Marine scientists on the Arctic Seas: Documenting the radiological record

The IAEA's Marine Environment Laboratory in Monaco is helping to assess the radiological picture in the Kara and Barents Seas

by
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Before 1992, not much was known internationally about radioactivity levels from dumping operations in the Arctic Seas. That picture has changed over the past three years, largely due to the joint efforts of scientists from Russia, Norway, and the IAEA's Marine Environment Laboratory in Monaco

In 1992, the Agency's Marine Environment Laboratory (IAEA-MEL) responded to an invitation by the Russian and Norwegian governments to participate in investigatory cruises to the Kara Sea and to assist in the assessment programme related to the disposal of radioactive wastes in the Kara and Barents Seas. The IAEA-MEL programme, organized later in the framework of the Agency's IASAP project, included:

- participation on four expeditions to the Kara Sea organized by the joint Russian-Norwegian expert group and by the Russian Academy of Sciences during the period 1992-94;
- assistance with *in-situ* and laboratory-based radiometric measurements of radionuclide concentrations in the Kara Sea;
- organization of analytical quality assurance intercalibration exercises among the participating laboratories;
- provision of a central database facility for the IASAP project, including all available data on past and present radioactivity concentrations in the Arctic Seas; and
- contributing to the international programme of local, regional, and global scale computer modelling of the potential dispersal of radionuclides released from the dumped waste and the assessment of the associated radiological consequences.

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Expeditions to the Kara Sea

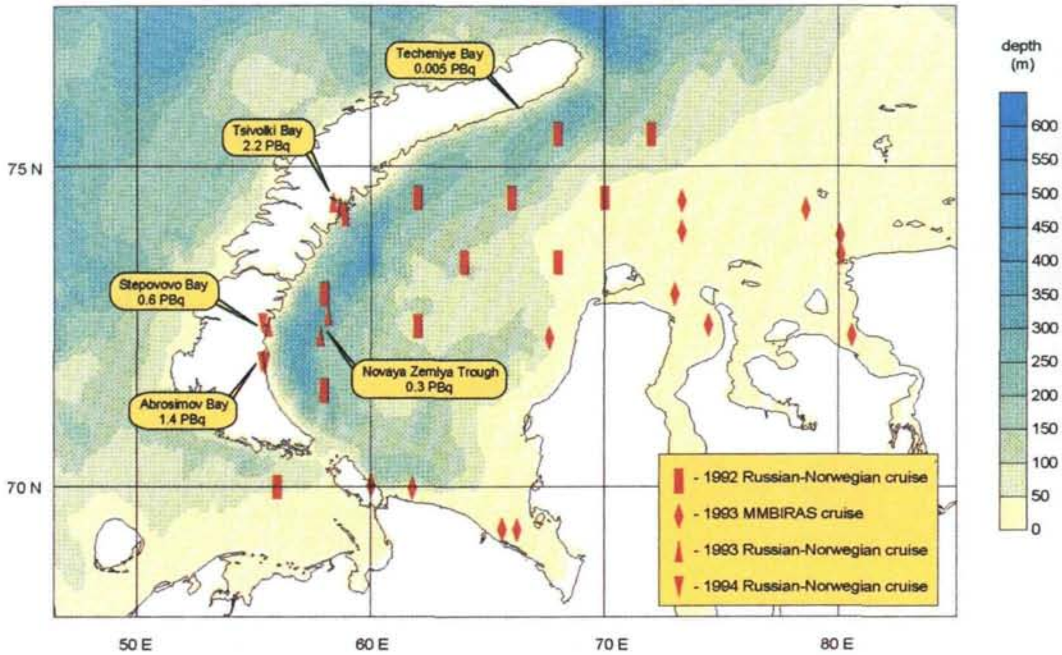
Few data exist in the open literature published before 1992 to document radioactivity levels in the Kara Sea. Those that exist are notably results of US and Russian surveys in the 1960s and 1980s. In 1992, following announcements about past dumping of radioactive wastes in the shallow waters off Novaya Zemlya, the Russian and Norwegian governments organized the first in a series of three joint expeditions to the Barents and Kara Seas and the IAEA was invited to participate in these. *(See map.)*

The scope of the first cruise was to investigate radioactive contamination of the marine environment in the open Kara Sea, with the aim of identifying and quantifying any contributions from local sources. In 1993, official information on the dumping was published, on the basis of which the 1993 and 1994 joint Russian-Norwegian expeditions were then planned. The objectives were to investigate the dump sites in the Tsivolki, Stepovovo, and Abrosimov bays and in the Novaya Zemlya trough in order to locate and identify the dumped objects, to document their state, and to measure the radioactivity levels in their environment. The sites were inspected using towed sonar systems, underwater spectrometers, and remotely operated vehicles.

