PNNL-13531

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Environmental Implications of the OSCAR II SSGN *Kursk* Submarine Accident

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April 2001

Prepared for U.S. Department of Energy
Under Contract DE-AC06-76RL01830

Murmansk Area

***Kursk* Submarine**

Captain 1st Rank Liachin
Commanding Officer, *Kursk*

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(8/2010)

April 2001

Environmental Implications of the OSCAR II SSGN Kursk Submarine Accident

Summary

The environmental threat posed by the sunken OSCAR II SSGN Kursk is a function of any damage to the submarine reactor plants and their containment systems, either by explosion(s), impact with the oceanographic features of the Kursk current resting place, an improperly controlled shutdown of the operating reactor, or a combination of these factors. The explosion(s), combined with the enhanced risk of multiple fuel element failure upon the probable automatic shutdown of the submarine's operating reactor, suggests a possible pathway for introduction of radionuclides into the immediate environment of the stricken vessel. The extent of reported damage, however, seems to indicate no release to date. Further, experience with the 1989 sinking of the Russian nuclear submarine Komsomolets suggests that, although of concern, any release of radionuclides from the Kursk is unlikely to cause widespread or long-term environmental damage. Nonetheless, the possibility exists that such releases could affect personnel exposure in radiation mitigation and vessel recovery efforts. Specifically, in the case of the Kursk:

- *The combined effects of tidal currents and the Murmansk Current are sufficient to cause limited mobilization of silty and fine sandy sediments in the Kursk wreck area, but are likely insufficient for the transport of heavier particles.*
- *Vertical mixing of bottom materials in the area owing to the wreck region's semi-permanent upwelling dynamic is similarly less applicable to heavier particles.*
- *The complete dilution of a first-order estimate of the Kursk's ^{90}Sr and ^{137}Cs inventories, combined with existing background radiation readings, yields estimated elevated background levels of <50 Bq/m^3 for ^{90}Sr and ^{137}Cs, both well below the World Health Organization (WHO) stated maximum safe level of 300 Bq/m^3.*
- *With regard to the concentration of radioactive materials in the food chain, the consumption of fish from the Barents Sea for the average individual and fishermen and their families is not likely to exceed safe levels.*

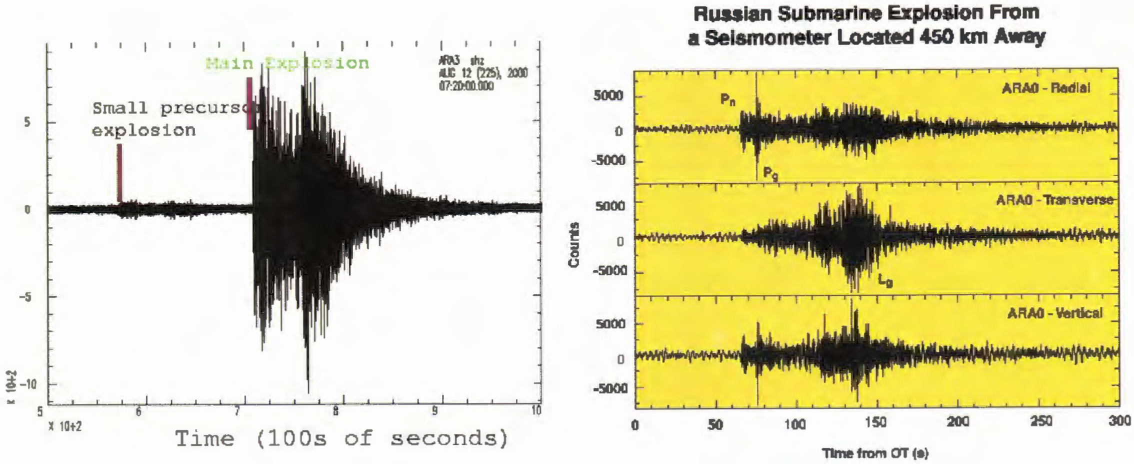
Background

The precise cause of the Kursk sinking is as yet unknown.

