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Accidents in Nuclear Ships

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Abstract

This report starts with a discussion of the types of nuclear vessels accidents, in particular accidents which involve the nuclear propulsion systems. Next available information on 61 reported nuclear ship events is considered. Of these 6 deals with U.S. ships, 54 with USSR ships and 1 with a French ship. The ships are in almost all cases nuclear submarines. Only events that involve the sinking of vessels, the nuclear propulsion plants, radiation exposures, fires/explosions, sea-water leaks into the submarines and sinking of vessels are considered. For each event a summary of available information is presented, and comments are added. In some cases the available information is not credible, and these events are neglected. This reduces the number of events to 5 U.S. events, 35 USSR/Russian events and 1 French event. A comparison is made between the reported Soviet accidents and information available on dumped and damaged Soviet naval reactors. It seems possible to obtain good correlation between the two types of events. An analysis is made of the accident and estimates are made of the accident probabilities which are found to be of the order of

$$10^{-3} \text{ per ship reactor year}$$

It is finally pointed out that the consequences of nuclear ship accidents are fairly local and does in no way not approach the magnitude of the Chernobyl accident.

It is emphasized that some of the information on which this report is based, may not be correct. Consequently some of the results of the assessments made may not be correct.

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1. INTRODUCTION

In the Nordic countries there is a considerable interest in the nuclear activities at the Kola peninsula. This also includes the naval nuclear activities. Norway and Finland have borders close to the areas where the nuclear activities take place. In case of an accident whereby radioactivity is released to the atmosphere, fall-out may be detected on their territory. The north of Sweden is further away, but still situated in the region. Denmark will not be directly affected by an accident at the Kola peninsula, but Denmark has - like Norway and Iceland - significant fishing interests in the North Atlantic where nuclear submarines patrol. In this connection it should be remembered that the Faroe Islands and Greenland are part of the Kingdom of Denmark.

For this reason it was decided to include a study of accidents with nuclear vessels in the 1994-1997 Nordic Nuclear Research (NKS) Programme. The present study is a continuation of a similar study which was carried out as part of the NKS programme of 1990-93. With new information becoming available there is a need to up-date the earlier study.

The report starts with an analysis of possible types of accidents which could lead, directly or indirectly, to release of radioactivity to the environment. Next a discussion of available information of accidents involving nuclear vessels is presented. Sea disposal of ship reactors and the status of submarines with damaged cores are also considered. Finally a statistical analysis of the risk of nuclear ship accidents is attempted, based on the information of such accidents.

At the end of the report a number of annexes containing data on Soviet/Russian submarines is given. These data have been collected from various sources. They are not always consistent and may also not be correct, so they should be used with caution.

2. SOURCES OF INFORMATION

Most of the accidents considered in this report involve naval vessels and therefore sensitive information related to national security. Nevertheless, during the recent years an increasing amount of information has become available on the topic considered in this report. There exists a considerable number of books, articles and reports in addition to naval handbooks which contain information on naval nuclear ships and on accidents which have occured with these ships. However, the information contained in these publications is not always - reliable. This is hardly surprising since naval authorities do not - for obvious reasons - wish to reveal design information on the strengths/weaknesses of their nuclear ships to potential adversaries.

The - understandable - lack of information may sometimes be used to mislead the public. The official authorities involved may use it to dowplay the seriousness of accidents while anti-nuclear or anti-military groups may use it to exaggerate the seriousness.

Also much of information available in this field has passed through people who do not have the necessary professional insight in the field of nuclear safety. They may therefore have misunderstood or misinterpreted the information that they pass on.

These factors, combined with the often limited information available, make it difficult to get a objective and correct assessment of the accidents. When reading this report it should therefore be kept in mind that the information given and the assessments made may not be correct. However as more information gradually becomes available, better understanding of the accidents and of their impact on nuclear safety is obtained.

Full information on the accidents which have involved loss-of-coolant accidents or criticality accidents could be of great value for nuclear safety research in general.

Even though the interest of the Nordic countries involves primarily the nuclear activities on the Kola peninsula, relevant nuclear vessel accidents which have occured elsewhere are also included because they are of equal importance for the improvement of our understanding of nuclear safety.

All available sources have been used in the preparation of this report whether they originate from official institutions, from environmental groups or any other sources. However, wherever possible an attempt has been made to evaluate the information and to discard what is not believed to be correct. A list of the most important references are found in section 9 of this report.

3. TYPE OF ACCIDENTS/INCIDENTS

It is unavoidable that nuclear ships becomes involved in incidents and accidents in the same way as ordinary ships. This is in particular so because almost all nuclear ships are naval vessels. Such vessels are designed for use and used - and the crews are trained accordingly - under circumstances where ordinary safety measures can not always be taken. However, in order to compensate for this, nuclear naval ships are likely to be designed with such safety features that even if accidents occur, the consequences should be limited.

The most common cases of nuclear ship incidents/accidents are collisions, problems with the nuclear power plant, groundings, fires and explosions as well as development of leaks in the sea-water systems of submarines.

It is of interest to note that collisions and groundings seldom lead to serious accidents. The reason is undoubtedly that naval ships are designed to function under very difficult circumstances, i.e. under enemy attack with exploding bombs, granates and depth charges. To survive under these circumstances the ship designs have to be very robust, and such designs also make the ships resistant to collision and grounding damage. As far as is known collisions and groundings have never lead to serious accidents in spite of the fact that they have occured in considerable number. Therefore these types of accidents will be neglected in the following.

In the present report assessments have been made of available information on nuclear ship accidents which (a) involved the nuclear propulsion plant, directly or indirectly, (b) serious radiation accidents, (c) fires/explosions, (d) leaks in the the sea-water systems or (e) the sinking of the vessel. Accidents in habours or at shipyards are in general not included since here the reactor(s) has in most cases not been operating for some time and since countermeasures can more easily be applied here.

Regarding accidents involving the nuclear propulsion plant the following are of particular interest:

3.1. Loss-of-Coolant Accidents (LOCA)

As far as is known, no western nuclear vessel has suffered a LOCA, but the Soviet nuclear navy has had some case of this type of accident. LOCA's are most likely to occur when a reactor is operating at full power, but they may also happen when the reactor is shut down. Since almost all ship reactors are pressurized water reactors, the following discussion is limited to this reactor type.

When a reactor is running at full power and the cooling of the core is for some reason stopped or significantly reduced, e.g. because of a major leak in the primary circuit or because of loss of the power supply to the main circulation pumps, boiling will start in the core. The steam formation will reduce the amount of water (moderator) in the core, and this will stop the chain reaction. The loss of cooling should also activate the control rod system, and the control rods will move into the core, thereby shutting the reactor down permanently.

However, even though the chain reaction is stopped there will still heat production in the fuel elements due to the decay heat of the radioactive materials in the fuel, in particular the fission products. Immediately after shut-down the power level will be 6-7% of the power level before shut-down. 24 hours later the power level will still be at about 0.5% of full power.

This decay heat will initially be removed by boiling of the coolant. However, the coolant will gradually disappear, either due to leakage or due to evaporation, and the water level in the reactor tank will decrease. If the supply of coolant to the core is not rapidly restored, the water level will fall below the top of the fuel elements. The upper parts of the elements will heat, up and fuel may reach its melting point. The fuel elements or part of them may undergo a melt-down whereby the reactor is destroyed and radioactive matter released to the surroundings. Examples of such accidents are given in section 4: July 1961. Soviet Hotel Class Submarine (K19) Accident; May 1968. Soviet Nuclear Submarine (K27) Accident; July 1979. Soviet Echo-I Class Submarine (K116) Accident.

The decay heat will gradually decrease, and so will the risk of a LOCA. However, some time after shut down the fuel may still reach the melting point and melt, if cooling is lost. Such a type of LOCA whereby some of the fuel was so deformed that it could not be unloaded from the core has been reported for the icebreaker Lenin (see: Autumn 1966. Icebreaker NS Lenin Accident).

According to western media an incident which could have resulted in a LOCA, occured at a naval base near Murmansk. The local power company decided to cut the electricity supply to the base since the navy had not payed its electricity bill. At the base a nuclear submarine was docked which had returned recently from a patrol and therefore needed electricity supply for its cooling system. This supply came from land. Since the cut of electricity could have resulted in a LOCA, soldiers from the base forced at gun point the utility staff to re-establish the power supply.

After a cooling time of a couple of years the decay heat can be expected to be so low that even if all cooling is lost, radiation heat transfer should be sufficient to avoid fuel melting. This means that most of the Russian, decommissioned submarines which have not as yet been refueled due to lack of storage facilities of for spent fuel would probably not suffer a LOCA, even if they lost all water in the primary circuit.

It should be mentioned that the release of radioactive matter to the surroundings in connection with LOCA's may well - depending on the circumstances - be fairly limited. In 1989 a Soviet Echo-II class submarine suffered a loss-of coolant accident near the Bear Island in the North Atlantic Ocean. In spite of the fact that the Norwegian authorities took water samples in the area shortly after the accident, little radioactivity was detected (see: June 1989. Soviet Echo-II Class (K192) Submarine Accident).

Loss of coolant accidents may also occur in spent fuel storage facilities, if the fuel is stored under water, and if the water for some reason drains out of the pool. However, unless the fuel has recently been in an operating reactor, such an accidents may perhaps more correctly be called a loss-of-shielding accident, because the risk involved is more likely to be the lack of water shielding rather than to be lack of water cooling.

Problems with fuel storage facilities at Kola has been reported, but it seems that they have not involve LOCA's.

3.2. Criticality Accidents

Criticality accidents may occur under variuos circumstances. However all such accidents involve an increase of the effective multiplication factor of a configuration of fissile material (fuel) to a point where the configuration becomes supercritical or even prompt supercritical. In such cases the power will rise with time constants which are in the millisecond range, and the destruction of the fuel configuration is usually unavoidable.

The western nuclear navies do not seem to have had criticality accidents, but the SL-1 reactor of the US Army suffered such an accident. The Soviet Navy have had some criticality accidents. It is of interest to note that criticality accidents have never occured during reactor operation, but always when the reactors have been shut down, e.g. in connection with refueling, changes in or installations of the control system or tests of the reactor system. Soviet criticality accidents are: Feb. 1965 Soviet November Class Submarine (K11) Accident; Aug. 1968. Soviet Yankee Class Submarine (K140) Accident; 1970. Soviet Charlie-II Class Submarine (K320) Accient; Nov. 1980. Soviet Nuclear Submarine (K222) Accident; Aug. 1985. Soviet Echo-II Submarine (K431) Accident.

Traditionally the excess reactivity of a reactor should have its maximum value immediately after refueling. With the long lifetime of submarine fuel and the extensive use of burnable poison in the fuel or in special absorber rods this may not be the case for modern submarines. Further, even if the excess reactivity of a submarine reactor just before refueling is at its minimum, it will still in cold condition and some time after the last full power operation have reactivity enough to go prompt critical, if all control rods are removed from the core. This is due to the negative temperature coefficient of naval reactors (PWR's) and due to the need to override the xenon poisoning during operation. This means that the criticality accidents may also occur during the last defueling of old submarines, if the defueling is not performed in a proper way. It should be added that while the excess reactivity of an old core may be at a minimum just before refueling, the content of fission products in the core will be at a maximum. Thus the potential radioactivity pollution with an old core is likely to be more severe than with a new core where the radioactivity content is limited to the fission products produced during the power excursion.

5 submarines, 2 American and 3 Soviet, rest at the bottom of the sea due to accidents during operation (see: April 1963. US SSN Thresher Accident; May 1968. US SSN Scorpion Accident; Apr. 1970. Soviet November Class Submarine (K8) Accident; Oct. 1986. Soviet Yankee-I Class Submarine (K219) Accident; Apr. 1989. Soviet Mike Class Submarine (K278) Accident). In all of these cases the accidents were not due to the reactor system, and there are good reasons to believe, that the reactors were shut down before the submarines sank. However, in the long run the corrosion of the sea water will affect the core materials. Should the control rod materials corrode more rapidly that the fuel materials, the reactor may at some stage go critical. If the increase of the reactivity with time is slow - which is likely to be the case - the consequences should be limited. The reactor will heat up and run at some low power level, thanks to its negative temperature coefficient. However, if the corrosion results in some sudden, major changes of the core configuration, e.g. the control rods suddenly dropping out of the reactor, the event may result in a power excursion.

The USSR has deposited 7 reactors containing spent fuel in the Kara Sea east of Novaya Zemlya. These reactors was not defueled because reactor accidents had made the removal very difficult. It is unlikely - although it can not with the available knowledge be totally excluded - that corrosion at some time in the future could make the reactors critical. Melting of fuel will usually make reactors more compact, and since submarine reactors are undermoderated, fuel melting is likely to make them even more undermoderated and thereby reduce the reactivity.

A special case is the Soviet K27 submarine (see: May 1968. Soviet Nuclear Submarine (K27) Accident). It has a November class hull, but is provided with two intermediate-energy-neutron reactors, cooled by a lead-bismuth alloy. The submarine suffered a LOCA accident in 1968 and was sunk with fuel in both reactors in 1981 near Novaya Zemlya. Since the reactors run on intermediate energy neutrons any in-leakage of water which is likely to happen some time in the future, is likely to improve moderation and to increase the reactivity. This could make the reactor super-critical. The problem was considered by Soviets experts prior to the dumping, and it was decided that such an accident was unlikely.

Finally criticality accidents could also occur in spent fuel storage facilities. These facilities usually use a so-called safe geometry storage. This means that even if the whole facility is filled with fuel, criticality will not occur. However, accidents may lead to unsafe geometries. Also in the present situation where all spent fuel storage facilities of the Russian Navy are filled up, it might be tempting to increase the number of spent fuel elements in the facilities. If this is not done properly, it could lead to criticality accidents.

4. NUCLEAR SHIP ACCIDENTS/INCIDENTS

There exist no agreed definition of nuclear ship accidents. In this report it will be defined, as mentioned above, as all events that are claimed to have involved the sinking of nuclear ships, leaks in sea-water systems, fires or explosions, damage to the nuclear propulsion plant, and/or serious radiation exposures. The list is not necessarily complete. Since today more information is available on Soviet/Russian than on Western submarine accidents it might well be that more western than Russian accidents are missing.

According to the information available the following accidents and incidents have occured:

1954. US Navy Reactor Accident?

According to Russian sources the US Navy had a reactor accident in 1954, whereby 4 persons were killed.

Comments: Such an accident is not known from western sources. It could be a mix-up with the reactor accident of the SL-1 reactor of the US Army at the National Reactor Testing

Station in Idaho where 3 persons were killed during refueling. However, this accident occured in 1961 and did not involve a submarine reactor.

Therefore this event will be neglected.

Sep. 1960. Soviet November Class Submarine (K8) Accident

According to Russian information the third November class nuclear submarine K8 which belonged to the Northern Fleet suffered an steam generator accident on October 13th, 1960, while participating in an naval exercise in the Barent Sea. It is not clear what actually happened, but it seems to have involved a major leak in the steam generator and also a leak of helium from the pressurizer (compensator) system, either a direct leak or through the steam generator. The valves for blocking off the leaks did not work. According to one source they were also damaged. Helium and steam appeared in the turbine compartment. The reactor was immediately shut down and arrangements made to ensure the cooling of the core. According to one source this was done by installing a provisional emergency water supply system. The accident gave rise to leakage of radioactive gases which spread to all compartments, but the contamination was in particular high in the last compartment. The personnel had to be evacuated from this compartment. The submarine sailed back to base by its own means.

The submarine was decontaminated at the base. 13 crew members were exposed to 180-200 (rem?) or higher doses. They were taken to a special medical center in Polyarny. One person died two years later.

According to western sources the same submarine, K8, suffered what seems to be a similar accident (a generator explosion) on September 9th or 13th, 1961. The accident resulted in the hospitalization of 13 members of the crew. Presumably it is the same accident. This is in agreement with Russian information.

Comments: The accident seems to have been caused by a major leak in one of the steam generators. Thus it involved the nuclear propulsion plant.

The major leak in one of the steam generators would cause a pressure drop in the primary circuit which again would lead to boiling in this circuit, including the core. The higher pressure of the primary circuit would cause a flow of steam/water from the primary circuit to the secondary through the defect steam generator. The pressurizer of the submarine presumably uses helium gas to regulate the pressure of the primary system. Else it is difficult to understand where the helium came from. If the pressure is regulated automatically, the reduction of the pressure of the primary circuit would activate the pressure control system which would send helium into the pressurizer. Once the helium has pressured all water out of the pressurizer, helium could move through the primary circuit and the damaged steam generator to the secondary circuit and from there to the turbine compartment. This is of course all speculations.

Russian sources do not mention anything about damage of the fuel due to overheating. However the high radiation doses and the decontamination of the last compartment seem to indicate that some of the fuel leaked. There is no indication that the damage of the fuel was so severe that the fuel could not be removed from the core by standard procedures.

July 1961. Soviet Hotel Class Submarine (K19) Accident

According to raw western intelligence reports a Soviet Hotel class submarine, carrying ballistic missiles, suffered a serious leakage in a coolant pipe of the nuclear power plant when the submarine was near the coast of the UK. The boat was returning from a training exercise. The leakage caused serious contamination of parts of the ship and radiation exposure of crew members. The radiation level was reported to be 5 R/hr in the area where the pipe broke. The submarine managed to reach its home base where it had to be ventilated for 2 month.

This report was confirmed in 1990 and later supplemented with information from several Russian sources.

The accident occurred in the first Soviet ballistic missile submarine, K19, of the Hotel class on July 4th 1961. K19 belonged to the Northern Fleet and was provided with 3 nuclear armed, ballistic missiles. The submarine was sailing submerged in the North-Western Atlantic where it was participating in a naval exercise together with Soviet diesel submarines several thousands kilometers from its home base. The Soviet ships were pursuing a fleeing enemy. When it was first reported around 4 o'clock in the morning that the pressure was dropping in the pressurizer, the captain did not react, so the submarine continued the pursuit at full speed. It should have been clear to the captain at that time that a leak had developed in the primary system in one of the two reactors of the submarine. The leak was due to a crack in a pipe which was part of the pressurizer system.

