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The Kursk Accident

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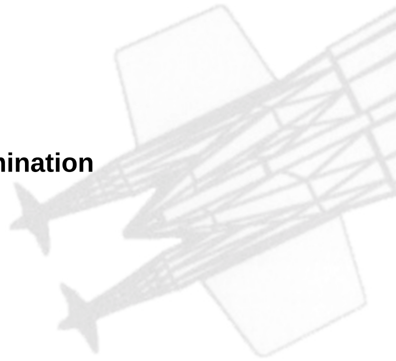

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1 Introduction

1.1. Background and aim of the report

On the morning of August 12th 2000, a Russian submarine sank in international waters east of Rybatschi Peninsula in the Barents Sea. The submarine, a Russian Oscar II class attack submarine, sank to a depth of 116 meters, north-east of Murmansk about 250 km from Norway and 80 km from the coast of Kola.

The main purpose of this report is to record the knowledge gained from the two expeditions to the Kursk in August with the DSV Seaway Eagle (Stolt Offshore) and in October with the MSV Regalia (Halliburton). The Norwegian Radiation Protection Authority (NRPA) joined these expeditions to give advice in evaluating the initial radiological conditions at the site and to perform measurements and take action if leakage occurred during the operation. The main aim was to ensure that radiation protection aspects were taken care of as part of the safety precautions for the divers and the general crew. For this purpose, radiation protection procedures were devised and a sampling programme was implemented along with the working procedures for the expeditions.

This report summarizes the radiation protection aspect, results from measurements made close to the Kursk, and inside the submarine as well. Conclusions from these analyses are naturally included. However, to give the reader a broader picture, we have also included the general operations of these expeditions and what was achieved. Some technical descriptions of the submarine and an estimation of the radionuclide inventory in the reactors are also shown. The report also includes an evaluation of the environmental impact following a hypothetical release of the total amount of radioactivity contained in the two reactors of the Kursk. We have given a brief overview of the ongoing marine monitoring programme, and what kind of additional monitoring programs we recommend to cover the Kursk accident specifically.

This report is performed by the Norwegian party of the Joint Norwegian-Russian Expert Group for Investigation of Radioactive Contamination in the Northern Areas. It will work as a discussion document in the ongoing joint work on environmental impact assessment regarding the Kursk accident.

1.2. Past and present sources of contamination

1.2.1. General sources

The most important sources of radioactive pollution in the northern oceans are fallout from nuclear weapons tests conducted in the 50's and 60's, discharges from the Sellafield reprocessing facility (UK), and fallout from the Chernobyl accident (AMAP, 1998). Other sources such as the previous Russian dumping of solid and liquid radioactive waste, transport of contamination through the large Russian rivers in the North and leakage from the sunken Russian submarine, the Komsomolets, have so far proven to be of minor importance for the environment as a whole.

Russia has dumped large amounts of solid and liquid radioactive waste, including several reactors, in the Kara Sea. Investigations in connection with earlier accidents and dumping of radioactive waste showed elevated concentrations of radioactive substances in close proximity to several of the dumped objects. The Kursk is the 6th in a list of American and Russian nuclear submarines abandoned on the sea floor because of accidents. The Russian submarine, the Komsomolets, sank in the Norwegian Sea in 1989. Norwegian authorities have been involved in investigations connected to possible environmental effects as a consequence of the loss.

Assessments connected to the loss of the Komsomolets and the dumping of radioactive waste in the Kara Sea are relevant in relation to the Kursk accident. Therefore, these two sources are described in more detail below.

1.2.2. The Komsomolets

Unlike most Russian nuclear submarines which contain two reactors, the Komsomolets contains only one nuclear reactor with an inventory of long-lived radioactive substances, estimated to be about : 2.8×10^{15} Bq of ^{90}Sr and 3.1×10^{15} Bq of ^{137}Cs. Two nuclear torpedoes with mixed uranium/plutonium warheads, situated to the fore of the hull, contain about 1.6×10^{13} Bq of weapons-grade plutonium. In 1999, minor releases of radioactive substances from the reactor compartment had been detected in the close vicinity of the submarine wreck. Surveys indicated releases of radioactive substances through a reactor ventilation tube. However, the likelihood of a large-scale release of radioactive substances from the Komsomolets submarine in the near future is small (AMAP, 1999).

Extensive studies of the radiological impact from the Komsomolets have been performed (CCMS/CDSM/NATO 1995, AMAP 1998, Lisovsky et al., 1996). The hull and several barriers inside the reactor are expected to prevent corrosion of the reactor fuel for about two thousand years. By that time, only plutonium and americium isotopes will be present in the reactor in significant amounts. In the intervening period, the main pathway for release of radioactive substances from the reactor will be through the reactor compartment ventilation tube. The warheads are not protected from seawater to the same degree, and are expected to be vulnerable to corrosion much earlier than the reactor fuel. Plutonium released is likely to be retained in marine sediments close to the point of release. The conclusion, after analysing bottom water, surface water and sediments, was that the Komsomolets currently poses no threat to the environment (Kolstad, A.K., 1995).

1.2.3. Dumping of radioactive waste

Reactors and reactor compartments, both with and without spent nuclear fuel, have been dumped in the Kara Sea. Six nuclear submarine reactors and one shielding unit from a nuclear powered icebreaker were dumped in the Arctic Ocean, containing a total activity of 85×10^{15} Bq. Additionally, 10 reactors without fuel were dumped (containing 3.7×10^{15} Bq), at depths varying between 12 and 300 m near Novaya Semlya. Joint Norwegian-Russian expeditions in 1992, 1993 and 1994 showed that levels of radioactivity in the water did not differ from the levels in the open Kara Sea (JNREG, 1996). Measurements have also been conducted on seawater and sediments in the other fjords at Novaya Semlya where radioactive material has been dumped. Elevated levels of radioactive substances were found in the sediments and also in the bottom water in the Stepovogo Fjord.

1.2.4. Former submarine losses

According to present knowledge, a total of six nuclear submarines, four Russian and two American, are lying on the seabed. All of them pose a threat to the environment. However, only local contamination is observed, if any, where such studies have been performed.

Russian submarines

K-8 (November class)
Lost: April 8th, 1970
Position: The Bay of Biscay
Depth: 4 680 meters

K-219 (Yankee class)
Lost: October 6th, 1986
Position: Atlantic Ocean, north of the Bermuda Islands
Depth: 5 000 meters

K-278 – Komsomolets (Mike class)
Lost: April 7th, 1989
Position: Norwegian Sea, south of Bear Island
Depth: 1 685 meters

K-141 - Kursk (Oscar II class)
Lost: August 12th 2000
Position: South in the Barents Sea
Depth: 116 meters

American submarines

USS Thresher (SSN 593)
Lost: April 10th, 1963
Position: 160 km south of Cape Cod
Depth: 2 600 meters

Studies show low levels of radioactivity in the sediments. (Ølgard, 1993).

USS Scorpion (SSN 589)
Lost: May 22nd, 1968
Position: 650 km southwest of the Azores
Depth: 3 600 meter

Measurements in the area show very low levels of radioactivity in the sediments (USS Scorpion).

2 The nuclear submarine, the Kursk

The submarine Kursk, of Project 949A K-141, with the NATO codename OSCAR-II, was designed by Rubin Central Design Bureau. It is a nuclear powered cruise missile attack submarin. The construction of the Kursk started in 1992 at the Sevmash shipyard in Severodvinsk and she was commissioned in 1995. The submarine is 154 m long, equipped with two pressurized water reactors and the submerged displacement is 24,000 tons. Each reactor has a thermal effect of 190 megawatts, or less than 10 % of a typical nuclear power plant reactor. The submarines of the Oscar-II class are among the largest and most capable in the Russian Northern Fleet. According to Russian sources, at least twelve submarines in the Oscar-II class were built. More detailed specifications are given below (Jane´s Fighting Ships; International Kursk Consortium, 2001; Leonid A. Kharitonov):

2.1. Specifications

Displacement:	14.700 tons surfaced 24.000 tons submerged
Speed:	32 knots dived 16 knots surfaced
Dimensions:	154 m length 18.2 m beam 9.5 m draught 13,7 m depth (excl. sail) 18,3 m depth (incl. sail & masts)
Propulsion:	2 VM-5 190 MWt pressurized water nuclear Reactors (OK-650b) (PWR) 2 steam turbines – 49.000 shp 2 propellers with 7 blades
Endurance:	50 days
Diving depth:	600 meters
Crew:	107 total

The Kursk submarine has an armament capacity for 24 cruise missiles (SS-N-19 / P-700) with conventional or nuclear warheads. The missiles are launched, while the submarine is submerged, from tubes fixed at an angle of approximately 40 degrees, arranged in two rows of twelve, each covered by six hatches on each side of the sail. These missiles have a range of 550 km. For the launching of torpedoes, the submarine was equipped with 4x650 mm and 4x533 mm torpedo tubes in the torpedo room in section 1 in the fore end of the submarine. In total, 24 torpedoes or ASW rockets could be launched.

The Kursk submarine is of double hull construction with 9 watertight compartments separated by hatches. The outer hydrodynamic hull is made of 8 mm steel plates covered by up to 80 mm of rubber. The purpose of the rubber is to prevent other submarines or surface vessels recognizing the submarine by reducing the echo from sonar signals. The inner pressure hull is made of 50 mm steel plates (quality HY-130) and the distance between the two hulls varies by about 1-2 m, connected with transverse stiffeners. In the compartment between the hulls, there are several tubes running from bow to stern. The submarine was equipped with two rescue hatches, situated in compartments no. IX and I. An ascending buoy for transmission of emergency and communication signals was located on the top of compartment no. VII. The buoy, in an emergency situation, should be automatically released by electric signals and float to the sea surface. This did not happen in the Kursk accident.

The separate compartments are numbered from I to IX sequentially from bow to stern:

I	Torpedo room
II	Control room
III	Combat station and radio room
IV	Living quarters
V	Different stations
VI	Reactors
VII	Main propulsion turbine
VIII	Main propulsion turbine
IX	Electric motors

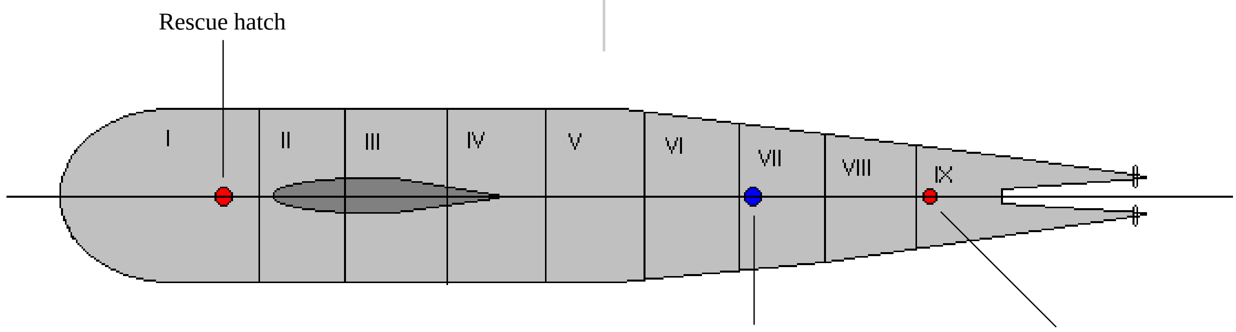


Fig. 1) Sketch of the 9 compartments of the Kursk and the locations of the ascending buoy and rescue hatches.

2 The nuclear submarine, the Kursk

There is little available information on propulsion and nuclear reactor construction in Russian submarines. Such information is kept secret for military purposes. It has been confirmed that propulsion is provided by two pressurized water reactors. The Russian navy almost consequently uses two reactors in each submarine. The two reactors are located in compartment no. VI, with one in front of the other on the centerline of the vessel. The distances from the top of the reactors to the top and bottom of the pressure hull are 5 m and 6 m respectively. It is likely that the primary cooling circuit, the steam generators and the main circulation pumps are located in the reactor compartment (no. VI), and that goes to the main turbines further astern.

3 The accident and subsequent actions

The Kursk left its home base of Vidiayevo in Uraguba bay on the 10^{th} of August,2000, with a total number of 118 men aboard (111 crew members, 5 officers of 7^{th} SSGN Division headquarters and 2 designers), for participation in military exercises in the Barents Sea. When the submarine operates in a submerged position, the crew is stationed with 7 members in compartment I, 36 in compartment II, 24 in compartment III, 12 in compartment IV, 15 in compartment V, 5 in compartment VI, 9 in compartment VII, 7 in compartment VIII and 3 in compartment IX (Leonid A. Kharitonov).

The NRPA received, at 09:50 on the morning of August the 14^{th}, a message from the Rescue Centre of Northern Norway in Bodø. The centre had received rumours of an accident on board the Russian nuclear submarine, the Kursk. The vessel was participating in a military marine exercise in the Barents Sea. The NRPA declared information emergency preparedness at 10:40 and the Norwegian "crisis committee for nuclear accidents" was activated. At 13.10 , the other Nordic countries and the International Atomic Energy Agency (IAEA) were informed with regards to the rumours. The crises committee came together later the same day and organised the work to follow the situation. It also decided to establish a programme for collecting water samples in the area of the accident.

In collaboration with the Headquarters of Defence Command in Norway, the NRPA carried out measurements on seawater samples taken as close as possible to the site. A Norwegian defence research vessel initially collected the samples. The choice of sampling location was decided after consultation with the Norwegian Institute of Marine Research, the Norwegian Meteorological Institute and the Norwegian Polar Institute. The NRPA gathered information from stations for monitoring radioactivity in the air at Viksjøfjell and Svanvik in eastern Finnmark. Furthermore, the NRPA also had access to data from monitoring networks in Russia, Finland, Sweden and Norway, which are continuously monitoring and registering possible increases in radioactivity levels At about 16.30 on the 14^{th}, the NRPA received a fax from the Norwegian embassy in Moscow where Russian authorities confirmed that there had been an accident on board the submarine, the Kursk. The accident site was in international waters east of Rybatschi Peninsula in the Barents Sea, about 250 km from Norway. The submarine sank to a depth of 116 m at the position $69^0$36,99N, $37^0$34,50E (fig.2). According to official Russian sources, the reactors were shut down during the accident and the submarine was not carrying nuclear weapons.