Kursk, Sayda Bay, 1998

The Kursk *currently rests in 108 m of water in the Barents Sea off the Kola Peninsula at approximately 69°40'N 37°55'E.*

On August 12, 2000, the *Kursk*, a Russian Navy nuclear-powered, OSCAR II class submarine, sank in the Barents Sea at a location near Murmansk, 20-30 km east of Kildenbanken, in 108 m (354 ft) of water. Despite rescue efforts by the Russians and later by other European military and civilian divers, no survivors were recovered from the submarine. Strong currents and low visibility over the accident site frustrated the efforts of crews trying to reach the vessel. The precise cause of the *Kursk* sinking is under debate. One explosion, followed by a much larger second explosion, was recorded by seismographs in the region of the sinking.



Seismographic recording of primary and secondary explosions onboard the *Kursk*, 8/12/00 (J. Wallace, University of Arizona)

It is not known what procedures were taken by the crew of the *Kursk* to shut down the nuclear reactors during the short time following the events that led to the sinking. Concern now exists regarding the potential leakage and subsequent transport of radioactive materials into the Barents Sea and connected water bodies. (See Figure 1)

Pathways for Radionuclides to the Environment

Currently, no evidence exists of large-scale release of radionuclides from the Kursk.

Shock damage from the explosion(s) that apparently caused the *Kursk* sinking, and subsequent shock damage from impact with its current resting place are the primary considerations with respect to possible degradation of reactor vessel and fuel element integrity. Although the reactor vessel itself is likely to withstand such stress, the associated piping is vulnerable to shock damage.

If significant fuel element failure is exhibited due to physical shock, insufficient cooling, or both, there are further, multiple levels of protection presented for the environment. The reactor fuel rods and reactor vessel itself must be breached, and a pathway must be opened from the reactor compartment to the surrounding environment, implying a breach of the *Kursk* pressure hull. A significant transmittal of highly radioactive materials to surrounding seawater, directly from the reactor vessel/reactor compartment, would seem to require greater damage to the Kursk than has been reported to date. A catastrophic failure of multiple systems so that primary/secondary loop boundaries are violated, with downstream leakage of radionuclides to the environment, also seems unlikely.

Potential Effects of Radionuclide Release from the *Kursk* to the Surrounding Environment

Widespread, environmentally significant contamination of the Barents Sea is unlikely. Short-term risks are present for salvage personnel working close to the Kursk.

Figure 1. Location of OSCAR II SSGN *Kursk* Submarine Accident and Russian Northern Fleet Sites (Bradley 1997).

Any release of radionuclides from the *Kursk* will likely remain close (within 1 km) to the submarine. This assertion is based on surveys of previous seaborne deposits of Russian reactor vessels and highly radioactive solid waste whose radioactivity level has been closely monitored over time. The Russian submarine *Komsomolets* that sank in the Norwegian Sea in 1989 has had no measurable radioactivity in the vicinity of the vessel following minor *in situ* repairs to damaged piping. Despite the *Kursk* sinking to a shallower depth (~110 m, as opposed to over 1500 m) and the stronger historical currents in the immediate vicinity of the *Kursk*, the inherent characteristics of the high-activity fission products (non-water-soluble, heavy metal) should preclude any meaningful transport of radionuclides. Indeed, the total amount of radioactive materials that could conceivably be deposited outside the *Kursk* is small compared to the amount of radioactivity deposited in the oceans of the world from nuclear fuel reprocessing and nuclear weapons testing activities.

The primary concern with respect to radioactivity from the *Kursk* is the future exposure of salvage workers to radioactive materials from the vessel. Close scrutiny of vessel integrity, however, coupled with an aggressive radioactivity monitoring campaign during rescue and salvage operations, should minimize the risk to these personnel.

Barents Sea's Influence on Possible Release of Radionuclides Resulting From the *Kursk* Accident

Radioactivity levels in the Barents Sea expected to remain below maximum safe levels.