It has been reported that the probable reason for the formation of the crack was an incident during the start-up tests of one of the submarines two reactors. When the first pressure test was performed the pressure went up to around 400 atm. because the pressure gauges did not work. The design pressure was 200 atm. The high pressure caused non-elastic deformations of the piping of the primary system and probably damage to welded and soldered joints. The captain of the submarine who was in charge of the test, did not report the incident to his superiors so that the required repair work was not performed.

Shortly after the first leakage report the automatic alarm system was activate. During reactor operation the temperature of the cooling water was around 300 °C. The reactor pressure, maintained by use of a high-pressure gas system, was two hundred atmospheres. The leak caused a rapid decrease in the reactor pressure which approached atmospheric pressure. The reactor water started to boil, and the cooling of the core became insufficient. The control system worked correctly and shut down the reactor automatically. The temperature in the reactor room reached at least 140 °C, the upper limit of the thermometer.

At this point a fire was ignited (the reason for the fire was not given) in the reactor room of the disabled reactor, but it was extinguished. The submarine surfaced, for the first time after several weeks of submersion.

Radioactivity started to spread in the submarine due to the leak and to the fire fighting. The dose rate in the control room of the submarine was (upto?) 50 R/hr, and it was very high in some areas of the reactor room. All compartments of the submarine were hermetically sealed, but it was impossible to stop all traffic between the compartments due to the development of the events.

The major problem was the cooling of the core. Before the accident the reactor had been operating at full power, and without continued cooling the fuel elements would overheat due to the decay heat. According to some sources the reactor had not been provided with an emergency core cooling system because this would have delayed the completion of the submarine, and because it was felt important to get experience with this new type of nuclear submarine. According to another source an emergency core cooling system was installed, but did not function. The temperature of the fuel increased continuously and reached 800 °C. Hence there was a risk of a core melt-down. This could result in a very serious situation.

In order to avoid this situation an improvised emergency core cooling system had to be manufactured and installed within a few hours with the means available on board. It was done by use of the drinking water supply. Other systems of the submarine, in particular the weapons systems, had to be cannibalized to provide the needed piping. The welding of the new cooling system had to be performed in the reactor room. The work was carried out by 3-man-teams who worked in 5-10 minute periods, only protected by gas masks and raincoats. However, the working period of the gas masks was only 40 min, and they were soon out of use. The staff who carried out this task was specialists, and they fully understood the risks involved in this operation.

The new cooling system proved to be effective. The continued increase of the fuel element temperature, the melting of the fuel (?) and a possible steam explosion in the core were avoided, but at a high cost of human lifes. According to a Russian source 7 of the persons involved died of radiation sickness within 7 to 10 days in a hospital in Moscow, a lieutenant and 6 sailors. It has been estimated that the dose received by these crew members was about 3 times the lethal dose. Another source claims that the doses were 50 to 60 Sievert (5000 to 6000 rem). Three month later a captain lieutenant died.

According to a western source 3 additional crew members received radiation doses much larger than the permissible dose. According to another western source 22 crew members were dead within 2 years after the accident and according to a third, western source the total number of crew members killed was 30. The total size of the crew was 139.

Almost no radioactivity escaped to the environment during the accident.

The submarine sailed towards its base by use of the other reactor. Several of the compartments were contaminated with radioactivity, and the submarine could not communicate with its base since its arials had been damaged during a cruise under the polar ice. Finally K19 met two Soviet diesel submarines. One source states that the crew except a small number was evacuated to the diesel submarine and that K19 was towed back to its base at the Kola peninsula. Another source reports that only the highly exposed crew members were transfered to the diesel vessels due to the storm and that towing was not possible. When the storm faded away, K19 was towed to its base by a salvage ship.

The submarine was later repaired and brought back into service. This was done by cutting the reactor compartment out of the submarine and replacing it with a new nuclear power unit. The old compartment of K-19 was dumped in the Abrosimov Gulf on the eastern side of Novaya Zemlya in 1965 with the fuel remaining in both reactors.

Comments: In this case it is seen that the raw western intelligence reports agree well with the later, more complete Russian information, and that the accident was in fact more serious than implied in the initial western reports.

The high radiation level in the control room seems to indicate that the only containment of the two reactors was the hull and the bulkheads at both ends of the reactor compartment and that the bulkhead doors had to be open due to the fire fighting and the repair work. Thus the spread of radioactivity from the reactor room to neighbouring rooms could not be prevented.

If the reactor fuel had remained undamaged, the reactor water would have lost most of its radioactivity within a few minutes after reactor shut-down. Thus the high radiation level in the reactor and the control room indicate that the fuel was damaged and fission products released before the new cooling system came into operation. This agrees with the fact that the fuel was not removed from the reactor compartment before dumping.

According to available information the reactor compartment was dumped with fuel in both reactors, even though only one reactor was involved in the accident. If this is correct, the reason could be that the reactor compartment was so contaminated that it was very difficult to defuel the undamaged reactor.

1962. US SSN Skate Incident

In 1962 the US attack submarine SSN Skate suffered a leak in a seawater circulation system according to media sources. The leak developed while the submarine was submerged at 400 ft on its way through the Baffin Bay off Thule, Greenland. The incoming sea-water started to flood the engine room. The submarine did not loose power and surfaced safely. At the surface where the outside pressure of the sea-water is greatly reduced, the flooding was stopped.

Comments: It seems reasonable to classify the event, if real, as an incident since the submarine and the crew suffered no damage. But it demonstrates the risk involved in leaks from the outside ocean into the boat to which deep diving submarines are always exposed. The nuclear propulsion plant was not involved in the incident.

Apr. 1963. US SSN Thresher Accident

The US submarine SSN Thresher departed from Portsmouth Naval Shipyard on April 9, 1963, to conduct sea trials following a 9 months overhaul period. There were 129 persons on board. Of these 106 were the crew, and the remaining were employees of the shipyard and US Navy representatives. At 7.47 AM on April 10, 1969, Thresher had a rendezvous with its escort ship. A few minutes later Thresher started a deep dive, reporting its course and depth changes to the escort vessel. It appeared that the dive was progressing satisfactorily. However, at 9.13 AM Thresher reported:"Experiencing minor difficulties. Have positive up angle. Are attempting to blow. Will keep you informed". Listeners at the escort vessel heard next sound of compressed air rushing into the submarine's balast tanks, as Thresher tried to surface.

3 minutes later a garbled transmission was received which is believed to have contained the words;"...test depth". That was the last contact with Thresher. Subsequent investigations of the US Navy concluded that a flooding casualty in the engine room is the most likely cause for the sinking of the submarine and that it is most likely that a piping system failure had occured in one of Threshers salt water systems, probably in the engine room. In all probability the incoming water affected the electrical circuits and caused a loss of power. Thresher sank 350 miles east of Boston and 160 km east of Cape Cod at a depth of around 2600 m (41°43'N, 64°57'). It was crushed by the pressure of the surrounding water and split in 6 major sections which now rests on the ocean floor. The major sections are the sail, the sonar dome, the bow section, the engineering spaces section, the operation spaces section, and the tail section. The majority of the debris were scattered over an area of about 400 m square. All 129 men on board, including 17 civilians, were killed. The wreck of the submarine was located and photographs of debris were taken at the sea bottom. No attempt was made to recover the remainings of the submarine.

Radiological monitoring of the area was carried out in 1965, 1977, 1983 and 1986. None of the samples taken contained fission products and uranium above the natural background. Very low concentrations of ^{60}Co, originating from corrosion of activated components of the primary circuit, were detected in the sediment; the maximum concentration found was 0.32 pCi/g, a factor of about 100 lower than the natural radioactivity of the sediment. No ^{60}Co was found in fish and other marine life specims collected in the area.

Comments: As mentioned above the cause of the accident does not seem to have anything to do with with the nuclear power plant of the submarine. But the flooding of the hull did of course lead to the failure of the plant.

1964. Soviet Nuclear Submarine (K27) Incident

According to western sources the first Soviet submarine with two liquid metal cooled reactors, K27, suffered an cooling incident during its maiden voyage in 1964. The submarine was a modified November class boat. The incident involved a freeze of the coolant in one(?) of its reactors. The coolant was later remelted and operation continued.

Comments: Since the submarine continued operating, though with difficulties until 1968 (see May 1968), the incident was not very serious.

Mid 1960s. Soviet Nuclear Submarine Accidents

According to western sources a first generation nuclear submarine (Hotel, Echo or November) suffers an accident in 1964 involving its reactor(s). Several crew members are killed. Western sources also mention two other accidents which should have occured in the mid 60s and which involved the reactors. In the first case the submarine was a Hotel boat and 15-16 people were killed. In the second the submarine was a November class boat and 6-7 people were killed. Due to the vague and limited information available it is unclear whether these accidents involve 3, 2, 1 or no accidents.

Comments: From the limited information available it can only be said that if the accidents are real, they have apparently involved the reactor system. However, the information is quite vague. They could be the July 1961. Soviet Hotel Class Submarine (K19) Accident, the 1964. Soviet Nuclear Submarine (K27) Incident, the Feb. 1965 Soviet November Class Submarine (K-11) Accident or the Nov. 1965. Soviet Echo-I Class Submarine (K74) Accidents.

Therefore these events will be neglected.

Feb. 1965. Soviet November Class Submarine (K11) Accident

According to Russian information on February 12 (10?), 1965, a November class nuclear submarine of the Northern Fleet, K11, suffered a criticality accident during refueling at the "Zvez-dochka" shipyard in Severodvinsk. According to a western source the core contained only new fuel at the time of the accident. During the refueling operation the pressure vessel lid was lifted by use of a crane. There was a permissible limit for the height to which the lid was allowed to be lifted. However, this height limit was not indicated correctly and not checked. Also no neutron detectors were in operation. The lid was lifted too high up above the vessel. The regulation rods were attached to the lid, and when they were moved out of the core, an uncontrolled chain reaction was started in the reactor. Radioactive steam was ejected from the reactor and part of the crew was exposed to radiation. The lid fell down in a tilted position on top of the pressure vessel. At the same time a fire started in the reactor compartment. The fire was fought, first with CO_2 fire-extinguishers, with fresh water and finally with salt water. A total of 250 t water was used. The water became radioactive with an activity of 0.001 Curie per liter. The water was not contained in the reactor compartment, but spread to other compartments. 7 persons suffered radiation injuries. The reactor compartment had to be replaced. The damaged compartment was the same year (1965) dumped in the Abrosimov Gulf on the east side of Novaya Zemlya with damaged fuel in one reactor.

A western source claim that there was two criticality accidents in the reactor. The first on April 7th when the lid was first lifted. Then all personnel were withdrawn. The next 5 days the experts tried to find the reason for the accident. However, they came to the wrong conclusions, and on the February 12th the lid was lifted again. The reactor went critical again and a fire started.

Another western source claims that the reason for the accident was that too much fuel was loaded into one of the reactor.

A third western source claims that the submarine involved was the liquid-metal cooled K27 submarine, that the radioactive cloud emitted moved towards Severodvinsk, and that dammage caused by the accident was so severe that the reactor compartment was cut out and dumped in Ambrosimova Bay at Novaya Zemlya. It was obviously not the K27 submarine (cf. May 1968. Soviet Nuclear Submarine (K27) Accident).

Comments: The accident was a criticality accident in connection with refueling and consequently the reactor system was involved.

Nov. 1965. Soviet Echo-I Class Submarine (K74) Accident

On November 11, 1965, the starboard turbine of an Echo-I class Soviet nuclear submarine of the Northern Fleet, K74, was destroyed due to failure of an automatic control system (gear box?) and subsequent turbine run-away. The incident did not claim any casualties.

According to a rather vague report a radiation incident took place in 1965 in the Sargasso Sea in a first generation Soviet submarine (November, Echo or Hotel). Whether this incident, if real, could be the same as the incident mentioned above is unknown. It could also be one of the accidents mentioned in: Mid 1960s. Soviet Nuclear Submarine Accidents.

Comments: The accident did not involve the reactor system, but the propulsion system.

Autumn 1966. Icebreaker NS Lenin Accident

According to western raw intelligence reports one of the 3 reactors of the Soviet icebreaker NS Lenin suffered a core meltdown in a sudden, catastrophic accident in 1966-67. Up to 30 people may have died and many others were affected by radiation sickness. The ship was abandoned for over one year before replacement of the old 3 reactors with 2 new could begin. Another report states that NS Lenin suffered a nuclear related casualty. There was also rumors that NS Lenin had been disposed of by sinking following the accident; these were of course untrue since NS Lenin continued its operation with the new reactors from 1970/71 until 1989.

Recently, Russian information has become available of the NS Lenin accident in the autumn of 1966. At this time the three reactors of the Lenin nuclear power plant were undergoing their second refueling. Due to an operator error the water was drained from the core of the second reactor before the refueling, and the core was left without water for some time. The decay heat of the core and the lack of cooling caused partial melting of part of the core. When after the accident the fuel was to be removed, it was possible to remove only 94 of the irradiated fuel elements. The remaining 125 elements could not be withdrawn from the core. The damaged fuel had to be removed from the reactor tank by removal of the core insert or basket consist- ing of the bottom grid plate and the cylindrical thermal shield.

No information has so far been made available on the details of the accident or on the number of casualties, if any.

The old reactor power plant with three OK-150 reactors was dumped in the Tsivolka Bay on the eastern side of Novaya Zemlya in 1967.

In the west it has been claimed that NS Lenin was towed to the position of dumping, and that here the whole reactor compartment was cut out of the hull by use of explosives and dumped directly to the sea bottom. This claim is not correct. The damaged power plant was cut out in Severodvinsk. The total activity of the dumped power plant has been estimated to be about 50 kCi, mainly ^{60}Co.

NS Lenin was later provided with a new nuclear power plant, containing two KLT-40 reactors, and continued its operation.

Since the damaged fuel could not be removed from the core basket, it was filled by a furfurol-based mixture, lifted out of the reactor tank and placed in a reinforced concrete container with a steel casing. The container was then disposed of by dumping in the sea, close to the dumping place of the Lenin power plant. The total activity of the dumped fuel at the time of disposal was about 100 kCi, about 50 kCi ^{137}Cs, about 50 kCi ^{90}Sr and about 2 kCi ^{238}Pu, ^{241}Am, and ^{244}Cm. The dumping of the fuel took also place in 1967.

Comments: The loss-of-coolant accident which NS Lenin suffered may have to do with the fact that unlike modern pressurized water reactors the OK-150 reactors had only the coolant outlet (and not the coolant inlet) placed above the top of the core. In OK-150 the inlet is placed at the bottom of the pressure vessel. Thus the draining of the core could be due to the opening of a valve in the inlet tube.

1966. Soviet Nuclear Submarine Accident

According to raw western intelligence reports a leak developed around 1966 in the reactor shielding of a Soviet nuclear submarine of the November class, when it was close to the port of Polyarnyy on the Kola Peninsula. The captain requested permission to proceed directly to the shipyard. The permission was not granted, but the captain took the boat there nevertheless. A special brigade was formed to repair the submarine and part of the crew was sent to a special health center on an island near Murmansk to be treated for radiation sickness. Those sent to the center never returned.

Comments: A leak in the reactor shielding system should not give rise to a serious radiation accident, provided the reactor is shut down immediately. The purpose of the water in the shield is to cool the shield and to slow-down the fast neutrons so that they can be absorped. As soon as the reactor is shut-down, the neutrons disappear and the need for the water for shielding and cooling is much reduced. The shielding water system is separated from the reactor cooling systems and run at low temperature. Further, the water looses its radioactivity rapidly after shut-down. If the accident is real there seems to be inconsistencies in the available information. The description of the event would make much more sense if the leak had been in the primary circuit of the nuclear propulsion system.

The account of the event is very similar to that of the May 1968 Soviet Nuclear Submarine Accident, and is likely to be identical to that event. According to Russian information the accident described above has not take place.

Therefore this event will be neglected.

Sep. 1967. Soviet November Class Submarine (K3) Accident

According to raw western intelligence reports the Soviet nuclear-powered attack submarine Leninskiy Komsomol of the November class suffered a fire accident near the North Pole on Sep. 8th, 1967, while sailing under the ice. The accident involved crew members being burned inside a compartment that was locked from the outside on both sides. The fire was caused by a spark of oxygen(?) and did not involve the nuclear propulsion system. The submarine was saved, but an unknown number of the crew members suffered burns. Several crew members died.

According to Russian information the K3 submarine of the Northern Fleet, the first Soviet nuclear submarine, suffered a fire in the first and second compartment when the submerged submarine was in the Norwegian Sea on its way back to base after having spent 56 days on patrol. K3 was the first Soviet submarine to reach and surface at the North Pole (in July 1962), but there is no Russian information confirming that this accident occured near the North Pole. The fire started 1700 nautical miles from base. A hydraulic pipeline in the first compartment sprang a leak and the inflammable oil used at that time in the system caused a short-circuit in a lamp whereby the fire was started in the first compartment. A burning oil beam broke through a bulkhead and burned all crew members present in the 1st and the port part of 2nd compartment. Another version states that when an attempt was made to evacuate crew members in the 1st compartment, the fire spread to the 2nd. The personel in the starboard part of the 2nd compartment died due to CO suffocation. Another version states that the automatic extinguishing system was based on CO_2, and when that was applied, it killed any survivors in the 1st and 2nd compartment. When the bulkhead door between the 2nd and the 3rd compartment was opened to see what happened to the crew members in the 2nd compartment, toxic gases entered immediately the third compartment where the command centre is located and made several persons unconscious. A special brigade of the 4th compartment evacuated the personnel of the 3rd compartment. The 1st and 2nd compartments were sealed off and the submarine surfaced. 4 days later the submarine returned to base. A total of 39 crew members died from the accident.

One western source claim that the accident also involved the cooling system, that the submarine was towed to Severodvinsk where the reactor compartment was cut out and replaced by a new. There seems to be no support for these claims. It is true that the original reactor compartment of K3 was replaced by a new one, but the reason for the replacement was that the quality of the original one was not good enough. The original reactor compartment was dumped at the Abrosimov Gulf at Novaya Zemlja in 1965, but without fuel in any of the two reactors.

