A review on status of marine radioecology in Indonesia after Fukushima accident

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Abstract. A brief overview of the current status of marine radioecology in Indonesia after the Fukushima accident is given. Indonesia waters as a part of a global oceanic current, taking an essential role in distributing radionuclide releases from the Fukushima accident. Recent years have seen significant work conducted on the radioactivity marine environmental monitoring on the seawater, sediment, and biota both in offshore and coastal of Indonesia marine area. This article mainly focuses on the radioactivities of 137Cs and 134Cs as an essential conservative radionuclide released from the Fukushima accident. The distribution of anthropogenic radionuclide was comprehensively monitored from the West part Aceh to Papua in the East. Moreover, seawater masses bringing radioactivity at inflow and outflow of Indonesian Through Flow (ITF) was also observed. The activity ratios of 134Cs/137Cs measured at several locations are evaluated to gain an insight of radioactivity origins. It is important to note that the 137Cs radionuclides detected in the Indonesia marine area have been very low and comparable to other regional marine areas. On the other side, 134Cs radionuclide has been not detected over the Indonesia marine area.

1. Introduction

Extraordinary radioactivity releases from the Fukushima Nuclear Accident (FNA) as a result of the devastating tsunami of March 2011 induced by the 9.0 magnitude Tohoku earthquake. More than 80% of the total amount of radioactivity released in time go into the oceans through various ways, such as the direct discharge and atmospheric deposition [1,2]. After the initial decay of those contaminants with half-lives below than days to weeks, while there reported different radionuclides released, much of the consideration still focused on 137Cs (t1/2= 30.07 years) for the reason that there was released in a more massive amount compare to other radionuclides [3]. The total of 137Cs released reached 4 to 90 PBq but with most estimations of the collective releases in the variety of 15–30 PBq [1,4,5]. Due to their property of biogeochemical and processes in the ocean, radionuclides from Fukushima can be distributed to the Indian Ocean from the NW Pacific Ocean. The interchange of seawaters take place in an inter-basin known as the Indonesian Through Flow (ITF) [6,7].

In line with its possible impact on Indonesian marine compartments, the accident at Fukushima has turn out to be a public concern in the nation, as it relies deeply on the ecosystem, as well as on marine fisheries products. Much investigation in the last decades has monitored Indonesia’s marine
environment concerning nuclear activities and the possible risk posed by Fukushima radioactive releases. Radioactive contaminants could already effect the open ocean areas, therefore calling for extra developing a radionuclide monitoring program in Indonesia. The proposed monitoring program will be important to confirming the protection of Indonesia's ecosystem and marine food products. Currently, the $^{137}$Cs and $^{134}$Cs activity concentrations of contaminated deep and surface seawater samples round the world ocean have been observed comprehensively [4,8] and on the seawaters surrounding the Indonesian archipelago many that have been studied. Investigating these radionuclides continuous and immediate in the marine environment after the FNPP accident is mainly important for finding the initial activity concentrations of $^{137}$Cs and $^{134}$Cs as they are strongly affected by physical oceanographic processes such as advection and mixing [9].

All environmental issues including radioactive contaminants require a scientific basis of knowledge in modeling, understanding, and monitoring of the marine environment that has not been well-known in Indonesian waters so far. This present review summarized radioactivity data in the last decade of national marine monitoring work focused on radioceium. This review will provide a significant point of view to understand better-generating effort or regulation related to radionuclide presence in the Indonesia marine ecosystem.