The searches in the bays were successful. They yielded detailed information on dumped reactor compartments, cargo ships, and tankers with solid waste; the liquid metal-cooled submarine in Stepovovo Bay; and large numbers of containers with solid waste. All cruises performed *in situ* and on-board radiometric analyses and returned sets of environmental samples and data needed to allow an assessment of the environmental and health impacts of dumping.

The sampling strategy was aimed at (1) providing evidence of leakage, if any, from the dumped waste; (2) evaluating dispersal from the sources and mapping radionuclide distribution

Sampling stations occupied during the 1992-94 Kara Sea cruises and estimated radionuclide inventories at sites



Note The estimated inventories of radionuclides refer to 1994 and pertain to naval reactors disposed at major dump sites based on IASAP working documents

patterns in bottom sediments; (3) evaluating different contributions to the radionuclide inventories; (4) assessing contamination of biota, radionuclide transfer, and site-specific concentration factors; and (5) investigating the time evolution of radioactivity levels.

Water and bottom sediment profiles, marine biota and, from the 1994 cruise, samples of soil, fresh water, and vegetation from the shores of the bays were collected for further detailed radionuclide analyses. This was done mainly in Russian and Norwegian laboratories and at IAEA-MEL. To assure the quality of radioactivity data, IAEA-MEL organized intercomparison exercises for radionuclides in sediment, water, and seaweed for the laboratories involved in analytical work on cruise samples.

An important contribution to inventories of artificial radionuclides in the Kara Sea can be attributed to inputs from land-based sources in the catchment areas of the Ob and Yenisey rivers. Therefore, in 1993, the IAEA-MEL also joined an international expedition organized by the Russian Academy of Sciences to investigate radioactivity in the southern part of the Kara Sea.

At IAEA-MEL, the analytical work on approximately 300 samples brought back from these four expeditions is in progress. Laboratory experiments have also been initiated with materials returned from the Kara Sea on the biokinetics of radionuclides and their interaction with sediments in specific Arctic conditions.

Radiometric investigations

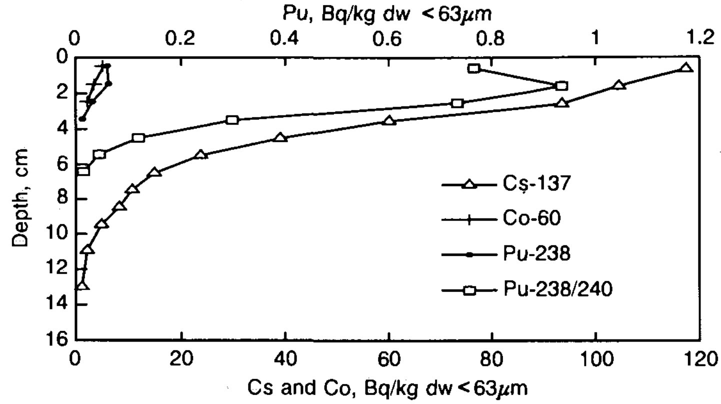
The results of radionuclide analyses of samples collected during expeditions to the Kara Sea show unambiguously that, as yet, there has been no major leakage from the disposed radioactive wastes. Perhaps the most persuasive piece of confirmatory evidence is IAEA-MEL's investigation of gamma-radiation at the sediment surface in the Stepovovo Bay dump site. The gamma-spectrum —obtained using IAEA-MEL's new underwater survey system which includes a cooled HPGe detector — is one of the first sets of high resolution marine gamma-spectra ever recorded *in-situ*. The system had first been tested successfully in the Irish Sea, near the Sellafield nuclear site, in summer 1993.

The spectrum shows at a glance the predominance of the gamma-ray lines from naturally occurring (background) radionuclides, namely from potassium-40 and the uranium and thorium decay series. The only identifiable anthropogenic radionuclide is caesium-137 at a concentration which is well below those of the natural radionuclides. Despite the vicinity to the dumped reactors and the sites of many past nuclear weapons tests, the concentrations of anthropogenic radionuclides are low, less than in many other areas of the world's oceans. *(See graph.)*

Radiometric analyses of Kara Sea sediments in the laboratory have also shown clearly that the present anthropogenic radioactivity of Kara Sea sediments is low. It is predominantly due to direct deposition and catchment run-off of global fallout from nuclear weapons tests, discharges from the reprocessing plants in Western Europe and the former Soviet Union, Chernobyl fallout, and local fallout from nuclear tests performed at Novaya Zemlya. However, at the major dumping sites in Abrosimov, Stepovovo, and Tsivolki bays off Novaya Zemlya island, areas with elevated concentrations of caesium-137 and cobalt-60 have been found. *(See graph.)* These results indicate that local contamination due to leakage from dumped low-level wastes has occurred but that this is not detectable beyond the dump sites.

