VM or OK-650M.01 190 1 x 50,000	18/ 10	TsKB-16 Malakhit (G.N.Tchernyshov)/ 82-/ Komsomolsk by Amur and Severodvinsk	8 compartments, crew – 73 men. Operational base: Saida Bay, Northwest-Russia and Tarya Bay, Pacific coast. Two vessels under construction in Komsomolsk-na-Amur.

Type/ project no. NATO/ Russian notation	Displacement surface/ submerged (metric tons) Speed (submerged/ surface) (knots) Diving depth/ max depth (meters) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ construction period/ shipyard	Comments (# of crew, description of compartments, status of certain vessels etc.)
Submarines with water-moderated and water-cooled reactors – fourth generation					
Ballistic missile submarine/ 885[15] GRANAY/ YASEN	NA 19/ 31 NA 111 × 12 × 8.4	NA OK-650 195 1x 43,000	0/ 0	TsKB-18 (Rubin), (J. Kormilitsin)/ 1993-/ Severodvinsk	8 compartments, crew – 50 man. One vessel (*Severodvinsk)* under construction.
Ballistic missile submarine/ 955 ---/ BOREI	NA / 19,400 NA NA NA	(OK-650 B)/ 2 NA 195 2x 98,000	0/ 0	TsKB-18 (Rubin) PO/ 1996-/ Sevmash-predpriyatiye, Severodvinsk	Two vessels under construction, *Yuriy Dolgoruky* (planned to be finished in 2006) and *Alexander Nevsky* (hull reported completed in 2004).[16]

Type/ project no. NATO/ Russian notation	Displacement surface/ submerged (metric tons) Speed (submerged/ surface) (knots) Diving depth/ max depth (meters) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ construction period/ shipyard	Comments (# of crew, description of compartments, status of certain vessels etc.)
Other submarines with water-moderated and water-cooled reactors					
Cruise missile submarine, 661 Papa/ ANCHAR	5,197/ 7,000 25/ 45 550/ 400 106.92 × 11.5 × 8.2	NA/ 1 177. 4[17] 2 x 40,000	1/ 0	TsKB-16 Malakit, (N.N.Isanin and N.F.Shul'zhenko)/ 1963–69/ Severodvinsk	9 compartments: (1) torpedo room and battery, (2) torpedo room and battery, (3) quarters and batteries, (4) command center and quarters, (5) reactors, (6) turbines, (7) turbo-generators, main switchboard, (8) auxiliaries (refrigerators, compressors), (9) electric motors and steering equipment, crew – 82 men.
Attack submarine, 685 Mike/ PLAVNIK	5,750/ 7,810 14/ 30.6 1000/ 1250 117.5 × 10.7 × 8	NA/ 1 OK 650 B-3/ OK-650B 190 1 x 43,000	1/ 0	Tskb-18 Rubin (N.A.Klimov and Yu.N.Kormilitsyn)/ 1978–83/ Severodvinsk	7 compartments: (1) torpedo room, batteries, special underwater, 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, crew – 57 men
Research submarine/ 10831 (A-23) X-RAY	1,600/ 2,100 6 1,000 60 × 7 × 5.1	NA/ 1 1 x 15,000	1/ 1	NA/ NA/ Severodvinsk	Small, deep-water nuclear submarines, crew – 25 men. Operational base: Yagri Island, Northwest-Russia.

Research submarine/ 1851 PALTUS/ NEHLMA	550/ 1,000 NA 1,000/ NA 53 × 53,8 × 5	NA/ 1 NA 10 1 x NA	2/ 2	NA/ 1982/ Sudomekh, Leningrad	A third vessel was started but never completed.[18] Operational base: Olenya Bay, Northwest-Russia.
Research submarine/ 1910 UNIFORM/ KASHALOT	1,390/ 2,000 10/ 30 1,000/ NA 69 × 7 × 5.2	10/ 1 NA 10 1 x 10,000	3 /3	NA/ 1982–95/ Sudamekh, Leningrad	Crew 36 men. Operational base: Olenya Bay, Northwest-Russia.

