Marine Pollution Bulletin 116 (2017) 385–394

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Modelling dispersal of radioactive contaminants in Arctic waters as a result of potential recovery operations on the dumped submarine K-27

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ARTICLE INFO

Article history:
Received 10 May 2016
Received in revised form 10 January 2017
Accepted 16 January 2017
Available online 22 January 2017

Keywords:
Nuclear submarine
Dispersion
Arctic
Marine
Modelling
Radioactive contamination

ABSTRACT

Of the wide variety of dumped objects containing radioactive materials in the Arctic seas, the submarine K-27 constitutes a major risk due to the large amount of highly enriched uranium onboard and its location in shallow waters. As the matter of potential operations involving raising of the submarine have entered the public arena, a priori assessment of the contamination in the Arctic marine environment that could result after a possible accident during such operations is a matter of some interest. The dispersion of contaminants within the Arctic has been assessed using a large scale hydrodynamic model for a series of plausible accident scenarios and locations under different oceanographic regimes. Results indicate that, depending primarily on the nature of a release (i.e. instantaneous or continuous), large areas of the Arctic marine environment will exhibit contamination to varying degrees.

1. Introduction

There are a multitude of dumped nuclear objects in the Arctic seas (AMAP, 1998; IASAP, 1999) some of which are of more cause for concern than others owing to various factors such as their associated radionuclide inventories or the possibility for significant releases to occur in the near future. One particular source that has received considerable attention in recent years is the dumped nuclear submarine K-27 (see Gwynn et al., 2016), reflecting the fact that the vessel still contains nuclear reactors containing partially spent nuclear fuel. The K-27 was the first submarine built using Liquid Metal Cooled (LMC) reactors (Sullivan et al., 2002), the keel being laid in June 1958 and the submarine being launched on the 1st of April 1962. The submarine had an overall displacement of 3410 m^3, was 109.8 m long, 8.3 m wide and had a draft of 5.8 m. Its first active service mid-Atlantic cruise took place in 1964, its second between June and August of 1965 and it subsequently underwent medium level repairs during 1966. During refueling in early 1967 problems were noted with the port reactor steam generators in relation to the formation of particulate matter in the coolant.

Following a serious accident in 1968, in which a reactor was damaged resulting in substantial releases of radioactivity and the incurrence of human fatalities, the submarine was removed from active service. K-27 remained at Gremikha Bay until 1973, the operational starboard reactor functioning as a test bed for LMC reactors, steam being pumped into the port reactor to keep the coolant liquid. In 1973 both reactors were allowed to cool resulting in solidification of the coolant in both. At the end of 1973 the submarine was towed to Severodvinsk and the vessel prepared for disposal. All frozen coolant was removed from the undamaged starboard reactor primary circuit, frozen coolant in the port reactor primary circuit being left intact. The control rods were fixed within the cores and channels and other voids were filled with a solidification agent (Furfural) capable of providing what was, at the time, considered to be an “ecologically safe barrier” to prevent contact of seawater with the nuclear fuel of the reactor and subsequent release of radioactive materials. In 1981, the submarine was towed to Stepovogo Fjord (72 31 28 N, 55 30 09 E) at Novaya Zemlya (see Fig. 1) and sunk at a depth of 30 m. The submarine contains an estimated (as of 2015) 10,000 Ci (370 TBq) of activity (Hosseini et al., 2015). Full and detailed information as to the submarine, its dumping and estimates of current inventories of isotopes may be found in Hosseini et al. (2015).

More than three decades after dumping of the K-27, the issue of its recovery has recently received attention. On the 24th of January 2013, Moscow hosted an interdepartmental seminar to discuss scientific and technical problems and their possible solutions in association with the lifting and subsequent handling of the nuclear

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http://dx.doi.org/10.1016/j.marpolbul.2017.01.034
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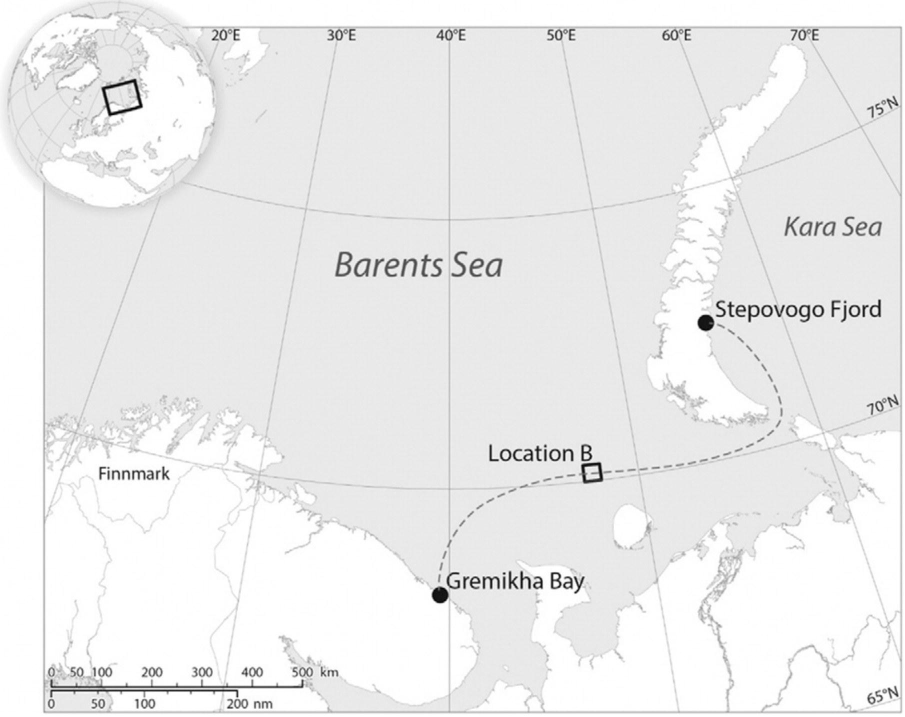