2. Radioactivity monitoring of Indonesia marine waters

The potential impact of the Fukushima radioactive release on Indonesian marine compartment was recently investigated in many marine areas, including coastal and deep-sea extending from the eastern to western areas of the archipelago by Programme of National Radioactivity Marine Monitoring [10]. Marine Radioecology Division conducted this National Programme, Center for Technology of Radiation Safety and Metrology, National Nuclear Energy Agency of Indonesia in collaboration with government research and development institutions and academic institutions, i.e., Indonesia Institute of Science, Agency for the Assessment and Application of Technology, Indonesia University, and Diponegoro University. Monitoring data on coastal and marine waters are available, it was observed the $^{137}$Cs and $^{134}$Cs activity concentrations in Sumatra, Java, Kalimantan, Sulawesi, and Papua marine waters. The outflow and the inflow area in between ITF were also monitored. In-depth marine monitoring program conducted by participated in at least eight research cruises of the research vessel Baruna Jaya which is operated by the Indonesian Agency for Assessment and Application of Technology, Technology Center for Marine Survey. Samplings were conducted in the West Sumatra Sea on November 2011 and September 2015, in the South Java Sea between September 2012 and September 2015, in East Indonesian Marine Waters during August 2012 to October 2015 by Sail Morotai, Komodo, Lombok, Raja Ampat, Karimata (Table 1). Station sampling during the program shows in Figure 1.

Table 1. National radioactivity marine monitoring program in Indonesia marine waters.

| Event | Time |
|-------|------|
| Ocean sampling (Indian Ocean – West Sumatra) | November 2011 |
| Ocean sampling – In Indian Ocean: South Java. | August 2012 |
| Sail Morotai From West to East Indonesia marine water. | 29 August – 21 September 2012 |
| Sail Komodo (Komodo Island) | 6 - 25 September 2013 |
| Sail Lombok (Lombok passage) | 15-25 September 2013 |
| Sail Raja Ampat (Input from the Halmahera Sea) | 17 August – 22 September 2014 |
| Sail Karimata Straith (Indonesian Sea Transfer/Exchange and Dynamic of Sunda and Karimata Straith) | 8-17 July 2015 |
| Fish Stock Assessment 2015 at 572 and 5731 Fishing Zone (West Sumatra, South Java, Nusa Tenggara) | 22 September – 7 October 2015 |
The $^{137}\text{Cs}$ activity concentrations studied in the sediment and surface waters on some Indonesian shores monitored in the West and East was observed [10]. The middle shores of Indonesia have been monitored in South and North Sulawesi as part of the Makassar Strait. A sampling at the Southern Sulawesi coast, Pare pare was performed in November 2011. The $^{137}\text{Cs}$ activity concentrations in the seawater and sediments in these areas were 0.13–0.32 Bq m$^{-3}$ and 0.72–1.03 Bq kg$^{-1}$. A sampling at Manado in Northern Sulawesi and Makassar South Sulawesi was done in March 2012. The $^{137}\text{Cs}$ activity concentrations in the sediment and seawater in these areas were 0.10–0.59 Bq kg$^{-1}$ and 0.12–0.31 Bq m$^{-3}$. Meanwhile, the MDA reported of both $^{137}\text{Cs}$ and $^{134}\text{Cs}$ in this studied were 0.03 Bq m$^{-3}$ [10].

The $^{134}\text{Cs}$ and $^{137}\text{Cs}$ activity concentrations were also observed in the West Sumatra Seas and South Java on board the research vessel of Baruna Jaya in May 2012 and September 2011 [10]. The activity concentration of $^{137}\text{Cs}$ in surface seawater at ten areas of the West Sumatra Sea ranged from lower than MDA to 0.28 Bq m$^{-3}$. The activity concentration of $^{137}\text{Cs}$ in surface seawater at five South Java Sea locations ranged from below minimum detectable activity (MDA) to 0.13 Bq m$^{-3}$. The MDA for $^{134}\text{Cs}$ was 0.02 Bq m$^{-3}$ and $^{137}\text{Cs}$ was 0.01 Bq m$^{-3}$, respectively.