Comment: The accident had nothing to do with the nuclear power plant. The cause of the fire given in the western sources sounds strange since oxygen in itself does not give rise to sparks. The Russian explaination is much more credible.

Dec. 1967. US Nuclear Submarine Accident(s).

According to press reports a US ballistic-missile nuclear submarine suffered serious damage during maneuvers in northern waters shortly before Christmas 1967. The information about the accident should have come from unidentified sources at the US Naval Base in Rota in Spain. It was suggested in press reports that the damage was caused by the pressure change during a dive to large depth.

There has also been press reports that a US submarine collided with a Soviet submarine in the Atlantic or Mediterranian in early 1968, causing severe damage to the US submarine which spent two month for repair at the Rota base.

Comments: The two accident, if real, could be one accident. Whether one or two, they had nothing to do with the nuclear power plant. In the former case it seems to have involved a sea-water leak into the submarine, in the latter a collision with another submarine which could have caused a sea-water leak.

1967. Soviet November Class Submarine Incident

According to unknown sources a Soviet November class nuclear-powered attack submarine had a mishap in the Mediterranean which is believed to be related to its propulsion system. The submarine was towed to base.

Comments: The available information on the event is very meager. According to Russian information such an incident did not take place.

Therefore this event will be neglected.

May 1968. US SSN Scorpion Accident

The US attack submarine SSN Scorpion sank en route from Gibraltar to Norfolk, Virginia, on May 22, 1968 at a position about 650 km southwest of the Azores at a depth of 3600 m. All 99 men on board were killed. The submarine was split in two major parts by the accident. The forward hull section including the torpedo room and most of the operations compartment is located in a trench, formed through the impact of the submarine section with the sea bottom. The sail is detached. The aft hull section, including the reactor and the engine compartments, is located in a separate trench. The aft section of the engine room is inserted forward into the larger diameter hull section in a manner similar to a telescope. The submarine was carrying 2 nuclear tipped Mark 45 ASTOR torpedoes. The warheads were low-yield tactical nuclear weapons. These weapons contain a plutonium and uranium core. It is likely that the plutonium and the uranium has corroded into heavy, insoluble oxides soon after the sinking and that these materials remain inside the torpedo room. If they were released outside the submarine they would settle at the sea bottom due to their high density and insolubility.

Naval Inquiry Court concluded that the certain cause of the loss of Scorpion cannot be ascertained from any available evidence. One month prior to the accident SSN Scorpion collided with a barge in the harbour of Naples during a storm, and the barge sank. Divers inspected the hull of the submarine and found no damage. It has recently been claimed that the most likely cause of the sinking of SSN Scorpion was due to a conventional torpedo explosion. According to this theory one of the conventional torpedoes somehow became armed. The crew jettisoned the torpedo to get rid of it. However, since the torpedo was designed to home on a sonic signal from a vessel. Since the submarine was the only sonic source in the vicinity, the torpedo turned around and hit the submarine, bursting its hull. Another theory is that the torpedo exploded inside the submarine. This does not seem to agree with the fact that the submarine was split in two parts of roughly equal size by the accident. An torpedo explosion should have taken place in the front end of the submarine. After the accident the US Navy made a thourough review of the torpedo safety systems and introduced a number of modifications. A Russian source claims that Scorpion had not undergone all the modifications which were decided after the sinking of NSS Thresher.

The area of the accident has been monitored for radioactivity in 1968, 1979 and 1986. None of the samples collected showed any evidence of release of radiocativity from the reactor fuel. Only very low ^{60}Co concentrations, corrosion products from the reactor circuit, were detected in sediment samples; the maximum concentration of ^{60}Co was measured to be 1.2 pCi/g. This is more than a factor of 10 lower than the natural radioactivity of the sediment. No ^{60}Co was found in fish or other marine life specimens.

Comments: There is no indication that the nuclear power plant was involved in the accident.

May 1968. Soviet Nuclear Submarine (K27) Accident

According to Russian information an experimental Soviet nuclear submarine, K27 of the Northern Fleet with two liquid metal cooled reactors suffered a reactor accident on May 24th, 1968. The hull of the submarine was that of a November class submarine.

The submarine became operational in November 1963. The two reactors were both cooled by a liquid alloy of lead and bismuth and the neutrons causing the fission reactions were of intermediate energy. After some years of operation a refueling of the reactors was carried out successfully. However, there were problems with leakage in the steam generators, in particular those of the port reactor. This leakage caused oxidation of the coolant whereby particle matter was formed. This material could block the coolant flow through the reactor core. For this reason the reactor designer required that the coolant was cleaned for particle matters with regular interval. In May 1968 K27 was ordered to participate in a naval exercise in spite of the fact that the reactors needed a clean-up of the coolant. The leading officers protested, but had to follow orders, and the submarine left the base on a test run.

On May 24th K27 was sailing at maximum power, testing the reactor parameters. Suddenly the power meters of the starboard reactor started to oscillate, and shortly after the power of the port reactor decreased to 7% of the maximum level. The port reactor was shut down.

After a leak (presumably in a steam generator of the port reactor) the coolant flow in parts of the core was blocked and the fuel overheated and melted. Hereby at least 20% of the fuel elements were damaged and radioactive material released to the primary circuit and to the safety buffer tank and from here to the reactor compartment. The radiation level in this room was above 100 Röntgen/hour. The radioactive contamination spread to the other compartments. The radiation alarm was activated, all doors between compartments were closed, and the submarine sailed towards its base at Gremikha in the Iokanga bay by use of the starboard reactor.

Due to the radioactive contamination of the submarine it was decided to surface to ventilate the compartments even though it ment longer travelling time back to the base. The speed at the surface was only 15 knots. Crew members tried to reduce the contamination from the damaged reactor. When the K27 approached the base, the leadership of the base suggested that the submarine should stay outside harbour and work on the overheated reactor there. But due to the radiological and technical situation on board K27 went straight to the quay where the submarine was moored.

The total crew was 124 men, of which 27 were officers. 12 crew members received dosis in the range of 600 to 1000 Röntgen. They were all hospitalized. 5 died, 4 of radiation and one suffocated in his gas mask. Later Russian information claims 9 dead due to radiation injury.

K27 stayed in Gremikha where the starboard reactor served as a test bed for liquid metal cooled reactors. The coolant of the port reactor was kept liquid by heating with steam from the starboard reactor. After 13 years the heating was removed and the coolant was permitted to solidify in both reactors. Extensive decontamination experiments were also carried out in the submarine.

In December 1973 K27 was towed to Severodvinsk where it had been built. In the reactor rooms the drive mechanisms for the control rods and the ionization chambers were removed, and all holes closed. The primary circuit was filled with liquid metal and the empty volume of the reactor rooms was filled with furfurol and bitumen. Finally K27 was in 1981 towed to the Stepovoy Inlet near Novaya Zemlya and sunk at 20 m depth with fuel in both reactors. The activity of the reactor fuel was about 200 kCi at the time of the sinking.

Comments: The accident was a clear reactor accident, caused by insufficient cleaning of the coolant and resulting in a loss-of-coolant accident.

Aug. 1968. Soviet Yankee Class Submarine (K140) Accident

According to Russian information a Yankee class nuclear submarine of the Northern Fleet, K140, suffered a criticality accident in Severodvinsk on August 23rd, 1968. The wiring of the control rods had not been done correctly. So when the power was switched on for a mechanical test of the control rods - and with no neutron monitors operating - the rods moved out of the core instead of into the core, and the reactor went critical. The excess reactivity is said to have been 12%(?). Initially the personnel did not understand what happened. The power level reached 20 times the nominal power level and the pressure 800 kg/cm^2, 4 times the nominal. Presumably the reactor shut itself down due to the damage of the fuel which resulted from the power excursion. The reactor system was strongly contaminated due to the fuel damage, but there was no casualties. It seems as if the primary circuit did not leak. After some years the submarine was repaired. The damaged reactor was in 1972 dumped in the Novaya Zemlya Depression in the Kara Sea.

Comments: The accident clearly involved a criticality accident. The reasons why there were no casulties are undoubtedly that the reactor vessel was closed and inside its shield and that the submarine hull was not open as it is during the refueling or defueling process.

1968. Soviet Nuclear Submarine Accident?

According to raw US intelligence reports a Soviet submarine, presumably nuclear powered, sank at the Kolskiy Zaliv estuary off Severomorsk at the Kola Peninsula. All 90 men on board died. When the submarine failed to return to base at the expected time, a search was started one or two days later, and the submarine was found. When the submarine was recovered, it was determined that all food on board had been consumed. It was estimated that the submarine had been at the location for 30 days.

Comments: No reason is given for the sinking of the submarine. It should have been known since the submarine is said to have been recovered. Since all food on board was consumed, the crew must have stayed alive for a significant number of days after the sinking. This again seems to indicate that the air cleaning and controlling system worked; else the crew would have died much faster due to suffocation. This system needs energy, and therefore it seems as if the reactor system has worked. Since the submarine sank not far from Severomorsk and at shallow water, the crew could have used the active sonar system (which needs power) or the emergency buoy system to signal its distress to its base. Thus the available information does not sound very coherent.

It may also be mentioned that according to Russian information only two sunken submarines have been recovered by the Soviet navy: S80 and K429 (see June 1983. Soviet Charlie-II Class Submarine Accident). S80 was a diesel submarine of the Northern Fleet which sank to a depth of 200 m om January 27th, 1961, with its crew of 68 men. It was recovered in 1969. Information from Russia states that this accident has never happened.

Therefore this event will be neglected.

Apr. 1970. Soviet November Class Submarine (K8) Accident

According to western sources a Soviet November class attack submarine was sighted dead in the water in heavy sea 480 km north-west of Spain on April 11 1970. Crew members was seen on the deck trying to rig a tow-line to two nearby Soviet merchant ships. Therefore, the submarine was believed to have suffered a propulsion failure. Some sources say that there was an internal fire in the boat. On the following morning US Navy P-3 patrol planes found only two oil slicks on the surface at the position where the submarine had been seen, i.e. at a position of 47°25'N, 19°40'W. It was assumed that submarine had been lost, and that the crew had been picked up by the two Soviet merchant ships. One source claims that lifes were lost when the crew tried to prevent the fire from reaching the nuclear power plant. The submarine may have carried two nuclear torpedoes.

After the accident Soviet survey vessels guarded the area for six months. Thereafter the Soviet Navy conducted routine patrols of the area until 1979. After 1979 only occational visits were made.

According to Russian sources two fires started simultaneously in the November class nuclear submarine K8 of the Northern Fleet when the submarine was sailing submerged in the Biscayan Bay on April 8th, 1970, returning from the exercise OKEAN. One fire started in the third (central) compartment, one in the eighth compartment. The automatic shut-down system of the reactors stopped their operation, leaving the submarine practically without power, since the diesel power plant could not be started. The submarine surfaced, and the crew tried to fight the fire without success. The control room and many other compartments were filled with fumes from the fires. Air was pumped into the aft ballast tanks to keep the submarine floating. However, on April 10th the air supply had been exhausted, and water started to flow into the 7tn and 8th compartment. K8 sank at 06.20 of April 11th at a depth of 4680 m. 52 of the crew members, including the captain, died during the accident.

The exists in raw western intelligence reports a record of another accident with a Soviet nuclear submarine which should have taken place in April-May 1970 near the Faroe Islands. It also involved a fire and a great loss of life. When the fire spread towards the reactor, the captain ordered the personel to abandon the submarine, the interior of the boat was flooded to prevent the fire from reaching the reactor room and the submarine sank. Since the description of this second event is almost identical to the first except for the geographical location and since the first event has been described by Russian sources while the second has not, there is every reason to believe that there was only one event. The mistake concerning the location could be explained in the following way. The accident took place 480 km north west of Spain or about 480 km south west of Britain. The latter position could have been mistaken for 480 km north west of Britain which is close to the Faroe Islands.

Comments: The cause of the accident was fires which from the information available had no connection to the reactor system.

1970. Soviet Charlie-II Class Submarine (K320) Accident

According to Russian sources a Soviet nuclear submarine of the Charlie-II type, K320, suffered a criticality accident at the end of its construction period at the shipyard "Krasnoye Sormovo" in Gorki (now Nizhniy Novgorod). The fuel had been loaded into the reactor, but only provisional control rods had been installed. Hydraulic tests of the primary circuit were performed. During these tests the provisional rods which had not been fixed sufficiently were lifted out of the core by the high velocity of the water coolant, and the reactor went critical. The accident resulted in the release of radioactive water to factory hall. The reactor and its fuel was later replaced.

Western sources claim that the accident also involved a fire, but this is denied in Russian information.

Comments: The accident was clearly a criticality accident. Since the factory hall was contaminated there must have been access from the primary circuit to the hall. It might be that the reactor and the submarine hull was open to the surroundings, but no information is available on this question.

Apr. 1971. Soviet Yankee Class Submarine Incident/Accident?

According to western sources a Yankee submarine experienced unknown problems in the Pacific in April 1971.

Comments: The very limited information available does not seem to indicate a serious accident, if at all real.

Therefore this event will be neglected.

1971. Soviet Submarine Radiation Incident/Accident?

According to a rather vague report a radiation accident occured in 1971 in a Soviet first generation submarine (November, Echo or Hotel). 6 persons were involved.

Comments: With the limited information available it is not possible to comment on the accident, if at all real.

Therefore this event will be neglected.

Feb. 1972. Soviet Hotel-II Class Submarine (K19) Accident

According to western sources a US Navy P-3 Orion patrol plane sighted and photographed a Soviet ballistic-missile Hotel-II class nuclear submarine on the surface about 1000 km north east of New Foundland on Feb. 24th, 1972. The submarine had apparently lost all power. Later the submarine started its journey back to its home base through heavy, stormy seas, moving at low speed and accompanied by a number of Soviet ships. On March 18th the submarine was still moving across the north Atlantic. On April 5th the boat had reached its home waters in the White Sea. Several deaths were thought to have occurred, but the basis for this claim was not given.

According to Russian information the Hotel class submarine K19 (cf. July 1961) suffered a fire at 10.23 in the morning of Feb. 24th, 1972, while sailing submerged in the Atlantic at a depth of 120 m on the way back to its base after a patrol. K19 was expected to reach its base in 8 days.

The fire started in the 9th compartment, which contained auxilliary installations, the galley and some cabins, arranged in 3 floors. The fire was caused by oil from the hydraulic system controlling the rudder. The oil had come in contact with an apparatus for combustion of CO and started a fire. Some days before a leak had been repaired in a tube of the hydraulic system, and either the repair had not been well done or the spilled oil had not been properly cleaned up. The sailor who discovered the fire went to wake the person responsible for the apparatus instead of giving the alarm and start fighting the fire. Hereby precious time was lost. Alarm was given, and the fire figting was started. However, the crew was not provided with gas masks and several lost consciousness due to the combustion gases. The fire caused the main pipeline with compressed air to explode, and this air release promoted the fire. The smoke spread through the ventilation system to the next compartment, the 8th, which contained the control room of the reactor. Gas masks were used where available, but not always with success because they had not been adapted to the persons to use them. The 9th compartment was evacuated, and all personel in compartment 8 that was not indispensible, was sent to the forward parts of the submarine.

The submarine tried to get to the surface. Unfortunately the fire spread to the 8th compartment where the electric generators were situated. The CO also reached the reactor control room, the reactors were closed down and the room evacuated. The 7th compartment which contained steam turbines, was also filled with smoke.

With the reactor shut down, the electricity disappeared. Attempts were made to start the emergency diesel generators in the 5th compartment, but they were not successful due to darkness and the smoke. When leaving the 5th compartment the personel forgot to close the air valves and nearly 200 t water entered the compartment and drowned the diesel generators, the main ventilation system and equipment for remote control of the reactor.

In the meantime the submarine had reached the surface where a storm was approaching.

12 crew members remained in the 10th compartment which contained quarters and two torpedo launching tubes and torpedoes. Due to the fire in the 9th compartment they were isolated. For a while they could communicate with the 1st compartment, but the fire interrupted the connection. Air was supplied to the 10th compartment through a pipeline ordinarily used for the balancing system and contaminated air was removed through the drinking water system. The crew members obtained drinking water by collection water condensing on the outer walls of the compartment. However, they had very little food. They were not relieved until March 18th.

Salvage and other ships had arrived, but due to the storm it was not possible for a long period to send assistence to K19. Later 40 crew members were transfered to these ships by use of helicopters and one of the ships supplied K19 with air and electricity. Crew members were also transfered to one of the ships by use of a cable, connecting the ship to the top of the sail of the submarine. Fresh personel was transfered to the submarine. Finally K19 was towed back to Severomorsk where it arrived on April 4th.

The accident cost the life of 30 crew members of which 28 were killed by the fire.

Another Russian source reports on an almost identical accident of K19, but on the 23rd of September 1972. The latter report must be due to a misprint.

Comments: The fire was not initiated in the propulsion system, but it spread in the submarine and caused shut-down of the reactors and thereby loss of propulsion. No radioactivity release seems to have been involved in the accident.

Mar. 1972. Soviet Yankee Class Submarine Accident?

On March 16th, 1972, a Yankee class submarine was sighted at the surface northeast of Iceland. It was assumed that the submarine had experienced problems.

Comments: The information available on this event is very limited.

Therefore this event will be neglected.

Dec. 1972 - Jan 1973. Soviet Yankee Class Submarine Accident

Raw western intelligence reports have mentioned two accidents which involved radiation accidents in Soviet nuclear submarines in the Atlantic.

The first occurred in December 1972 off the U.S. Atlantic coast in the mine-torpedo department in the forward section of the submarine and involved a nuclear leakage from a nuclear torpedo. Doors were immediately shut and some crew members were trapped within the space where the radiation leakage had occured. The trapped crew initially consumed dry rations that were permanently stored in the compartment. Later they received food through a small opening from the weather deck. Upon arrival in Severomorsk the crew members was allowed to disembark. Several men died shortly after the accident, others later. The majority of the crew suffered from some form of radiation sickness.

The second accident occurred in December 1972 or in January 1973. An undetermined accident crippled a Soviet nuclear submarine in the Atlantic. The submarine was towed at a speed of two to three knots for six weeks to Severomorsk on the Kola Peninsula. The crew was trapped in the forward space , initially consuming dry rations that were permanently stored in the compartment. Later they received food through a small opening in the weather deck. Upon arrival in Severomorsk, the crew members were allowed to leave the submarine. Several died shortly after the accident, others later. The majority of the crew suffered radiation sickness.