Type/ project no. NATO/ Russian notation	Displacement surface/ submerged (metric tons) Speed (submerged/ surface) (knots) Diving depth/ max depth (meters) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ construction period/ shipyard	Comments (# of crew, description of compartments, status of certain vessels etc.)
Liquid-metal-cooled submarines Russian military marine reactors					
Attack submarine/ 645 (November class hull)/ ZhMT	3,414/ 4,370 14.9/30.2 300/ 270 109.8 × 8.3 × 6.28	RM-1/ 2 NA 73 2 × 17,500	1/ 0	V.N.Peregudov and A.K.Nazarov/ 1958–63/ Severodvinsk	9 compartments: (1) torpedo room, (2) batteries and quarters, (3) command center, (4) reactors, (5) turbo-generators, diesel generators, refrigerators, auxiliaries, (6) turbines, engine control room, (7) electric motors, (8) quarters and refrigerators, (9) quarters, steering gear, crew – 105 men
Attack submarine/ 705 ALFA/ LIRA	2,300/ 3,180 14.0 / 41 350/ 420 84.1 × 10 × 7.6	VM-40 / 1 OK-550 155/ 1 x 40,000	4/ 0	TsKB-16 Malakhit (A. Petrov, M. Rusanov), SKB-143 Volna, (V. Romin)/ 1977–83/ Adm. Yard, Leningrad, and Severodvinsk 1970 –1983	Six, only two manned – 30 men. Titanium alloy hull, highly automated
Attack submarine/ 705K ALFA/ LIRA	2,280/ 3,180 14.0 / 41 350/ 420 79.6 × 10 × 7.6	VM-40A/ 1 OK-550 155/ 1 x 40,000	3/ 0	TsKB-16 Malakhit, A. Petrov, M. Rusanov SKB-143 Volna, V. Romin 77–83 Admiralty Yard, Leningrad, and Severodvinsk 1970 –1983	Six, only two manned – 30 men. Titanium alloy hull, highly automated

ANNEX I.B MILITARY AND CIVILIAN SURFACE SHIPS

The meaning of the different terms employed in Annex I.B below is as follows:

Type/ project no.	Surface vessels are traditionally divided into groups describing their main function (missile cruiser, command ship, icebreakers)
NATO/ Russian Class:	NATO designation, always a name./ Russian designation; always a project number, sometimes also a name
Displacement:	Standard displacement/ loaded displacement (metric tons).
Speed:	Standard/ using reserve propulsion (knots).
Diving depth:	Design depth/max. Depth (meters).
Dimensions:	Length × beam × height (meters).
Reactor model:	In most sources, a name or abbreviation is used for the specific type of reactor in the submarine. All reactors used are pressurized power reactors
# of reactors:	Russian surface vessels use one or two reactors.
Steam generator unit:	The steam-producing part of the vessel often has a separate designation compared to the reactor model.
Power:	Maximum thermal power output of one reactor.
Total shaft power	Number of shafts and each shaft horse power.
Number built:	Total number of vessels built.
No. op. 2003:	Number in operation in mid-2003.
Design:	Name of design bureau and chief designer(s).
Construction period:	Period during which construction took place.
Shipyard:	Yard where the submarines were built.
Comments:	Number of compartments, if data available, also the use of the compartments. Total number of crew members. Other information relevant to the presentation in the text.

Type/ project no. NATO/ Russian notation	Displacement standard/ loaded (metric tons) Speed (standard/ reserve) (knot) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ constr. period/ shipyard	Comments (# of crew, status of certain vessels etc.)
Water-moderated and water-cooled Russian military marine reactors – surface ships[19]					
Missile cruiser 1144 BALCOM-1/ ORLAN (ALSO KNOWN AS THE KIROV CLASS)	24,300/ 28,000 31/ 14 251.2 × 28.5 × 9.1	KN-3/ 2 NA 300 2 x 70,000	1/ 0	Nevskii PKB (B. Kupyenskiy and V. Perevalov)/ 1974–96/ Baltic Yard, Leningrad	Crew – 610 man, one vessel (Kirov, renamed Adm Ushakov)
Missile cruiser 1144.2	24,300/ 28,000 31/ 14 251.2 × 28.5 × 9.1	KN-3/ 2 NA 300 2 x 140,000	4/ 4	Nevskii PKB (B. Kupyenskiy and V. Perevalov)/ 1974–96/ Baltic Yard, Leningrad	Crew – 610 man, four vessels (Frunze, renamed Adm Lazarev; Kalinin, renamed Adm Nakhimov; Yuri Andropov, renamed Petr Velikiy; Admiral of the Soviet Fleet Kuznetsov)
Aircraft carrier 11437	65,800/ 75,000 30 knots 321.2 × 42 × 83.9	KN-3–43/ 4 NA 305 4 × 50,000	0/ 0	Nevskii PKB (L. Belov and Y. Varfalameev)/ Nikolaev/ 1988–92/ NA	Crew – 3,400 men. The ship was completed 20%, then in October 1992 completely stopped.