Fig. 2) Location of the Kursk. (AMAP Datacentre)

According to the Norwegian seismic array service (NORSAR), two seismic events were recorded in several countries (Norway, Canada, Alaska) early on the morning of August the 12^{th}. Registrations at stations in Finnmark, Spitsbergen and Hedmark showed data that indicated two explosions (fig.3). With these recordings

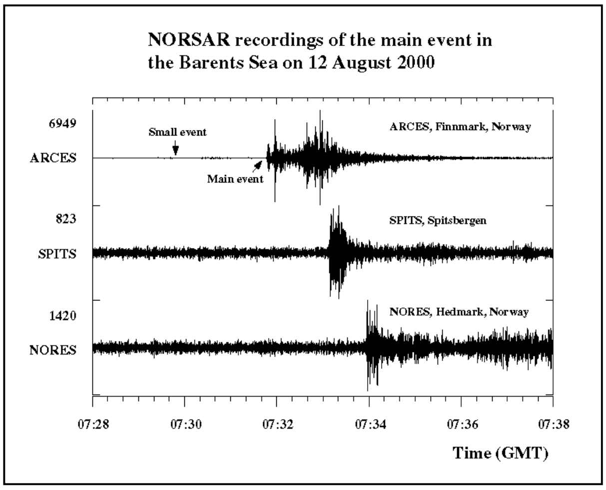


Fig. 3) NORSAR seismic readings of the explosion on the Kursk, 12th August 2000.

from different geographical positions it was possible to estimate the origin of the signals. The first explosion was at 7.29.50 GMT and had a strength of 1.5 on the Richter's scale. The second, and much larger explosion, was a few minutes later at 7.32.00 GMT with a strength of 3.5 (NORSAR). British and American submarines, as well as a Norwegian military research vessel which was present in the area, detected these events at the time. Later investigations showed that the submarine lay upon the seabed by the stern, and the fore end penetrated the seabed at an angle of 2^0 downwards. The hull leans by about 1.5^0 to the port side (International Kursk Consortium, 2001).

Later that night, on Saturday August the 12th, a Russian rescue ship, the Mikhail Rudnitskiy, arrived at the site of accident with a submersible rescue vehicle on board. The vessel located the Kursk lying on the seabed in the early morning of August the 13th. Over the following days a salvage operation was conducted to try to attach the rescue vehicle to the rescue hatch of compartment no. IX. The aim was to rescue the crew, because they believed that some could still be alive. The salvage operation was conducted by the commander of the Northern Fleet, Admiral Viacheslav A. Popov. The bow of the submarine was inspected by video cameras and serious damage was revealed. Several attempts to attach the rescue vehicle to the submarine failed. Unconfirmed information from Russian sources was given to the press indicating that signals from crewmembers inside the submarine had been heard. From the Russian side, information on extremely bad weather conditions, the damaged rescue hatch and a 60^0 lean of the hull, were given to explain the unsuccessful operation during the first days. In total, 22 vessels and 3000 sailors were involved in the Russian operation to rescue the crew during the first week after the accident.

On Wednesday August the 16th, the NRPA received the first water samples collected by a Norwegian military vessel from the surrounding area, about 60 km west of the site of accident; about 69°37"N, 37°34"E. Analyses of the water samples and air filters from the vessel showed no traces of radioactivity from the reactor on board the Kursk.

A few days after the accident, several countries, among them Norway, Great Britain and USA offered to assist the Russians in the ongoing rescue operation. At first the Russians did not want foreign assistance. However, after several unsuccessful attempts to rescue the crew, the Russian president Vladimir Putin decided (on Thursday August the 17th) to accept foreign assistance.

The divers on board the Seaway Eagle opened the upper and lower rescue hatches in compartment no. IX. The expedition with the Seaway Eagle lasted from 17th to 22nd August. The operation is described in detail in chapter 4.

During the first weeks, the NRPA sent out several press releases and updated their web site regularly with news, information and results of measurements. Two NRPA Bulletins were released in August 2000 giving information on the accident, possible consequences of radioactive contamination and the marine surveillance programme (Strålevernsinfo 5, 2000; Strålevernsinfo 6, 2000). Later, two other bulletins have also been published on this subject (Stråleverninfo 9, 2000; Stråleverninfo 3, 2001).

The NRPA was, together with collaborating institutions, adjusting their ongoing marine monitoring programme to allow for the rapid detection of potential leakage from the sunken submarine, the Kursk. A joint co-operation pertaining to the Kursk accident was also discussed within the framework of the existing Norwegian-Russian expert group on radioactive contamination in the northern areas. Working groups were initiated for the modelling of potential releases of radioactive contamination from the submarine and to estimate the total radionuclide inventory of the reactors inside the Kursk.

The Russians started to plan a new expedition to Kursk to open up compartments by cutting holes through the hulls of the submarine, in order to recover the bodies of the casualties. Russian authorities officially applied to Norway to assist the company, Halliburton Norge AS, who had finally signed the contract with the Russian client Rubin (Rubin Central Design Bureau for Marine Engineering) to accomplish this task. A vessel,the MSV Regalia, designed specially for diving and work operations in the oil fields of the North Sea, would be used for this operation. The operations of the MSV Regalia, from October 16th to November 7th, are described in detail in chapter 4.

4.1. Expedition in August 2000 with the DSV Seaway Eagle

4.1.1. Purpose

The Russian company Rubin and the Norwegian company Stolt Offshore signed a contract regarding an expedition to the Kursk. Rubin was therefore assigned as the client in this project. Rubin is the company which designed and built the Kursk. They also designed and built the nuclear submarine the Komsomolets, which sank south of Bjørnøya in 1989. From the Russian side the whole operation with the DSV Seaway Eagle was administered by the North Fleet of the Russian Navy. The main purpose of the expedition was to open the rescue hatches in compartment no. IX in an attempt to rescue parts of the crew if anyone were still alive.
The expedition took place during the period 17th - 22nd August 2000.

A British company had offered their assistance with regards to rescuing any possible survivors with a specially designed rescue submarine called the LR-5, which could be attached to the rescue hatch of the Kursk. The Russian client accepted the offer and the submarine was transported to Værnes airport in Trondheim by plane. The submarine was then transferred to a cargo vessel and brought out to the site of accident.

The Headquarters of Defence Command in Norway applied to the NRPA on Thursday, August the 17th, to assist the Norwegian personnel onboard the Seaway Eagle with regard to radiation safety, and to give advice on radiation related matters. The aim was also to collect seawater and sediment samples to determine if any leakage of radioactive components from the reactors inside the Kursk had occurred. The NRPA decided the same day to send 3 experts on the expedition. The personnel went onboard the DSV Seaway Eagle in Tromsø the day after, Friday 18th August at 10:00.

The DSV Seaway Eagle.

4.1.2. Preparation

The Seaway Eagle is a specially designed vessel equipped with facilities for saturation diving in deep waters, and with advanced technology for ROV (Remote Operated Vehicle) operations. The vessel is mainly employed in the offshore oil industry. On the expedition to the Kursk, specially trained British and Norwegian deep-water divers boarded in Tromsø on Friday morning, 18th August. The NRPA received only 24 hours notice to prepare for the expedition and several boxes with equipment were transported to Tromsø during the late evening of Thursday, 17th August. On board, the Norwegian delegation was under the leadership of Captain Paul Svendsen from the Headquarters of Defence Command Northern Norway.

4.1.3. Course of events

The vessel left Tromsø on Friday, 18th August, at about 13:00 and arrived on site at 20:00, 19th August. During the trip, there were several briefing meetings with the crew and the offshore manager, Graham Mann. Radiation related aspects and equipment for dose rate measurements under water were discussed. It was important to equip the ROV and divers with Geiger Muller (GM) monitors for dose rate readings directly at the working site by use of cameras. The GM-counters were delivered by OIS (Oil Industry Services, Kristiansand, Norway) and brought out to the Seaway Eagle by helicopter. A three-party meeting was arranged on the morning of Saturday, August 19th, between the Norwegian, Russian and British delegations.

The leader of the Russian delegation, Rear Admiral in the Russian Northern Fleet, Gennadij Verich, described the situation and what kind of assisstance the Russian rescue operation wanted. Their conclusion was that none of the crew on board the submarine was alive and therefore the need for the British rescue submarine LR-5 was no longer necessary. Later that evening, at 22.45, a new meeting was arranged without the British delegation. The Russian client allowed the ROV to submerge to the seabed for visual inspection of the submarine. The area of inspection was restricted by the Russian participants, and only the stern part of the submarine was allowed to be investigated (from the propellers to the reactor compartment). The main task for the divers was, initially, a visual inspection of the rescue hatch and a control valve for the inlet/outlet of air in the rescue shaft. There were still uncertainties about whether the compartment was flooded and if there was any air inside. The air release scenario, with possible radioactive contaminantion when both hatches were opened, was discussed.

Next morning on Sunday, 20th August, the ROV began to survey the stern of the submarine. The readings of the GM-counter mounted on the ROV never exceeded the background level of 0.1 µSv/h. Sediment samples were collected by use of the ROV close to the hull on each side of the submarine. Samples of surface and bottom water were also collected. The divers tried to open the upper rescue hatch also by using the hydraulic arms of the ROV without success. In order to detect any possible radioactive contaminants in the air released from inside compartment no. IX when opening the rescue hatch, an air sampler was placed on the deck of the Seaway Eagle. The NRPA personnel devised a risk assessment plan for the divers in relation to the opening of the hatch. The risk of inhalation of radioactive particles was unlikely because of their self-contained breathing apparatus. The divers use of the GM-dose rate meter gave an overview of the ambient radiation level. Readings in the range of 500-1000 µSv/h would halt work at that location, and further discussions would be made as to whether or not to terminate the operation or whether a time schedule for further work should be made.

During the night, the divers managed to open the upper rescue hatch by employing a 500 l balloon filled with air. The space inside the rescue shaft was filled with water and no casualties were found inside. At a strategy meeting on the morning of Monday, 21st August, it was discussed how to handle the situation when the lower rescue hatch was opened. It was agreed that monitoring close to the lower hatch and collection of air and water samples from inside the submarine should be conducted.

The MSV Regalia.

A special tool for opening the lower hatch was constructed at 10.30, and the divers then managed to open the hatch. A rather large volume of air from inside flowed to the surface, and measurement with GM-counters and sampling of water in the vicinity of the air bubble on the surface was performed. No enhanced levels of radioactivity were observed. Compartment no. IX was flooded with water and the divers recorded film from inside the compartment using a video camera mounted on a rod, deployed through the hatch.

On the evening of Monday, 21st August, a meeting between the Norwegian and Russian delegations was arranged with the participation of the leader of the Russian Northern Fleet, Admiral Popov.

Admiral Popov requested Norwegian assistance in bringing out the casualties from the Kursk. This new scenario was not on the task plan for the cruise, and negotiations with Stolt Offshore and other international contractors for a recovery operation of casualties was needed.

On the morning of Tuesday, 22nd August, the decision was made that the objectives of the operation were fulfilled, and at 15.00 most of the Norwegian delegation left the Seaway Eagle by helicopter, heading for Kirkenes.

4.2. Expedition in October 2000 with the MSV Regalia

4.2.1. Purpose

After the expedition with the Seaway Eagle in mid August, the Russians started to plan the next expedition to gain access for divers to enter the interior of the Kursk. The main objective was to recover the bodies of the casualties. However, this expedition would also provide unique opportunities for looking into documents and instrumentation to seek the reason for the catastrophe. A detailed survey of the hull damage could also give additional information of much significance. The Russian authorities officially applied to Norway for assistance. The expedition took place during the period of the 20th October to the 7th November 2000 with the MSV Regalia. The platform-like vessel is especially suitable for diving activities in the North Sea.

4.2.2. Preparations

The contract with Halliburton was signed at a late stage (about three weeks prior to the start of the expedition) giving very little time for preparation by both sides. At that time, Halliburton owned the vessel the MSV Regalia, which is a vessel specially designed for diving and working operations in the oil fields in the North Sea. Employees from Halliburton visited Russia to discuss with Russian specialists the best methods and most suitable spots for cutting into the hull of the Kursk. The Russian divers went onboard the MSV Regalia in Bergen before it left the port on Monday, 19th October. During the ten days of travelling to

Honningsvåg and further to the location of the Kursk, they had some time for test diving, training routines and checking of equipment together with the Halliburton crew.

It is evident that the Russians, and the Northern Fleet, do not have the necessary equipment for performing "saturation-diving" which is necessary for this kind of operation. Working for many days at a depth of more than 100 m is only possible using diving bells and saturation chambers. The divers entering the Kursk worked at a pressure of 10 bars and had to stay in the small six person saturation chambers during the whole

The main deck on the MSV Regalia.

operation (3-4 weeks). When each diving team was ready to work, they were lowered down to the bottom in the diving bell. The Regalia had two diving bells and three saturation chambers. For the operation on the Kursk, a total of eighteen divers from Russia, Great Britain and Norway worked during the whole period. At an early stage it was decided that only the Russian divers should actually enter the submarine while the other divers were responsible for cutting access holes to enter the Kursk. The diving activity was organised in six teams; three Russian and three Halliburton teams. A Russian team consisted of two Russian divers (one diver went into the submarine while the other one stayed outside the access hole) and one Halliburton diver who stayed in the diving bell for safety reasons.

4.2.3. Course of events

Halliburton was in charge of diving safety, all equipment needed and the planning and fulfilling of cutting the holes in the submarine. The Russian Northern Fleet, and the Russian company Rubin, were the clients and determined where and when the holes should be cut. Prior to the work a schedule including the cutting of eight compartments was agreed (fig.4).

On route to the site of accident, several briefing meetings with the crew, marine group and the divers were arranged. With regards to safety aspects of the operation, many were concerned with radiation and the possible leakage of radioactivity from the submarine. Therefore, many questions were raised regarding the risk of radioactive contamination. Procedures for sampling, dose rate measurements and strategy regarding radiation protection were presented by the NRPA (appendix 2).

The MSV Regalia arrived at the position of the Kursk at about 03.30 on Friday, 20th October. Close to the site, the vessel stopped and test diving was performed. The Regalia produces its own drinking water by distillation of seawater and the intake was stopped before entering the site due to the fear of possible radioactive contamination. A stop in intake of saltwater for some days does not cause any problems. The working ROV was then sent out, equipped with a dose rate meter, and went in front of the Regalia for the last part of the voyage. Arriving on site, the ROV went down for an initial survey of the submarine. A few hours later, water and sediment samples were taken close to the submarine (see chapter 5 for details). No indications of radiation were detected and the vessel started producing freshwater again.

