Journal of Environmental Radioactivity 182 (2018) 52–62

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

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

Norwegian monitoring (1990–2015) of the marine environment around the sunken nuclear submarine Komsomolets

Justin P. Gwynn[a,*], Hilde Elise Heldal[b], Janita K. Flo[b], Ingrid Sværen[b], Torbjörn Gäfvert[c], Hallvard Haanes[c], Lars Føyn[b], Anne Liv Rudjord[c]

[a] Norwegian Radiation Protection Authority, The Fram Centre, N-9296 Tromsø, Norway
[b] Institute of Marine Research, PO Box 1870 Nordnes, N-5817 Bergen, Norway
[c] Norwegian Radiation Protection Authority, PO Box 55, N-1332 Østerås, Norway

A R T I C L E I N F O

Keywords:
Komsomolets
Norwegian Sea
Monitoring
Radionuclides
Source terms

A B S T R A C T

Norway has monitored the marine environment around the sunken Russian nuclear submarine Komsomolets since 1990. This study presents an overview of 25 years of Norwegian monitoring data (1990–2015). Komsomolets sank in 1989 at a depth of 1680 m in the Norwegian Sea while carrying two nuclear torpedoes in its armament. Subsequent Soviet and Russian expeditions to Komsomolets have shown that releases from the reactor have occurred and that the submarine has suffered considerable damage to its hulls. Norwegian monitoring detected ^{134}Cs in surface sediments around Komsomolets in 1993 and 1994 and elevated activity concentrations of ^{137}Cs in bottom seawater between 1991 and 1993. Since then and up to 2015, no increased activity concentrations of radionuclides above values typical for the Norwegian Sea have been observed in any environmental sample collected by Norwegian monitoring. In 2013 and 2015, Norwegian monitoring was carried out using an acoustic transponder on the sampling gear that allowed samples to be collected at precise locations, ~20 m from the hull of Komsomolets. The observed $^{238}Pu/^{239,240}Pu$ activity ratios and $^{240}Pu/^{239}Pu$ atom ratios in surface sediments sampled close to Komsomolets in 2013 did not indicate any releases of Pu isotopes from reactor or the torpedo warheads. Rather, these values probably reflect the overprinting of global fallout ratios with fluxes of these Pu isotopes from long-range transport of authorised discharges from nuclear reprocessing facilities in Northern Europe. However, due to the depth at which Komsomolets lies, the collection of seawater and sediment samples in the immediate area around the submarine using traditional sampling techniques from surface vessels is not possible, even with the use of acoustic transponders. Further monitoring is required in order to have a clear understanding of the current status of Komsomolets as a potential source of radioactive contamination to the Norwegian marine environment. Such monitoring should involve the use of ROVs or submersibles in order to obtain samples next to and within the different compartments of the submarine.

1. Introduction

The Russian nuclear submarine Komsomolets (K-278) sank in the Norwegian Sea on the 7th of April 1989 following the outbreak of a fire that began in the steering compartment. The submarine sank after initially surfacing and now lies at a depth of 1680 m, south west of Bear Island (73°43′16″ N, 13°16′52″ E) (Fig. 1). Komsomolets was powered by a single 190 MW OK-650b-3 pressurised water reactor that was shut down in the early stages of the accident and was carrying two nuclear torpedoes in its armament when it sank (Gladkov et al., 1994). Of the 69 crew members, 42 were killed as a result of the accident and eventual sinking. The total activity of the inventory of the reactor at the time of sinking has been estimated at 29 PBq with a further 16 TBq of $^{239,240}Pu$ contained within the two nuclear warheads (Gladkov et al., 1994; Høibraaten et al., 1997). Following the sinking, a number of Soviet and subsequent Russian expeditions were carried out between 1989 and 2007 with the aid of manned submersibles to investigate the status of the sunken nuclear submarine and the surrounding marine environment. In addition, UK and German expeditions collected samples of sediment and seawater in the area around Komsomolets in 1989 and 1995, respectively. The use of manned submersibles in the Soviet and Russian expeditions allowed for the visual inspection of the submarine and for the collection of samples and in situ measurements next to the hull. Initial investigations showed that the front part of the