Pacific Fleet command ship (missile tests) 1941[20] KAPUSTA/ TITAN	32,780 /34,640 265 × 29.9 × 7.81	VM-16/ KN-3/ 2 OK-900 B 171 ? × 66,500	1/ 1	Baltic Yard, Leningrad	Crew – 923 men. Kapusta class (Project: 1941 (Titan)). Pacific Fleet command ship

Type/ project no. NATO/ Russian notation	Displacement (metric tons) standard/ loaded Speed (standard/ reserve) (knots) Dimensions (meters)	Reactor model/ # of reactors/ Steam generator unit Power (MWt) Shaft power (horse power)	# built/ # operational end of 2003	Design/ constr. period/ shipyard	Comments (# of crew, status of certain vessels etc.)
Civilian icebreakers – first generation					
Icebreaker *LENIN* 1958–1966	15,940/ 17,810 19.6 knots in open sea, 3–4 knots in 2.4 m ice 134×27.6×16.1 m	OK-150/ 3 NA 90 44,000	1/0	1955–59/ Admiralty Yard, Leningrad	Reconstructed with two reactors in 1970
Civilian icebreakers – second generation					
Icebreaker *LENIN* 1970–1989	15,940/ 17,810 t NA 134×27.6×16.1 m	OK-900/ 2 NA 159 44,000		1966–70/ Admiralty Yard, Leningrad	Crew – 230, withdrawn from service in 1989

Icebreaker	21,000/23,400	OK-900 A	2/2	Central Design Office “Aisberg”/ 1971–77/ Baltijskij Shipyard, Leningrad	Crew – 183, *Arktika* and *Sibir* built, *Arktika* still in active service, *Sibir* withdrawn
ARKTIKA	20.8 knots in open sea	NA			
		171			
	47.9 × 29.9 × 17.2	75,000			
Icebreaker	22,920	OK-900 A	3/3	1981–92/ Baltijskij Shipyard,Leningrad	Crew – 171. *Rossija, Sovetsky Soyus* and *Yamal*. All in active service.
ROSSIJA	20.8 knots in open sea	NA			
		171			
	50 × 30 × 17.2	75,000			
Civilian icebreakers – third generation					
Icebreaker	20,000	KLT-40	2/2	1984–89/ Wartsila Marine Shipyard, Finland – Baltiskij Shipyard, Leningrad/	*Taimyr* and *Vaigach* in active service.
TAIMYR	18.5 knots in open sea	NA			
		171			
	151.8×29.2×15.2 m	50,000			
Icebreaker (freighter)	33,900/61,800	KLT-40 M	1/1	1984–88/ Baltic Shipyard, Leningrad,	In active service
	20.5 knots in open sea	NA			
SEVMORPUT		135			
	260.3 × 32.2 × 18.3	40,000			

ANNEX II:
RUSSIAN NUCLEAR MARINE BASES AND SHIPYARDS

ANNEX II.A. NAVAL BASES OF THE NORTHERN FLEET

Existing and former naval bases and other nuclear facilities of the Northern Fleet:

Andreeva Bay, Murmansk Region. Undergoing decommissioning. Storage of spent fuel and radioactive waste

Ara Bay, Murmansk Region. Naval base, Akula, Sierra, and Oscar-II subs (?),
storage of decommissioned submarines

Berpich’ya Bay, Murmansk Region. Storage of decommissioned submarines

Belomorskaya Navy base. Murmansk Region. Storage of decommissioned submarines and compartment units

Bolshaya Lopatka, Zapadnaya Litsa Bay, Murmansk Region. Naval base, Oscar-II and Victor-III, storage of decommissioned submarines

Gadzhievo, Murmansk Region. Name of main base (Olenaya Bay, Skalisty).

Gremikha, Murmansk Region. Undergoing decommissioning. Earlier Alfa submarines, storage of decommissioned submarines and one-compartment units, storage of fuel.

Nerpichya, Zapadnaya Litsa Bay, Murmansk Region. Naval base, Typhoon submarines

Oleniya Bay, Murmansk Region. Naval base, Delta-4 and Delta-3 submarines, storage of decommissioned submarines

Ostrovnoy, , Murmansk Region (Gremikha?). Naval base, Delta-1 submarines

Saida (Sayda) Bay, Murmansk Region. Long-term storage of compartment units planned

Severomorsk. Home base for the Northern Fleet, Balcom-1 cruisers.