By using cameras mounted on the two ROVs (a working ROV and an observation ROV) it was possible to take a closer look at the damage, especially at the bow part of the Kursk. This activity was an essential task of this expedition and was performed initially before the divers went down and during the operation. The observation ROV was relatively small, about 1,5 m long, 1 wide and 0.5 m height, and was sent in among the wreckage at front of the submarine.

The whole bow part of the submarine had disintegrated. Only about 4-5 m in front of the tower was relatively undamaged, which means that about 18 meters of the

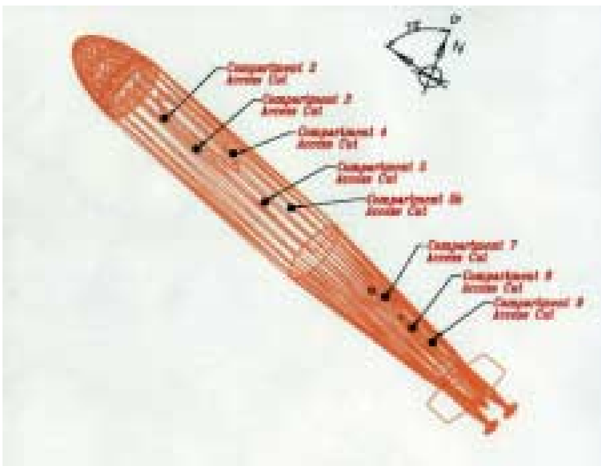


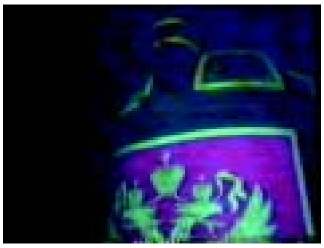
Fig. 4) The original working plan for cutting access holes in the Kursk (Source: Halliburton)

submarine was destroyed. At the location where the bow part should be, only a mass of wreckage and metal debris was observed. Pieces from compartment no. I were spread over a large area. A large part of compartment no. II was also seriously damaged. On the starboard side, two large cracks were observed starting at the front and progressing backwards. The large one, at the upper part of the submarine, reached about 3-5 m past the front part of the tower. A smaller crack was located at the lower part of the submarine and ended about 2-3 m in front of the tower. Also, smaller cracks could be observed further back on the submarine. Two pieces of the outer hull, immediatly below the two cracks described above, were later cut out to undergo detailed analysis by the Russian party.

All around the Kursk, a lot of debris was scattered around. During the operation the ROV performed a survey and marked all pieces with coordinates and picked up the most interesting parts. In front of the submarine, several pieces from torpedoes were discovered and taken up.

The first divers went down to the Kursk during Friday night, and Saturday morning to begin work on compartment VIII. The first task was to depressurise tubes between the outer and inner hulls, which may be pressurised up to 400 bar. Then the cutting started at specific sites decided on by the Russians. Halliburton engineers then planned how each specific cut should be performed. The main cutting device was a circular and linear device pumping high-pressure water containing grit (mainly consisting of Fe (55%) and SiO_2 (35%)) through a 2 mm nozzle. In principal, these devices can cut through 150 mm solid steel. The pressure hull is 50 mm solid steel (type: HY-130) and the outer hull is 8 mm solid steel. The Kursk is coated with an 80 mm thick rubber-layer, which eliminates echoes from sonar signals.

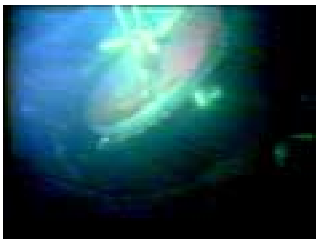
The Russian divers did not use their GM dose rate meter when going inside



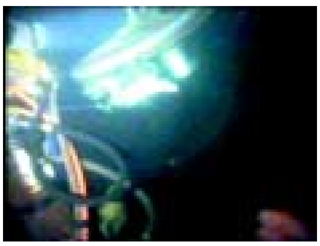
Underwater picture of the front part of the tower on the Kursk.

A diver is cutting hole in the submarine.

Damages in the front part of the submarine.



Part of pressure hull is lifted out by use of the crane on the Regalia.



Part of pressure hull from is lifted out of the submarine.

the submarine because they considered it would be in their way. However, a procedure was made to lower a meter down so they could take a reading inside the submarine and then send the meter back up again.

During the night of Saturday, the 21st and Sunday, the 22nd, the first piece of the submarine, a section of the outer hull of compartment no. VIII was lifted up to the Regalia. Then the divers started to cut the pipes between the hulls to gain access to the pressure hull. First a small piece with a diameter of 19 cm was cut out to depressurise the interior, in order to be able to take a water sample and for obtaining a hold of a larger piece, of about 1 m^2, which was the next step. During the night between the 23rd and the 24th the operation was halted due to very strong wind making it difficult for the Regalia to stay in fixed position. At 05.00 on Wednesday the 25th, the large piece of the inner hull was lifted up to the Regalia. Later the same day, the divers moved the equipment over to compartment no. VII, which it was agreed would be the next location, and started on the next cut. At about 15.00, the Russian divers were ready to go inside compartment no. VIII. A helmet mounted video camera sent pictures to monitors mounted at different locations on the Regalia. The visibility was good in compartment no VIII and there were, as far as we could judge, no visible signs of any kind of fire having taken place. However, the Russian diver did not move very much from the access hole, but started to open the hatch to compartment no. IX which was located just one meter from the hole. The door was locked, but the diver kicked the door open with his foot quite easily. When starting to open the door it became evident that dust and ashes in the water inside no. IX made the visibility very poor.

The rescue hatch in compartment no. IX was opened to send in a camera and to give more light to the diver working inside (the hatch was too narrow to be used as access hole). On the first floor, the diver did not find any casualties. However, it was difficult to go very far from the hole due to a small walking passage and bad visibility. On going down the ladder to the next floor, the diver found the first casualty who was lifted out of the submarine by use of a rope. A little later, he found two more, which were also taken out. The casualties showed clear signs of having been badly burnt. Later that day, Wednesday the 25th, a new Russian diving team went into compartment no. IX and found two more casualties who were lifted up to a fenced area at one corner of the Regalia.

Next morning, the Russian Rear Admiral in the Northern Fleet said at the information meeting that Russian specialists that night had examined the bodies and a note was found on one of them. It stated that all crew members in compartments no. VI, VII and VIII had moved to compartment no. IX and that there were 23 of them. According to official information from the Northern Fleet, available on Internet only a few hours later, the note contained information of importance for solving the question as to why the Kursk went down. As a result of the information in this note, the cutting in compartment no. VII was stopped, and the Russians wanted to start cutting two holes in compartment no. IX to provide better working conditions and access for the divers to retrieve more casualties.

At the information meeting on Friday the 28th, it was evident that the Russians had not yet given information as to where the holes in compartment no. IX should be cut. Halliburton suggested starting cutting in compartment no. V in the meantime to save time, and also asked for a written note from the Russians stating that changes to the original plan had been made. Later that day, they obtained information on where to cut in no. IX and started the work.

On Saturday the 28th, a Russian helicopter brought the casualties to Murmansk. Later that day a new Russian diving team went down and found another casualty (no. 6). They also found documents, oxygen masks, a survival suit and a bag, which were brought up to the surface. Later the same day they found more casualties, some of them being found in a separate room. The total number of recovered bodies was ten. Not all of them showed signs of having been burnt.

On Sunday the 29th the Russians decide to postpone further cutting in no. IX because they wanted to prioritise the work further inside that compartment instead of waiting for better access through a new hole. They suggested starting cutting in compartment no. III through the conning tower. Consequently, the equipment was moved from no. IX to no. III. The plan was to continue the cut in no. IX when the divers could not gain more access through the present hole. It was decided that the hole in no. VIII should be sealed when the Russian divers were finished. The divers found two more casualties that day which meant that the total number was now twelve. Later it became evident that these two were to be the last casualties to be taken out of the Kursk on this expedition.

On Monday morning, it was stated that the cutting equipment would be moved from no. III to continue the cut in no. IX when the divers were finished, probably during the same day. Later the same day, new information was provided that it would not be necessary to continue the cut in no. IX. The reason for this was, as far as we know, that the location of the hole would not provide the access they had hoped for. Therefore, the vertical cut in the conning tower in no. III could continue during Tuesday and Wednesday. While working on this cut, the divers located a hatch close to the cutting location which provided access to the interior of the conning tower.

On Wednesday 1st November the cut in the conning tower was completed and a large piece from the outer hull, together with pipes and a ladder between the outer hull and the pressure hull, was taken up to the Regalia. Late on Wednesday, air bubbles were observed coming up from the cut in the pressure hull. This air was sampled and brought up to the Regalia. At 01.00 on Thursday morning, the cut in the pressure hull of no. III was finished and the removed piece was brought up to the surface. Closer inspection of the pressure hull piece made it clear that there had been a very active fire in that compartment. The divers found the inside with cables, ashes, and debris strewn all over. It was decided that it was not possible to enter this compartment and hence, the piece from the pressure hull was used as a lock and was screwed back into the original hole.

Having decided not to enter compartment no. III, the cutting in compartment no. IV was started. The cutting work was delayed because of bad weather conditions and was completed on Saturday the 4th November at 11.00. The piece of the pressure hull showed no sign of fire and the visability inside the compartment was quite good.

A visual inspection of the damage at the bow and some debris were performed using the ROV video camera. This work was performed in parallel with the cutting work to prepare for the lifting of debris on to the Regalia.

Russian divers worked inside compartment no. IV during the night. No casualties were observed in the divers working area, and the focus was therefore set on collecting debris and documents from the command section. Location and visual inspection of debris on the seabed at the bow and stern of the wreck was continued during the night. On Sunday the 5th the cutting work on pieces from the bow was ended and they were brought up on deck together with some debris.

Monday morning the diving and cutting work was finished and all the collected pieces were transferred to the Russian supply ship the Altai. During the night and early morning of Tuesday 7th, 6 sediment cores, 3 from each side of the front half of the submarine, were collected for a geological seabed survey.

The last items of debris collected could not be brought on board the Altai because of bad weather conditions, therefore the Regalia, when returning to Norway, went closer to the Russian coast to transfer debris to the Altai in calmer waters.

The operation concluded with a commemorative ceremony on the main deck in the presence of an admiral from the Russian Northern Fleet.

Dose rate measurements on the Regalia, of a piece of the pressure hull from compartment III.

Dose rate measurements on Regalia, of a piece of the pressure hull from compartment IV.

On

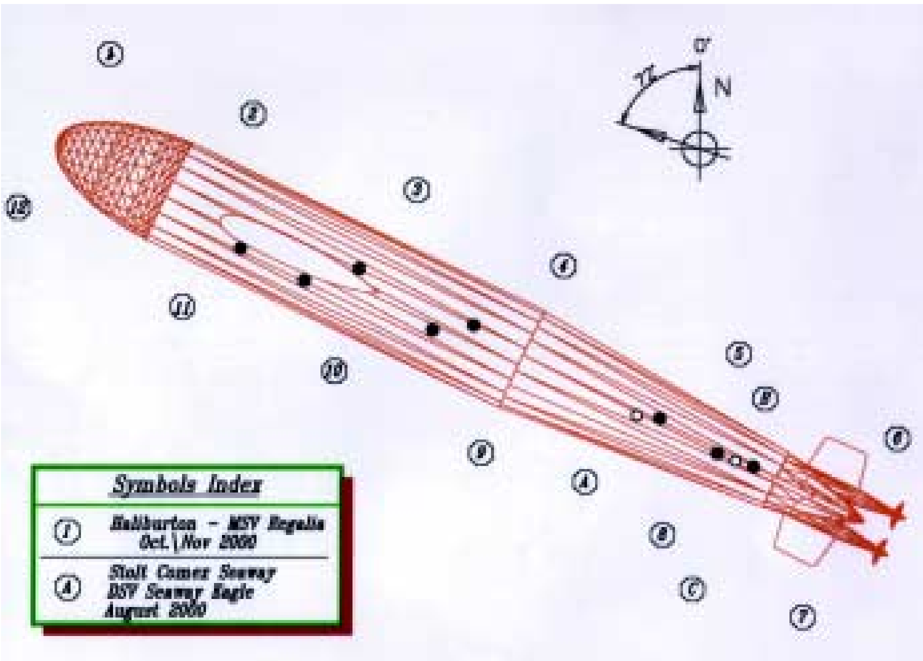


Fig.5) Depiction of the locations where sampling of sediments was conducted; samples A-C and 1-12 were taken in August and October 2000 respectively (Source: Halliburton).

5.1. Sampling methods

5.1.1. Sediment sampling

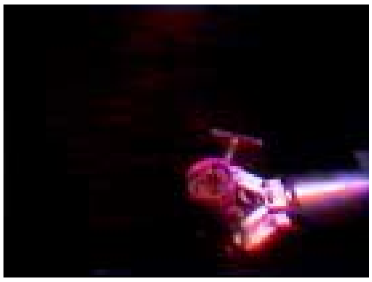
DSV Seaway Eagle

The sediment sampling was performed in the close vicinity of the Kursk (fig. 5). Three samples were taken during the August expedition with the DSV Seaway Eagle. Two of the samples were taken from the left side and one from the right side of the submarine. Two samples were taken by the ROV, one from the left side at a distance of 5 m from the reactor compartment and one from the right side, by the escape hatch, also at distance of about 5 m. These samples were taken using a plastic cylinder with an inner diameter of 67 mm. The cylinder was lowered into the sediment using the hydraulic arms on the ROV and it was then sealed at the bottom when the arm activated a lever on the cylinder. A grab sampler was used to collect the last sediment sample located on the left side between the reactor compartment and the rescue hatch at a distance of about 15 m from the submarine.

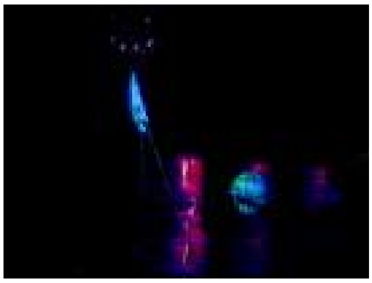
A rack of six corers, used for sediment sampling (red colour), is mounted on top of the basket. The Nansen water sampling device is mounted in front of the basket.