* Corresponding author.
E-mail address: justin.gwynn@nrpa.no (J.P. Gwynn).

https://doi.org/10.1016/j.jenvrad.2017.11.015
Received 21 February 2017; Received in revised form 3 July 2017; Accepted 13 November 2017

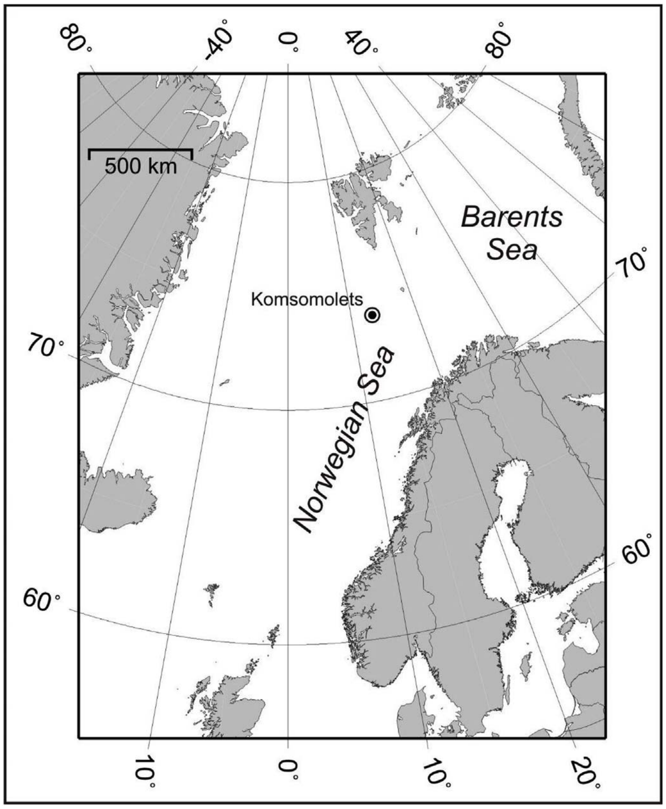

Fig. 1. Location of the sunken nuclear submarine Komsomolets in the Norwegian Sea.

submarine had suffered considerable damage, with holes and cracks in both the outer hull and inner pressure hull (Yablokov et al., 1993). Damage to the outer and inner pressure hull was observed above the torpedo compartment and it was reported that the nuclear material in the warheads were in contact with seawater (Yablokov et al., 1993). The six torpedo tubes along with some holes in the torpedo section were sealed with titanium plates during the expedition in 1994 to reduce the flow of seawater into the torpedo compartment (Kasatonov, 1996). Releases of radionuclides (^{60}Co, ^{134}Cs and ^{137}Cs) from Komsomolets have been detected by in situ measurements in a ventilation pipe that forms an open connection between the compartment next to the reactor and the open sea (Nejdanov, 1993; Gladkov et al., 1994; Kazennov, 2010). Activity concentrations of ^{137}Cs detected in this ventilation pipe in 1994 were of the order of 1 MBq/m^3 decreasing to 4 kBq/m^3 in the zone around the outlet (Gladkov et al., 1994). Based on rates of water flow in the ventilation pipe, annual releases of ^{137}Cs from the sunken submarine were estimated at that time to be around 500 GBq/yr (Gladkov et al., 1994). In 2007, annual releases of ^{137}Cs from the ventilation pipe were reported to have decreased by more than 30 fold (Kazennov, 2010), whilst more recently, Vysotsky et al. (2014) estimated releases of ^{137}Cs and ^{90}Sr from Komsomolets at 0.1 GBq/yr.