Skalisty, Murmansk Region. Naval base, Delta-III, Delta IV and Yankee submarines.

Snezhnogorsk, Murmansk Region. Naval Town.

Ura Bay, Murmansk Region. Naval base, Akula, Sierra, and Oscar-II subs (?), storage of decommissioned submarines

Vidiaevo, Murmansk Region. Naval town and name of main base (Ara Bay, Ura Bay)

Yag(y)elnaya Cove, Murmansk Region. Delta-3, Delta-2, earlier Yankee submarines

Zaozersk, Murmansk Region. Naval Town

Zapadnaya Litsa Bay, Murmansk Region. Name of main base (Andreeva Bay, Nerpichya, Bolshaya Lopatka, Malaya Lopatka)

Naval bases of the Pacific Fleet:

Abrek Bay, Primorsky Krai Region?

Konyushkova Bay, Primorsky Krai Region

Krasheninnikova Bay, Kamchatska region. Undergoing decommissioning

Palovskiy Primorsky Krai Region. Delta-I submarine

Pavlovskogo Bay, Primorsky Krai Region. Storage of decommissioned submarines

Razboinik Bay, Primorsky Krai Region. Long-term storage of compartment units planned

Rybachiy. Delta-3, Delta-1 and Yankee submarines

Severnaya Bay, Primorsky Region

Sysoyeva Bay, Primorsky Krai Region. Undergoing decommissioning. Construction of site for storage of spent fuel containers

Ust-Kut Bay, Primorsky Krai Region?

Ustrichnyi (Oyster) Cape between Chazhma Bay and Razboinik Bay, Primorsky Bay

Postovaya Bay, Khabarovsk Region. Storage of decommissioned submarines Soviet Gavan, Khabarovsk Region

Krasheninnikova Bay, Kamchatska Region. Undergoing decommissioning. Storage of decommissioned submarines

Petropavlovsk-Kamchatski, Kamchatska Region

Ribachly, Kamchatska Region

Gorbusheja, Pacific

Some of the bases listed above are given by the name of the bays where they are situated, some by a name. Therefore, it may well be that some of the bases are listed twice, both by their name and by the bay where they are situated.

ANNEX II.B NAVAL SHIPYARDS

Russia has shipyards for construction of new naval vessels, for maintenance and repair, and for decommissioning. Shipyards for construction of new vessels are:

Northwest Russia
Admiralty Yard, Leningrad
Baltijskij Shipyard (Baltic Yard), Leningrad (surface ships only)
Krasnoye Sormovo Shipyard, Gorkiy
SevMash Shipyard, Severodvinsk, Arkhangelsk Region. The main shipyard for
new units. Participates also in decommissioning work.
Sudomekh, Leningrad

Pacific
Komsomolsk-by Amur

Over the past decade SevMash seems to have been the only Russian shipyard involved in construction of new naval vessels.

Maintenance and repair shipyards for nuclear vessels are:

Northwest Russia
Malaya Lopatka, Zapadnaya Litsa Bay, Murmansk Region. Repair shipyard
Murmansk, Murmansk Region. Shipyard, storage of spent fuel and radioactive waste.
Nerpa repair and decommissioning shipyard, Snezhnogorsk, Murmansk Region
Polyarninsky repair and decommissioning shipyard, Polyarniy, Murmansk Region (The 10th shipyard or Shkval Polyarniy ?)
Roslyakovo, Murmansk Region. Repair shipyard.
Sevmorput shipyard, Murmansk Region
Service and Repair Enterprise “Atomflot”, Sevmorput, Murmansk Region.
Construction of site for storage of spent fuel containers
Zvezdochka repair and decommissioning shipyard, Severodvinsk, Arkhangelsk Region. Construction of on-shore de-fueling facility and site for storage of spent fuel containers

Pacific
Zvezda, Bolshoi Kamen, Primorsky Krai Region (near Vladivostok). Construction of on-shore de-fueling facility and site for storage of spent fuel containers
Chazhminsky Ship Repair Plant, Primorsky Krai Region (near Vladivostok)
SVRTs MOD RF, Federal State Unitary Enterprise, Kamchatka
Vilyuchinskiy Ship Repair Plant, Kamchatka

The maintenance and repair yards are also where most of the decommissioning and dismantling of old naval vessels take place.