Previous studies of releases of liquid radioactive waste into the Barents Sea by the former Soviet Union, and of radioactive material released from western European sources that is transported to the Barents Sea via ocean currents, indicated the impacts on human, as well as the other aspects of the ecosystem of the Barents Sea, would not exceed World Health Organization (WHO) recommended safe levels. Thus, regardless of the ecological or physical pathway examined, the distribution of the estimated available inventory of radioactive material in the Kursk reactors from a potential catastrophic release from the Kursk into the Barents Sea ecosystem would no more than double the extant radioactivity in the Barents Sea water column over a 1- to 5-year period. Given the results of previous studies, this doubling also would not exceed 11 percent of the WHO maximum safe level of 300 Bq/m^3. Therefore, in either the case of consumption of 30 kg/year of fish from the Barents Sea for the average individual, or of as much as 220 kg/year— more typical of the consumption by area fishermen and their families, who represent a critical fraction of those potentially affected by radioactive releases in the past—safe levels would not be exceeded (Sazykina and Kryshev 1994). The potential increases from a catastrophic release would likely not increase long-term levels to a point of concern. The short-term effects of a catastrophic release could be more severe, but would depend on the timing relative to fish hatches, egg laying, and other biological productivity issues. As the most likely scenario for a tangible effect on the environment, these issues should be taken into account in light of current plans to salvage the Kursk continue to develop.

Sediment and Circulation Patterns

Many parameters effect the movement of radionuclides and radioactive contamination, including sediment regimes, seasonal/cyclic sea circulation, and long-term, regional sea circulation patterns.

Upwelling – The net upward transfer of nutrients in a body of water or region.

The combined effects of tidal currents and the Murmansk Current are sufficient to cause limited mobilization of silt and fine sand sediments in the *Kursk* wreck area, but likely are insufficient for the transport of heavier particles. Vertical mixing of bottom materials in the area, owing to the wreck region's semi-permanent upwelling dynamic is similarly less applicable to heavier particles. If radionuclides or contamination were released from the *Kursk* reactors or associated systems, the pollutants and contaminated radioactive materials would tend to accumulate within the surrounding sediment.

Background Radiation

Becquerel (Bq) – A unit of radioactivity equal to one nuclear disintegration per second. One curie (Ci) equals $3X10^{10}$ Bq.

The background levels of radioactivity in the surface waters of the Barents Sea are 4 to 24 Bq/m^3 of ^{90}Sr and 2 to 4 Bq/m^3 in the vicinity of the *Komsomolets* in the bottom of the Barents Trench at about 1600m (Sazykina and Kryshev 1994). The background level of ^{137}Cs at the surface is 6 to 40 Bq/m3 in the rest of the Barents Sea, whereas the near-bottom concentrations are about 5 Bq/m^3 (Strand et al. 1993). Background levels of ^{137}Cs in fish prior to the *Kursk* were 1 Bq/kg; post-*Kursk* levels of radiation, on August 13, 2000, were reported at 0.23 Bq/kg (Bellona 2000). Maximum safe levels in seawater, according to the World Health Organization (WHO), are 300 Bq/m^3.

Projected Maximum Release Levels

The *Kursk* is reported to have been in operation for 5.5 years (Bellona 2000). However, it is not known whether the fuel rods have been changed (refueled core). At present, little information is available about the radioactive inventory in the two reactors aboard the *Kursk;* however, some estimates can be made from available public information. The *Kursk* is reported to have two OK650-B reactors (Bellona 2000). The reactors are probably similar to the single OK650-B3 reactor in the *Komsomolets*. If so, an estimate of the radioactive inventory can be made from the published *Komsomolets* data.

Terabecquerel (TBQ) - A derived unit of radioactivity equal to 10^{12} nuclear disintegrations per second. One TBQ equals 33.33 Ci. .