MSV Regalia

Twelve sediment samples were taken on Friday the 20th of October 2000, prior to diving activity. Six samples were taken on a straight line on either side of the Kursk. Each sample was about 30 m from the other and taken at a distance of approximately 3-6 m from the hull of the submarine. The working ROV took the sediment samples by using a hydraulic titanium arm. A special steel corer device with a small hole in the bottom was made on the Regalia which made it possible for the ROV to pick up each corer from a rack of six corers. The diameter of the steel corer was 70 mm with a depth of 400 mm. The ROV picked the corer out of the rack, moved to the predefined sampling location and lowered it into the sediments once or twice to get bulk samples from the sediment surface. The sediment sampling depth was estimated to about 10-30 cm. After each sample was taken, the corer was placed back in the rack. When all six were obtained, the basket with the rack of six samples was lifted up onto the main deck for retrieval. Then the basket was lowered for the second time to take the samples from the left side of the submarine. The co-ordinates for the sediment samples are shown in table A in appendix 1. When the whole operation was over, one sediment grab sample, for radioactivity analysis was performed on the starboard side using the crane. It was taken about 3 meters from the reactor section. The first attempt on the port side failed and there was no time to retry. The 12 sediment samples collected at the beginning of the operation were split and divided for the Russian and Norwegian sides.



The ROV has just taken a sediment sample by use of the Titanium arm.



The ROV are placing the sediment sample, by use of an elastic band, to the rack on the basket located at the seabed.

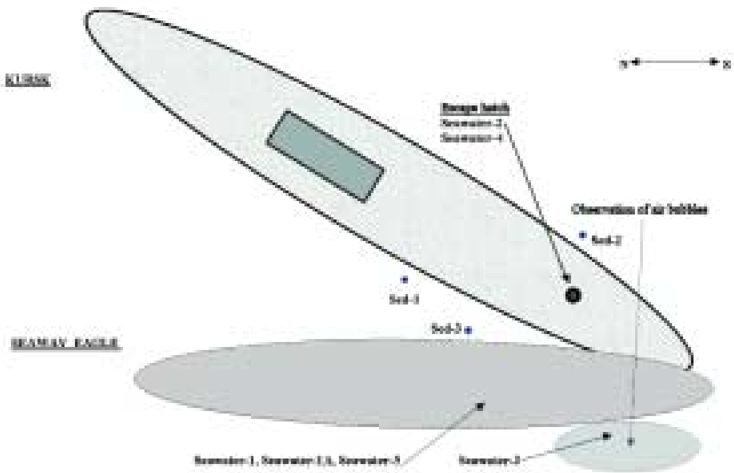


Fig. 6) Location of the Seaway Eagle relatively to the Kursk. The environmental sampling locations at the August expedition are shown.

5.1.2. Water sampling

Six water samples were taken on the August expedition (fig 6). Four of the samples consisted of surface water taken by using a pump onboard the vessel (seawater 1, 1A, 3 and 5). Sample no. 3 was taken immediately after (within 20 minutes) the large air-bubbles broke the surface as a consequence of opening the rescue hatch. One water sample was taken right outside the escape hatch by use of the ROV (seawater 2) and the other sample was taken from the bottom of the rescue hatch, when both the inner and outer hatch were open (seawater 4). Samples 1, 2, 3 and 4 contained 1-1.5 litres, while sample 1A and 5 contained 100 and 125 litres respectively.

On the the Regalia expedition, two water samples were taken on Friday the 20th October at the same time as the sediment sampling was being performed. A Nansen water sampling device, with a volume of approximately 5 litres, was fastened to the same basket as the sediment rack, and lowered down to the submarine. The basket was placed at the left side of the reactor compartment at sampling location no. 9 and about 3 m from the hull of the submarine. Still attached to the basket, the ROV activated a mechanism to close the lids at each end of the tubes and sealed the water inside the Nansen sampler. On the second occasion the basket was lowered at the same position and a new sample was taken. The water samples were taken prior to the sediment sampling.

Water sampling device used for collecting water from inside the submarine at the Regalia expedition. Flexible rubber tubes (yellow) were lowered into Kursk and into a 25 litres plastic container.

After cutting a hole in the pressure hull of compartment no. VIII, a water sample from inside the submarine was taken. Upon opening the pressure hull of compartment no. VIII, no difference in pressure between the inside and outside of the submarine was noticed. Hence, there was not much mixing of water when the water sampling was performed. The sampling was achieved by use of a manual drainage pump with two flexible tubes on each side. One of the tubes was lowered down into the submarine, approximately 2 m, while the other was placed in a 25 litres water can orientated in an upside down position. By pumping, the diver replaced the water in the can with water from inside the submarine. The can was sealed and lifted onto the main deck. A similar water sampling procedure was used in compartment III and IV.

Using the fire-hose on the main deck, 1000 l of sea-water was pumped through a rig with a 1 µm prefilter and two ceasium sorbent cartridges. The water intake was located 16 metres below the surface. Use of sorbents allows radioactive ceasium in seawater to be concentrated for subsequent gamma spectrometric analysis. The fire hose was also used to sample 200 litres of water, after pumping it through the 1 µm filter, for plutonium analysis onshore.

5.1.3. Air sampling

During the Seaway Eagle expedition in August, the divers collected an air sample using a gas-tube as air was coming out of the submarine as a consequence of opening the rescue hatch. Onboard the Seaway Eagle, some of the air was transferred to a 3 litres balloon which was analysed by gamma-spectrometry using the NaI detector. On the Regalia expedition two air samples were collected in compartment III and IV after opening the pressure hull. The divers used a funnel and a plastic can to collect air coming out of the hull.

An air sampling device, drawing 140 m^3/hour through a Whatman GF/A glassfiber filter, was used on both expeditions. This device is used to get a picture of airborne radioactivity at a specific site. The filter, with a diameter of 22 cm was analysed using the HpGe detector. On both expeditions the device was placed outside on the main deck. On the expedition in August, the air sampler was started at 17.00 on Sunday the 20th. The first filter was taken out and replaced by a new one on Monday, at 23.00. On Saturday, October 21st, at 22.30, the air sampling device was set up on the Regalia. The next day, on October 22nd at 13.00, the filter was taken out to be used as a reference filter, and it was replaced by a new one prior to completing the first cut into the submarine. The next filter was taken out on October the 28th and analysed at our laboratory onboard the Regalia.

5.2. Measurements

5.2.1. Personal dosimeters

On both expeditions all divers involved in the operations used personal dosimeters (badges) from the National Radiation Protection Board (NRPB). Each diver received his own badge to wear under his diving suit while he was in the water. When he was not diving, the dosimeter was collected by the diving supervisors and handed back next time the diving bell was going down into the water. These procedures are routine for every type of operation involving the possibility of being exposed to elevated levels of radiation. The

Two operators are preparing the ROV for a new working period.

personal dosimeters are not a radiation protection device but show the total dose received during a certain working period. After the expedition in August, four of the six divers did not receive a radiation dose above the detection limit of 100 µSv. The two other divers received a radiation dose of 200 µSv. By comparison, employees working with radiation can receive a radiation dose of 20.000 µSv each year as a general rule under both Norwegian and British legislation. Results from the personal dosimeter readings from the October expedition showed that radiation doses for every badge were below detection limit.


Front part of the ROV is shown with the titanium arm (left) and the dose rate meter in the water-proof housing (upper left).

5.2.2. Dose rate measurements

Two different types of equipment were used to perform dose rate measurements in the water. The divers were equipped with, initially, three sets of dose rate meters (GM-counters) manufactured by OIS (Oil Industry Services). The ROV was equipped with an Automess 6150AD1 SF dose rate meter, which was put inside a specially made pressure-proof box and placed in front of the camera on the ROV. All the dose rate meters employed were checked against a standard radioactive source before the operation started. The readings showed good agreement, and no significant deviation was observed between the different meters.

On both expeditions to the Kursk , the remote operating vehicle performed an initial survey around the Kursk with a dose rate meter. A camera on the ROV showed the display and hence the radiation levels were continuously available for the working crew. The purpose of this survey was to monitor the radiation levels to make sure that the working conditions were safe for the divers. On the first expedition, the ROV was only allowed to survey the stern part of the submarine, at the position of the reactor compartment (compartment no. VI), and backwards. On the October recovery expedition, the ROV went all around and on top of the submarine. The distance from the dose rate meter to the submarine was estimated to be 0.5 –1.0 m.


A diver is measuring the dose rate when an access hole in the Kursk is completed.

Dose rate measurements were performed outside the submarine by the divers during their work and also by the ROVs with cameras pointing at the mounted Automess dose rate meter. On the August expedition, a dose rate measurement was performed after opening the rescue hatch. In October, each diving team entering the submarine was equipped with a dose rate meter. Immediately after cutting holes in the outer or inner hull of the submarine, the divers measured the dose rate at or inside the hole. This procedure was followed when the divers were cutting their way through compartments no. VIII, III and IV. For making readings inside the submarine the Russian divers received a dose rate meter placed in a basket or mounted on a stick and held it in front of the camera for making readings inside the submarine.

All samples of water and sediments, which were taken up to the Seaway Eagle and the Regalia, were monitored by dose rate meters before they were taken to the mobile laboratory established on the vessels. The dose rate measurements were performed to ensure safe handling of the samples, and to prevent any kind of contaminated material entering the main public area onboard. The measurements were performed by use of an Automess 6150AD1 SF meter equipped with a gamma probe.

Measurements onboard the Regalia of a piece of the outer hull from compartment III.

Initially, onboard the MSV Regalia, dose rate measurements were performed on equipment which was lowered down to the submarine, e.g. cutting devices and the ROVs. These measurements were performed mainly as a result of requests by workers handling these devices on the main deck. All readings showed background levels in the range 0.0-0.1 µSv/hour.
On the October expedition, a number of holes were cut in the submarine to provide access for the divers entering the submarine. Compartment no. VIII was the location of the first cut. A large piece of the outer hull was cut out and lifted onto the main deck of the Regalia. A dose rate measurement was performed on the piece. This procedure was followed for all parts being cut out of the submarine. Also pieces of pipe-work and instruments or equipment from between the two hulls were lifted onto the MSV Regalia and measured.

An oxygen mask found floating out of the hole was taken up and measured for dose rate on the main deck. A personal dosimeter from one of the casualties was brought to the laboratory on the MSV Regalia. The Russians said that the dosimeter belonged to a worker from the reactor compartment, compartment no. VI. Cover suits used by the divers, who worked inside compartments no. VIII and IX of the submarine, were brought up onto the Regalia and measured.

A Russian sorbent rig for the measurement of levels of radioactive ceasium in seawater, was, on October 29th, brought up onto the main deck of the Regalia by mistake. The Russians explained that these sorbent rigs were sent out by the research vessel the Akademic Keldysh. Dose rate measurements performed on the rig showed only background levels.

5.2.3. Gamma-spectroscopy measurements

Onboard both the DSV Seaway Eagle and the MSV Regalia, mobile laboratories were established to perform gamma spectroscopy measurements. Two types of instruments were used for this purpose; a high resolution (2.0 keV for ^{137}Cs) germanium detector (HPGe) and sodium iodide detectors (NaI) with lower resolution (58 keV for ^{137}Cs) but higher efficiency. Two types of NaI equipment were used; a 2" x 2" detector with an EasySpec multi-channel analyser and a 3" x 3" detector with a Canberra series 10 multi-channel analyser.

The sediment samples, water samples and air filters were all analysed by the HPGe detector. All readings and data analyses were also checked manually by studying every individual peak which was registered. Most of the samples were also analysed using the NaI detector, especially for the purpose of screening and for obtaining a quick indication of whether activity levels above normal were present. Other types of samples; like the ceasium sorbents, small pieces from the submarine and equipment from inside the submarine were also measured by a HPGe- or NaI-detector at the mobile laboratory on site.

*Some of the equipment at the mobile laboratory on the Regalia. From left: Automess dose rate meter; Bicron dose rate meter; EasySpec with 2"*2" NaI detector; Canberra serie 10+ with 3"*3" NaI detector with a 200 ml. sample box on top.*

The mobile laboratory at the Regalia. A HPGe detector, mounted on a stand is shown in the back.

The cover suits used by the divers, working inside compartments no. VIII and IX of the Kursk, were also measured using the HPGe detector. The suits were put in a plastic bag, placed on top of the detector and measured over-night to determine whether it was possible that radioactive dust and particles from inside the compartments was attached to the cover suits.

The small piece of the inner hull of compartment no. VIII was measured by the NaI detector, which was placed on top of the 50 mm thick steel piece and measured over-night. The resulting spectrum is shown in fig. 8.

A measurement of a piece of the pressure hull from compartment VIII is performed by use of the EasySpec multichannel analyser with the NaI detector.

After the expeditions, all the samples were brought to the NRPA laboratory on shore for more accurate and extended analyses.

5.3. Monitoring results

All dose rate measurements made by the ROVs, on both expeditions, showed normal background levels in the range 0.0-0.1 µSv/hour. Therefore, they did not show any evidence of leakage from the submarine. Neither did readings conducted outside the reactor compartment nor close to visible cracks in the submarine, show any sign of elevated levels. Due to shielding by the hull and the distance, it is estimated that the water inside the reactor section must exceed an activity concentration of about 37 kBq/litre before it is possible to detect enhanced dose rate levels outside the hull.

The dose rate measurements performed by the divers working outside the submarine, at the holes in the submarine and inside compartment no. VIII and no. IX, did not show radiation levels above normal. All readings were in the range of 0.0-0.1 µSv/hour.

The dose rate measurement of equipment (oxygen mask, personal dosimeter, cover suits) and pipes and pieces from the submarine showed only normal levels in the range 0.0-0.1 µSv/hour.

Samples of water and sediments from the Kursk were analysed by gamma spectrometry in the mobile laboratories established on both the Seaway Eagle and the Regalia. These preliminary results did not indicate the presence of radionuclides that may have leaked from the submarine and did not indicate activity levels above normal. Some of the spectra obtained from NaI measurements onboard the Regalia on the October expedition, are shown in figures 7-9. They originate from screening measurements of sediment and water samples from inside the Kursk and from an air sample taken from compartment IV. As shown in the figures, the dominating radionuclides were the naturally occurring ^{40}K and ^{214}Bi.

Table 1 shows the concentrations of radionuclides in selected samples of sediments, seawater and air filters from the expeditions after they had been analysed at the low-background NRPA laboratory onshore at Østerås, Norway. A concentration range of 0.7 – 1.5 Bq/kg of ^{137}Cs was detected in the sediments. This level is similar to concentrations normally found in the Barents Sea (AMAP, 1998; Grøttheim, 2000) and therefore they do not originate from the Kursk. Concentrations of ^{131}I, ^{134}Cs and ^{60}Co were not detected in any of the samples. Six sediment samples from the front part of the submarine have been measured for ^{238}Pu and ^{239,240}Pu activity. Activity concentrations in the range 0.006 - 0.015 Bq/kg and 0.03 - 0.07 Bq/kg were detected for ^{238}Pu and ^{239,240}Pu, respectively. These concentrations are normally found in the Barents Sea. A ^{238}Pu to ^{239,240}Pu ratio in the range 0.03 - 0.07 indicates that the plutonium originates mainly from the global fallout, having a reported ratio of about 0.04 (UNSCEAR, 1982).

