Radiological impact assessment associated with hypothetical accident scenarios for the nuclear submarine K-27

There is increasing concern over potential radioactive contamination of the Arctic due to the presence of a wide range of nuclear and radiological sources within this region. Dumped radioactive materials contribute the greatest proportion to the total man-made activity found in the Arctic followed by historic releases from the Sellafield reprocessing plant and global fallout. Of these, dumped objects containing Spent Nuclear Fuel (SNF) constitute the greatest potential radioecological hazard.

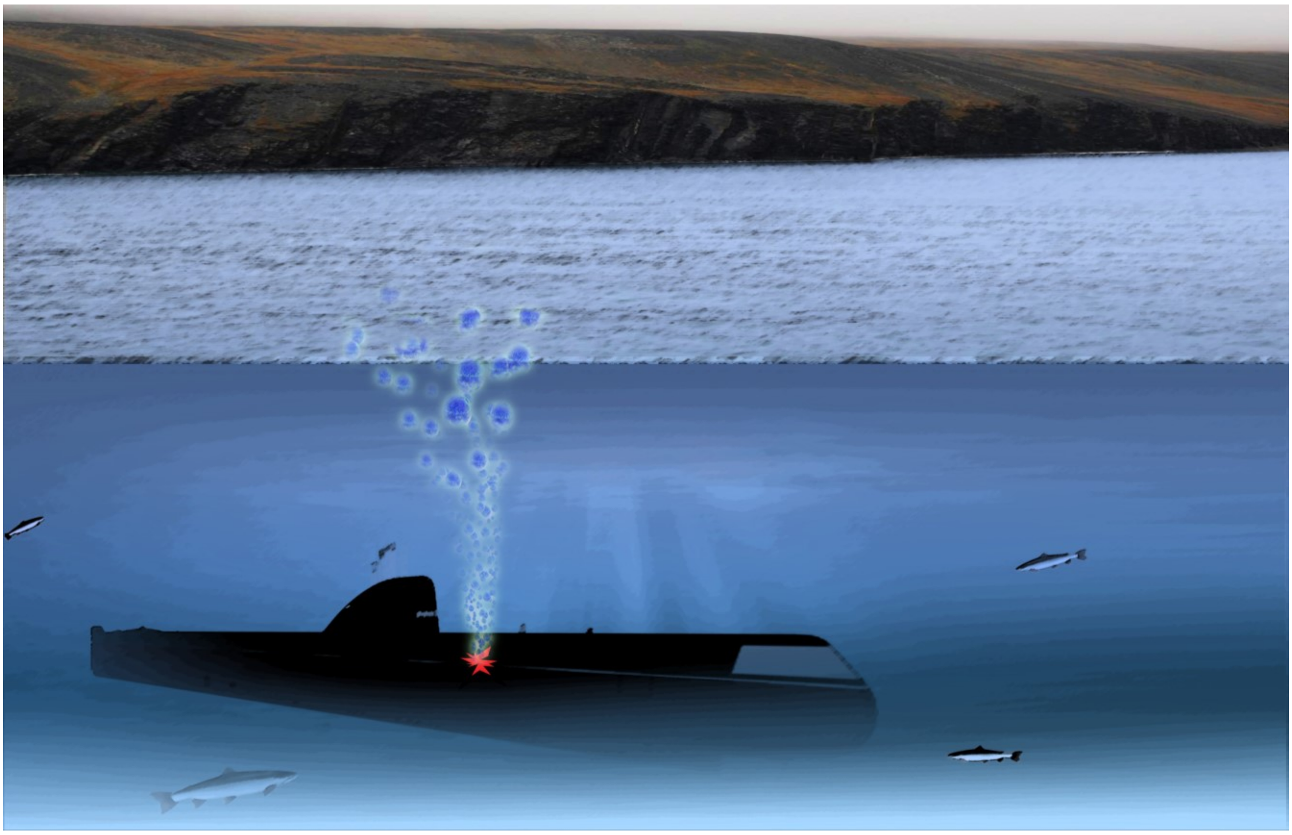

Figure 1. The nuclear submarine K-27 was dumped in Kara Sea at Stepovogo Fjord in 1981.