The Kurchatov Institute reported the inventory for the single *Komsomolets* reactor was 2800 TBQ for ^{90}Sr and 3100 TBQ for ^{137}Cs (Bellona 2000). For two reactors in the *Kursk,* we can therefore make a first order estimate of the radioactive inventory of about 5600 TBQ for ^{90}Sr and 6200 TBQ for ^{137}Cs. The estimated volume of the Barents Sea is 311 x 10^{12} m^3 seawater (Sazykina and Kryshev 1994). If all the material were mixed with the total estimated volume of the Barents Sea, the projected increase in radioactivity would be 20 Bq/m^3 for ^{137}Cs and 18 Bq/m^3 for ^{90}Sr. Because the existing background levels are 17 Bq/m^3 for ^{137}Cs and 12 Bq/m^3 for ^{90}Sr, the estimated increased background levels would be 37 Bq/m^3 for ^{137}Cs and 40 Bq/m^3 for ^{90}Sr. This increase is within the WHO maximum safe level, that is, 300 Bq/m^3 (Bellona 2000).

Transport Pathways

In the previous section, a potential radioisotope loading is established for the Barents Sea in the event of a catastrophic release from the *Kursk* reactors. The question of the ways in which this loading might redistribute itself throughout the Barents Sea ecosystem and water column remains as the last element in estimating the potential impact to local and distant populations of short-term or long-term release of this radioactive inventory. First, we must establish potential ecosystem pathways and then use the distribution patterns from the long-term water circulation to determine effects on the ecosystem. We must also balance this potential release against any existing background levels of radioisotopes from other sources. The standard by which we judge potential impacts is the safe level of 300 Bq/m^3.

The transport of radiation from the south-central Barents Sea can take place through several mechanisms. They include radiation that is transported as dissolved material in the water column, or attached to particulate material, incorporated into ice, or accumulated by fish or marine mammals and plants. Radioactive material in the water column can become hazardous to the ecosystem if the radioactive material is concentrated up the food chain to the higher trophic level feeders, including humans. Concentration factors for the arctic seas ecosystems have been calculated by several authors, based on observations of several individual species from the field, and generalized to categories of plants and animals (Table 1).

Trophic level – The level in a food chain (more recently, the food web) where an organism resides.

Concentration factor – The degree to which a substance is concentrated through higher trophic levels in a food chain or web.

Table 1. Concentration Factors for Arctic Seas Ecosystems (Sazykina and Krychev 1994)

Component	^{90}Sr	^{137}Cs
Algae	5±2	50±30
Zooplankton	2±1	30±20
Benthos	10±4	30±20
Fish	10±6	200±90
Sea Birds	50±20	60±40
Sea Mammals	40±20	100±70
Sediments Coastal	1000±500	3000±1000
Sediments Deep Water	200±100	2000±1000

These concentration factors were based on long-term exposure over the last 30 years of the arctic ecosystem to radioactive loading in the Barents Sea and other marginal seas of the Arctic Ocean. Results have been presented as part of extended arctic radio-ecology studies during the 1980s and 1990s in cooperation with the International Atomic Energy Administration (IAEA) and are in general agreement with previously accepted concentration factors. As part of these studies, comparable study areas in other parts of the world were grouped to allow comparison with the Barents Sea. As a part of Project MARINA, four groups of marginal seas where fishing was prevalent were categorized by water-column levels of radioactivity derived from ^{137}Cs. The data were from the period 1980-1985 and represent a snapshot in time, but are still relevant for comparison to the *Kursk* situation. The four groupings are for seawater with the following radioactivity levels: a) less than 20 Bq/m^3; b) 20 to100 Bq/m^3; c) 100 to 200 Bq/m^3; and d) greater than 200 Bq/m^3.