Activity concentrations of ^{90}Sr, ^{137}Cs, Pu isotopes and ^{241}Am in seawater and sediment samples collected by Soviet, Russian, UK and German expeditions between 1989 and 1995 from the area around Komsomolets have not indicated any releases from the submarine (Camplin and Read, 1992; Kuznetsov et al., 1993; Grøttheim, 1999; Nies et al., 1999a, 1999b; Stepanov et al., 1999; Astakhov et al., 2000; Nies et al. unpublished). However, above background activity concentrations of ^{90}Sr and ^{137}Cs were reported in some samples of benthic fauna collected close to Komsomolets in 1994, although not for any other year (Kuznetsov et al., 1996, 1999). Additionally, ^{60}Co was reported to have been detected in 3 samples of echinoderms (3.5–27 Bq/kg) collected close to the Komsomolets in 1993 (Kuznetsov et al., 1999). Plutonium activity and atom ratios in seawater sampled in the torpedo compartment and in sediments sampled close to Komsomolets in 1994 and 1995 were reported to be comparable to background measurements (Stepanov et al., 1999; Astakhov et al., 2000).

Norway's national marine monitoring programme (Radioactivity in the Marine Environment - RAME) charts trends in radionuclides in seawater, sediments and marine biota in the Norwegian marine environment and provides information on levels of radioactive contamination to relevant stakeholders. As part of this work, it is important for Norway to maintain an up-to-date overview of any source of radioactive contamination that may cause concern for fisheries and the general public.

Norway has carried out monitoring of the marine environment in the area around Komsomolets annually since 1990. When sampling from surface vessels using traditional sampling gear lowered to the bottom, it is almost impossible to know the exact position of the sampling gear when the samples (seawater or sediment) are collected, or how the position of the samples collected relates to the actual location of the submarine. This is due in part to the great depth at which Komsomolets lies, but also to the varying strengths and direction of bottom currents in the area (Aleinik et al., 1999; Lukashin, 2008). In 2013 and 2015, monitoring was carried out using an acoustic transponder on the sampling gear that allowed samples to be collected at precise locations, ~20 m from the hull of the submarine. Even with the use of an acoustic transponder, there is still a need to maintain a safe operating distance from Komsomolets in order to avoid the possibility of fouling the sampling gear on the submarine.

This study presents for the first time a complete overview of all the results of the Norwegian monitoring of Komsomolets between 1990 and 2015 and compares the Norwegian findings with a compilation of the available data from previous Soviet, Russian, UK and German expeditions. Data from Norwegian monitoring between 1990 and 1994 have been previously reported in the non-peer reviewed internal reports by Blindheim et al. (1994) and Kolstad (1995). Additionally, some data for other years have been reported in the non-peer review RAME reports by the Norwegian Radiation Protection (www.nrpa.no) as well as in the MSc thesis by Flo (2014). Selected data for sediment from the Norwegian monitoring of Komsomolets in 1999 have been published previously by Heldal et al. (2002) and will be referenced as such.

2. Material and methods

2.1. Sample collection and preparation

Samples of seawater and sediment were routinely collected on annual research cruises to the site of Komsomolets from research vessels belonging to the Institute of Marine Research (IMR), Bergen. Overall samples have been collected between March and October, but the timing of the sampling in any particular year varied from year to year. In addition, samples of seawater and sediment were collected by the Norwegian Radiation Protection Authority (NRPA) during Russian cruises in 1993 and 1994 by the research vessel Akademik Mstislav Keldysh. These samples were processed and analysed by the NRPA and are presented as part of the Norwegian monitoring data in this paper.

Surface seawater samples were collected via seawater intakes, whereas bottom seawater samples were collected using Niskin bottles on a water-sampling array ~10 m from the seafloor. Seawater samples for ^{90}Sr (50 l), ^{239,240}Pu and ^{241}Am (200 l) analysis were acidified to pH 2 immediately after collection with 12 M HCl. Seawater samples for ^{137}Cs (75–200 l) were either collected directly in plastic cans or passed directly through filter arrays impregnated with copper hexacyanoferrate as a Cs selective exchange resin (Roos et al., 1994). In 1993, 1994, sediment samples were obtained using a sediment grab (gross sample) as well as by operations with Russian MIR manned submersibles that allowed for sediment cores (diameter 8.7 cm) to be taken next to the hull of Komsomolets. For all other years, sediment samples were taken using a Smøgen box corer (30 × 30 cm), with any