Measurements of gamma emitting radionuclides in seawater samples did not show elevated activity concentrations. All readings were below detection limits of 0.5 Bq/l for ^{131}I, ^{137} Cs, ^{134}Cs and ^{60}Co. Plutonium analysis were performed on water samples from both expeditions. These results showed activity concentrations of 0.003 and 0.005 Bq/m^3 of ^{239,240}Pu which is normally found in these waters. A ceasium sorbent was also measured after flushing with 1000 litres of seawater from the water intake on the Regalia located 16 m below sea level. This sorbent was measured onshore resulting in an activity concentration of 3.4 x 10^{-3} Bq/l.

The analysis of radionuclides in filters from the sampling of air-borne activity using the air-sampling device on board of the DSV Seaway Eagle and the MSV Regalia, showed only the occurrence of natural radionuclides and normal radioactivity levels in air. These analyses were performed onboard by use of the HPGe-detector. Screening analyses of air samples from inside compartments no. III, IV and IX showed normal background levels. Also, the measurements of gamma activity from the air filters, conducted at the NRPAs low background laboratory onshore, showed activity levels below the detection limit of 1 x 10^{-5} Bq/m^3. These readings showed, not surprisingly, that no airborne radionuclides from the Kursk were detected by the air-sampler.

Air filters					
Sampling locality SeawayEagle; SE Regalia; REG	**Period of measuring, date in 2000**	***Concentrations in air (Bq/m^3)***			
		I-131	Cs-137	Cs-134	Co-60
	20.08-21.08	< 0,0109 10^{-3}	< 0,0109 10^{-3}	< 0,0109 10^{-3}	< 0,0109 10^{-3}

Sediments						
Sample no.	**Sampling date**	**Concentrations in sediments (Bq/kg) d.w.**				
		I-131	Cs-137	Cs-134	Pu-238	Pu-239,240
Sed-1SE	20.08	< 0,7	0,7 +- 38%	< 0,6	n.a.	n.a.
Sed-2SE	20.08	< 0,6	0,7 +/- 25%	< 0,6	n.a.	n.a.
Sed-3SE	22.08	< 0,3	0,7 +/- 11%	< 0,3	n.a.	n.a.
Sed-1REG	20.10	< 0,7	1,3 +/- 10%	< 0,6	0,006 +/- 67%	0,04 +/- 61%
Sed-2REG	20.10	< 0,7	1,0 +/- 10%	< 0,6	0,013 +/- 38%	0,04 +/- 40%
Sed-3REG	20.10	< 0,7	1,2 +/- 12%	< 0,6	0,015 +/- 47%	0,07 +/- 42%
Sed-4REG	20.10	< 0,7	1.0 +/- 20%	< 0,6	n.a.	n.a.
Sed-5REG	20.10	< 0,7	1,2 +/- 8%	< 0,6	n.a.	n.a.
Sed-6REG	20.10	< 0,7	0,9 +/- 11%	< 0,6	n.a.	n.a.
Sed-7REG	20.10	< 0,7	1,2 +/- 8%	< 0,6	n.a.	n.a.
Sed-8REG	20.10	< 0,7	1,2 +/- 9%	< 0,6	n.a.	n.a.
Sed-9REG	20.10	< 0,7	0,7 +/- 11%	< 0,6	n.a.	n.a.
Sed-10REG	20.10	< 0,7	1,5 +/- 7%	< 0,6	0,014 +/- 50%	0,03 +/- 52%
Sed-11REG	20.10	< 0,7	1,4 +/- 11%	< 0,6	0,015 +/- 40%	0,04 +/- 36%
Sed-12RLG	20.10	< 0,7	0,9 +/- 17%	< 0,6	0,008 +/- 63%	0,03 +/- 61%
Sed-13REG	07.11	< 0,7	1,2 +/- 9%	< 0,6	n.a.	n.a.

Water samples					
Sample no.	**Sampling date**	**Concentrations in water (Bq/l)**			
		I-131	Cs-137	Cs-134	Co-60
Seawater-1-5SE	20.08	< 0.5	< 0.5	< 0.5	< 0.5
Seawater 4 REG	27.10		3,4 · 10^{-3} +/- 4%		
		Concentrations in water (Bq/m^3)			
		Pu-238		Pu-239,240	
Seawater 1A+5 SE	20-22.08	0,0004		0,0034 +/- 0,00007	
Seawater 5 REG	28.10	< 0,0005		0,0050 +/- 0,00009	

Table 1) *Activity concentrations of samples taken in close vicinity of the Kursk.The sample numbers refers to the locality of sampling as shown in Fig. 5 and 6 (n.a. = not analysed).*

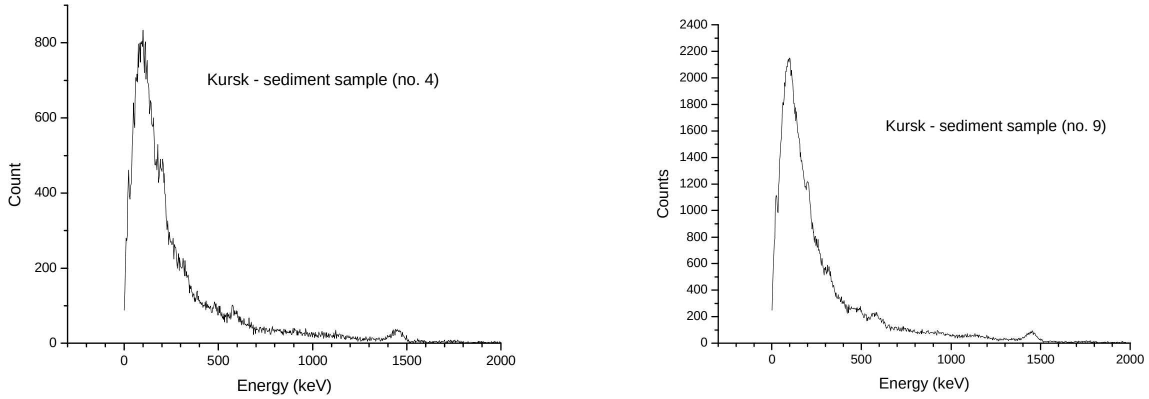


Fig. 7) *NaI spectrums for sediment sample SED-4REG (left) and SED-9REG (right) at a distance of 3-6 m from the submarine outside the reactor compartment (compartment VI). The total number of counts as a function of the energy (keV) is shown. Sample no. 9 was taken from the left side of the submarine, while no. 4 was taken on the right side. (Note that the Y-axis, showing total number of counts, should not be compared because the timeperiod of counting is not identical for the two samples).*

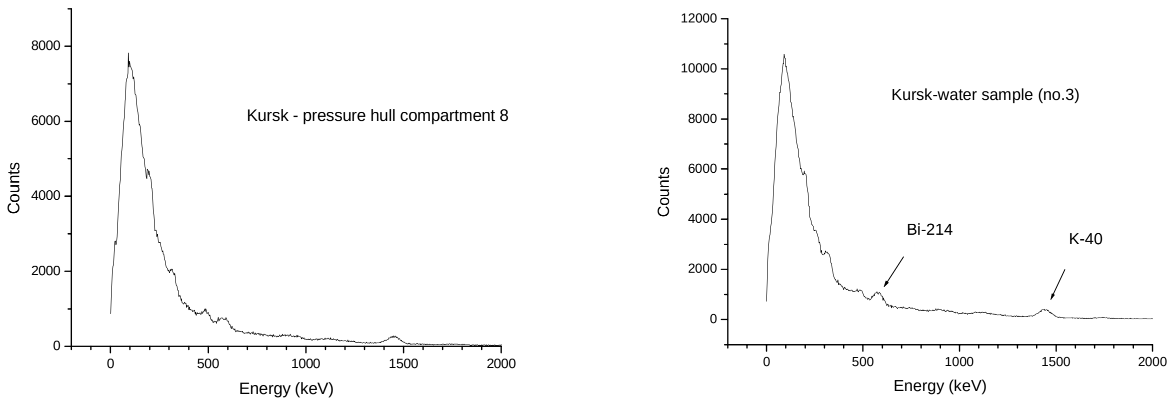


Fig. 8) *NaI spectrum from a small piece of the pressure hull from compartment VIII (left). To the right is a spectrum from the water sample, which was taken inside compartment VIII of the submarine. The natural occurring radionuclides ^{214}Bi and ^{40}K is indicated in the figure to the right. (Note that the Y-axis, showing total number of counts, should not be compared because the period of time is not identical for the two samples).*

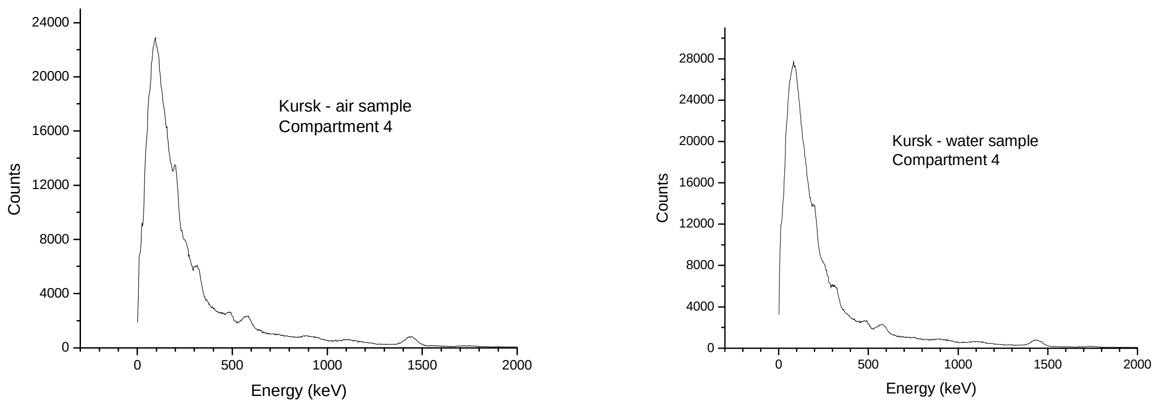


Fig. 9) *NaI energy spectrum of air sample (left) and water sample (right) from inside compartment no. IV. The total number of counts is shown as a function of energy (keV).*

Potential impact of radioactive releases from the Kursk

An assessment of the potential impact of radioactive releases from the Kursk is based on several independent factors that have to be assessed or calculated. Some of the most important factors which need to be taken into account are:

- ✓ **radionuclide inventory**: the total content (types of radionuclides and activity levels) in the two submarine reactors;
- ✓ **source term**: description of the release of radionuclides over time;
- ✓ **mobility**: the possibility of transport of different types of radionuclides in the seawater; solubility, rate of fixation to sediments and the current speed and direction at the seabed is taken into account;
- ✓ **uptake** of radionuclides in the marine food-chain, and estimation of the human consumption of these products.

All these factors must be estimated to be able to model the impact of releases from the submarine. Large uncertainties are attributed to each of these factors and these determine the uncertainties in the final result. However, at present, the numerical level of uncertainty is not established for each of these factors due to lack of accurate information or lack of data. The largest uncertainty is due to estimation of the source term; the rate of releases from the submarine.

6.1. Radionuclide inventory of the Kursk

6.1.1 Technical data for the Kursk - a discussion

The inventory of the Kursk has been calculated on the basis of a computer reactor model of the Kursk reactors using a set of assumed operational parameters for the submarine. The tool for modelling the reactor has been the computer software HELIOS, developed and supported by Studsvik Scandpower. HELIOS has been extensively validated by comparisons with experimental data and international benchmark problems for reactor physics codes as well as through feedback from applications (R.J.J Stammler et.al, 1996). Some of these benchmarks and studies provide for fuel enrichments of up to 90% and for Russian naval reactors (Criticallity Considerations, 1998). Table B in appendix I contains two sets of the fission products and actinides inventory data for each of the two reactors in "the Kursk". The results are discussed together with the results from the evaluations of source term and the mobility and uptake of radioisotopes in chapter 6.3.

The basic source for the computer model has been technical data for the Russian icebreaker the Sevmorput as presented in its safety report (Safety Report of Sevmorput). The Russian icebreakers have been used to test reactor and fuel configurations in the overall development of marine reactors in Russia. Based on earlier efforts to model the fuel behaviour in Russian naval reactors, a reactor model with the hexagonal lattice and the Sevmorput fuel assembly geometry (fig. 10) was chosen as the basis for this work. The reactor and fuel data, which are discussed below, are summarized in table 2. Most of the reactor data on active Russian military submarines is classified due to military restrictions, and a detailed discussion of the technical data and model is necessary in this context. Several choices are made on the basis of secondary and oral sources, an inevitable weakness when considering the interior of submarine reactors.

Considering open source information, the IAEA study (IAEA, 1997) is important, especially for submarines older than the Kursk. The best known portion of the data relateing to the Kursk and its reactor, is the classification: the Kursk is a submarine of third generation, NATO-class Oscar II, with two PWR-reactors, each reactor of 190 MW (Leonid A. Kharitonov). While US submarines usually have one reactor in each submarine together with extremely high fuel enrichment (often weapons-grade material), the Russian Navy almost certainly employs two reactors in each submarine, at least when using PWR, and with

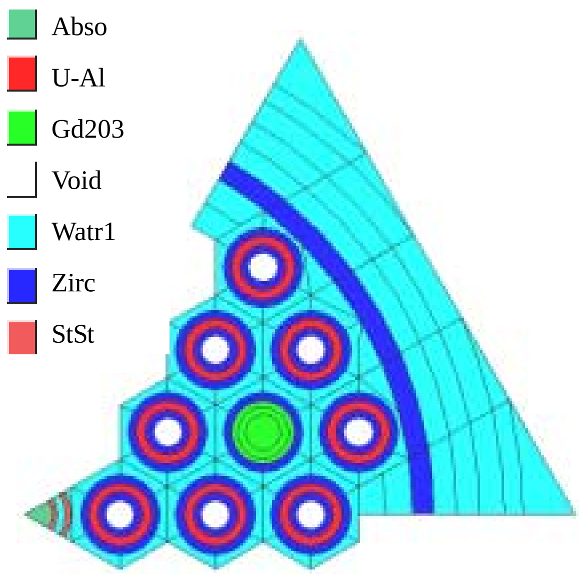


Fig.10) One-sixth of one fuel assembly in the Kursk reactor model (U-Al, alloy, 30% enriched, 150,7 kg U-235, 241 assemblies, 6 Gd pins per. assembly).

subsequently lower fuel enrichment. These properties are important when evaluating how the reactor is controlled, the possibilities for criticality and the amount of some actinides present over a time span of one decade, while the effects on the amount of fission products are less important (fig. 10).