With the present background level for ^{137}Cs in the Barents Sea previously noted as 17 Bq/m^3, the Barents Sea falls in Group A, both for the present, as well as the previous two decades (1980s and early 1990s) (Bellona 2000). The Group B seas, which include the North, Kattegat, Skagerrak, Sound, and Belt Seas between Sweden and Denmark, and the Norwegian and Barents Seas, all were clearly influenced by the radioactive input from Sellafield in northern England. Radioactivity levels in Group C seas, including those along the northwest coasts of Scotland and Northern Ireland, are determined largely from Sellafield (Camplin and Aarkrog 1989). An estimated simultaneous release of the total inventory of ^{60}Co, ^{90}Sr and ^{137}Cs from the *Kursk* reactors would double the existing loadings in the Barents Sea from 17 Bq/m^3 to 34 Bq/m^3; this doubling would still place the levels within the Group B range, at about 11 percent of the maximum safe level specified by WHO. The contributions to the inventory that support the present background levels of radioactivity in the Barents Sea as of 1993 are shown in Table 2.

Table 2. Estimated 1993 Inventory in Arctic Seas for ^{90}Sr (^{137}Cs) (OTA, 1995)

Source	Deposition in Arctic Sea
Fallout from atmosphere	2590 (4107) TBq
Fallout from terrestrial runoff	1517 (518) TBq
Sellafield Nuclear Facility	-------(9990-14985) TBq
Chornobyl Reactor Accident	------- (999-4995) TBq
Estimated *Kursk* Inventory for 2000	5600 (6200) TBq

Note: Units are Bq/kg wet weight for living matter and Bq/l for sediments.

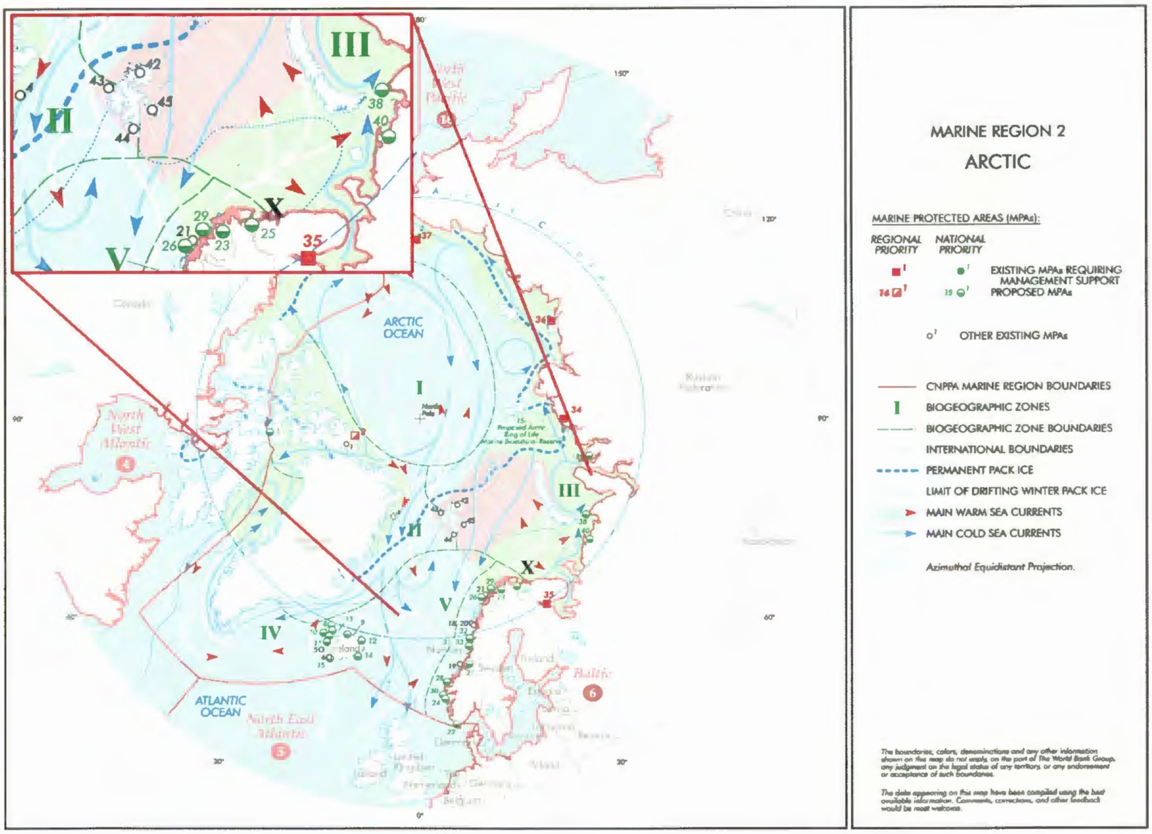
Background Information on Sediment and Circulation Regimes