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[1] Russia uses several notations for their submarines, reactors systems and parts thereof. Russian nuclear submarines are numbered by use of a letter (earlier K, but for the Typhoon class a TK, after the establishment of the Russian Navy 'B') followed by a number, e.g. K-3 or TK-20. The numbers are not issued according to the age or the class of the submarine, but quite randomly distributed. Once in a while the numbers may be changed, for example after upgrading or modernization of the vessel itself or of the different operational or military systems onboard. The submarines are also given a name. Some times other numbers are used to refer to specific nuclear submarines. The steam-generating system as such, including the reactor, has been given as designation consisting of `OK` and a number, without giving any specific explanations about how these notations being established. The nuclear reactors themselves, or the core and core configuration, are given a designation which seems to be based on the moderated medium. All registered notations are included in Annex 1 for further study.

[2] The main source regarding Russian submarines of first generation [Apalkov1], [Kotcher] and [Gladkov2].

[3] 627A had a torpedo system with larger caliber.

[4] SKB is a Russian abbreviation for "special construction bureau". SKB-143 in St. Petersburg was later merged into TsKB -16 Malakhit. Malakhit built the first Soviet nuclear submarine, the *Leninsky Komsomol*. The Malakhit Design Bureau was created in 1948 for developing submarines with energy sources independent of atmospheric oxygen. Such a submarine (Design Project 617) was created and tested. In the late 1950s, when the nuclear-powered submarine program had been expanded substantially, a portion of the work was transferred to the Rubin Central Design Bureau. In 1974, TsKB-18 and SKB-143 merged to form the present St. Petersburg Malachite Marine

[5] TsKB is a Russian abbreviation for "central construction bureau". Rubin has for many years been the central construction bureau for Ocean Technology; Malakhit is another one

[6] 658M was identical in construction to 658, but was equipped with missiles which could be launched while submerged.

[7] 658S was a modernization of 658, as for example K-19 experienced 1978–79.

[8] K-145 was called project 701 after the steam generators were changed in December 1965.

[9] 675K was a modification for using submarines for launching satellites into space.

[10] The main sources regarding Russian submarines of second generation are [Apalkov1], [Apalkov2] and [Demjanovski].

[11] [Jane's], p. 586.

[12] [Handler] discusses a general type Viktor with the properties of VM-4/ OK-300A, 69-70 MWt 4 pumps and steam generators, Handler (1995) One variant is, as seen in this annex, VM-4 AM, a two-reactor configuration, same fuel type as that stolen in Andreeva Bay in 1993.

[13] The main sources regarding Russian submarines of third generation are [Apalkov1], [Apalkov2] and [Demjanovski].

[14] [Jane's], p. 580.

[15] These data are taken from the www.fas.org website August 1, 2004.

[16] These data are taken from the www.bellona.org website August 20, 2004.

[17] [Handler], p. 1.

[18] [Jane's], p. 587.

[19] The main sources regarding Russian surface vessels are [Apalkov3], [Apalkov4] and [Jane's].

[20] The information here is based on the Bellona website (www.bellona.no) accessed August 10, 2004.

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Abstract	In order to establish a systematic approach for future proliferation and environmental analyses of Russia's marine nuclear reactor systems, this paper summarizes and analyzes the available open-source information on the design properties of reactor systems and nuclear fuels. The most distinctive features of Russian marine reactor development are pointed out, and similarities and differences between Russian military and civilian reactor systems and fuel are discussed. Relevant updated information on all Russian vessels using nuclear propulsion is presented in Annex I. The basic analytic division in this paper follows vessel generations – first to third generation; and reactor types – PWR and LMC technology. Most of the available information is related to nuclear icebreakers. This information is systematically analyzed in order to identify stages in the development of Russia's civilian naval nuclear reactors. Three different reactor models are discussed: OK-150, OK-900 and KLT-40, together with several versions of these. Concerning military reactors, it is not possible to identify characteristics for the individual reactor models, so the basic division follows vessel generations – first to third generation. From the information available, however, it is possible to identify the main lines along which the design of submarines of especially the first and the second generation has been made. The conclusions contain a discussion of possible implications of the results, in addition to suggestions for further work.
Key words	submarines, icebreakers, Russia, design, marine reactors, naval reactors, OK-150, OK-900, KLT-40

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