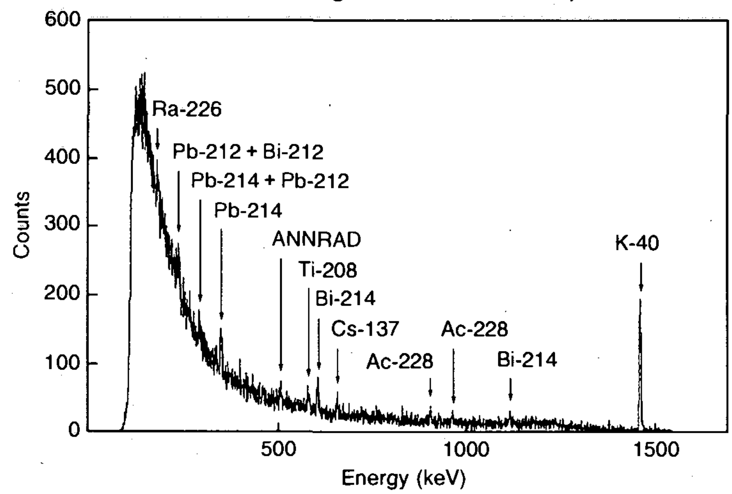
Our study, along with the work of Russian and Norwegian colleagues, shows that there is no evidence of major leakage from the reactor components and other wastes disposed of into the Kara Sea. Past and present radionuclide concentrations in seawater and sediments of the Kara Sea have generally been and still remain very low. The major residual issue regarding these disposals is therefore not what has happened so far but what could happen in future. The main scientific challenge is to predict the possible magnitude, nuclide composition, dispersal, transfer, and radiological consequences of any future leakage from the dumped reactors and other nuclear wastes.

Stepovovo Bay Sediment core (water depth 57m)



Date of data: 27 September 1993.

Kara Sea Sediment, Stepovovo Bay (High resolution gamma spectrum recorded with germanium detector)



Date of data: September 1993. Spectrum accumulation time: 9500 s

Results of radiometric investigations in the Kara Sea

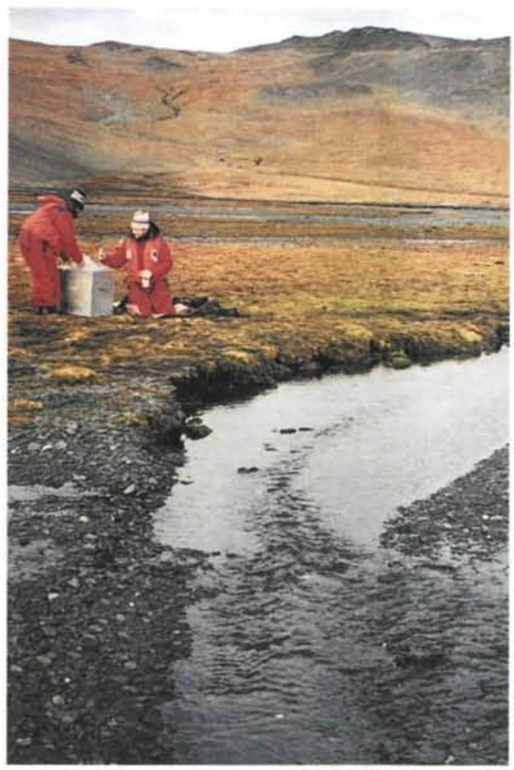
Radioactivity database

A further contribution by IAEA-MEL within the framework of IASAP is via its Global Marine Radioactivity Database (GLOMARD) programme. The laboratory is acting as a central facility for the collection and synthesis of all data on marine radioactivity, i.e. in seawater, sediments, and biota. The database provides a scientific resource designed to serve several important functions, such as the provision of immediate and up-to-date information on radioactivity levels, the generation of snapshots of activities at given times and locations, the investigation of temporal changes, and the identification of gaps in available information.

The database has links to IAEA-MEL's in-house analytical quality control database. This allows immediate checks on laboratory practice. In the specific context of the Arctic Seas, the database will provide input to the evaluation of the environmental radioactivity levels of the region and to the assessment of the radiation doses to marine biota and local, regional, and global human populations. Some of the uses of the database within the Arctic assessment programme are immediate. They include the evaluation of nuclide ratios, investigation of time trends, inventory calculations, dose estimation, and model validation.