The Gulf Stream enters the Barents Sea from the south and spreads eastward into the Barents Sea where it becomes the Murmansk Stream. Cold water enters the area from the east and north, blending with the Murmansk Stream during much of the year. During spring ice retreat and periods of high river run-off to the White Sea, the less dense, warmer surface water provides rich nutrients for phytoplankton. With increasing sunlight in the spring and early summer, a vast production of zooplankton provides nutrition for spawning fish stocks and makes the Barents Sea one of the most productive of the world oceans. (See Figure 2.)

<u>Sediment Regime</u>

Most of the clastic material supplied into the Barents Sea is due to coastal erosion. Several specific provinces are listed as follows:

Figure 2. Arctic Circle Composite Showing Location of Warm and Cold Sea Current Flows Near the Location of the *Kursk* (noted as X)



- Kola Peninsula: Due to the strength of the magmatic and metamorphic rocks composing the coast, a small amount of coarse-grained material of variegated composition is supplied from this source.
- Bolshezemelakaya Tundra, Kanin Peninsula, Kolguev Island: A significant source of material since low coasts, composed of loose Quaternary deposits are eroded at rates of 3-5 to 10-15 meters per year.
- Novaya Zemlya: This mountainous land provides a main source of clastic sediments to the basin from extensive loose glacial deposits and transport through fluvial and glacial melt-water streams.
- Franz Jozef Land: A specific distributive province from which iceberg rafting is the main transport mechanism.
- Suspended solids are also supplied in the form of silt load from the Pechora River in the eastern Barents Sea at about 60 g/m^3 and provide 4.7 to 7.8 million tons/year to the eastern Barents Sea.
- Winter discharge of freshwater from the White Sea into the Barents Sea is about 250 km^3/year and includes fine sediments from the Onega, Severnaya Dvina, and Mezen rivers.

Seasonal Circulation

The southern and western portions of the Barents Sea are well mixed during most of the year. Annual temperature and salinity at 100 m depth range from 3.5°C to 6°C and 34.6 to 34.8 ppt, respectively. During the summer period of ice melt and high freshwater runoff, the surface layer freshens slightly. This freshening, combined with solar heating, leads to the formation of a stratified layer in the upper 25 to 50 m that is present from August through October. The thickness of the layer depends on the frequency and intensity of storms and the amount of open water. During the remainder of the year, the water in the southwestern Barents is well mixed and of relatively constant temperature and salinity (Pavlov et al. 1993).

The wind-driven currents in the Barents can also contribute significantly to the velocity. These have not been well documented by direct measurement, but have been derived from wind measurements. Annually occurring wind events are expected to cause currents to exceed 1 knot (kn) in the western part of the sea and may exceed 75 cm/s (1.5 km) at recurrence intervals of 5 years (Pavlov et al. 1993).

The wave conditions that accompany strong wind events can also provide severe and challenging conditions for the fishing fleet. The calmest period is between June and August, when wave heights exceed 6 m (20 ft) only 1 to 1.5 percent of the time. Waves are 3 m or less >80 percent of the time during this period. During winter storms, wave heights have been observed to exceed 14 m (46 ft). Storms and breaking waves contribute to mixing of the water column. Some reports indicate sediment re-suspension to the bottom, due to combined wave action and baro-tropic currents during storm events (Ivanov 1993).