Fig. 1. Location of the dump site of K-27 at Stepovogo Fjord, the intermediate site used for dispersion studies denoted Location B and the probable post-recovery location of the submarine at Gremikha. Dotted line indicates envisioned transport route after eventual recovery.

submarine K-27 (NES, 2013). While there are, at the time of writing, no concrete plans as to further actions regarding the K-27, three options have been drafted: Option I: take no action, Option II: in–situ entombment of the submarine, and Option III: raising of the submarine from the seabed and transportation to land. Earlier analyses (IASAP, 1999) have shown that there is a potential for radionuclide release from K-27, commencing within the next century or two, owing to the corrosion and degradation of various reactor components should the submarine be left in-situ.

Option 3 reflects a situation which not only involves an instantaneous release it also considers transportation of the submarine to land for defueling. The latter represents a possibility for contamination of other areas in the Arctic, beyond the Kara Sea, that are of major importance for Norway (e.g. fishing areas in the Barents Sea). Based on these considerations the third management option was taken as the main focus of this study.

The objective of this work was the elucidation of the possible behaviour and fate of a passive tracer (assumed to adequately represent relatively conservative long-lived radionuclides such as ^{137}Cs and ^{90}Sr) with time following a simulated potential release from the K-27 submarine. In this regard, the possible spread of contamination within the Arctic marine environment was assessed. Furthermore, to provide insight into the possible influence of various factors on dispersion, instantaneous and continuous release patterns as well as various current regimes were also considered.

2. Methodology

The numerical model used for experiments outlined in this work was a version of NAOSIM (North Atlantic/Arctic coupled Ocean Sea Ice Model) (Karcher et al., 2003; Köberle and Gerdes, 2003). The model, derived from the Geophysical Fluid Dynamics Laboratory modular ocean model MOM-2 (Pacanowski, 1995), is coupled to a dynamic-thermodynamic sea ice model with a viscous-plastic rheology (Hibler, 1979). The version employed here had 30 unevenly spaced vertical levels, starting from 20 m thickness down to 100 m depth with the thickness gradually increasing with depth. The model domain covers the Nordic Seas, the Arctic Ocean and the northern North Atlantic to 50° N and the Canadian Archipelago, allowing throughflow between the central Arctic and the Labrador Sea. The model has an open boundary in the Bering Strait where a total inflow of 0.8 Sv is imposed to cover the approximate amount of observed inflow of Pacific Water into the Arctic Ocean. It also has an open boundary in the south, where barotropic flow from a larger scale version of the model is prescribed. At both boundaries the flow profiles can develop freely. The open boundary conditions have been implemented following Stevens (1991), thereby allowing the outflow of tracers and the radiation of waves. The initial hydrography in January 1948 was adopted from the PHC winter climatology (Steele et al., 2001), while a yearly mean climatology was used as a reference for surface salinity restoring over a time scale of 180 days. The restoring of sea surface salinity is a common method used to prevent the ocean salinity from drastically drifting away from the observed ocean state (Steele et al., 2001), compensating for a mismatch between freshwater forcing data (e.g., precipitation and runoff) and model physics. Parametrization of river runoff was conducted using negative salt fluxes proportional to seasonal climatologies of runoff for each of the major rivers which follows the Arctic Ocean Model Intercomparison Project (AOMIP protocol) (Holloway et al., 2007). The model was driven with daily atmospheric forcing from 1948 to 2010 (NCEP/NCAR reanalysis, Kalnay et al., 1996). The tracer release experiments began in July for each of the experiments, as summer was assumed to be the most likely season for a recovery of the submarine. NAOSIM has been validated and used successfully in a number of applications focusing on Northern Sea circulation (Karcher et al., 2008; Gerdes et al., 2005) and tracer dispersion (Karcher et al., 2004).