With the former Norwegian Nuclear Energy Safety Authority as initiator and Russian data for selected fission products (ceasium, strontium) and plutonium, Scandpower AS performed calculations of probable configurations and fuel enrichment in the Komsomolets (Scandpower, 1991). One of the results was an estimate of the fuel enrichment, and that the Russian data could be consistent with fuel enrichment of 30%. This is also consistent with other studies referring to fuel enrichment in third generation Russian submarines as between 21% and 45% in one core (Oleg Bukharin et. al., 1995). Another piece of basic data used in the model is the amount of ^{235}U present. Sources claim this to be about 115 kg. However, few independent sources exist, and the calculations include a variation from 100-200 kg. The median value, 150 kg, is consistent with the content in the icebreaker the Sevmorput. Uranium oxide was fuel material was used in early forms of Russian naval fuel, such as in the icebreaker the Lenin. However, as military prerequisites for increased speed and range have increased, while still taking into account the limited space available, the preferred choice has been an alloy of uranium-zirconium or uranium-aluminium. The latter material has been extensively used in research reactors.

The fuel geometry of the reactor is, as is all other data, a matter of much secrecy. The general functions and purposes of solid reactor fuel plates or rods are to maintain a permanent location of the fissile material in the core, retain fission products and fissile material, resist volume changes and provide for optimum transfer of heat. Several geometries covering the arrangements of the assemblies in the core and pins or plates in the assemblies are used in naval fuel, including circular pins and assemblies, and probably also rectangular fuel plates, at least in US submarines (Chenyan et.al., 2000). Another possibility, among others, is dispersion fuel with the fissile material dispersed in a matrix of non-fissile material. Because of the fuel properties of U-Al, together with the fact that several reports claim that such alloys form the basis for modern Russian naval fuel, this fuel was chosen in this project. The basic fuel geometry was taken from the Sevmorput report (The Sevmorput Safety Report).

	Used in model of "Kursk"		Used in model of "Kursk"
Generation	Third	**Core diameter:**	121.2 cm*
Max thermal power (MWt)	200 MW	**Assembly:**	Outer diameter. 6 cm*
U-235 (kg)	Basic: 150.7 kg* Range: 75 – 200 kg	**Outer clad:**	Thickness: 0.06 cm Material: Zr*
Enrichment	Basic: 30% Range: 20-90%	**Inner clad:**	Thickness: 0.06-0.006 cm Material: Zr*
# Fuel assemblies	241*	**Number of pins/assembly**	55*
Fuel composition	1) U-Al alloy foil cladded in Zr tubes. 2) U-Al alloy dispersed in a matrix	**Active core height:**	100 cm*
Fuel geometry	Circular pins in hexagonal lattice*	**Coolant flow area:**	0.26 m^2 *
U-235 pr. fuel assembly (kg)	Basic: 0.625 kg	**Reactor burn:**	12000/24000 MWd

*Table 2) General reactor core and fuel assembly dimension data as a basis for inventory calculations for the Kursk. * The asterisk refers to data taken directly from the Sevmorput safety report.*

6.1.2. Operational data

The second set of input parameters necessary to calculate the core properties is the operational history. This has to be reconstructed on the basis of indicators such as a) earlier operational data for Russian submarines, b) the economy of the Russian Northern Fleet, c) Russian public sources after the accident (describing the recent events for the Kursk), d) other similar sources. Two cases have been developed as part of this work as described in tables 3 and 4. These two sets are based upon the same reactor and fuel configuration. The basis for the two different sets is an average operation of 50 days per year for the submarine, for each year since its commissioning in late 1994, but also including extensive operation of one or both reactors in port to produce electric power (table 4).

Based on assumptions outlined in this chapter, the inventory in each of the reactors in the Kursk is shown in table B, appendix I. The table includes both short- and long-lived radionuclides, and shows the activity for specific radionuclides at the time of the accident and after time periods of one year and one hundred years. However, in the long run, only radionuclides with long half-lives will have any impact while the short-lived ones have disintegrated (disappeared). Cs-137, with a half-life of 30 years, is of major importance both due to the high activity in the reactor but also because it is readily dissolved in the water-phase. It is also very bioavailable and accumulates in edible parts of fish and shellfish.

	1995		1996		1997		1998		1999		2000	
Power MW	40	0	40	0	40	0	40	0	40	0	0	40
Days	50	315	50	315	50	315	50	315	50	295	180	30
Σ MWd	2000		4000		6000		8000		10800		12000	

Table 3) Operational data. The estimated total reactor burn is 12 000 MWd with a basic time of operation of 50 days per year (Case 1).

	1995		1996		1997			1998			1999			2000	
Power MW	40	0	0	40	40	0	15	15	0	40	40	0	15	15	40
Days	50	315	315	50	50	115	200	200	115	50	70	75	220	180	30
Σ MWd	2000		4000		9000			14000			20100			24000	

Table 4) Operational data. The estimated total reactor burn is 24 000 MWd. The basic time of operation is 50 days per year, but it includes an extensive operation of reactors in port to produce electric power.

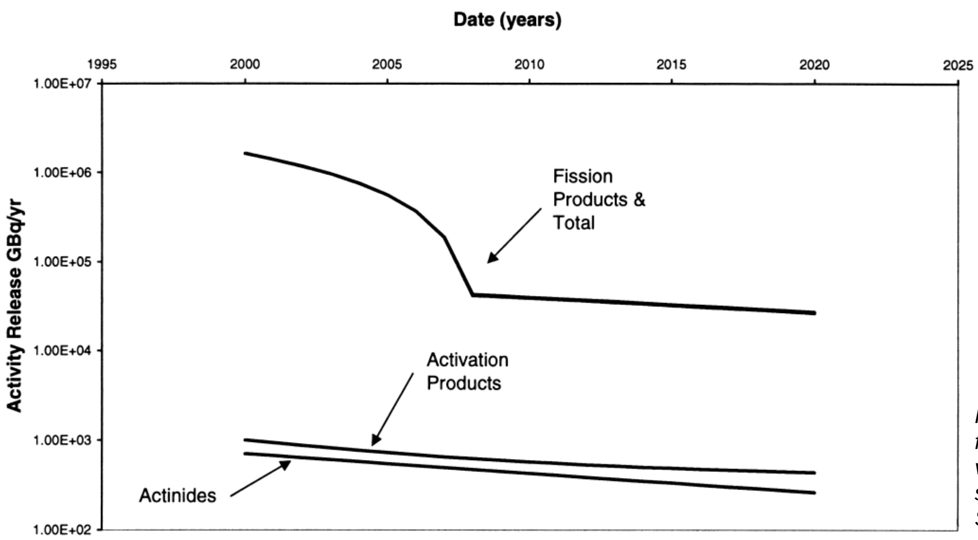


Fig.11) Activity released from reactor pressure vessels in a sunken submarine (NATO Pilot Study, 1999).

6.2. Source term

The source term is a description of the release over time, including the amounts of actinides, fission products, activation products and noble gases. Due to the lack of data on the situation concerning the fuel, the reactor, the reactor compartments and the Kursk itself, these descriptions will be based on given scenarios and not calculations. As a consequence, the results in this report will only take into account two specific scenarios. However, any operation or attempt to recover the submarine has to be based on such calculations as specified by the relevant nuclear safety-, environment- and health governmental authority. An example of a source term is shown in fig. 11.

Concerning releases and source terms from similar submarine accidents, samples from seawater and sediments taken at the sites where the sunken American submarines the Tresher and the Scorpion are resting, at great depths in the North Atlantic, show only minor amounts of ^{60}Co, indicating leakage from the reactor primary system. As described in chapter 1.2.2 measurements of samples in close vicinity of the Komsomelets show only minor releases from the submarine. All of these vessels are at great depths with possible damage to reactor compartments.

Relevant studies include a NATO study (NATO Pilot Study, 1999), which discusses radioactivity release from sunken nuclear submarines, and the Source Term Working Group of the International Arctic Seas Assessment Project (IAEA, 1997). Evaluation of the sinking of an undamaged submarine with fuel cladding intact is included in the former study. Seawater has free access to the reactor pressure vessel outer surface from the time of sinking, resulting in releases only of activation products in the reactor pressure vessel. The release under these conditions is assumed to be 3 GBq annually over 20 years. The latter study includes an evaluation of the source term from the sinking of a damaged submarine. One assumes that damage (collision and sinking) opens the reactor compartment and the primary pipework of one reactor only. In this scenario, the releases are dominated by fission products as the fuel cladding has been damaged in the accident, and the fuel starts to dissolve at the time of accident. In the IASAP study, the release to the sea over 20 years is presented in the following groups:

- ✓ Order of magnitude for release of volatile fission products: 10^6 GBq (over 8 years);
- ✓ Order of magnitude for release of non volatile fission products: 10^6 GBq (over 20 years);
- ✓ Order of magnitude for release of activation products: and actinides: 10^3 GBq (over 20 years).

6.2.1. Source term for the Kursk

Independent sources have claimed that the accident happened within seconds, initiated by an explosion large enough to be detected by NORSAR (NORwegian Seismic ARray), followed by an even larger explosion, perhaps as a result of detonation of explosives inside the front end of the submarine. It is claimed that the reactors were not affected by the accident. According to Russian authorities they were shut down with the implementation of the emergency shut down mechanism as a result of the explosion.

At the moment, it is not possible to calculate radioactivity release from the Kursk on the basis of corrosion and similar mechanisms due to lack of information on materials used and material dimensions. However, if the Kursk remains on the seabed indefinitely, fission products, activation products from the reactor fuel and activation products from the reactor pressure vessel (and other parts of the reactor), will eventually be released to the sea. The release rate, its time dependence and the chemical forms of the release must therefore be estimated from qualitative comparisons with the cases discussed in the studies above.

The following two scenarios have been selected as representative and relevant:

Scenario 1:
An abnormal event after one year during lifting operation, 100 % of inventory released.

Scenario 2:
Assuming that seawater penetrated the reactor compartment at the time of sinking, primary pipework, damaged in the accident, resulted in the penetration of seawater into the reactor pressure vessel, the fuel cladding being initially intact. Assuming that the fuel cladding has *corroded away* after 100 years, and 100% of inventory is released after 100 years.

In considering the actual barriers, the first barrier to the fuel is the cladding. Other barriers are the primary circuit, the reactor compartment and the shielding layers around the compartment. Whether the fuel cladding is zirconium or stainless steel is not known. As long as the fuel cladding is intact, there is no leakage from the fuel at all. Stainless steel cladding can remain intact in seawater for decades, zirconium cladding for hundreds, possible even thousands of years. However, if galvanic corrosion takes place, (pitting corrosion) even zirconium cladding may be penetrated in months.

6.3. Model calculation of potential transport and uptake of radionuclides

A number of different approaches can be used to model the transport of radionuclides in seawater and the impact of possible future releases. Some approaches are based on hydrodynamic current models covering the Barents Sea, other approaches use three dimensional models incorporating wind-speed, internal density distributions, tide and ice transport. Tide water simulations show that tidewater is dominating the water-current in the area of interest and therefore should be an important parameter in the modelling work. Several Norwegian institutes are involved in this kind of modelling work (e.g. Norwegian Polar Institute, Norwegian Meteorological Institute, Norwegian Marine research Institute, SINTEF and NRPA).

NRPA have further developed a box-model for estimating the transfer to biota and the doses to human populations from transport of radionuclides by seawaters (Iosjpe et al., 1997; Iosjpe et al., 2001). The present model is a revised version of the box model which was described by Nielsen et al. (1995).

Results obtained using the box-model are presented in this chapter. The scenarios 1 and 2, described in chapter 6.2.1, are used as a basis for modelling. By using two sets of total operation time for the reactors (12000 MWd and 24000 MWd), four sets of inventory data are available. These data sets are shown in table B in appendix 1.

Scenario 1 represents a hypothetical an abnormal event to occur e.g. during a lifting operation. In the calculations it is assumed that 100% of the inventory in both reactors is released immediately. Furthermore, an operational period of 24000 MWd are used as one example. All these assumptions are highly conservative and represent a “worst case” scenario and not a prediction of the most likely event to occur in case of an accident. However, based on present knowledge we can not exclude the possibility of a criticality accident even though it is not likely that it will happen during an accidental event. The possibility of such an event should be looked at in more detail.

Fig. 12) Dispersion of ^{137}Cs (Bq m^3) after a potential release of radionuclides from the submarine the Kursk into the Barents Sea.

Dispersion of ^{137}Cs in the oceanic water as a result of a potential accidental release from the submarine the Kursk is shown in Figure 12. The dispersion is shown for the surface water boxes relating to seafood catchments areas. Transport of radionuclides between the different boxes as a function of time is estimated. The model also includes the interaction of each radioisotope between the water- and sediment phase. However, only ^{137}Cs is shown on the figure because it is by far the most significant radionuclides regarding radiation dose to man. Data on the size of the biota and fish catches in the area are included in the model.

Calculations show that 0.5 years after release, the water concentration in an area adjacent to the submarine may be about 150-200 Bq/m^3 and it will decrease rapidly. After 10 years it is estimated that the water concentration in the Barents Sea will be in the range 0.1 – 2.8 Bq/m^3.

The dynamics of the ^{137}Cs concentration in fish for the Barents Sea region are shown in Fig. 13. Calculations correspond to the “worst case scenario” with a serious accident one year after shutdown (scenario 1), an operational period of 24000 MWd and assuming a release of 100 % of the radionuclides in the two reactors. Maximum, minimum and average activity concentrations in fish correspond to areas with maximum, minimum and average ^{137}Cs concentrations in the sea water.

The plots in Fig. 13 indicate that during the first period of the potential dispersion of the radionuclide, ^{137}Cs concentration in fish would vary widely depending on the habitat of fish, because during the beginning of the dispersion, the Barents Sea would contains regions with both relatively high contamination and without contamination at the same time. Therefore, the monitoring of the actual areas and sea production is currently a central task. The model calculations show a maximum value in the range 80-100 Bq/

kg of ^{137}Cs during the first year as a result of the “worst case” leakage from the Kursk while the average concentration is in the range 10-20 Bq/kg. However, these calculations are attributed to large uncertainties, and other more hypothetical transfer pathways to fish (e.g. ingestion of particles) has not been considered. Currently, the average concentration of ^{137}Cs in fish in the area is in the range 0.2-0.5 Bq/kg (Brungot et al. 1999). The European Commision has recommended an intervention level of 600 Bq/kg for radioceasium, in terrestrial and marine food products.