Long-Term Circulation

The Murmansk Current (Figure 2) that is derived from the northeastern branch of the North Atlantic Drift, or Gulf Stream extension, in the Norwegian Sea penetrates to the bottom on the southwestern side of the Barents Sea along the Kola Peninsula. The velocity of the current ranges from 25 to 5 cm/s with higher velocities near shore, decreasing in the offshore direction. Along the Kola Peninsula, the current is 30 to 50 km wide and has an estimated transport of 3.1 Sverdrups (Sv) (Sv = 10^6 m^3/s). At the southwest end of Novaya Zemlya, the current splits, with one portion entering the Kara Sea and other proceeding along the north side of Novaya Zemlya (Figure 2). The branch on the north side forms a counter clockwise gyre in the Barents Sea and eventually departs the Barents Sea through the Bear Island Trough back into Fram Strait at a depth of 500 to 1500 m, with a net transport of 1.6 Sv. Another leg of the current on the north side of the island, of approximately 2.4 Sv transport, travels northeastward along the coast of Novaya Zemlya and enters the east Kara Sea and then the Arctic Ocean through the Santa Anna Trough.

A small volume of water (about 0.03 Sv) from the Barents Sea, including the majority of the Pechora River discharge, leaves the Barents Sea and enters the Kara Sea south of Novaya Zemlya through the Karsky Varota or Kara Gate via the Pechora Current. This volume is balanced by an equal exchange of 0.03 Sv from the Kara Sea to the Barents in the Litke Current. However, the return flow is composed of Barents Sea water that leaves the northeastern Barents and circles Novaya Zemyla Island, and returns via the Kara Gate to the Barents Sea. Thus, it also contains continental runoff from Novaya Zemyla, as well as sea ice melt, and can have total transport in the range of 0.15 to 0.54 Sv.