Amongst dumped objects in the Arctic, the Russian submarine K-27, that was dumped in the Kara Sea in 1981, has received much attention due to particular concerns related to its two reactors with highly enriched SNF. It lies at a depth of about 30 m in Stepovogo Bay on the east side of Novaya Zemlya.

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ISSN 0806-895x • 7 December 2016

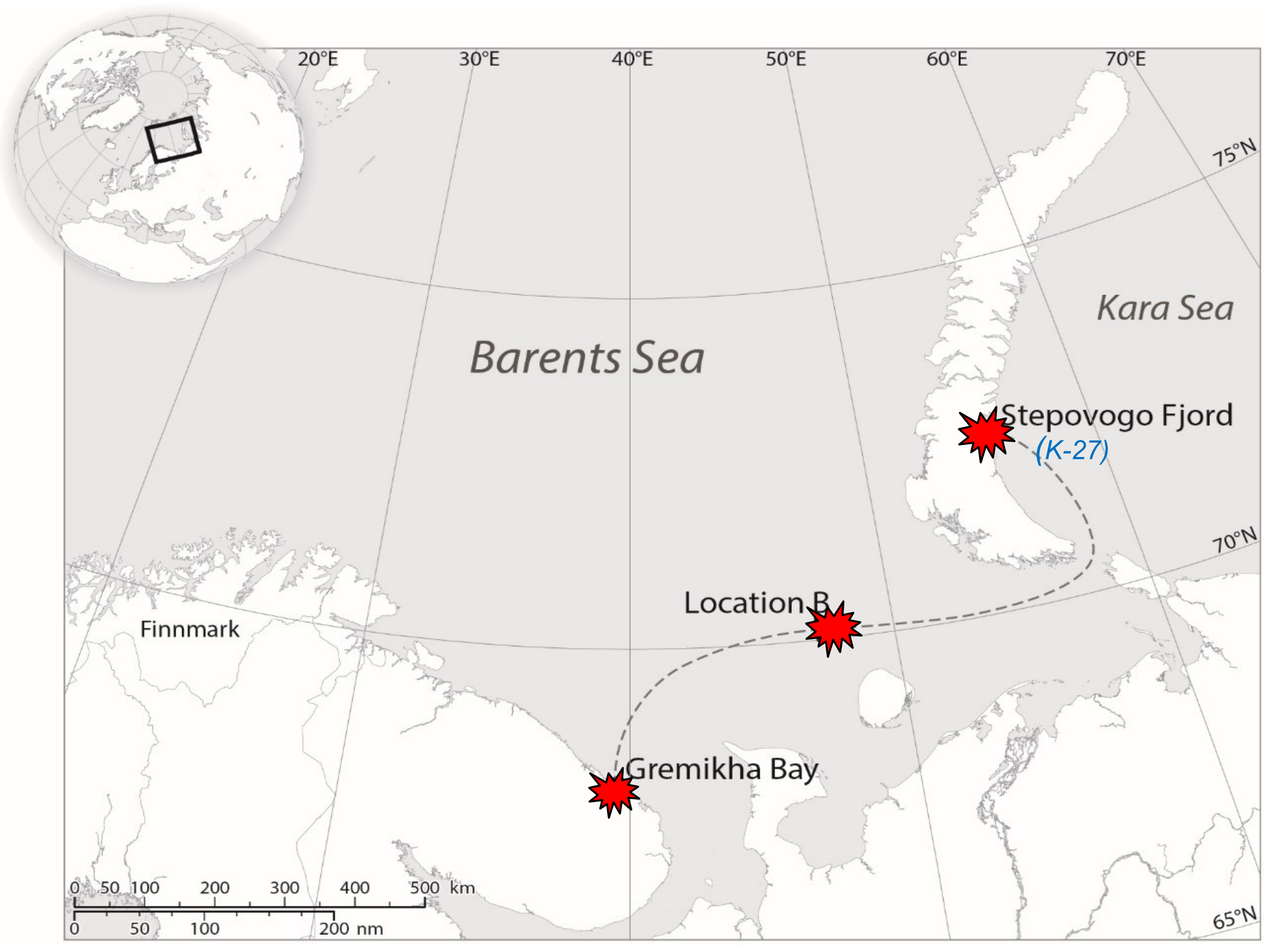

Figure 2. Location of the dumped nuclear submarine K-27 at Stepovogo Fjord, the intermediate site used for dispersion studies denoted Location B and the probable post-recovery location of the submarine at Gremikha. The dotted line indicates envisioned transport route after eventual recovery.

To address these concerns, the Norwegian Radiation Protection Authority (NRPA) initiated a study to examine the radiological consequences of K-27 for both humans and the environment. The study is based on derivation of different hypothetical accident scenarios and evaluation of possible associated consequences of potential releases with particular focus on possible salvage operations. The issue of a Spontaneous Chain Reaction (SCR) potentially occurring within one of the reactors has also been considered and fully elaborated.

The results and findings of this study are presented in two reports. The First Report, published in 2015, provides an overview of the extant and available facts and information regarding the submarine, characterising the source term and considering the various conditions under which a spontaneous chain reaction might occur. The new report moves from compiling facts and relevant data to computer simulations using pre-defined scenarios. The report focuses on the transport of radioactivity in the environment and its fate with regards to exposure situations relevant for environmental impact assessments and secondly it deals with the consequences of releases of radioactivity into the environment and calculation of doses.