Since the time and the latter part of the two stories is practical identical, they deal in all probability with the same accident and should be considered as one accident. The submarine has been reported to be a Yankee class ballistic missile submarine.

Comments: The report of the first accident seems rather strange. Nuclear torpedos do contain radioactive materials (plutonium and/or uranium) on solid, not liquid or gaseous form, and they are provided with an outer, protective casing. Even if the outer casing was damaged due to e.g. a fall of the torpedo, the escape of radioactivity would be small, and there seems to be no reason for locking up the crew members in the torpedo room.

The second accident could be due to a reactor accident involving fuel damage and release of radioactivity into the compartments around the reactor, but this is pure speculation. It could explain that the submarine was towed back to base, and that the crew moved to the forward compartment, as far away from the contaminated parts of the submarine as possible. It could also explain why the majority of the crew members suffered radiation sickness. However, according to Russian information none of these events have occurred.

Therefore these events will both be neglected.

1972. Soviet Alfa Class Submarine (K377) Accident

According to Russian sources an Alfa class submarine, K377, suffered a reactor accident in 1972 during sea trials. The liquid metal coolant (Pb-Bi) solidified. It was not possible to remelt it and to get the fuel out. The submarine was subsequently dismantled. The reactor compartment was filled with furfurol and bitumen. It was the intension to dump it in the Kara Sea. However, before it could be done, the Soviet Union signed the London convention. Instead of dumping the reactor compartment is stored at a naval base.

Comments: The accident was clearly a loss-of-cooling accident.

Apr. 1973. US SSN Guardfish Incident

On April 21st, 1973, the US nuclear attack submarine SSN Guardfish experienced a leak in the primary cooling circuit while sailing submerged 600 km south-southwest of Purget Sound, Washington. The boat surfaced, ventilated, decontaminated and closed the leak without external assistance. Four crew members were later transfered to the Purget Sound Naval Hospital for check of radioactivity contamination.

Comments: Though some claim that this was an accident it is difficult to see the basis of such claim. It is a type of event which can be expected to occur once in a while. The important thing is the size of the leak and the ability of the reactor system to replace the leaking water so that the reactor remains cooled until it can be repaired. It is true that had the leakage been larger and had the emergency core cooling system failed the event could certainly have developed into an accident.

June. 1973. Soviet Echo-II Class Submarine (K56) Accident

According to western sources a Echo-II class submarine, K56, collided on June 14th, 1973 in the Pacific Ocean near Nahodka with a Soviet research vessel Akademik Berg. 27 people were killed. Another western source claims that the K56-accident was a reactor accident, that it took place on June 13th and that 27 persons were killed.

Comments: It is obvious that there can only have been one accident, either a collision or a reactor accident. Since the information available on the collision is much more detailed it is believed that the accident involved a collision. As mentioned in the introduction collisions are in general not considered in this compilation. However, due to the loss of lives, an exception is made here. It is not clear whether the 27 people killed belonged to the research vessel or the submarine.

Aug. 1973. Soviet Yankee Class (K219) Accident

According to a western source a Soviet Yankee class ballistic missile submarine, K219, suffered a missile tube accident in the Atlantic on August 31st, 1973. One person was reported killed.

Comments: Due to the limited amount of information it is not possible to assess the severity of the accident/incident. It obviously did not involve the nuclear power plant, but could, if real, have involved a nuclear warhead. According to Russian information this accident did not occur.

Therefore this event will be neglected.

Apr. 1974. Soviet Yankee Class Submarine (K420) Incident/Accident

According to Russian information a Yankee submarine of the Northern Fleet, K420, suffered a fire in the 10th compartment on April 6th, 1974. There was no casualties.

Comments: With the limited information available it is not possible to assess the incident/accident except to state that there is no indication that the nuclear power plant was involved. Later Russian information have stated that this event never took place.

Therefore this event will be neglected.

Mar. 1976. Soviet Nuclear Submarine Accident

According to western sources a Soviet nuclear submarine (class unknown) suffered in March 1976 a fire in the turbogenerator after a patrol of 70 days in the Pacific. The event occured near Petropavlovsk. The submarine almost sank after loosing power.

Comments: The accident did involve the propulsion system, but not the reactor system. Whether the submarine "almost" sank, is a subjective judgement and therefore difficult to assess.

Sep. 1976. Soviet Echo-II Class Submarine (K47) Accident

According to a western source the Echo-II class submarine K47 sailed in September 1976 in the Barent Sea on on its way to the home base when a fire broke up in the 8th compartment. 8 crew members dies from injuries.

Comments: There is no incication that the accident involved the nuclear power plant.

Oct. 1976. Soviet Yankee Class Submarine Accident

According to raw western intelligence reports a fire started in the missile launch compartment of a Soviet Yankee class nuclear submarine with ballistic missiles on patrol in the Atlantic in October 6th, 1976. Three officers were killed according to one source. The submarine returned to base on its own power.

Comments: The nuclear power plant was obviously not involved in the accident, but radioactivity could have been released if the warheads of the missiles were damaged. According to Russian information this event did not take place.

Therefore this event will be negelcted.

1977. Soviet Echo-II Class Submarine Accident

According to raw western intelligence reports a Soviet Echo-II class cruise missile nuclear submarine suffered a fire in the Indian Ocean in 1977. The submarine surfaced in attempt to fight the fire which it took several days to extinguish. The submarine was towed to a port near Vladivostok by a Soviet trawler.

Comments: Since the submarine was towed back to base, the propulsion plant, but not necessarily the reactor, seems to have been involved in the fire.

1977. Soviet Nuclear Submarine Radiation Accident

According to raw western intelligence reports about 12 Soviet naval officers, serving on a nuclear submarine in the Atlantic, were in 1977 taken from the submarine to Canada by a Soviet trawler. From here they returned to Leningrad on an Aeroflot flight. Intelligence sources suggest that this may have been a medical emergency connected with radiation exposure.

Comments: The evidence that there was an radiation exposure is rather uncertain. If the event is real, the cause of the accident is unknown, but it is likely to have involved the reactor. According to Russian information this accident did not take place.

Therefore this event will be neglected.

Aug. 1978. Soviet Echo-II Class Submarine Incident

According to western information a Soviet Echo-II class nuclear submarine was sighted dead in the water near Rockall Bank, 225 km north-west of Scotland in August 1978. It had appparently experienced problems with its propulsion plant. On August 20th a US P-3 Orion aircraft observed the submarine south of the Faroe Islands, under tow towards its home base in the USSR. There is no indication of the cause of the propulsion problem or on any personnel casualties.

Comments: The submarine obviously suffered a break-down of its propulsion system, but not necessarily of the reactor system. According to Russian information such an incident did not take place. It is nevertheless taken into account since the submarine was observed by western planes. It could have been a minor incident which was disregarded by the Northern Fleet.

Sep. 1978. Soviet Yankee Class Submarine (K451) Accident/Incident

According to Russian information a Soviet Yankee nuclear submarine of the Pacific Fleet, K451 suffered a fire in the compartment of the turbogenerators on September 2nd 1978. There was no casualties.

Comments: With the limited information available it is not possible to asses the accident/incident. However the reactor system was not involved.

Dec. 1978. Soviet Delta-I Class Submarine (K171) Accident

According to Russian information a Delta-I class ballistic missile nuclear submarine of the Pacific Fleet, K171, suffered a reactor accident followed by incorrect actions by the crew on December 28th, 1978. 3 crew members died due to the accident.

Comments: Due to the very limited information no assessment of the accident is possible except to say that it involved the reactor system.

July 1979. Soviet Echo-I Class Submarine (K116) Accident

According to western sources one of the two reactors of the Echo-I (-II?) nuclear submarine K116 of the Pacific fleet (Order No. 541) suffered a loss-of-coolant accident in July 1979 while at sea near Russia. The reason for the accident was a human error. The reactor control panel of the submarine was placed in front and at the side of the operator, who often operated the switches on the side panel, while looking at the front panel. In the case of the accident the operator misplaced his hand and operated a wrong switch whereby he turned off the main circulation pumps. The emergency core cooling system did not work, and due to the confusion that followed, the error was not rectified. The core was exposed, and part of the fuel melted. None of the crew members seems to have died because of radiation exposure and no radiation escaped to the outside. The submarine is now awaiting decommissioning at Pavlovsk submarine base of the Pacific fleet.

Comments: As mentioned above the accident was due to human error. Even considering the confusion that followed after the mistaken switching-off of the main circulation pumps it is difficult to understand that the error was not rapidly corrected. The reason could be an inexpedient display at the control desk or insufficient training of the operators or both.

Dec. 1979. Soviet Nuclear Submarine Accident

According to a western source a Soviet nuclear submarine suffered a radiation accident and sunk in the Atlantic Ocean in December 1979. The number of casualties is not given.

Comments: Such an accident has never been confirmed by other sources and is in contradiction with Russian information.

Therefore this event will be neglected.

Late 1970s. Soviet Nuclear Weapons Accident

According to a western source a Soviet ballistic missile, nuclear submarine jettisoned a nuclear warhead in the Pacific Ocean near the Soviet coast, possibly near Petropavlovsk in the late 1970s. The warhead was later recovered.

Comments: The accident did not affect the submarine and did not give rise to radioactive contamination.

Therefore this event will be neglected.

Aug. 1980. Soviet Echo-II Class Submarine Accident

On August 21 1980 a Soviet Echo-II class cruise-missile nuclear submarine suffered an internal fire 460 km east of Okinawa according to one source. According to another the submarine suffered a fire in the propulsion area of the submarine 140 km east of Okinawa. At least 9 crew members are believed dead and 3 injured. A Soviet freighter evacuates the crew and a tugboat towed the submarine to Vladivostok, escorted by several warships. The USSR informed Japan that there was no radioactive leakage, but the Japanese subsequently reported evidence of radioactive contamination in water and air samples. How solid this evidence is, is not known.

Comments: The submarine has obviously suffered a breakdown of its propulsion system. Since reactor compartment does not ordinarily contain large amounts of inflammable materials while the engine compartment does (oil in gear boxes, bearings etc.), the fire did probably start in this room.

Sep. 1980. Soviet Nuclear(?) Submarine Accident

According to raw western intelligence reports a Soviet nuclear submarine (class unknown) suffered when sailing in the Baltic Sea in September 1980 (one source says 1981) a series of strong and sudden physical shocks, and the boat was no longer navigable. An emergency was declared, and some crew members were sealed in the compartment where they were on duty. The submarine was taken on tow to Kaliningrad. The towing took 36 hours since it was only done during darkness. The crew members that had been sealed off were flown to Riga and hospitalized, showing signs of terminal radiation sickness.

According to another source the submarine was a conventional Whiskey-class submarine which became involved in a collision whereby one of the torpedoes with nuclear warhead was damaged and radioactivity released and crew members exposed to radiation.

Comments: From the available evidence it seems reasonable to assume that the event did not involve a nuclear submarine which never operated in the Baltic. This is confirmed by Russian information. Even if crew members had been present in the torpedo room during the collision and damage to the nuclear torpedo, it does not seem clear why they were isolated in this room. It is also not clear why the towing should only be done during the night, in particular in a situation where some crew members were exposed to radiation. As is apparent from this report towing of Soviet submarines during the day is not something unique.

Therefore this event will be neglected.

Sep. 1980. Soviet Nuclear Submarine (K222) Accident

According to Russian information the submarine K222 suffered a criticality accident on September 30th, 1980, (one source says November 30th, 1980) when it was undergoing a major overhall at a shipyard in Severodvinsk. At a time when all the crew members had left for lunch and only shipyard personnel were present, the personnel supplied power to the control rod drives while the instrumentation system was not activated. The rods moved out of the core, and due to a failure of the automatic control system, the reactor went critical. As a result the core was damaged. One source claims that the primary circuit was "destroyed". There was no casualties and no contamination of the surroundings has been reported. The two reactors - not the reactor compartment - was dumped without fuel in the Techeniye Inlet at Novaya Zemlya in 1988.

Comments: The accident is clearly a criticality accident. The reasons for the lack of casualties and the apparent lack of contamination could be that the reactor tank and also the submarine hull was not open to the surroundings. The fact that the reactors were dumped without fuel, seems to indicate that the fuel damage was limited. This contributes also to reduce any release of radioactivity.

1980. Soviet Delta-III Class Submarine Accident

According to western sources a Soviet Delta III class submarine suffered a reactor accident in 1980. 2 persons were killed.

Comments: It is not possible to comment on such limited information, if real.

Apr. 1982. Soviet Alfa Class Submarine (K123) Accident

According to Russian information a Alfa nuclear submarine of the Northern Fleet, K123, suffered an accident on April 8th, 1982, during a patrol in the Barent Sea. The coolant of the primary circuit, a lead-bismuth alloy, solidified, and the submarine had to be towed back to base.

A western source claims that the K123-accident took place on August 8th, 1982, and that it involved a leak of the liquid metal cooling in the steam generator. Approximately two tons of the alloy leaked to the reactor compartment and the core of the reactor was damaged beyond repair.

The recommissioning of the submarine which involved replacement of the reactor compartment, took 9 (8) years and was carried out at a shipyard in Severodvinsk. The accident claimed no casulties.

Comments: This accident was clearly a loss-of-cooling accident, whether it involved solidifying or leakage of the coolant or both.

June 1983. Soviet Charlie-I Class Submarine (K429) Accident

According to western intelligence reports a Charlie-I class cruise-missile nuclear submarine sank somewhere east of the Soviet naval base at Petropavlosk, near the southern tip of the Kamchatka Peninsula. The cause of the accident was not given, but since there was no release of radioactivity it was probably a mechanical failure, not a nuclear reactor accident. Figures given for the number of crew members killed vary from unknown to 16 to all of the 90 persons on board. The submarine sank at a depth of 50 m. The submarine was salvaged by the Soviet Navy in August 1983.

According to Russian information a Charlie-II class nuclear submarine from the Pacific Fleet, K429, should on June 24, 1983, perform a routine balancing test in the Krasheninnikov Bay to ajust the density of the submarine to that of the sea. The submarine was 60 t heavier than expected, i.e. it had negative buoyancy, and the crew members that should have checked the weight of the submarine, had not done this. When water was let into the ballast tanks, K429 sank to the bottom of the sea at a depth of 35 m. It did not help that all the depth meters were switched off.

Water started entering K429 since all exits of the ventilation system had been left open because it was not intended that the submarine should submerge. Alarm was given and the captain ordered the main ballast tanks emptied. Unfortunately the operator used the wrong handle, and the compressed air did not enter the ballast tanks, but was released to the sea. Around midnight all the valves of the ventilation system were finally closed. It had to be done manually since the remote operation system had been flushed by the incoming water and did not work. At this time the compressed air reserves were down to 30%, not enough to raise the submarine. In addition K429 rested at the sea bottom with an inclination of 15°; this prevented the release of the emergency buoys and the rescue chamber by which 4 man could go to the surface.

In some of the compartments the pressure increased and the temperature rose to 50 °C. There was only diving equipment for 50 persons while the crew consisted of 107 man. At dawn on the 25th June the two batteries, which supplied the electricity, exploded. Later this day two crew members decided to leave the submarine through the vertical missile launching tubes in the first compartment. They were immediately picked up by naval ships at the surface. Alarm had already been ordered when the air bubles from the air release were observed at the surface.

The rescue work started at 23 o'clock in the evening. Divers brought diving sets down to the submarine and in 24 hours 104 crew members were rescued. 2 (17?) crew members died during the operation. Before leaving the submarine the crew had prepared it for raising which took place some month later. After K429 had been repaired, it sank again at the shipyard, close to the quay. It is raised again and later - according to a western source - used as a dock side trainer at the Ribachiy submarine base.

Comments: The nuclear propulsion system was not involved in the accident.

Sep. 1983. Soviet Nuclear Submarine Accident

According to a western source a Soviet nuclear submarine was observed dead in the Pacific Ocean and later sunk in September 1983. No information is given on submarine class or casualties.

Comments: Such an event has not been confirmed by other sources and is in contradiction with Russian information.

Therefore this event will be neglected.

June 1984. Soviet Echo-I Class Submarine (K131) Accident

According to Russian information an Echo-I class nuclear submarine, K131, suffered a fire in the electro-technical (the 8th) compartment on June 18th 1984 while returning to its base at the Kola peninsula after a patrol. The fire started when one of the crew members was working on some electric installations and his clothes caught fire. 13 or 14 crew members were killed by the accident.

Comments: The information available on the fire does not indicate whether the nuclear power plant was involved in the accident or not.

Aug. 1985. Soviet Echo-II Submarine Accident

On August 10, 1985, an uncontrolled chain reaction suddenly occured in the port reactor of a nuclear submarine of the Echo-II class, that was completing refueling at a pier of the Naval shipyard in the town of Shkotovo-22 at the Chazhma Bay, Maritime Territory, about 60 km SSE of Vladivostok. One western source claimed that the submarine was a Victor Class submarine, but a picture of the submarine shows clearly that it was a Echo class submarine and it has later been confirmed that it was a Echo-II submarine. The reactor had been refueled, but the lid of the reactor tank had not been placed properly and had to be relifted to be placed correctly. When this was done, the control rods had not, in violation of the regulations, been detached from the drive mechanisms on the lid and were lifted out of the core. This caused an uncontrolled chain reaction which resulted in a steam explosion.

The steam explosion destroyed the forward and aft machine rooms and the forward compartment of the control system. One freshly loaded fuel element was blown out of the reactor to a distance of 70-80 m, landing 30 m from the shore. The explosion also caused damage to the pressure hull of the submarine in the aft portion of the reactor compartment. Immediately after the explosion a fire broke out. It was brought under control after 4 hours. The combustion products along with fission products, activation products and particles of unburned fuel fell down in the form of fine particles or slurries over an area with a radius of 50-100 m around the submarine. The dose rate exceeded 600 R/hr.

