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The global scenario and challenges of radioactive waste in the marine environment

by S. A. Di Pietro, JC Juan Edward, N. Priest, and H. Garelick

Radioactive material has been directly and indirectly discharged into the aquatic environment. This may be a result of reactor accidents (*e.g.,* Fukushima), fuel production facilities (e.g., Port Hope -strictly a great lake), fuel reprocessing plants (*e.g.,* Windscale/Sellafield), aircraft accidents (*e.g.,* Palomares and Thule) and reactor disposals (*e.g.,* Soviet ice breaker, Hanford Site in Washington State, USA, and submarine reactors in the Kara Sea) [1].

There has been a rise in the number of known sources of anthropogenic radionuclides in the marine environment. The most significant global source is fallout from atmospheric nuclear tests, including ^{3}H and ^{137}Cs [2]. The deposition of radionuclides from anthropogenic sources is unevenly distributed in the global ocean. The Irish Sea is arguably the most contaminated following decades of fuel-reprocessing waste discharges containing long-lived fuel derived radionuclides (including Pu isotopes and ^{241}Am) and fission products (including ^{137}Cs, ^{90}Sr and ^{99}Tc)– all within historic authorized limits. These discharges, like others elsewhere have resulted in uptake by biota—some which (*e.g.* fish and seaweed) have entered the human food chain. In 2011, the Fukushima nuclear disaster released a significant amount of radioactive contamination. It is estimated that 18,000 TBq of radioactive ^{137}Cs was discharged into the Pacific Ocean.

Radioactive waste includes any material that is either intrinsically radioactive, or has been contaminated by radioactive materials, and is deemed to have no further use [3]. Radioactive waste is typically classified as either low-level (LLW), intermediate-level (ILW), or high-level (HLW), dependent on its level of radioactivity [4]. Although studies have been conducted, there is lack of collective data on the level of radioactive contamination in marine waters. The threats of radioactive food chain contamination are common causes of alarm within exposed populations.

The assessment of marine radioactivity in a marine environment needs a thorough knowledge of the potential sources and an understanding of oceanic processes. Their measurement may present unique radiochemical challenges. Radionuclides may become widely redistributed by ocean currents, and may be accumulated by biota or be returned to the land by sea to land transfer. Discharges to the sea have been used to map ocean currents. They also may present a

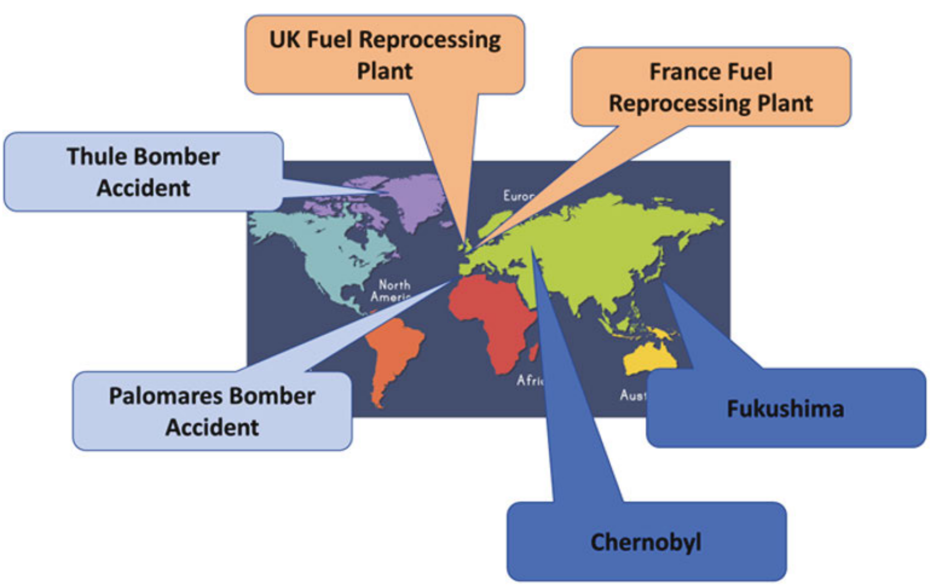

Figure 1. In addition to global fallout, discharges, and accidents have resulted in widespread marine contamination, particularly in the northern hemisphere.