Results of the preliminary calculations of the collective doses to man are shown in Table 5. Calculations correspond to an estimated release of all radionuclides in each of the two reactors for four different cases. The table shows that doses to man are dominated by the contribution from ^{137}Cs. It also shows that a collective dose of 61 manSv were attributed to intake of ^{137}Cs from the Barents Sea alone for the “worst case scenario”, while the total collective dose from all radionuclides from the whole marine area were estimated to 97 manSv. Total collective doses, from ^{90}Sr, ^{134}Cs, ^{241}Am and ^{106}Ru, for the same scenario, are estimated to 6.5, 4.4, 2.2, and 0.27 manSv, respectively. Considering the scenario representing corrosion leading to a release after 100 years, the total collective dose was estimated to 8.4 manSv, with an operational period of 12000 MWd. Calculations show that more than 80% of the collective dose originating from the Barents Sea is due to ^{137}Cs exposure. Plutonium-239 is shown to contribute very little to the collective dose compared to ^{137}Cs for scenario 1, but for total collective doses corresponding to scenario 2, ^{239}Pu impact can be compared with ^{137}Cs due to radioactive decay of ^{137}Cs. For comparison, the collective dose to the European population as a result of releases from Sellafield is estimated to be 4600 manSv (AMAP, 1998).

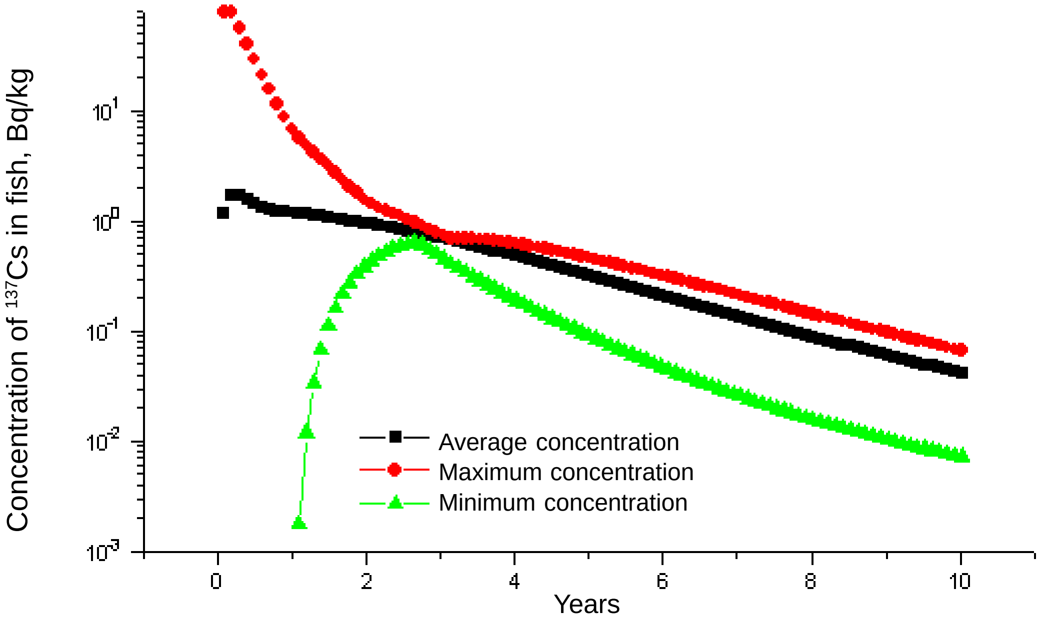


Fig. 13) *Dynamic of the ^{137}Cs concentration in fish (Bq/kg) for the Barents Sea regions in the first ten years after release to the environment.*

Scenarios / operational period	Collective dose in the Barents Sea (manSv)			Total collective dose (manSv)		
	^{137}Cs	^{239}Pu	All radio-nuclides	^{137}Cs	^{239}Pu	All radio-nuclides
Scenario 1 12000 MWd	29	0.25	34	33	3.2	43
Scenario 1 24000 MWd	61	0.42	73	69	5.5	97
Scenario 2 12000 MWd	3.1	0.25	3.8	3.6	3.2	8.4
Scenario 2 24000 MWd	6.1	0.42	7.4	6.9	5.5	19

Table 5) *Collective doses to man (manSv) during a time period of 1000 years for two different scenarios and two different operational periods for the reactors. Scenario 1: criticality accident after 1 year. Scenario 2: corrosion after 100 years.*

Monitoring programmes in the Barents Sea

7.1. Present monitoring programmes

The existing Norwegian marine monitoring programmes give a good overview of levels of radioactive substances in the Barents Sea and the sources contributing to those levels. In general, fish from the Barents Sea contain very little radioactivity, and less than fish from the Baltic Sea or from the Irish Sea.

Norwegian authorities has for many years conducted a comprehensive monitoring programme in the marine environment, including the Barents Sea. Much knowledge has also been gained through Norwegian-Russian joint expeditions to northern areas, e.g. the Kara Sea expeditions to Russian dumping sites in 1992, 1993 and 1994.

In 1993 the NRPA started a comprehensive systematic sampling and monitoring programme of fish and shellfish from the available fishing grounds in the Northern Seas in collaboration with the Institute of Marine Research and the Norwegian Directorate of Fisheries. This programme is financed by the Norwegian Ministry of Fisheries. The programme was started mainly in order to be able to respond to rumours and speculation regarding radioactive pollution of the Northern Seas by presenting updated data on activity levels in marine food products together with information on sources of radioactive contamination. Results from the monitoring programme are published in NRPA reports (Kolstad AK, 1995; Brungot et al., 1997, 1999).

The Norwegian Food Control Authority started the project «Identification and monitoring of radioactivity in salt-water fish from the northern areas» in 1993. Each year at regular intervals, samples of fish are collected along the Norwegian coast, the fishing grounds and in the Barents Sea. A total of about 200 samples of fish and shrimps have been collected during the period 1993-1999 (Øvrevoll B., 2000).

In 1999 a more comprehensive marine surveillance programme was established by NRPA with finance from the Norwegian Ministry of Environment. The purpose of the programme is to monitor trends in the radioactive pollution of water, sediments, fish and other important marine species and to assess the consequences of such contamination. This programme is also focusing on possible national sources of contamination of the marine environment e.g. from nuclear research installations, hospitals and offshore activities. With a time interval of three years, monitoring activity is taking place in the largest fjords of the western part of Norway for studying the river transport from the catchments areas that were heavily affected by radioactive fallout from the Chernobyl accident.

The concentration of radionuclides in fish is to a large degree proportional to the concentration in the water. The highest concentrations of ^{137}Cs can be found in whiting and cod from Skagerak with a level of around 1 Bq/kg fresh fish and the concentrations in seawater and fish decreases to the north.

7.2. Need for future monitoring programmes in relation to the Kursk accident

Even though no leakage of radioactivity from the Kursk has been observed (see chapter 5), there is a need for further study and surveillance of the radiation situation in the vicinity of the Kursk. It is of importance to be able to continuously obtain official documentation of the radioactivity levels in fish and in the environment. In case of possible leakage it is important to receive that information as soon as possible. No one can be completely sure that the reactors are not damaged and that no leakage will occur in the future. If the submarine is not raised, it will start to leak sooner or later due to corrosion processes. Another important aspect is that the Kursk lies in a very important fishing area, which represents large economical interests for several countries. The fishing industry is very sensitive, and only a rumour of radioactive contamination can lead to serious economical consequences for the fishing industry. This was experienced for many years following the accident with the Russian submarine the Komsomolets which went down south of Bjørnøya in 1989. Already in October 2000 the general director for Rubin, Mr. Spaskij, said there were plans for raising the submarine the Kursk during 2001 and that the work to obtain international funding had already started. Later, the president Vladimir Putin officially stated that the submarine should be raised. At the time of writing this report there are uncertainties regarding the raising of the submarine. However, a plan for raising the Kursk in the period July - September 2001 have been worked out.

In Norway, the task of intensifying a marine monitoring programme is of interest for several ministries. Therefore, the NRPA worked out a plan for how this work could be organised and presented it to the Ministry of Foreign Affairs, the Ministry of Health, the Ministry of the Environment and the Ministry of Fisheries. Many Norwegian institutions will play a central part in this programme, which is headed by the NRPA. The following sketch shows the main components of the programme.

Intensified monitoring of radioactivity levels in fish
The monitoring programme on fish should be extended and should include different kinds of species. Samples should cover the most important fishing grounds at any time. Analysis of other radionuclides apart from just radioceasium should be conducted.

Placement of a buoy for continuous monitoring of radioactivity in seawater
A floating buoy with a radiation detector (NaI) capable of continuously measuring radioactive contamination in seawater should be placed at the location of the Kursk. This detector is particularly suitable for monitoring ^{137}Cs, but will also be able to detect other radionuclides. It is possible to place detectors both at the surface and at the bottom. This kind of buoy can carry instruments for measuring physico-chemical parameters such as current velocity, salinity and temperature. The readings are transferred through satellite communication and signals can be read off at any location.

Monitoring in the marine environment
Expeditions to the submarine for performing sampling of water, sediments and biota should be done once or twice a year. These expeditions should be planned in close co-operation with the Russian authorities. Furthermore, a location for monthly sampling of water and seaweed should be established in the eastern part of Finnmark. Such a station is now established at Grense Jakobs Elv.

Impact assessments and model calculations
It is essential to gain knowledge on the possible impact of future leakage of radionuclides from the Kursk. This work will involve information on the radioactivity content of the reactor, transport of different radionuclides in the water phase, sedimentation rates, current velocity, uptake into the marine food chain etc. Such impact assessment will be performed through co-operation between several institutes with competence in the fields of meteorology, marine research, water transport modelling and marine radioecology.

Information and reporting
The results from this enhanced surveillance project should be presented in a suitable way. It is essential that monitoring results and impact assessment should be made available for everyone with interests in this field. Furthermore, it is important to have an updated printed version of the environmental status at any time, with special focus on activity levels in fish. In addition to ordinary reporting, the obtained information should be made available on the Internet as soon as possible. The information should always be presented in a way, which is most amenable to the media, the general public, governmental authorities and the fishing industry.

An important aspect of the future marine monitoring-programme will be to continue the close co-operation with the relevant Russian authorities and institutions. This will mainly be conducted through the existing Norwegian-Russian Environmental co-operation which was established in 1988. In 1992, as a result of new information on Russian dumping of radioactive waste in the Kara Sea, a specific group was established called “Norwegian-Russian Expert Group for Investigation of Radioactive Contamination in the Northern Areas”. This contact network was utilised at a very early phase in the Kursk accident for providing mutual information on monitoring activities conducted by both countries.

The five point programme presented above was discussed at a meeting with Russian officials which took place in Moscow in early December 2000. It was agreed to continue the close co-operation in this field and that monitoring data and general information should be exchanged. A common database should be established. Furthermore, joint expeditions to the Kursk should be planned and a working group should be formed to assess the impact the submarine may have, whether it is raised or not. These joint activities will offcource be performed in accordence with the plans for raising the submarine

The Russian Ministry of Foreign Affairs officially responded to these suggestions on the 15th March 2001. They stated that they were positive to the co-operation including joint expeditions and establishing of a working group on impact assessments. However, the placing of a monitoring buoy for continuously monitoring of radioactivity directly at the location of the Kursk was not considered to be necessary.

8 Conclusions

The loss of the Kursk with its 118 crew members was first of all a human disaster. The letter found on one of the casualties in compartment no. IX indicated that the crew in the back of the submarine, compartments no. VI, VII, VIII and IX were alive after the explosions. As of the time of writing it is not publicly known how this tragedy actually occurred. However, one of the theories is that an internal explosion in the bow part, compartment no. I, caused all or several of the torpedoes to explode.

Based on viewing the pieces from the hull taken up to the Regalia, and what could be seen by the use of the videocameras from inside compartments no. III, IV, VIII and IX, it can be assumed that there was fire in compartment no. III and no. IX and no sign of fire in compartment no. IV and no. VIII. The reason for this is not clear but one explanation may be that the fire in no. IX did not originate from the explosions in the bow part but rather from an ignition in the electrical system or from a cigarette or match, perhaps in combination with the increased oxygen content as a result of higher air pressure or from available oxygen tanks.

No indications of leakage from the submarine have so far been observed. Elevated levels of radioactivity have not been detected in any dose rate readings or any of the measurements on environmental samples taken close to the Kursk. Furthermore, no increased levels were measured on debris from the submarine or from water and air sampled inside different compartments at the October expedition. These analyses have been performed by the NRPA. However, according to our information, the measurements performed by Russian institutions and authorities do not indicate elevated levels either.

The fact that no elevated radioactivity levels have so far been observed indicates that the reactors have been shut down, as stated by the Russian authorities during the initial phase. It also indicates that the reactor compartment is not flooded with contaminated water. If the reactor compartment were flooded with highly radioactive contamination, radiation would most probably have been detected by dose rate measurements taken close to the hull outside of the submarine. The shielding of 50 mm steel from the pressure hull, about 1-2 meters of water between the hulls and finally 8 mm steel and 8 cm rubber of the outer hull would probably not be enough to attenuate the high energy gamma radiation.

Based on the modelling of possible transport of radionuclides in the water and uptake to fish and biota, the impact on man and environment from the Kursk should not be considered very serious. Experience from the Komsomolets accident supports this conclusion even though it lies on a depth of 1670 meters and in a much less productive fishing area. The “worst case” hypothetical scenario represents an abnormal event to occur during a lifting operation one year after the accident. The concervative modelling calculations indicate an activity concentration of ^{137}Cs in fish of the order of about 80-100 Bq/kg if 100% of the radioactivity in the reactors is released to the environment. However, such estimates are of course attributed to large uncertainties. The present activity levels in fish from the Barents Sea is normally below 1 Bq/kg and the intervention level in Norwegian food-products is 600 Bq/kg of ^{137}Cs. However, the economical impact following a serious leakage from the Kursk is hard to estimate. These markets are very sensitive and such a situation may result in severe economical losses for companies with fishing interests in these areas.