A radioactive plume moved in northwestern direction towards, but never reached, Vladivostok. It intersected the Dunay (Shkotovo) peninsula and extended towards the coast of the Ussiri Inlet. The plume width was several hundred meters, and its length about 6 km. Fall-out of aerosol particles occurred in the Ussuri Inlet up to 30 km from the submarine.

The release of radioactive material into the atmosphere was 7 MCi of which 2 MCi was noble gases. 7.5 hours after the accident the dose rate in the area of the accident reached 0.25-0.5 R/hr. Submarines and special vessels near the accident site piers and the shipyard structures were significantly contaminated. A large part of the Chazhma Bay was was contaminated due to the fall-out from the plume and due to radioactive water from the reactor compartment entering the water through the hole formed in the pressure hull. Two month after the accident the radioactivity of the seawater was back to the background level.

During the accident and the clean-up, 290 persons did receive significant radiation doses. 10 persons died (instantly?) of their injuries (8 officers and 2 sailors). 10 persons developed radiation sickness, and 39 displayed radiation reactions. Another source reports that according to calculations by the Russian navy only "a handful of individuals" received more than 140 rads and that most exposures were around 2 to 4 Rad.

No attempt was made to repair the submarine which initially stayed at the dockside of the Chazma facility. Later it was moved to the Pavlovsk submarine base.

Comments: The accident was clear refueling accident.

Dec. 1985. Soviet Echo-II/Charlie Class Submarine Accident

According to a western source the reactor of a Charlie class submarine (K314) overheated while the submarine was returning to base outside Vladivostok in December 1985. Another western sources claims that it was a Echo-II class submarine (K431) of the Pacific fleet that suffered overheating of the reactor (loss-of-coolant accident) while at sea in December 1985. According to both sources the submarine is now awaiting decommissioning at the submarine base of the Pacific Fleet at Pavlovsk. The two accidents are so similar that they are in all probability the same. The reason why one is called a a Charlie class and the other is called an Echo-II may be due to a mix-up of the number of the submarine; 431 consists of the same digits as 314. However, according to Annex IV, K431 is a Echo-II submarine, while K314 is a Victor-I submarine. K313 is a Charlie-I submarine.

According to the first source the accident was caused by an infringement of technical regulations which resulted in a break in the primary cooling system of the reactor plant. A valve which should have closed when the pressure of the system dropped, failed to do so. The fuel was exposed and melted. The cooling water that escaped, passed below the "biological zone"(shield?) and into the bilge below the reactor. Even though the accident was due to a construction defect, the crew did not do enough to isolate the accident. The whole crew was irradiated, but no crew members died due to the radiation exposure and no radioactivity escaped the submarine.

Comments: The accident was clearly a loss-of-coolant accident. Whether it was an Echo-II or a Charlie class submarine is difficult to say. The correct number points towards the Echo-II class submarine and so does the fact that there are reports of submarines of the Echo class with damaged cores at the Pacific Fleet while there are no such reports on a Charlie class submarines. The more detailed account of the second accident points towards the Charlie class submarine.

1985. Soviet Echo-II Class Submarine Accident

According to western sources an Echo-II class submarine suffers a reactor accident in 1985. As a consequence of the accident the submarine was retired.

Comments: The accident is obviously a reactor accident. However the information on the accident is limited and consisting with the preceeding accident. Since there are 3 submarines with damaged cores at the Pacific Fleet (cf. section 5) the accident is probably identical to Dec. 1985 Soviet Echo-II Class submarine (K431) Accident.

Therefore this event will be neglected.

Jan. 1986. Soviet Echo-II Class Submarine Incident

On January 13th, 1986, a Japanese maritime patrol plane located a Soviet Echo-II class cruise-missile nuclear submarine under tow by a Soviet salvage ship 450 km north west of Okinawa in the East China Sea. The ships were heading towards the north. The submarine had obviously suffered a failure of its propulsion system. The cause of the accident and the number of possible casualities are unknown.

Comments: The reactor system may have been involved in the propulsion failure.

Oct. 1986. Soviet Yankee Class Submarine (K219) Accident

On October 3rd, 1986, a Yankee class ballistic-missile submarine of the Northern Fleet, K219, suffered an explosion in the No. 13 missile launching tube while sailing submerged about 800 km east of Bermuda. The explosion was followed by a fire which ignited the liquid fuel of the SS-N-6 missile. The explosion caused damage to the hull. Four crew members were according to Russian sources killed by the accident. Others were wounded. The crew fought the fire with the submarine at the surface. On October 5th the fire was under control. The boat was towed by a Soviet merchant ship, but on October 6th, the crew was transfered to the merchant ship and the submarine was abandoned, sinking at a depth close to 5000 m 1400 km south-east of New York or 1000 km north-east of Bermuda. The submarine was armed with 16 SS-N-6 misiles, each containing one or two nuclear warheads. In addition it may have been armed with 2 nuclear torpedoes.

A more detailed Russian account of the accident has later become available. Early in the morning of Oct. 3rd, 1986, when the Yankee-class ballistic missile submarine K219 was changing depth, water started invading the third missile launching tube on the port side. The water crushed the missile wall and caused an explosion in the 4th compartment, and the cover of the launching tube was torn off. The liquid rocket fuel burned and developed poisonous gases, while the water continued to invade the compartment. The submarine surfaced, and the second reactor was started. The fire was localized and the fire fighting started. However, the combustion of the rocket fuel produced very poisonous gases which spread as an orange fog to other compartments through pipelines damaged by the fire. Some crew members suffered suffocation and all personel in the 4th compartment was ordered to leave it. Hereby the crew was divided into two parts, one in the forward and one in the aft part of the submarine.

After 15 hours of fire fighting the water caused a short-circuit which apparently prevented the full shut-down of the starboard reactor. The control rods were not fully inserted. Attempts were made to send personel into the reactor room to insert the control rods manually. The first attempts were unsuccessful due to the high concentration of poisonous gas and high temperature. Finally two crew members succeded in inserting the rods. During the operation one of them had to leave due to suffocation, but the other inserted the last rod. When he tried to get out of the reactor compartment, he could not open the door because in the meantime the air pressure on the outside had increased. Several attempts were made to get him out, but without success.

Finally the captain ordered the crew of the 8th compartment next to the reactor compartment to leave it. At the same time the submarine started for unknown reasons to sink. The crew was transfered to the Soviet ships next to the submarine. On October 6th at 11.03 K219 disappeared in the waves and sank to a depth of 5-6 km. The total number of crew members killed were 4.

Comments: The accident did not directly involve the nuclear power plant, but of course one of the nuclear armed missiles. The problems experienced with the insertion of the control rods of the starboard reactor are of course relevant for the nuclear propulsion plant. However, the consequence of the submarine sinking without full insertion of the control rods does not seem very clear. As long as the reactor is shut down, it should not matter that the control rods are not fully inserted. The reason for the manual insertion of the control rods could possibly be to ensure that if the submarine sank and tilted over, the control rods could fall out of the core and make the reactor critical.

Apr. 1989. Soviet Mike Class Submarine (K278) Accident

On April 7th, 1989, at 11.03 the Mike class nuclear submarine of the Northern Fleet, K278, suffered an internal fire in the Norwegian Sea on its way back to its base at the Kola peninsula (Zapadnaya Litsa?) after a patrol at low depth (160m). The name of the submarine is "Komsomolets". At that time the submarine was running submerged, 180-190 km south-west of the Bear Island in the Norwegian Sea and 490 km from the Norwegian coast.

The fire started in the 7th compartment. However one source says it started in the 6th, the aft engine room which contained reduction gear and/or diesel engines. The submarine had a total of 7 compartments.

The reason for the fire seems uncertain. A liquid had been seen leaking from a hydraulic system, and this may have been the cause of the fire. Another source says that the fire was caused by a short circuit. Subsequent investigations indicated that a series of shortcomings and flaws was the reason for the fire.

The fire alarm was activated. There was one crew member in the 7th compartment. He was called over the intercom system, but did not answer. It was then decided to send freon into the compartment. This should have extinguished the fire, but an electric arc cut a hole in a compressed air pipeline, and the resulting injection of air revived the fire. A few seconds later a beam of fire burned through to the 6th compartment where the crew members hardly had time to put on their gas masks.

The crew stopped the starboard generator and the port generator stopped by itself. The automatic control system shut the reactor down, possibly due to loss of power. Thus the submarine was without propulsion power which made it more difficult to reach the surface. The fire spread to the 5th compartment, and the cooling pump in the 4th compartment started to leak and could break down any minute. Shortly after the vertical rudder got stuck and the telephone connection between the compartments failed. It was not possible to inject freon into the 5th and 6th compartments since crew members were fighting the fire in these compartments.

The control rods were fully inserted into the reactor core to ensure that the reactor would stay subcritical. The submarine rose slowly in the water and at 11.14 it surfaced. Here K278 tried to get in radio contact with the base. Only at 12.25 was the receipt of the SOS-signal confirmed. Real connection with the base was established at 13.27. A small fire started in the command center (in the 3rd compartment?); it was rapidly extinguished, but the center was filled with smoke. The personel started to use breathing masks which were connected to the compressed air system. However, the high pressure in the 7th compartment had injected CO_2 into this system, so the personel in the command center soon had to remove the breathing masks.

An attempt was made to rescue crew members in the damaged part of the submarine. A rescue team first entered the 4th compartment (reactor compartment?) and arranged for its ventilation. Next the team moved on to the 5th compartment, where they found a number of severely burned crew member. They were taken up to the deck, where an emergency hospital had been organized. The team also tried to enter the 6th compartment, but that was impossible due to smoke and fire.

Around 2 o'clock a Soviet plane arrived over the area and helped to maintain radio communication.

At 16.24 the hull vibrated due to internal explosions, probably originating in the tanks of the regeneration system that was used to remove CO_2 from the air in the submarine. As a result water started to flow into the submarine. K278 started to tilt and it was impossible to stand on the deck, so crew members jumped into the water. The captain ordered the crew to abandon the ship. The rescue rafts were with some difficulty released, but only one of the two main rafts inflated. Rubber rafts were dropped from a plane, but they did not inflate. At 17.06 Komsomolets sank at a position of 73°43'16"N, 13°15'52"E, 300 nautical miles from the Norwegian coast and at a depth of 1680 m. The submarine went into a muddy ground to a depth of 2 to 3 m.

At the time of sinking 6 crew members, including the captain, were still inside the submarine. 5 of them succeded in reaching the rescue chamber, but it did not release from the submarine, before it reached a depth of 600 m. At this point the submarine suffered an explosion, and the chamber was released and moved upwards. The 5 men tried to put on their respiration gear, but only two succeded. When the chamber reached the surface, the top lid opened, and the two survivors were thrown out in the water, while the others went down with the chamber which sank rapidly. One of the survivors drowned in the 2°C cold water.

At 18.20 a supply ship rescued 30 survivors, but of these 3 died before they reached Severomorsk. Of the 69 crew members a total of 4 died due to the fire and 38 drowned.

The use of the compartments that were affected by the fire is not quite clear. One source states that the 3rd compartment contained the command center and possibly the reactor control room. The 4th compartment contained the reactor, just behind the sail, and the 5th the pumps of the primary circuit. The 6th compartment may have contained the two turbo-generators.

The Komsomolets became operational in 1983 with the Northern fleet, and was thus a rather new submarine. Only one submarine has been built of this class, in the west called the Mike class. One western source has claimed that it was provided with a liquid metal cooled reactor, another that it was provided with two reactors. However from official Soviet and Russian sources it is known that Komsomolets was provided with <u>one</u> pressurized water reactor with "modestly" enriched uranium as fuel.

If the enrichment of the fuel was 5 to 10%, the fuel elements might have consisted of UO_2-rods, contained in zirconium (or possibly stainless steel) cladding tubes. If the enrichment was higher, say 20 to 40%, the fuel material might have been a zirkonium-uranium alloy. It has been estimated that the reactor fuel at the time of the accident contained 42-76 kCi ^{90}Sr and 55-83 kCi ^{137}Cs. This corresponds to an energy production of the order of 20 000 MW_{th}. The core also contained 2 kg Pu. To increase their lifetime the fuel elements contain burnable poison rods as an integral part.

At the time of sinking the reactor had been cooled down to 40 °C. The remaining decay heat production could be transfered to the sea by natural circulation. For this reason there was no risk of core melt-down. Before the Komsomolets sank, the control rods were locked in the core by use of a special mechanism to prevent random displacement. Corrosion of this mechanism could affect the reactor criticality only in the case of capsizing and only after

1995. Such capsizing could only occur if an attempt was made to raise the submarine.

The reactor tank is made of steel of special quality and the inner surface of the tank is covered by a corrosion resistant layer, presumably stainless steel. In fig. 1 the arrangement of pressure vessel, steam generator, pressurizer and the main circulation pumps is shown. On fig. 1 is also shown the points where it according to Russian information is believed that the high outside pressure at the sea bottom is likely to have ruptured the primary circuit. In fig. 2 is indicated probable leakage routes for radionuclides of the primary circuit.

The submarine was provided with a double hull of a titanium alloy. The thickness of the inner, pressure hull is about 10 cm, and that of the outer hull about 1 cm. The use of a titatium hull made it possible for the K278 to dive down to a depth of 1000 m. This depth was reach by Komsomolets on August 5th, 1983. No other large submarine has ever reached such a depth.

While titanium is very corrosion resistant in seawater, its electrochemical potential is rather different from that of steel. This means that electrolytic corrosion will take place between the titanium of the hull and the steel of the reactor system and other steel parts in the submarine. Consequently special techniques has to be used for joining the titanium hull to e.g. steel components. However, the rate of corrosion is influenced by a number of factors. For corrosion to occur oxygen has to be present in the water; if the flow rate of the water is low, the available oxygen will be consumed and the corrosion reduced. Only free titanium surfaces will give rise to electrolytic corrosion and parts of the titanium surface may be covered by paint. If the fuel rods are clad in zirconium rather than steel, the corrosion-rate will be affected. The corrosion rate is strongly dependent on the actual titanium, steel and zirconium alloys used. This makes it difficult to predict the corrosion rate. It has been mentioned that it is not unrealistic to believe that the first pinholes in the fuel cladding will develop in 5 to 10 years.

The corrosion rate of the burnable poison rods may be larger than that of the fuel rods. This could lead to re-criticality. However, should this occur, it is unlikely thet it will lead to

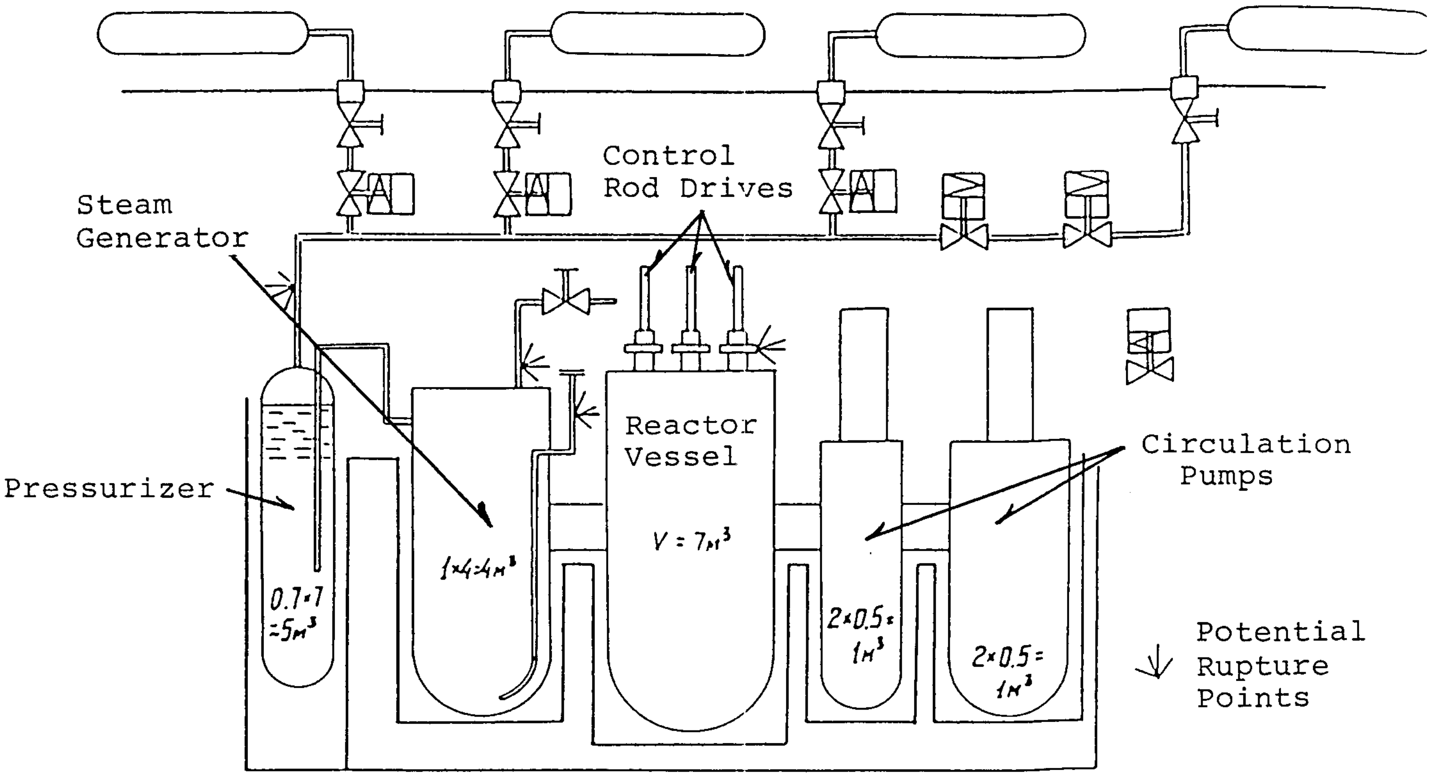

Fig.1. The primary circuit of the Komsomolets nuclear power plant with indication of where the high overpressure at the sea bottom is likely to have ruptured the circuit.