Figure 2. The project was presented by the project leaders—Silvi Di Pietro and JC Juan—and Nick Priest at the IUPAC's Chemistry and Environment Division meeting in Siem Reap, Cambodia.

hazard to biota and man. For example, ^{106}Ru in edible seaweed, ^{99}Tc in lobsters, and ^{137}Cs in fish have all been shown to have entered the human food chain and are commonly claimed to present a health hazard. However, information on radionuclides in the ocean is thin [1].

In addition to naturally occurring radionuclides (most importantly ^{40}K, ^{232}Th and U isotopes) anthropogenic radionuclides can enter the aquatic environment by several routes. Global weapons fallout deposition, reactor accidents, routine reactor discharges, fuel production and reprocessing plants pipeline emissions, aircraft carrying nuclear weapons accidents, reactor disposals, and fallout from the burn-up of satellite nuclear power sources on atmospheric re-entry, are all examples of direct inputs. Indirect inputs include the redistribution of terrigenous global fallout, by windborne dust from contaminated land, and washout to river systems. It follows that while some radionuclides are deposited close to the sites of their release, where they may produce a local hazard, others are redistributed globally by ocean currents. Given the complexity of the marine environment, the measurement of radionuclides may present unique radiochemical, biochemical, and regulatory challenges [5].

As described above, contaminated biota that enters the human food chain is of widespread concern. However, of particular concern is the putative risk to some coastal communities that may have much higher-than-average exposure to radionuclides present in coastal air, sediments, and biota. While there is general agreement that marine radionuclides levels are currently of low concern, they, and their sources, are subject to strict, national and international regulatory control [5]. A IUPAC project "*The global scenario and challenges of radioactive waste in the marine environment*" aims to bring together a series of reviews and original papers within this journal special issue that are concerned with the diverse aspects of the fate and transport of radionuclides and radioactive waste in the marine/aquatic environment.

The project comprises a series of critical reviews that are concerned with aspects of the fate and transport of radionuclides and radioactive waste in the marine environment. In line with the objectives of the project, reviews describe the problems of detection, identification, and behaviour of radionuclides within different aquatic environmental compartments, including land-to-sea and sea-to-land transfer; and the future challenges presented by a resurgent nuclear industry [5].

The project was also presented a large audience at the quadruple meeting APCE-CECE-ITP-IUPAC held in Siem Reap, Cambodia 6-10 November, 2022 [5]. The new project was presented to IUPAC by Nick Priest, Silvi Di Pietro, and JC Juan (Figure 2). Many were involved in the development of the project, and the task group includes M. Burkitbayev, M. A. Hurlbert,

I. Ilona Matveeva, Y. Onda, L. Pantoja-Munoz, F. Sakellariadou, D. Tsumune.

A selection of nine papers is published in this special issue of *Pure and Applied Chemistry* (PAC). The topics covered are:

- The quantification, analysis and detection of radionuclides in the environment using Diffusive Gradients in Thin Films (DGT) [1].
- An overview of marine radionuclides, from sampling to monitoring [6].
- The speciation and mobility of uranium isotopes in the Shu River: impacts for river to sea transfer [7].
- Impact of fluvial discharge on 137Cs in the ocean following the Fukushima Daiichi Nuclear Power Station accident [8].
- Transport of radioactive materials from terrestrial to marine environments in Fukushima over the past decade [9].
- The sea to land transfer of irradiated uranium in Cumbria, UK [10].
- Public knowledge, sentiments, and perceptions of low-dose radiation (LDR) and power production, with special reference to reactor accidents [11]
- Radionuclides in marine sediment [12].

Anthropogenic radionuclides are introduced in marine systems (*i.e.,* ocean, rivers, ponds, *etc.*) from radioactive fallout. The fallout is a result of atmospheric nuclear weapons testing, nuclear power plant accidents, nearshore discharges from nuclear facilities, radioactive waste dumping, and nuclear-powered ships accidents to name a few. Moreover, terrestrial environments are also the culprit due to radionuclides deposited groundwater systems (*i.e.,* Hanford Site in Washington State, USA). Ultimately, radionuclides sink and settle on the seabed. To further understand the importance and impact of radioactive fallout in marine systems, this *PAC* special issue "*The global scenario and challenges of radioactive waste in the marine environment*" brings together a series of reviews and original papers that are concerned with the diverse aspects of the fate and transport of radionuclides. The authors hope that the compilation of nine papers published in this issue present the reader with a state-of-the art critical review, basic understanding of radionuclides fate and transport, and provide current perspectives and current challenges on the topic of nuclear industry.

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