Three main scenarios are considered. The first is the «zero-alternative», i.e. investigate the current and future impact assuming no interventions. The second considers an accidental scenario at its current position involving the raising of the submarine and the third an accidental scenario related to the transportation of the submarine to shore for defueling and decommissioning.

A summary of the most up-to-date assessment of the inventories of the submarine's reactors is presented in Table 1. The results indicate that the total inventory of the submarine is of the order of 3.7E+14 Bq (as of 2015), of which about 82% is formed by fission products.

Table 1. Summary of various potential activities present in both reacors of the nuclear submarine K-27 (Bq).

	Portside reactor		***Starboard reactor***	
	2015	***2020***	***2015***	***2020***
Fission products	1.5E+14	1.4E+14	1.6E+14	1.5E+14
Actinides	1.5E+12	1.4E+12	1.7E+12	1.5E+12
Tritium	4.0E+12	3.0E+12	4.3E+12	3.2E+12
Activation products	1.3E+13	1.3E+13	1.4E+13	1.3E+13
Europium in CPS rods	1.3E+13	1.0E+13	1.4E+13	1.1E+13
SUM	1.8E+14	1.7E+14	1.9E+14	1.8E+14

Regarding a SCR, in cases involving the destruction of the reactor protection barrier, water, which acts as a neutron moderator, could penetrate into the reactor core and increase the reactivity of the reactor. The starboard and the portside reactors would attain critical states when the amount of water that has penetrated reaches 5-6 and 18-20 liters, respectively. Table 2 shows various possible release scenarios involving the occurrence of a SCR.

Table 2. Variants of accident scenarios involving SCR.

Scenario	***Depth, m***	***SCR type***	***Release recipient***
At the dumping location	30	Periodic	RC*, water
		Fast with destruction of the RC	Water, air
Lifting	0-30	Single, impulsive	RC, water, air
At the surface	0	Single, impulsive	RC, water, air

**RC stands for reactor compartment*

Depending on the scenario considered, analyses indicate that a total amount of up to 4.8E+14 Bq of short-lived fission products could be released to the surrounding water and, of this, 2.5E+14 Bq might end up in the atmosphere. For longer-lived radionuclides, the amounts that could be released to the atmosphere and water are 9.2E+11 Bq and 5.8E+12 Bq respectively.