It is needed to further improve the assessment of the long term environmental impact from the Kursk and what kind of impact a possible raising operation may lead to which relates to the state of the reactors. For performing this work, more information regarding the inventory and source term are needed. Such information will hopefully be provided by the Russian participants in the joint working group on impact assessment.

As long as the Kursk is lying on the seabed, it will be of great importance to run a surveillance programme for monitoring the radioactivity levels in the environment in the area. It is essential to be able to provide information to the press, the public, the fishing industry, governmental bodies etc. regarding the status of environmental contamination and the estimated impact. It is important to continue the co-operation and have a close contact with the relevant Russian institutes and authorities to gain optimal use of resources and to exchange information. The already established Norwegian-Russian environmental co-operation will be used for this purpose.

At the present time, June 2001, there exists plans for raising the submarine in the periode July-September this year. However, there are uncertainties whether it is possible to raise the Kursk in that time period.

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Appendix 1

Table A) *Co-ordinates for sediment samples in close vicinity of Kursk. The samples were taken 20th October 2000.*

Sample no.	North	East
1	69°, 37.016'	37°, 34.287'
2	69°, 37.011'	37°, 34.326'
3	69°, 37.004'	37°, 34.369'
4	69°, 36.997'	37°, 34.408'
5	69°, 36.990'	37°, 34.454'
6	69°, 36.982'	37°, 34.495'
7	69°, 36.966'	37°, 34.474'
8	69°, 36.973'	37°, 34.435'
9	69°, 36.981'	37°, 34.387'
10	69°, 36.987'	37°, 34.348'
11	69°, 36.993'	37°, 34.308'
12	69°, 37.002	37°, 34.265'

Table B) *List of isotopes in Kursk reactor model (one reactor) for 12000 MWd and 24000 MWd of operation at reactor shutdown, after 1 and 100 years of cooling time.*

Operation time	12000 MWd			24000 MWd		
Cooling time after end of operation	0 year (at reactor shutdown)	1 year	100 year	0 year (at reactor shutdown)	1 year	100 year
Isotopes	(Bq)	(Bq)	(Bq)	(Bq)	(Bq)	(Bq)
Kr-85	1.6E+14	1.5E+14	2.5E+11	3.1E+14	2.9E+14	4.9E+11
Sr-89	2.0E+16	1.3E+14	nil	3.9E+16	2.6E+14	nil
Sr-90	1.3E+15	1.3E+15	1.1E+14	2.7E+15	2.6E+15	2.3E+14
Y -91	2.2E+16	3.0E+14	nil	4.4E+16	5.8E+14	nil
Zr-93	2.9E+10	2.9E+10	2.9E+10	5.7E+10	5.7E+10	5.7E+10
Zr-95	2.4E+16	4.6E+14	nil	4.7E+16	9.1E+14	nil
Nb-95	9.2E+15	9.7E+14	nil	1.8E+16	1.9E+15	nil
Mo-99	7.5E+16	nil	nil	1.5E+17	nil	nil
Tc-99	2.0E+11	2.0E+11	2.0E+11	3.9E+11	4.0E+11	4.0E+11
Ru-103	1.6E+16	2.6E+13	nil	3.3E+16	5.2E+13	nil
Ru-105	1.4E+16	nil	nil	2.9E+16	nil	nil
Ru-106	1.0E+15	5.2E+14	nil	2.3E+15	1.2E+15	nil
Rh-105	1.3E+16	nil	nil	2.9E+16	nil	nil
Pd-107	2.1E+08	2.1E+08	2.1E+08	5.0E+08	5.0E+08	5.0E+08
Ag-110m	4.0E+11	1.5E+11	nil	2.0E+12	7.3E+11	nil
Ag-111	3.1E+14	nil	nil	7.5E+14	nil	nil
Sb-125	5.7E+13	4.4E+13	nil	1.2E+14	9.1E+13	nil
Sb-127	2.1E+15	nil	nil	4.3E+15	nil	nil
Te-127m	7.0E+13	8.2E+12	nil	1.4E+14	1.6E+13	nil
Te-129m	5.9E+14	3.2E+11	nil	1.2E+15	6.5E+11	nil
Te-132	5.3E+16	nil	nil	1.1E+17	nil	nil
I -129	2.5E+08	2.5E+08	2.5E+08	5.0E+08	5.1E+08	5.1E+08
I -131	3.3E+16	nil	nil	6.7E+16	nil	nil

I -135	7.7E+16	nil	nil	1.5E+17	nil	nil
Xe-133	8.1E+16	nil	nil	1.6E+17	nil	nil
Xe-135	4.7E+16	nil	nil	6.3E+16	nil	nil
Cs-134	1.9E+14	1.3E+14	nil	7.5E+14	5.4E+14	nil
Cs-135	1.2E+10	1.2E+10	1.2E+10	1.7E+10	1.7E+10	1.7E+10
Cs-136	2.8E+14	1.2E+06	5.6E+02	7.8E+14	nil	nil
Cs-137	1.4E+15	1.3E+15	1.4E+14	2.7E+15	2.7E+15	2.7E+14
Ba-140	6.1E+16	1.5E+08	nil	1.2E+17	3.0E+08	nil
La-140	5.9E+16	1.7E+08	nil	1.2E+17	3.4E+08	nil
Ce-141	3.4E+16	1.4E+13	nil	6.8E+16	2.8E+13	nil
Ce-143	7.3E+16	nil	nil	1.4E+17	nil	nil
Ce-144	1.2E+16	5.0E+15	nil	2.4E+16	1.0E+16	nil
Pr-143	5.5E+16	5.1E+08	nil	1.1E+17	1.0E+09	nil
Nd-147	2.3E+16	2.3E+06	nil	4.7E+16	4.6E+06	nil
Pm-147	3.0E+15	2.5E+15	nil	5.6E+15	4.7E+15	nil
Pm-148	8.7E+14	nil	nil	3.2E+15	nil	nil
Pm-148m	2.6E+14	5.7E+11	nil	8.1E+14	1.8E+12	nil
Pm-149	1.4E+16	nil	nil	2.9E+16	nil	nil
Pm-151	5.3E+15	nil	nil	1.1E+16	nil	nil
Sm-151	1.9E+13	1.9E+13	8.8E+12	2.4E+13	2.4E+13	1.1E+13
Sm-153	3.0E+15	nil	nil	8.7E+15	nil	nil
Eu-154	7.1E+12	6.5E+12	2.2E+09	2.9E+13	2.7E+13	9.1E+09
Eu-155	1.4E+13	1.2E+13	5.4E+06	2.2E+13	1.9E+13	8.0E+06
Eu-156	4.4E+14	2.6E+07	nil	1.2E+15	7.2E+07	nil
Eu-157	1.0E+14	nil	nil	2.6E+14	nil	nil
Tb-160	1.6E+11	4.7E+09	nil	7.5E+11	2.3E+10	nil
Tb-161	2.6E+12	nil	nil	7.6E+12	nil	nil
U -234	2.5E+11	2.5E+11	2.5E+11	2.3E+11	2.3E+11	2.3E+11
U -235	1.1E+10	1.1E+10	1.1E+10	9.7E+09	9.7E+09	9.7E+09
U -236	6.9E+09	6.9E+09	6.9E+09	1.3E+10	1.3E+10	1.3E+10
U -237	5.5E+15	nil	nil	2.0E+16	nil	nil
U -238	4.3E+09	4.3E+09	4.3E+09	4.3E+09	4.3E+09	4.3E+09
Np-237	8.2E+08	8.6E+08	8.6E+08	2.8E+09	3.0E+09	3.0E+09
Np-238	2.4E+14	nil	nil	1.8E+15	nil	nil
Np-239	1.4E+17	nil	nil	3.0E+17	nil	nil
Pu-238	5.6E+11	5.8E+11	2.7E+11	3.9E+12	4.0E+12	1.9E+12
Pu-239	2.9E+12	2.9E+12	2.9E+12	4.8E+12	4.9E+12	4.9E+12
Pu-240	6.1E+11	6.1E+11	6.0E+11	1.9E+12	1.9E+12	1.9E+12
Pu-241	4.4E+13	4.2E+13	3.5E+11	2.7E+14	2.5E+14	2.1E+12
Pu-242	3.7E+07	3.7E+07	3.7E+07	5.0E+08	5.0E+08	5.0E+08
Am-241	8.1E+10	1.5E+11	1.3E+12	4.9E+11	9.0E+11	8.1E+12
Am-242m	1.6E+09	1.6E+09	9.8E+08	1.6E+10	1.6E+10	9.9E+09
Am-243	3.3E+07	3.3E+07	3.3E+07	9.1E+08	9.1E+08	9.0E+08
Cm-242	1.7E+12	3.6E+11	8.1E+08	2.2E+13	4.7E+12	8.2E+09
Cm-243	4.9E+07	4.8E+07	4.3E+06	1.3E+09	1.3E+09	1.2E+08
Cm-244	2.9E+08	2.8E+08	6.2E+06	1.6E+10	1.6E+10	3.6E+08

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Strategy regarding radiation protection

The Norwegian Radiation Protection Authority has prepared the following strategy regarding radiation protection for the work at the Kursk.

Objective

To protect the divers (and general workers) from radiation exposure due to possible radioactive releases from the Kursk.

At present there are no indications of radioactive releases from the Kursk.

Radiation Protection Equipment

When operating near or inside the Kursk the divers shall be equipped with a GM-counter which at all times will show the radiation dose rate.

The divers, and, if required, some of the staff onthe Regalia, shall wear a personal dosimeter during the whole operation. When the operation is over the NRPA will collect the dosimeters for control and after analysis on land, provide feedback on the total radiation dose each person has received.

A dose rate meter will be placed on the ROV prior to and during the operation to indicate the radiation level at the spot.

Water, sediment and, if possible, air-samples, will be collected for more detailed analysis of radionuclides at the radiation protection laboratory established on the Regalia.

Dose limits

The general dose limit for employees working with radiation and radioactive sources (e.g. in hospitals and in nuclear facilities etc.) is 20 000 µSv/year. According to international recommendation, a maximum of 50 000 µSv/year may be reached as long as the total dose in a five years period does not exceed 100 000 µSv.
For comparison, the dose limit for the general population is 1 000 µSv/year.

According to the Norwegian regulations, the general population are not allowed to enter areas with radiation levels above 7.5 µSv/hour, i.e. these areas will be defined as controlled areas. (International recommendations state that if the dose rate is below 7.5 µSv/hour, no specific restrictions for radiation shielding are required.)

Reccommended working procedure at the Kursk

According to the dose rate measurements made at the Kursk in August, a normal dose rate, with no sign of radioactive releases, is 0.0-0.1 µSv/hour.

Divers masks and external air supplies will automatically protect the divers from inhalation of radioactive particles and air pockets with a contaminated atmosphere will thus not represent any health hazard due to inhalation.

If dose rates above 7,5 µSv/year are measured, special precautions should be taken before continuing the operation. These levels may indicate that there has been leakage of radioactive substances. The dose rate meter should be checked frequently.

If dose rates above 500 – 1000 µSv/hour are measured, the divers should quickly retreat. Dose rates above this level are only acceptable for a limited period of time, and discussions should be done to decide whether the operation at that location should be terminated or whether a time schedule for further work should be established.

Strategy for sampling and measurements in connection with the rescuing of casualties after the Kursk accident

The Norwegian Radiation Protection Authority has prepared the following programme for measurement and sampling inside the wrecked submarine the Kursk and in the submarines environs. The main purpose will be to verify that the divers and remaining crew on board the rescue ship will not be exposed to radiation exceeding what is laid down in the international recommendations for occupational exposure. The programme is based on direct dose rate measurements in the environment where the divers are working, together with sampling of water and sediments near the submarine to verify whether or not leakage of radioactive substances is taking place. The objective will be to carry out the sampling programme and to incorporate this work into the other activities that will be performed on board the rescue ship. Working conditions, time considerations and possible changes in the radioactive contamination level might result in adjustments of the programme during the rescue operation.

Starting point

Air measurements:
The air sampler is started. Decisions on how often to change and measure the air filters are made under way.

Dose rate measurements:
The ROV is equipped with Automess for dose rate measurements close to the submarine. The instrument is read off via cameras on the ROV each 10 meters.

Sediment samples:
The ROV is equipped for sampling of bottom sediments from 5 sampling points in close proximity to the hull on each side of the submarine (approximately 500 g from each point for measuring on board the ship).

Water samples:
Sampling of surface water (approx. 5 litres for measuring on board the ship) and minimum 200 litres samples for filtration through a Cs-rig. For plutonium measurements 200 litres samples are taken and distributed to 8 25 litres cans for transportation to land (add HCl).

Sampling of bottom water at the most favourable points considering the currents (approx. 5 l for measuring on board). 200 l samples of bottom water are also taken and filtrated through a Cs-rig.

During the operation

Dose rate measurements:
The ROV is equipped with an Automess meter and is read off when needed.

Divers are equipped with GM-monitors, which are read off via cameras when needed.

Equip divers entering the submarine with GM-monitors. Divers are also equipped with individual dosemeters under their diving suits.

Water samples:
Sampling of surface water (approx. 5 l for measuring on board) and a minimumof 200 l samples for filtration through a Cs-rig.

Sampling of water inside each of the seven sections before opening the side of the hull. Samples are also taken inside each section after opening the hull (approx. 5 l for measuring on board). The water sampler is lowered down to the divers with a winch.

Air samples:
Sampling of air inside each section if possible.

Samples of surface water will be taken and dose rate measurements with an Automess meter will be conducted on the deck of the rescue ship if air bubbles are surfacing from the submarine.

If measurements show releases of radioactive substances, an evaluation will be made on whether to measure equipment (ROV, diving suits), which has been near the submarine.

After operation is completed

Sediment samples:
The ROV is equipped for sampling of bottom sediments from 5 sampling points in close proximity to the hull on each side of the submarine (approx. 5 g from each point for transportation to land).

Water samples:
Sampling of minimum 200 l samples of surface water for filtration through a Cs-rig. 200 l samples for plutonium measurements are also taken and redistributed to 8 25 l cans and transported to land (add acid).

Sampling of bottom water at the most favourable points considering the currents (approx. 200 l for filtration through a Cs-rig).

Sampling time	Layer	Sediment, number of samples	Water, number of samples/litres	
			Total gamma, Cs	Pu
Before	Surface Bottom	 10	1/5, 1/200 1/5, 1/200	1/200
During	Surface Bottom		?/5, 1/200 ?/5, -	
After	Surface Bottom	 10	-, 1/200 -, 1/200	1/200

Overview of water and sediment sampling.