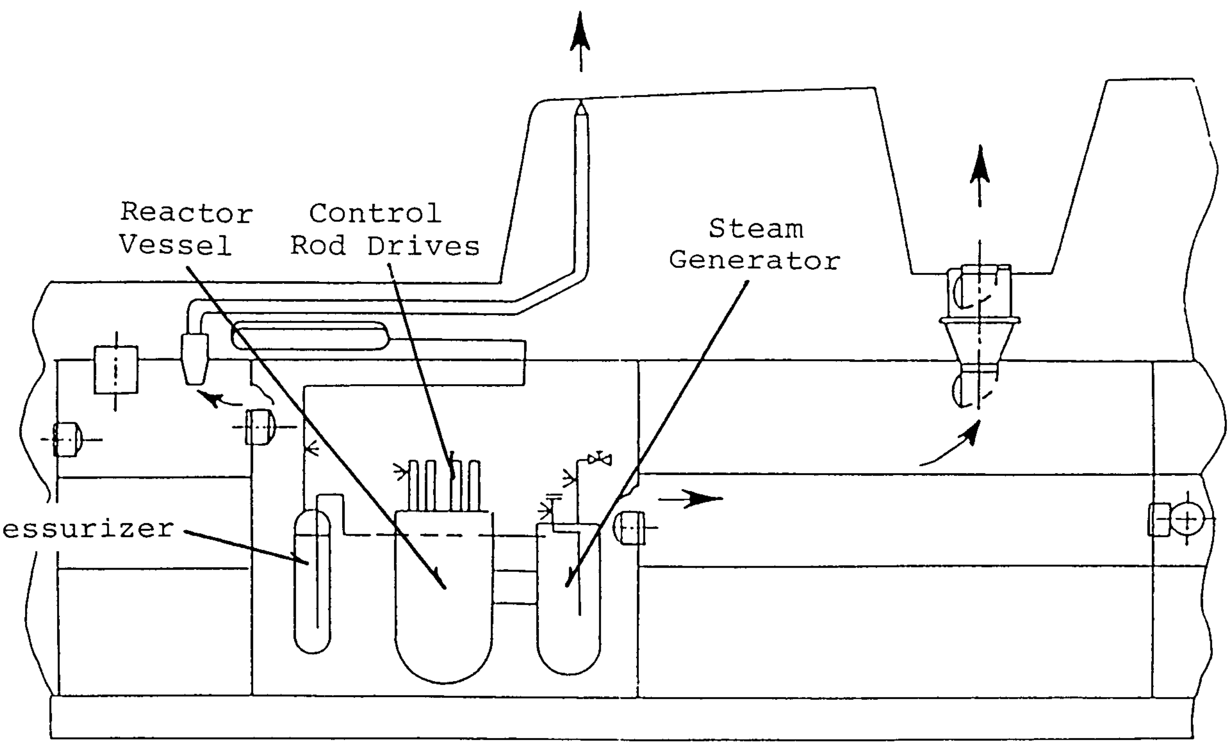

Fig.2. Probable leakage routes for radio-nuclides of the primary circuit of the Komsomolets submarine.

a reactor excursion since corrosion will lead to gradual and very slow removal of the burnable poison, i.e. very slow increase of the reactivity. Only if a fast, large increase in the reactivity should occur will an excursion be physically possible, and such a reactivity increase is rather unlikely. Corrosion of the burnable poison would in all probability lead to a steady state operation of the reactor at low power due to its negative temperature coefficient. If an attempt was made to salvage the submarine, a mishap during such an operation might lead to removal of major amounts of absorber materials from the the reactor core. In such a case an excursion might be possible. Russian experiments and calculations have shown that long term corrosion of the core will not result in the formation of a new critical configuration.

A western source claims that two additional crew members died later under rather strange circumstances. They felt fine after a medical examination at the naval hospital in Murmansk, but died suddenly after having smoked one cigarette each. If true, their death can hardly be due to radiation sickness as claimed by the media. As a matter of fact radiation did not play any role during the accident.

On April 8th a 400 m by 100 m oil slick was all that could be seen at the ocean surface at the scene of the accident. Shortly after the accident the submarine was located by deep-water submersibles of the Soviet Navy, and the pressure hull of the boat was inspected. No visible damage was detected around the reactor compartment. The fact that crew hatches, air vent pipes and some other systems were open when the submarine sank, ensured a pressure equalization between the inside and the outside of the boat.

During the first examination of Komsomolets in May 1989 it was found that it rested practically without any heal or trim at the sea bottom.

During the second examination in 1991 it was found that the hull had sunk into the mud at the sea bottom at least 2.5 m at the bow and up to 4.5 m at the stern, both depth measured relative to the baseline of the submarine. It also revealed that the upper part of compartment 1 was damaged. There was a large hole (20 m^2) in the inner pressure hull above the torpedoes in the compartment 1. Measurements of the ^{137}Cs concentration of the seawater around the submarine showed concentrations less than 0.4 Bq/l, much less than the maximum permissible concentration for drinking water.

The third examination in May 1992 indicated further damage to the pressure hull in the bow end of the submarine. Along the port side at the bulkhead between compartment 1 and 2 a transverse crack, about 2 m long and up to 5 cm wide, was found. Along the same port side of the pressure hull a long longitudinal crack had appeared, about 3 cm wide along its entire length. It ran from the big hole in compartment 1 to the front of compartment 3 beneath the sail or possibly further. In some areas the crack had an opening reaching 40 cm. In the upper part of compartment 2, along the port side and near the attachment of the emergency flotation buoy the hull damage comprised a crack at least 3 m long and up to 30 cm (?) wide. The maximum concentration of ^{137}Cs was found to be 0.18 Bq/l. The rescue chamber was discovered 300 m from the submarine.

The Komsomolets had several roles to play. It was a laboratory to investigate the world below the sea surface. It was a prototype of an ocean-going underwater ferry intended for high velocity transport of freight and passengers. And it was an attack submarine which should deal with western ballistic missile nuclear submarines. It was according to western sources armed with SS-N-21 cruise missiles and heavy-weight type torpedoes. Both of these weapon types may be nuclear armed. According to information from Russian authorities Komsomolets contained 2 missile torpedoes with nuclear warheads which contain 7 kg ^{239}Pu.

Comments: The accident was caused by a fire which did not originate in the reactor compartment, and the reactor was shut down in an orderly way. When the reactor sank, the primary circuit had been cooled down to 40°C, and the remaining decay heat can undoubtedly be removed by natural circulation. After the submarine had reached the sea bottom, the pipes of the primary system ruptured due to the high outside pressure, but very little radioactivity has escaped. The description of the later death of two crew menbers sounds strange and may not be correct.

June 1989. Soviet Echo-II Class Submarine (K192) Accident

At 04.30 (Moscow time) on June 26 (25), 1989, a leak developed in one of the components of the primary circuit of one of the two reactors of an Echo-II class cruise missile submarine, K192, of the Northern Fleet on transit from the Mediterranean Sea to Severomorsk. At that time the submarine was located 350 km south of the Bear Island or 110 km north-west of Sørøya in northern Norway. The reactor was shut down, the submarine surfaced and the auxiliary diesel system started. By use of this system and towing the submarine sailed towards its home base in Severomorsk with a speed of about 5 knots. Smoke and/or steam rose from the submarine. The Soviet authorities stated that it was only smoke from the diesel plant while the Norwegian authorities was of the opinion that there was also steam, possibly coming from the leak in the reactor system.

The leak in the primary circuit was of such magnitude that the water supply in the submarine did not suffice to compensate for the leakage. For this reason ships were sent out to the submarine to supplement its fresh water supplies. The water leaking out of the primary system was not dumped overboard, but collected in a special tank. According to later Russian information part of the fuel melted.

Due to the shut-down of the reactors of the submarine the electric power production was substantially reduced. For this reason the air-condition system had to be switched off. This caused the temperature in the submarine to rise to 25 to 30 °C, and the crew was allowed on the deck to get fresh air.

The temperature of the reactor coolant continued to decrease. In the morning of June 26th, it was 150 °C, in the evening 120 °C. On June 27th it had dropped to 108 °C.

According to one western source the crew tried to close the leak which was located in a pipe of the cooling system on June 26. Therefore the water supply from the water supply ship was disconnected. It is claimed that a crew member forgot to reopen the water supply line before he went to dinner. An alarm indicated a temperature rise in the reactor and the water supply line was opened again. This source also claims that the heavily contaminated water of the reactor compartment was pumped over to one of the escorting ships. However, the treatment plant of this ship broke down. After that cooling water was taken directly from the sea and pumped back into the sea again. After the return to the Ara Bay base facility the activity of the contaminated water was estimated to be 0.3 Ci/l totalling 2000 Curie. The crew recieved radiation doses up to 4 Rem.

The submarine was visited by experts, including health physicists, on June 27th. They took water and air samples and found that the radiation situation was normal. According to Soviet statements there was no overexposure of the personnel and no risk of contamination. According to later Russian information all crew members were exposed to overdoses. Sea water and air samples were taken both by Soviet and Norwegian ships. The first Norwegian samples indicated no release of radioactivity from the submarine. Later there were indications of a small leakage since ^{131}I and radio-lanthanides were detected. One sample of water contained 0.02 Bq ^{131}I/kg.

The submarine arrived at its home base on the Kola Peninsula on June 28th. The radiation level was found to be normal. Nevertheless 4 crew members were hospitalised for observation for radiation sickness. No sign of such sickness was found.

Later Norwegian measurements of air samples seem to indicate that ^{131}I was also released to the atmosphere, presumably contained in steam. The release could have taken place early during the accident to reduce the pressure in the reactor compartment. Norwegian authorities have interpreted the presence of ^{131}I as indicating that a loss-of-coolant-accident and a partial core melt-down may have occured.

The submarine is now located at the navy No. 10 - Shkval. Compressed air is pumped into the hull to maintain buoyancy. The damaged fuel can not be removed by ordinary procedures.

Comments: There can be little doubt that the accident was a loss-of-coolant accident which caused damage to the reactor core. The leak in the primary system must have been fairly large since new supplies of fresh water had to be delivered to the submarine. The very slow cooling-down of the primary system as compared e.g. to the Komsomolets accident (cfr. Apr. 1989) seems to indicate increased flow resistance through the core and thus reduced cooling. This increased friction is undoubtedly due to fuel damage or partial core melt-down.

The release of steam from the submarine, on which there is conflicting statements, could be done to avoid a too high pressure in the reactor compartment at the early phases of the accident. At this time the steam is not very radioactive since the fuel damage is still quite limited. A somewhat similar system exists in the early USSR-designed VVER-230 power plants. It should also be noticed that the destillation process has a high decontamination factor so that only a small part of the radioactive nuclides released from the damaged fuel will be carried away with the steam. This could be the reason why only very low concentrations of ^{131}I were measured.

July 1989. Soviet Alfa Class Submarine Incident/Accident

On July 17, 1989, the Norwegian authorities announced that fire had broken out in an Alfa-class submarine in the Barent Sea, 120 km east of Vardø in northern Norway. Initially the Soviet authorities announced that the smoke was part of a military exercise. However, later it was stated that while the submarine was submerged during a naval exercise the control system indicated a fault in the reactor system. The reactor was shut down and the submarine surfaced. Here the diesel engine was started, and it was the smoke from this engine that looked as a fire. The alarm of the control system is believed to be an error. The submarine returned to its base on the Kola Peninsula.

A western source claims that the accident was due to a leak in a steam pipe. This source also states that the "level of radiation did not change for the worse".

Water samples, taken by the Norwegian authorities in the area, contained small amounts of ^{131}I, presumably originating from the submarine.

Comments: The second Soviet statement sounds reasonable though it is always a bit worrying when an explaination is changed. If the western source is correct, there may well have been an accident. Since no figures are available on the ^{131}I content of the sea water samples it is difficult to assess whether it is an indecation of an accident or not. The fact that the submarine sailed back to base without any assistance could be taken as an indication that the event was an incident.

Dec. 1989. Soviet Delta IV Class Submarine Accident

According to western sources control of a missile was lost during a test launch from a Delta-IV class submarine in Dec. 1989, and the missile fuel was dumped to prevent a more serious accident.

Comments: The accident seems to have involved a missile failure rather than a submarine accident.

Therefore this event will be neglected.

Jan. 1990. Soviet Admiral Ushakov Class Cruiser Incident-/Accident

According to reports of unknown origin the Soviet nuclear powered cruiser Admiral Ushakov (ex Kirov) had problems with one of its two reactors in January 1990 when the ship was cruising in the Mediterranean. The event seems to have involved a small leakage in the primary circuit. The cruiser returned to its base on the Kola Peninsula on its own power. According to a western source the cruiser remained inactive since the event.

Comments: If the event is real, it would seem reasonable to characterize it as an incident since the cruiser could return to base without external assistance. On the other hand, the cruiser has remained inactive since its return so the event may have been an accident. It obviously involved the propulsion system.

Sep. 1991. Soviet Typhoon Class Submarine Incident

According to a Russian source a Typhoon class nuclear submarine performed missile firing tests in the White Sea in the autumn of 1991. A missile was ejected from the launching tube, but apparently the rocket engine failed to ignite, and the missile fell back close to the submarine. The incident claimed no victims.

According to a western source an incident happened on September 27th, 1991, during a missile test launch by a Typhoon submarine. The missile was fired in spite of orders to cancel the test. It is likely to be the same test as mentioned above.

Comments: The accident did not involve the submarine directly, but was a missile failure. The SS-N-20 missiles carried by Typhoon submarines each have 10 nuclear warheads, but they have without any doubt been removed before the test firing.

Therefore this event will be neglected.

Mar. 1994. French Emeraude Nuclear Submarine Accident

On March 30th, 1994, the sea-water cooling system of one of the two steam condensers of the French nuclear attack submarine Emeraude failed. This failure resulted in a pressure build-up in the condenser which ultimately exploded. The explosion sent steam and debris into the turbine-generator compartment and killed 10 persons, including the captain. The crew brought the submarine back to port in Toulon by use of its diesel engine and batteries.

Comments: The accident involved the propulsion system of the submarine, but not its reactor system.

5. COMPARISON BETWEEN THE SOVIET ACCIDENTS OF THIS REPORT AND THE DUMPED AND THE DAMAGED REACTORS

In ref. 6 sea disposal of a number of Soviet submarine reactor compartments, submarine reactors and a nuclear submarine most of which had been involved in accidents, is reported. In this section a comparison will be made between the Soviet submarine accidents discussed in this report and the data of sea-disposed reactors given in ref. 6 to see whether the events can be correlated.

In 1965 the Northern Fleet dumped 3 reactor compartments in the Abrosimov Inlet on the eastern side of Novaya Zemlya. All contained two reactors. In one case (nuclear submarine fa.no. 901) both reactors contained fuel, in another case (nuclear submarine fa.no. 285) only one of the reactors contained fuel and in the last case (nuclear submarine fa.no. 254) none of the reactors contained fuel. According to available information submarine fa.no. 901 is the Hotel class submarine K19 which suffered a loss-of-coolant accident in one of its reactors in 1961 (cf. July 1961. Soviet Hotel Class Submarine (K19) Accident). The reason why the fuel was not removed from the undamaged reactor could be that the submarine was so contaminated that it would be very difficult to get the fuel out. Submarine fa.no. 285 is believed to be the November class submarine K11 which suffered a criticality accident in one of its reactors in 1965 (cf. Feb. 1965. Soviet November Class Submarine (K11) Accident). Finally submarine fa.no. 254 is believed to be the November class submarine K3. The reason for dumping its reactor compartment was not because it had been involved in an accident. However, it was the first Soviet submarine, and early operation had shown a number of weaknesses in the design. To overcome these weaknesses the reactor compartment was replaced by a new and better one.

In 1966 the reactor compartment from submarine fa.no. 260 with two reactors without fuel was dumped in the Abrosimov Inlet. The compartment is believed to originate from November class submarine K5, the second Soviet nuclear submarine. Like in the case of K3 the replacement was not due to an accident, but to the need for better reactors.

In 1967 the three reactors from the NS Lenin icebreaker was dumped in the Tsivolka Inlet at Novaya Zemlya together with a container with the damaged core from the loss-of-coolant accident which one of the NS Lenin reactors suffered in the autumn of 1966 (cf. Autumn 1966. Icebreaker NS Lenin Accident).

In 1972 a reactor with fuel from submarine fa.no. 421 was dumped in the Novaya Zemlya Depression. This submarine is believed to be identical to the Yankee class submarine K140 which suffered a criticality accident in 1968 (cf. Aug. 1968. Soviet Yankee Class Submarine (K140) Accident).

The Pacific Fleet sank 2 reactors without fuel in the Sea of Japan in 1978. This disposal could possibly be related to an accident (e.g. Mar. 1976. Soviet Nuclear Submarine Accident) , but could equally well - since there was no fuel in the reactors - originate from planned replacement of reactors in one or two nuclear submarines.

In 1981 the Northern Fleet dumped an entire submarine fa.no. 601, which is identical to K27. This submarine which was provided with two liquid metal reactors, suffered loss-of-coolant accident in 1968 (cf. May 1968. Soviet Nuclear Submarine (K27) Accident). It was sunk in the Stepovoy Inlet with fuel in both reactors.

Two reactors without fuel from submarine fa.no. 538 was disposed of by the Northern Fleet in 1988 in the Techeniye Inlet on the eastern coast of Novaya Zemlya. This submarine is believed to be identical to the submarine K222 involved in the criticality accident in 1980 (cf. Sep. 1980. Soviet Nuclear Submarine (K222) Accident).

In 1989 the Pacific Fleet disposed of a core plate with thermal shield, but without fuel from submarine fa.no. 714 east of Kamchatka. This disposal could possibly be related to the Dec. 1978. Soviet Delta-I Class Submarine (K171) Accident, but equally well to a planned replacement of the reactor insert or basket in one of the submarines of the Pacific Fleet.

It should be noted that both the Northern Fleet and Pacific Fleet have submarines with damaged cores which are awaiting disposal. According available information the Northern Fleet has two submarines with damaged cores and the Pacific Fleet has 3. A western source claims that the Pacific Fleet has 4 submarines with damaged cores, but there is little evidence to substantiate this claim, so it will be disregarded.

The two submarines with damaged cores at the Northern Fleet are believed to be the Echo-II class submarine K192 which suffered a loss-of-coolant accident in 1989 (cf. June 1989. Soviet Echo-II Class Submarine (K192) Accident) and the Alfa class submarine K377 which in 1972 lost its cooling when the liquid metal coolant solidified (cf. 1972. Soviet Alfa Class Submarine (K377) Accident).