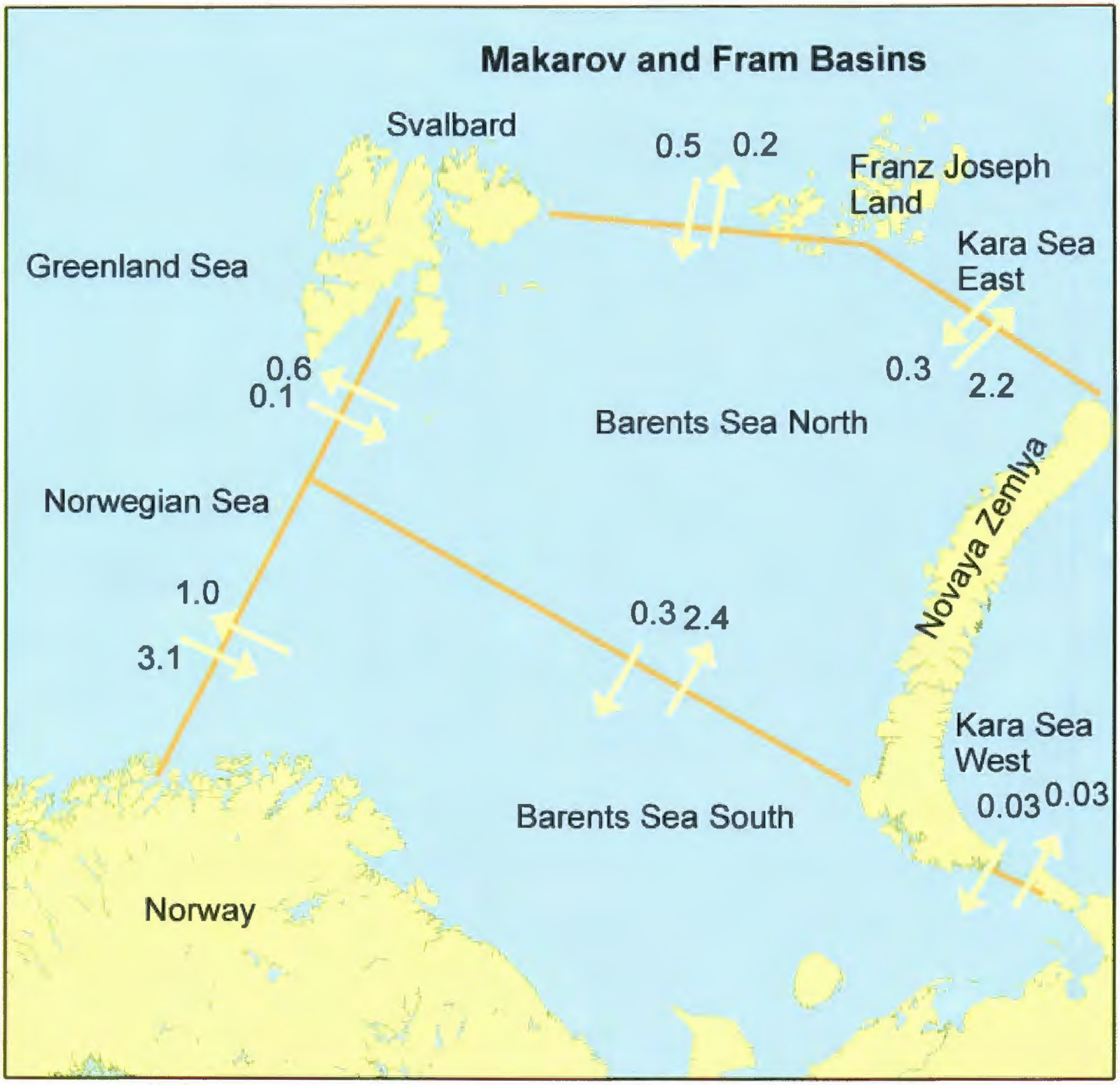
These net transports do not have a sum of zero, because of the numerous small exchanges between the various basins surrounding the Barents Sea (Figure 3). Due to the difficulty of maintaining current meters under the perpetual ice cover between Svalbard and Franz Jozef Land, estimates of the net transport gains or losses from this sector in the Barents Sea are in doubt. Aagaard et al. (1983) cited a single year-long current-meter record as having net northward transport of 0.2 Sv through the western passage between Svalbard and Franz Jozef Land that supports the values cited here (Aagaard et al. 1983).

Amphidrome - A stationary point around which tides rotate in a counterclockwise (clockwise) sense in the northern (southern) hemisphere. The vertical range of the tide increases with distance away from the amphidrome, with the amphidrome itself being the spot where the tide vanishes to zero or near zero.

After accounting for all of the exchanges in the Barents Sea, the mean residence time for water entering the Barents Sea is estimated to be about 5 years (Pavlov et al. 1993). However, Rudels (1987) estimated the time it takes a particle of water to traverse the Barents Sea from west to east near Novaya Zemyla (through the area in which the *Kursk* lies) as 1 year. This includes the effects from wind mixing, density-driven currents, and tidal mixing. Tides in the Barents Sea are semidiurnal (two high and two low tides per day). Tides are driven by a tidal amphidrome located between Nordcap, Norway, and Svalbard, and they rotate counterclockwise about the Barents Sea. The tidal wave enters the sea from the west and develops peak velocities of about 0.25 cm/s (0.5 kn).

The near shore tidal current combined with the Murmansk Current creates velocities that may exceed 50 cm/s (1 kn) and that are sufficient to mobilize the silt and fine sand bottom sediments. Because the water column in the Barents Sea is only slightly stratified during the summer, the sediment has the potential to mix through the water column (Pavlov 1993). Pavlov (1993) reported a large area of semi-permanent upwelling in the vicinity of the reported wreck location that could enhance vertical mixing of material from the bottom throughout the water column.

Figure 3. Water Exchanges for the Barents Sea from a Box Model (transports are in Sv) (After Sazykina and Kryshev 1994)



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