Computer modelling and radiological assessment

Dispersion and radiological modelling has begun on three geographical scales, namely global, regional and local. This is being done in order to predict the possible consequences for the world at large and for those populations living near to the disposal sites. For modelling dispersal



Scientists from IAEA-MEL have taken part in four expeditions to study the radiological situation in the Kara Sea, sometimes under difficult sea conditions. In addition to soil samples collected on the island, researchers collected biota and other samples in the waters of the Kara Sea.

(*Credit: I. Osvath, IAEA-MEL*)

of radioactive pollutants on a global scale, IAEA-MEL has developed and implemented a number of compartmental models.

This class of models is particularly suited to long-range (greater than 100 years) assessments and has been previously used in other programmes (e.g. the Nuclear Energy Agency's CRESP and the European Commission's MARINA). The accuracy of results from such models is also well suited to the detail required for radiological assessments.

The work reported here is based on the 16-box ARCTIC-2 model, with enhanced structure in the Arctic region. The model provides a satisfactorily accurate prediction of Sellafield caesium-137 dispersion through the northern seas.

Doses to the world population (committed effective collective doses integrated over 300 years following release) and maximum individual dose rates for hypothetical critical groups were calculated based on the marine fish ingestion pathway. The oceanographic part of the model produces radionuclide concentration data as output. The radiological component translates radionuclide concentrations in water into corresponding concentrations in fish, using IAEA-recommended concentration factors. Catch values are derived from fishery statistics data of the Food and Agriculture Organization and ICES. Radionuclide intake by humans is quantified assuming that 50% of total fish catch is normally consumed, with the exception of the Arctic Seas where a consumption of 80% is assumed. Fish catch is taken as constant over the period of interest, and no delay between catch and consumption is considered. The final conversion to dose is achieved using dose conversion factors for adults based on those contained in ICRP-60 of the International Commission on Radiological Protection.

A range of source-term scenarios has been developed on the basis of available information on the nuclear wastes, including reactors, dumped in the Arctic. The calculations have been performed for 20 long-lived radionuclides both at time of dumping and 500 years thereafter.

For a gradual release of caesium-137 over 20 years following dumping from the naval reactors containing spent nuclear fuel disposed in the Kara Sea, the model predicts maximum concentrations of about 10 Bq per cubic meter averaged throughout the western Kara Sea bottom water compartment. This corresponds to less than 1% of the natural radioactivity of sea water. Local and regional models, with enhanced spatial resolution, will be used to localize and quantify smaller scale maxima.

A simple evaluation was made, on the basis of available information, of the radiological effects for a worst case scenario. Dose calculations based on estimated maximum inventories in reactors dumped in the Kara Sea indicate a committed collective effective dose in the order of 10 man Sv, if instantaneous release occurs at the time of dumping. More than 70% of this dose is delivered by caesium-137, and most of the remaining part is contributed by activation products (cobalt-60 and carbon-14). These computations are based on the assumption that the fish catch in the Kara Sea is about 20 kilotons per year.

The assumption of instantaneous nuclide release is, however, an extremely unrealistic one. The mechanism of release for the bulk part of the inventory would normally be via corrosion, occurring over periods of up to hundreds or even thousands of years. In particular, the dissolution of cobalt-60 from steel and other structural components is unlikely to be quantitative within the short mean lifetime (about 7.6 years) of this nuclide. Thus, from a rapid release of reactor-derived radionuclides, caesium-137 is indeed the main deliverer of dose beyond the immediate disposal region. For a delayed release of radionuclides, e.g. after 500 years of containment, 99% of the fish ingestion dose commitment will arise from carbon-14.

To assess the impact on a regional scale, three-dimensional circulation and dispersion models developed at the University of Hamburg are now being employed. Preliminary calculations performed to test model predictions show that, for a continuous release of 1 TBq per year of caesium-137 in Abrosimov Bay, the average caesium-137 concentrations in the entrance of the bay could reach 2 kBq per cubic meter.

Documenting the radiological situation

The IAEA-MEL's radiometric and preliminary modelling contributions to IASAP have yielded important results so far. They suggest that only radiological effects on regional and local scales may be of importance. The global radiological impact of past waste dumping in the Arctic Seas will be comparable to or less than those resulting from other anthropogenic and natural sources of radioactivity.

Scientists from IAEA-MEL will continue to be actively engaged in many facets of this important international project to investigate and document the health and environmental implications of past radioactive waste dumping practices in the Arctic Seas. ❐