Western sources claim that K192 rests moored at the naval shipyard Shkval in Polyarny, and that air is pumped into the hull to keep the submarine floating.

As regards K377 the reactor compartment and the two adjacent compartments was cut out, sealed and prepared for sea disposal. However, according to western sources, before it could be done the Soviet Union ratified the London Convention which prohibits dumping of highly radioactive waste. Today it is stored floating at Severodvinsk, but western sources claim that there are plans to move it to Gremikha.

The three submarines with damaged cores at the Pacific Fleet are believed to be the Echo-I class submarine K116 which suffered a loss-of-coolant accident in 1979 (cf. July 1979. Soviet Echo-I

Class Submarine (K116) Accident), the Echo-II criticality accident in connection with refueling in 1985 (cf. Aug. 1985. Soviet Echo-II Submarine Accident) and the Echo-II class submarine, which suffered a loss-of-coolant accident in 1985 (cf. Dec. 1985. Soviet Echo-II/Charlie Class Submarine Accident).

6. ANALYSIS OF THE ACCIDENTS/INCIDENTS

In section 4 of this report 61 nuclear vessel events have been considered. Six events involve US vessels, one event a French vessel and 54 events Soviet/Russian vessels. Even though there can be little doubt that the safety record is considerably better for nuclear vessels in the west that in the Soviet Union, the ratio of 7 to 54 may be misleading. The US Navy may simply have been better to avoid publicity of its events than has been the case in Russia.

Of the 54 Soviet/Russian events, 19 can as discussed in section 4 be neglected because the information available is too meager, is incredible or covers events treated elsewhere. This leaves 35 events to be considered in more detail.

Of these 11 were caused by fires/explosions, and in 3 of the 11 cases the submarine was lost. This seems to indicate that Soviet submarines were not designed properly with respect to fire prevention or that the crews were not sufficiently well trained in this field or both. Similar criticism have been raised in ref. 4 and 14. Insufficient fire protection of civilian nuclear power stations in the USSR have also been criticized. Fires at ships are always very dangerous, but they are particular dangerous in submerged submarines. The fires of the three lost submarines all started while they were submerged, but they managed to get to the surface and started to fight the fire, unfortunately not successfully.

It is worthwhile noting that in none of the three cases where Soviet submarines were lost at sea, were the nuclear power plants involved. In addition to the three sunken submarines one sank due to mistakes by the crew, but most of the crew was saved and the submarine was later recovered.

As discussed in section 3 the use of nuclear power plant involve the risk of two types of accidents: Loss-of-coolant accidents (LOCA) and criticality accidents. The Soviet/Russian nuclear Navy have experienced both these types of accidents.

Loss-of-coolant accidents play an important role in the accidents of Soviet submarines. There have been 6 LOCAs, three due to development of major leaks, one due to draining of the core after shut-down, one due to the shutting down the main circulation pumps by mistake and one due to blokage of fuel channels by metal oxides in a liquid-metal-cooled reactor. In addition to these 6 cases the liquid-metal-cooled reactors which use a coolant that melts at about 125°C, have suffered 3 cases of coolant solidification due to too low temperature in the primary circuit. This type of accident may be called loss-of-cooling accidents. The severity of such solidification accidents vary very much. In one case the coolant could be remelted, in one case the repair of the submarine took 8 years and in one case the submarine was dismantled and the reactor compartment cut out for disposal.

It is hardly surprising that of the 9 loss-of-coolant/-cooling accidents 4 occured in liquid metal cooled reactors and the remaining four in first generation submarines (Hotel and Echo) and in the first icebreaker Lenin. Early Soviet nuclear power plant had emergency core cooling systems with limited capacity, and the same could be expected for the early nuclear naval reactors. Some sources claim that they had no emergency cooling system at all.

The Soviet navy has experiences 5 criticality accidents, all occuring when the reactor was shut down, and all due to human errors and lack of operating instrumentation. Two of the accidents occured during refueling, two in connection with work on the control rod systems and one in connection with a hydraulic test of a reactor. It is interesting to note that criticality accidents are likely to occur when the reactor is shut down, not when it is operating at power.

In two cases the accident is stated to be a reactor accident, but no details were given. It may have leaks in the primary circuits. These accidents are not believed to be very severe, since it is possible to account for all dumped reactors and all reactors with damaged fuel without taking these two accidents into account (cf. section 5).

There has been 6 cases of propulsion failures, but in most cases no details are given. One case involved a major leak in the steam generator system and one case a turbine run-away. Propulsion failure may of course have involved the reactor system, but there is no indication that major damage has been caused to this system. As mentioned above it is possible to account for all dumped and damaged reactors without taking these 6 accidents into account.

It is worth noting that in spite of the fact that the Soviet/Russian nuclear fleet has suffered a significant number of severe accidents with a substantial number casualties, little radioactivity seems to have been released to the environment in connection with the accidents. Even though Soviet designed reactors has not - until recently - been known for their effective containments, the Soviet reactor compartments or submarine hulls seems to act as good containments. From a radioactive pollution point of view criticality accidents in connection with refueling are probably the most polluting accidents since the reactor core must be open to the environment during refueling.

Summing up the distribution of the accidents is as follows:

Fires:	11 events
LOCAs:	9 events
Criticality:	5 events
Reactor accident:	2 events
Propulsion failure:	6 events
Other reasons:	2 events
TOTAL	35 events

Of these about 20 were severe accidents, i.e. the lead to sinking of the vessel, replacement of the reactors, decommissioning or more than 5 death.

The event listed in section 4 contain six events involving U.S. submarines of which one is neglected. Of these 3 events seem to involve leakage of seawater into the submarine, and in 1 of these cases the submarines were lost. In one case a defect weapons system seems to be the most likely cause of the accident;

in this accident the submarine was lost. The fifth event is the only that involved the nuclear power plant; it was a small leak in the primary circuit that could be repaired at sea without external assistance.

Section 4 contain one accident with a French nuclear submarine, killing 10 persons.

This means that of the 6 western events 3 were severe accidents.

For ship reactors it is not possible to calculate the probability of accidents. The technical information on the design of these reactors needed to perform a probabilistic safety analysis (PSA) is not available to outsiders. However, due to the non-negligible number of accidents it is possible to estimate accident probabilities directly from accident data.

The total number of ship reactor years (sry) up to 1994 of the nations with nuclear vessels has been estimated from available data. The number of reactor years is equal to the number of years the naval reactors of a given nation has been in operation. The following data was obtained:

USA	3600 sry
UK + France	500 sry
West total	4100 sry
USSR/Russia	7700 sry
China	100 sry
The World	12000 sry

The high value of the USSR/Russian nuclear navy is due the fact that most of its submarines are provided with 2 reactors while other countries use one only and that it has built more nuclear vessels than all the other countries together.

From the data given above the following accident probabilities (AP) may be obtained for all events, P_{all}, severe events, P_{sev}, and nuclear events, P_{nuc}:

World AP, all events: $P_{world,all} = 41/12000 = 3\ 10^{-3}$ sry

World AP, sev. events: $P_{world,sev} = 23/12000 = 2\ 10^{-3}$ sry

World AP, nuc. event: $P_{world,nuc} = 16/12000 = 1\ 10^{-3}$ sry

USSR AP, all events:	$P_{USSR,\ all}$ =	35/7700	= 5 10^{-3} sry
USSR AP, sev. events:	$P_{USSR,\ sev}$ =	20/7700	= 3 10^{-3} sry
USSR AP, nuc. event:	$P_{USSR,\ nuc}$ =	16/7700	= 2 10^{-3} sry
West AP, all events:	$P_{West,\ all}$ =	6/4100	= 1 10^{-3} sry
West AP, sev. events:	$P_{West,\ sev}$ =	3/4100	= 7 10^{-4} sry
West AP, nuc. event:	$P_{West,\ nuc}$ =	0/4100	= 0 sry

It is noted that while the western safety record is better than the Soviet/Russian, the difference is not orders of magnitudes, but a factor 3 to 4. However, when it comes to nuclear events the west has so far had a unique safety record with no nuclear accidents.

In the field of commercial nuclear power reactors the requirement is today that the accident probability for severe accidents must be below 10^{-5} per reactor year.

Nuclear ship accident probability should not be constant with time. With safer reactor plants, improved quality control and - probably most important - improved safety culture and crew education there is room for improvements of the safety of nuclear vessels. Judging from the accidents of the Soviet/Russian Navy there are condiderable room for improvements of the safety culture at all levels in the Russian Navy.

8. CONCLUDING REMARKS

In any forseeable future nuclear vessels will sail in the oceans. As long as this is the case the risk remains that accidents will happen. It is likely that the number of nuclear vessels will decrease in the future from the present 400 to say 200. With an improved probability for severe accidents of 10^{-4} this would mean that there will be a serious accident every 50 year. It will be a considerable improvement as compared to today, but there will still be accidents.

Both experience and theoretical investigations have shown that even though serious accidents with nuclear vessels have had and can in the future have very serious consequences for the crews involved, they have a quite modest impact on the environment. Even in the case of refueling accidents where radioactivity is released directly to the atmosphere the impact seems in practice to be limited to an area around the vessel with a radius which is of the order of 10 km.

At several occations it has been claimed that accidents with nuclear vessels could have the same or even larger magnitude as the Chernobyl accident. Such claims have no realistic basis for several reasons. Firstly, the power levels of naval reactors are about a factor of 30 lower than the Chernobyl reactor. This means that the amount of fissions products that could be released in an accident is about a factor of 30 lower. Secondly, the safety features of the pressurized water reactors (PWR) used in naval vessels are drastically different from the RBMK type of Chernobyl. While PWR's are self-stabilizing, RBMK reactors are inherent unstable. Further the design of the control rod system of the RBMK type revealed serious deficiencies during the accident; PWR reactors do not have similar features. Finally, the RBMK reactors contain large amounts of graphite which can burn and contribute to the release of radioactivity to the environment. PWR's contain no graphite.

For these reasons any naval reactor accidents can not be nearly as severe as the Chernobyl accident. However, while severe accidents with submarine reactors can not have the same long-distance consequences as the Chernobyl accident, they may still have severe consequence for people living close to the place where the accidents occur and they may in particular have grave consequences for the naval personnel involved. So the consequences of naval reactor accidents should by no means be belittled.

In this report available information on accidents with nuclear ships have been reviewed, and an attempt to evaluate the information has been made. As already mentioned the information presented may not be correct and consequently the analyses may not be correct either. The author of this report would appreciate very much to receive any additional information, corrections or criticism of the information and analyses so that any later, revised version of this report can be more correct.

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Annex I

Nomenclature Used for Soviet/Russian Nuclear Naval Ships

The data in this annex have been obtained from ref. 5 and 18. The data is not always consistent so the information should be used with caution. The first column gives the NATO designation of the vessel type. Initially the various vessel types were in the Soviet Union designated by a project number, and when the types were modified, a letter was added; these letters are given in the equivalent western letters. The project numbers are given in the second column. Later the Russians started also to use names for the various vessel types. These names are listed in the third column. In the fourth column the number of vessels given in ref. 5 are listed. This is presumably the number of vessels in operation when ref. 5 was published. The last column gives the number of reactors per vessel.

NATO name	Russian project number	Russian name	Number in op. 92?	No. of reactors
SUBMARINES:				
November	627,A	KIT	5	2
November-ZhMt	645		0	2
Hotel	658,M,U,701	KS	1	2
Echo-1	659,T		3	2
Echo-2	675,M,MKV		17	2
Victor-1	671,R,V,K	YERSY?	15	2 (1?)
Victor-2	671 RT		7	2
Victor-3	671 RTM	SJCHUKA	25	2
Yankee	667 A	NAVAGA/NALIM	10	2
	667 M	ANDROMEDA	1	2
Yankee-Notch	667 AT	GRUSHA	6	2
Charlie-1	670 A	SKAT	10	1
Charlie-2	670 M	SKAT M	6	1
Papa	661	ANCHAR	1	2
Alfa	705,ZMT,K	LIRA	5	1 (2?)
Delta-1	667 B	MURENA	18	1
Delta-2	667 BD	MURENA-M	4	2

NATO name	Russian project number	Russian name	Number in op. 92?	No. of reactors
Delta-3	667 BDR	KALMAR	14	2
Delta-4	667 BDRM	DELFIN	7	2
Oscar-1	949	ANTEY(GRANIT?)	2	2
Oscar-2	949 A	ANTEY	8	2
Typhoon	941	AKULA	6	2
Sierra-1	945		2	1
Sierra-2	945 B	MARS	3	1
Akula	971	BARS,SHCHUKA-B8		2 (1?)
Mike	685	PLAVNIK	0	1
Severodvinsk	885		0	1
X-ray	678		1	1
Uniform	1910(1851?)		1 (3?)	1
	10831	AS-12	0 (1?)	1
AIRCRAFT CARRIER				
Blekkom-5	1143.7		1	4
CRUISERS				
Balkom-1(Kirov)	1144	ORLAN	4	2
MISSILE TEST SHIP				
Kapusta	1941	TITAN	1	2

Annex II

Number of Nuclear Naval Vessels Built in USSR/Russia

Type	Bellona Total	Bellona North	Bellona Pacific	ВМФ	This report
November	13	10	3	5	13
November-ZhMT	1	1	-	-	1
Hotel	8	6	2	1	10
Echo-I	5	0	5	3	5
Echo-II	29	11	18	17	29
Victor-I	15	13	2	15	17
Victor-II	7	7	0	7	7
Victor-III	26	16	10	25	26
Yankee	34	24	10	10+7	34
Charlie-I	11	0	11	10	12
Charlie-II	6	6	0	6	6
Alfa	7	7	0	5	6
Papa	1	1	0	1	1
Mike	1	1	0	-	1
Sierra	6	6	0	5	4
Akula	13	6	7	8	13
Delta-I	18	9	9	18	18
Delta-II	4	4	0	4	4
Delta-III	14	5	9	14	14
Delta-IV	7	7	0	7	7
Typhoon	6	6	0	6	6
Oscar	13	9	4	10	12
Severodvinsk	0	0	0	-	-
X-ray	1	1	0	1	1
Uniform	3	3	0	1	3
Project 10831	1	1	0	-	-
Kirov	4	2	2	4	4
Blekkom-5	-	-	-	0	-
Kapusta	1	0	1	1	1
Total	255	162	93	191	255

The figures given in this annex aim at obtaining an estimate of the total number of naval vessels built by USSR/Russia. The first column gives the figures for total number of vessels built as presented in ref. 18. The figures of the next two columns are according to ref. 18 the distribution of the vessels built between the Northern Fleet and the Pacific Fleet. In this connection it should be remembered that a vessel has sometimes been transfered from one fleet to the other during its operational life, so the figures may contain a certain amount of ambiguity. The fourth column gives the number of vessels in operation about 1992 as obtained from ref. 5. Finally the last column is a Danish estimate of the total number of vessels built, based on western naval handbooks and The Strategic Balance from IISS.

Annex III

USSR/Russian Naval Reactor Data

The data presented in this report has been obtained from ref. 18. The data are not always consistent with data given elsewhere, so they should be used with caution.

Vessel Class	Reactor Data
November	2 PWR model VM-A, 2*70 MWt (2*17500 hp), U-enrichment 21%
NovemberZhMT	2 LMR (Pb+Bi) model VT-1, 2*73 MWt (35000 hp) U-enrichment 90%
Hotel	As November class
Echo-I	As November class
Echo-II	As November class
Victor-I	1 PWR model OK-300 with VM-4 core, 75 MWt (31000 hp (15500 hp?)), U-enrichment 21%
Victor-II	2 (1?) PWR model OK-300 with VM-4 core, 2*75 MWt, U-enrichment 21%
Victor-III	2 PWR model OK-300 with VM-4 core, 2*75 MWt, U-enrichment 21%
Yankee	2 PWR model OK-700 with VM-4 core, 2*90 MWt (2*20000 hp), U-enrichment 21%
Charlie-I	1 PWR model OK-350 with VM-4 core, 89.2 MWt (18000 hp), U-enrichment 21%
Charlie-II	1 PWR model OK-350 with VM-4 core, (2*?)75MWt (90 MWt?), U-enr. 21%
Alfa	1 LMR (Pb+Bi) model OK-550/BM(MB?)-40A, 155 MWt, U-enrichment 90%
Papa	2 PWR model VM-5m, (2*?)177.4 MWt (80000 shp)
Mike	1 PWR model OK-650b-3, 190 MWt (43000 shp) U-enrichment 21-45%
Sierra	1 PWR model OK-650, 190 MWt (47000 hp) U-enrichment 21-45%
Akula	1 PWR model OK-650b, 190 MWt (43000 shp) U-enrichment 21-45%

Delta-I	2 PWR model OK-700 with VM-4 core, 2*90 MWt, (2*20000 shp), U-enrichment 21%
Delta-II	As Delta-I class
Delta-III	2 PWR model OK-700 with VM-4-2 core, 2*90 MWt, (2*30000 shp (2*20000 shp?)), U-enr. 21%
Delta-IV	As Delta-III class
Typhoon	2 PWR model OK-650 with VV core, 2*190 MWt (2*50000 shp), U-enrichment 21-45%
Oscar-I	2 PWR model OK-650b, 2*190 MWt (2*50000 shp) U-enrichment 21-45%
Oscar-II	As Oscar-II class
Severodvinsk	1 PWR model KPM, 200 MWt (43 000 hp)
X-ray	1 PWR, 10 MWt
Uniform	1 PWR, 10 MWt (10000 SHP)
10831	1 PWR, (10000 hp)
Admiral Ushakov	2 PWR model KN-3, 2*300 MWt (140000 shp)
Kapusta	2 PWR model KN-3 (OK-900) w. VM-16 core, 2*171 MWt

Annex IV
The Russian Nuclear Naval Fleet

The data contained in this annex is based on ref. 18 and ref. 5. The data do not always agree, so it should be used with caution. For example there is a number of cases where the same code, e.g. K-52 and K-114, is used for two different submarines. Each Soviet/Russian submarine is given a code consisting of one (sometimes two) letter and a number. The letter is usually K, but the Russian B has been used for the November and the Victor class according to ref. 5. The code of the individual submarines is listed in the first column. In the second column the NATO code name is given. In the third column the Russian type designation, the project number, is given. Next follows a letter, either N or P which indicates to which fleet the vessel belongs (N for Northern Fleet, P for Pacific Fleet). In the fifth column the fabrication number is given; this number is sometines used for identification of a submarine instead of the code number. Finally it is indicated if the code has been changed. If the name of the submarine is known, it is given in the next line.