The work includes application of a state-of-the-art 3D hydrodynamic and atmospheric dispersion models to investigate the transport, distribution and fate of relevant radionuclides following hypothetical accidents that result in releases to aquatic and terrestrial ecosystems. Figure 3 illustrates two examples from outputs of the applied dispersion models.

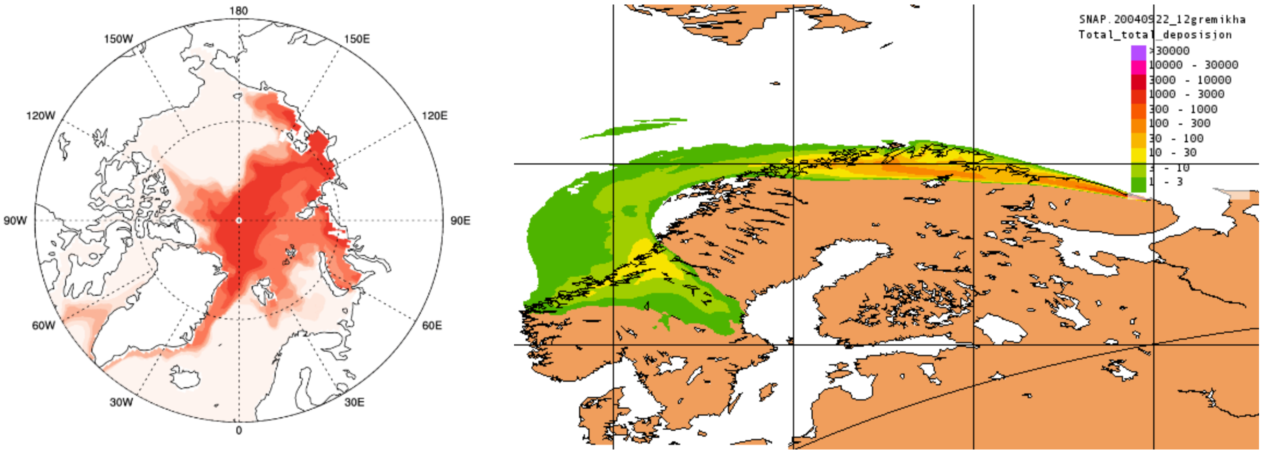

Figure 3. Model simulated dispertion of radioactivity in both marine (left) and atmospheric (right) environment.

The outputs from these dispersion models have been used as inputs to food-chain transfer and environmental dosimetry models and the resultant activities in and doses to human and biota have been calculated. Table 3 shows some of the calculated activities for fish at the 3 considered locations.

Table 3. Maximum activity concentration in seawater and marine fish at considered locations along with associated empirical values.

Location	*Activity concentration, Cs-137*			
	Water (Bq/l)		*Fish (Bq/kg f.w.)*	
	Calculated	*Measured*	*Calculated*	*Measured*
Stepovogo Fjord	*18*	*1.5E-03 – 1.8E-03*	*153*	*<0.3*
Barents Sea	*13*	*1.6E-03 – 2.0E-03*	*72*	*<0.3*
Gremikha Bay	*21*	*1.1E-03 – 5.9E-03*	*129*	*<0.5**

** Caught at coastal waters of Finnmark and Troms.*

Bearing in mind the socio-economic impacts of other accidents involving nuclear and radiological materials, such as the sinking of the Kursk, as well as public unease evident in relation to the Fukushima accident, there remains a cause for concern. The study indicates the potential for widespread contamination of the Arctic environment and elevated levels of radioactivity in local areas compared to the present situation, in the event of an incident involving a SCR. Such contamination and public perception of the significance of its extent and magnitude is difficult to predict, but previous incidents indicate that there could be a potential impact with respect to consumer confidence in marine products.