Submarines

K-1	Echo-II	Proj. 675,	N,	fa.no.535,	
K-3	November	Proj. 627,	N,	fa.no.254,	
	Leninskiy Komsomol				
K-5	November	Proj. 627,	N,	fa.no.260,	
K-7	Echo-II	Proj. 675,	P,	,	later K127 (K107?)
K-8	November	Proj. 627,	N,	fa.no.261,	
K-10	Echo-II	Proj. 675,	P,		
K-11	November	Proj. 627,	N,	fa.no.285,	
TK-12	Typhoon	Proj. 941,	N,		
TK-13	Typhoon	Proj. 941,	N,		
K-14	November	Proj. 627,	P,	fa.no.262,	
K-16	Hotel	Proj. 658,	N,	fa.no.905,	
TK-17	Typhoon	Proj. 941,	N,		
K-18	Delta-IV	Proj. 677BDRM,	N,		
K-19	Hotel	Proj. 658,	N,	fa.no.901,	

TK-20	Typhoon	Proj. 941,	N,		
K-21	November	Proj. 627,	N,	fa.no.284,	
K-22	Echo-II Krasnogvardeets	Proj. 675,	N,	fa.no.538,	
K-23	Echo-II	Proj. 675,	P,		
K-25	Charlie-I	Proj. 670A,	P,		
K-26	Yankee	Proj. 677A,	N,	fa.no.422,	
K-27	NovemberZhMT	Proj. 645,	N,		
K-28	Echo-II	Proj. 675,	N,	fa.no.536,	later K-428
K-31	Echo-II	Proj. 675,	P,	,	later K-431
K-32	Yankee	Proj. 667A,	N,	fa.no.423,	
K-33	Hotel	Proj. 658,	N,	fa.no.902,	
K-34	Echo-II Kefal	Proj. 675,	P,	,	later K-134,
K-35	Echo-II	Proj. 675,	N,	fa.no.539,	
K-38	Victor-I	Proj. 671,	,	fa.no.600,	
K-40	Hotel	Proj. 658,	N,	fa.no.904,	
K-42	November Rostovsky Komsomolets	Proj. 627,	P,		
K-43	Charlie-I	Proj. 670A,	P,	,	
K-44	Delta-III	Proj. 667BDR,			
K-45	Echo-I	Proj. 659,	P,		
K-47	Echo-II	Proj. 675,	N,	fa.no.534,	
K-48	Echo-II	Proj. 675,	P,		
K-50	November	Proj. 627,	N,	fa.no.290,	
K-51	Delta-IV	Proj. 667BDRM,	N,		
K-52	November	Proj. 627,	N,	fa.no.283,	
K-52	Echo-II	Proj. 675M,			
K-53	Victor-I	Proj. 671,	,	fa.no.603,	
K-55	Hotel	Proj. 658,	P,	fa.no.903,	
K-56	Echo-II	Proj. 675,	P,		
K-57	Echo-II	Proj. 675,		,	later K-557
K-59	Echo-I	Proj. 659,	P,		
K-64	Delta-IV	Proj. 667BDRM,	N,		
K-66	Echo-I	Proj. 659,	P,		
K-69	Victor-I	Proj. 671,	,	fa.no.601,	later K-369
K-71	Echo-II	Proj. 675,	N,	fa.no.530,	later K-166
K-74	Echo-II	Proj. 675,	N,	fa.no.537,	

K-84	Delta-IV	Proj. 667BDRM,	N,		
K-86	Echo-II	Proj. 675,	N,	fa.no.532,	
K-87	Charlie-I	Proj. 670A,		,	later K-212
K-90	Echo-II	Proj. 675,	P,		
K-92	Delta-II	Proj. 667BD,	N,	fa.no.352,	
K-94	Echo-II	Proj. 675,	P,		
K-104	Echo-II	Proj. 675,	,	fa.no.531,	later K-144
K-107	November	Proj. 627,		,	earlier K-7?
K-108	Echo-II	Proj. 675,	P,		
K-114	Delta-IV	Proj. 667BDRM,	N,		
K-114	Victor-III	Proj. 671RTM,	N,		
K-115	November	Proj. 627,	P,	fa.no.265,	
K-116	Echo-II	Proj. 675,	P,		
K-117	Delta-IV	Proj. 667BDRM,	N,		
K-119	Occar-II	Proj. 949A,	N,		
	Vorone				
K-121	Charlie-I	Proj. 670A,	P,		
K-122	Echo-I	Proj. 659,	P,		
K-123	Alfa	Proj. 705,	N,	fa.no.105,	
K-125	Echo-II	Proj. 675,	N,	fa.no.542,	
K-127	Echo-II	Proj. 675,	P,	,	earlier K-7
K-128	Echo-II	Proj. 675,	P,		
K-129	Delta-III	Proj. 667BDR,			
K-132	Oscar-II	Proj. 949A,	P,		
	Belgorod				
K-133	November	Proj. 627,	P,		
K-133	Echo-I	Proj. 659T,			
K-134	Echo-II	Proj. 675,	P,	,	earlier K-34,
	Kefal				
K-135	Echo-II	Proj. 675,	P,		
K-137	Yankee	Proj. 667A,	N,	fa.no.420,	
	Leninets				
K-138	Yankee	Proj. 667A,			
K-138	Victor-III	Proj. 671RTM,	N,		
K-140	Yankee	Proj. 667A,	N,	fa.no.421,	
K-141	Oscar-II	Proj. 949A,	N,		
	Kursk				
K-144	Echo-II	Proj. 675,	N,	fa.no.531,	earlier 104

K-145 Hotel	Proj. 658,	N,	fa.no.906,
K-147 Victor-I	Proj. 671,	,	fa.no.602,
K-148 Oscar-II	Proj.949A,	N,	
Krasnodar			
K-149 Hotel	Proj. 658,	N,	fa.no.907,
Ukrainsky Komsomolets			
K-157 Akula	Proj. 791,	N,	
Tigr			
K-159 November	Proj. 627,	N,	
K-162 Papa	Proj. 661,	N,	fa.no.501, later K-222
K-166 Echo-II	Proj. 675,	,	fa.no.530, earlier K-71
K-171 Delta-I	Proj. 667B,	P,	fa.no.340,
K-172 Echo-II	Proj. 675,	P,	
K-173 Oscar-II	Proj. 949A,	P,	
Chelyabinsk			
K-175 Echo-II	Proj. 675,	P,	
K-178 Hotel	Proj. 658,	P,	fa.no.908,
K-180 Delta-III	Proj. 667BDR,		
K-181 November	Proj. 627,	N,	fa.no.287,
K-182 Delta-II	Proj. 667BD,	N,	fa.no.351,
K-184 Echo-II	Proj. 675,	P,	
K-186 Oscar-II	Proj. 949A,	N,	
Omsk			
K-189 Echo-II	Proj. 675,	P,	
K-192 Echo-II	Proj. 675,	N,	fa.no.533,
K-192? Yankee	Proj. 667A,		
K-193 Delta-II	Proj. 667BD,	N,	fa.no.353,
K-201 Charlie-I	Proj. 670A,	P,	
TK-202 Typhoon	Proj. 941,	N,	
K-203 Echo-II	Proj. 675M,		
K-206 Oscar-I	Proj. 949,	N,	
Murmansk			
K-207 Yankee	Proj. 667A,	N,	fa.no.400,
TK-208 Typhoon	Proj. 941,	N,	
K-209 Charlie-II	Proj. 670M,	N,	fa.no.911,
K-210 Yankee	Proj. 667A,	N,	fa.no.401,
K-211 Delta-III	Proj. 667BDR,		
K-212 Charlie-I	Proj. 670A,	P,	, earlier K-87

K-214	Yankee	Proj. 667A,	N,	fa.no.452,	
K-216	Yankee	Proj. 667A,	N,	fa.no.424,	
K-218	Victor-III	Proj. 671RTM,	N,		
K-219	Yankee	Proj. 667A,	N,	fa.no.460,	
K-222	Papa	Proj. 661,	N,	fa.no.501,	earlier K-162
K-223	Delta-III	Proj. 667BDR,			
K-223	Victor-II	Proj. 671RT			
K-229	Victor-III	Proj. 671RTM,			
K-228	Yankee	Proj. 667A,	N,	fa.no.470,	
K-236	Yankee	Proj. 667A,	P,		
K-239	Sierra	Proj. 945,	N,		
	Carp				
K-241	Yankee	Proj. 667A,	N,	fa.no.462,	
K-242	Victor-III	Proj. 671RTM,	P,		
K-244	Victor-III	Proj. 671RTM,	N,		
K-245	Yankee	Proj. 667A,	N,	fa.no.450,	
K-247	Victor-III	Proj. 671RTM,	P,		
K-249	Yankee	Proj. 667A,	N,	fa.no.402,	
K-251	Victor-III	Proj. 671RTM,	P,		
K-252	Yankee	Proj. 667A,	P,		
K-253	Yankee	Proj. 667A,	N,	fa.no.414,	
K-254	Victor-III	Proj. 671RTM,	N,		
K-255	Victor-III	Proj. 671RTM,	N,		
K-258	Yankee	Proj. 667A,	P,		
K-259	Echo-I	Proj. 659,	P,		
K-263	Akula	Proj. 971,	P,		
K-264	Victor-III	Proj. 671RTM,	P,		
K-266	Oscar-II	Proj. 949A,	N,		
	Severodvinsk, later Orel				
K-267	Akula	Proj. 971			
	Drakon				
K-276	Sierra	Proj. 945,	N,		
K-278	Mike	Proj. 685,	N,		
	Komsomolets				
K-279	Delta-I	Proj. 667B,	N,	fa.no.310,	
K-284	Akula	Proj. 971,	P,		
K-292	Victor-III	Proj. 671RTM,	N,		
K-298	Victor-III	Proj. 671RTM,	N,		

K-299 Victor-III	Proj. 671RTM,	N,	
K-302 Charlie-I	Proj. 670A,	P,	
K-305 Victor-III	Proj. 671RTM,	P,	
K-306 Victor-I	Proj. 671,	,	fa.no.604,
K-308 Charlie-I	Proj. 670A,	P,	
K-313 Charlie-I	Proj. 670A,	P,	
K-314 Victor-I	Proj. 671,	,	fa.no.610,
K-316 Alfa	Proj. 705,	N,	fa.no.905,
K-317 Akula Pantera	Proj. 971,	N,	
K-320 Charlie-I	Proj. 670A,	P,	
K-322 Akula	Proj. 971,	P,	
K-323 Victor-I	Proj. 671,	,	fa.no.605,
K-324 Victor-III	Proj. 671RTM,	N,	
K-325 Charlie-I	Proj. 670A,	P,	
K-327 Victor-III	Proj. 671RTM,	N,	
K-328 Akula Leopard	Proj. 791,	N,	
K-331 Akula	Proj. 791,	P,	
K-336 Delta-I	Proj. 667B,	P,	
K-336 Sierra Okun	Proj. 945,	N,	
K-355 Victor-III	Proj. 671RTM,	P,	
K-358 Victor-III	Proj. 671RTM,	N,	
K-360 Victor-III	Proj. 671RTM,	P,	
K-366 Delta-I	Proj. 667B	P,	
K-367 Victor-I	Proj. 671,	,	fa.no.609,
K-368 Victor-I	Proj. 671R		
K-369 Victor-I	Proj. 671,	,	fa.no.601, earlier K-69
K-370 Victor-I	Proj. 671,	,	fa.no.606,
K-371 Victor-II	Proj. 671RT,	N,	fa.no.802,
K-373 Alfa	Proj. 705,	N,	fa.no.910,
K-377 Alfa	Proj. 705,	N,	fa.no.900, earlier K-47?
K-380? Oscar	Proj. 949,		
K-385 Delta-I	Proj. 667B,	N,	fa.no.324,
K-387 Victor-II	Proj. 671RT,	N,	fa.no.801,
K-388 Victor-III	Proj. 671RTM,	N,	
K-389 Yankee	Proj. 667A,	P,	

K-391 Akula Proj. 971, P,
K-395 Yankee Proj. 667A, N, fa.no.415,
K-398 Victor-I Proj. 671, , fa.no.611,
K-399 Yankee Proj. 667A, P,
K-403 Yankee Proj. 667AT, N, fa.no.441,
converted to Yankee Notch
K-407 Delta-IV Proj. 667BDRM, N,
K-408 Yankee Proj. 667A, N, fa.no.416,
K-410 Oscar-II Proj. 949A, N,
Smolensk
K-411 Yankee Proj. 667A, N, fa.no.430,
converted to carry 2 minisubs.
K-412 Victor-III Proj. 671RTM, P,
K-415 Yankee Proj. 667A, N, fa.no.451,
K-417 Delta-I Proj. 667B, P,
K-418 Yankee Proj. 667AT, N, fa.no.431,
converted to Yankee Notch
K-419 Akula Proj. 971, P,
K-420 Yankee Proj. 667A, N, fa.no.432,
converted to Andromeda
K-422 Yankee Proj. 667AT,
converted to Yankee Notch
K-421 Delta-II Proj. 667BD, N, fa.no.354,
K-423 Yankee Proj. 667A, N, fa.no.442, K-422?
converted to Yankee Notch
K-424 Delta-III Proj. 667BDR,
K-426 Yankee Proj. 667A, N, fa.no.440,
K-428 Echo-II Proj. 675, N, fa.no.536, earlier K-28
K-429 Charlie-I Proj. 670A, P,
K-430 Yankee Proj. 667A, P,
K-431 Echo-II Proj. 675, P, , earlier K-31
K-431 Victor-I Proj. 671R,
K-432 Alfa Proj. 705, N, fa.no.106,
K-433 Delta-III Proj. 667BDR,
K-434 Yankee Proj. 667A, P,
K-436 Yankee Proj. 667A, P,
K-438 Victor-I Proj. 671, , fa.no.608,
K-441 Delta-III Proj. 667BDR,

K-442	Oscar-II	Proj. 949A,	P,		
	Tomsk				
K-444	Yankee	Proj. 667A,	N,	fa.no.461,	
K-446	Yankee	Proj. 667A,	P,		
K-447	Delta-I	Proj. 667B,	N,	fa.no.311,	
K-448	Victor-III	Proj. 671RTM,	N,		
K-449	Delta-III	Proj. 667BDR,			
K-450	Delta-I	Proj. 667B,	N,	fa.no.312,	
K-451	Yankee	Proj. 667A,	P,		
K-452	Charlie-II	Proj. 670M,	N,	fa.no.901,	
	Berkut				
K-454	Victor-I	Proj. 671,	,	fa.no.612,	
K-455	Delta-III	Proj. 667BDR,			
K-456	Oscar-II	Proj. 949A,	P,		
	Kasatka				
K-457	Delta-I	Proj. 667B,	N,	fa.no.325,	
K-458	Charlie-II	Proj. 670M,	N,	fa.no.902,	
K-460	Delta-I	Proj. 667B,	N,	fa.no.337,	
K-461	Akula	Proj. 971,	N,		
	Volk				
K-462	Victor-I	Proj. 671,	,	fa.no.613,	
K-463	Alfa	Proj. 705,	N,	fa.no.915,	
K-465	Delta-I	Proj. 667B,	N,	fa.no.326,	K-456?
K-469	Victor-I	Proj. 614,	,	fa.no.614,	
K-472	Delta-I	Proj. 667B,	N,	fa.no.338,	
K-475	Delta-I	Proj. 667B,	N,		
K-476	Victor-II	Proj. 671RT,	N,	fa.no.803,	
K-477	Delta-I	Proj. 667B,	P,		
K-479	Charlie-II	Proj. 670M,	N,	fa.no.903,	
K-480	Akula	Proj. 971,	N,		
	Bars				
K-481	Victor-I	Proj. 671,	,	fa.no.615,	
K-487	Delta-III	Proj. 667BDR,			
K-487	Victor-II	Proj. 671RT,			
K-488	Victor-II	Proj. 671RT,	N,	fa.no.804,	
K-490	Delta-BDR	Proj. 667BDR,			
K-492	Victor-III	Proj. 671RTM,	P,		

K-493 Alfa Proj. 705, N, fa.no.107,
K-495 Victor-II Proj. 671RT, N, fa.no.621,
K-496 Delta-III Proj. 667BDR,
K-497 Delta-I Proj. 667B, P,
K-500 Delta-I Proj. 667B, P,
K-502 Victor-III Proj. 671RTM,
K-503 Charlie-II Proj. 670M, N, fa.no.904,
K-506 Delta-III Proj. 667BDR,
K-507 Victor-III Proj. 671RTM, P,
K-508 Charlie-II Proj. 670M, , fa.no.905,
K-512 Delta-I Proj. 667B, P,
K-512 Oscar Proj. 949,
K-513 Victor-II Proj. 671RT, N, fa.no.625,
K-517 Victor-II Proj. 671Rt, N, fa.no.627,
K-523 Delta-I Proj. 667B, P,
K-524 Victor-III Proj. 671RTM, N,
K-525 Oscar-I Proj. 949, N,
Minsky Komsomolets, later Arkhangelsk
K-530 Delta-I Proj. 667B, P,
K-530? Oscar Proj. 949,
K-557 Echo-II Proj. 675, P, , earlier K-57
K-? Sierra Proj. 945, N,
Barracudas
K-? Sierra Proj. 945, N,
Condor
K-? Akula Proj. 971, N,
Vepr
K-? Akula Proj. 971, N,
Gepard

Mini Submarines

AS-11 X-ray Proj. 1851, N,
AS-12 Proj. 10831, N,
AS-15 Uniform Proj. 1910, N,
AS-16 Uniform Proj. 1910, N,
AS-? Uniform Proj. 1910, N,

Cruisers

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