Suseno et al. (2017), in general, showed the activity concentrations of $^{137}\text{Cs}$ at inlet of ITF in surface waters were less than the activity concentration for waters from the Pacific Ocean [11]. A study by [10–14] showed that $^{134}\text{Cs}$ were under detection limits from all monitoring stations. This result approves that there was no input of $^{137}\text{Cs}$ from the Fukushima radioactive release, as labeled being close to 1 by the ratio of $^{134}\text{Cs}/^{137}\text{Cs}$ in seawater samples [15]. The nonappearance of $^{134}\text{Cs}$ showed that $^{137}\text{Cs}$ in Indonesian surface water was resulting from global fallout. In addition, this should be shown by the similarity characteristic between $^{137}\text{Cs}$ in the Pacific Ocean, Indonesia's source through Flow waters.

The ITF is one of the waterways for distributing radioactive contaminants from Fukushima to the Pacific Ocean, and finally into the Indian Ocean. The Kuroshio outlet distributes water to North Pacific Intermediate Water (NPIW), this contributes to the Mindanao Current (MC) and the ITF as part of global ocean circulation [17]. Inside the ITF, that was reported 10–15 Sv of equatorial Pacific water is distributed to the Indian Ocean [7]. In the North Pacific Water, the upper thermocline is a important component of the ITF that it is distributed into the Indonesian Seas through the Makassar strait [6,16]. There are three main routes of the ITF, the first is a western route where the MC flows to the Celebes Sea, along the Makassar Strait, into the Flores Sea and the Lombok Strait or the Ombai Strait the Indian Ocean. The second is the South Pacific sub-thermocline water from the South Equatorial Current (SEC) through the Maluku Sea and the Lifamatola Strait into the Banda Sea and

![Figure 1. Station sampling on National Radioactivity Marine Monitoring Program](image-url)
through the Ombai Strait or the Timor Passage into the Indian Ocean. The third route transports water through the Halmahera and the Seram Seas before joining the second route in the Banda Sea [19].

The Flores Sea, and Lombok Strait as part of the outflow, ITF, were also monitored [13]. Sampling was conducted on 15 - 24 November 2013 in the Flores Sea and Lombok Strait. Analysis for the Lombok Strait presented that $^{137}$Cs activity concentrations at the 1000 m depth, thermocline layer, and surface layer were $<$ MDA (0.01 Bq m$^{-3}$), 0.42 Bq m$^{-3}$, 0.27 Bq m$^{-3}$, respectively. The water activity concentration of $^{134}$Cs at all monitoring stations has similarity with previous, reported were under MDA (0.01 Bq m$^{-3}$). The results of the study indicate that the radiocesium input was from global fallout. The distribution of radiocesium in the Indian ocean was also observed with its relation to the exit passage of the ITF [14]. In this research, seawater samples were collected from the deep layers, thermocline, and the surface, during the expedition. The activity concentration of $^{137}$Cs on the deep layers, thermocline, and the surface were in range 0.046–0.680 Bq m$^{-3}$; 0.008–0.795 Bq m$^{-3}$; and 0.042–1.003 Bq m$^{-3}$. The $^{134}$Cs activity concentration has similarity with previous discussion was less than the detection limit, which is showing that the $^{137}$Cs come from global fallout. Summarized data $^{137}$Cs in seawater and sediment are reflected in the contour of distribution of $^{137}$Cs in Indonesia marine waters and sediments shows in Figures 2a and 2b.

![Figure 2a](image1.png)

![Figure 2b](image2.png)

**Figure 2.** The contour of distribution of $^{137}$Cs in Indonesia marine waters (a) and sediments (b)

3. **Contribution Indonesia marine radioactivity data to ASPAMARD**

The database that referred to as the Asia-Pacific Marine Radioactivity Database (ASPAMARD) was compiled data on radionuclide levels in the oceans and seas of Asia (including the Indian subcontinent) and, to a limited extent, the South Pacific region. The development of ASPAMARD was funded by the International Atomic Energy Agency Regional Cooperative Agreement (IAEA/RCA)
with cooperation to the United Nations Development Program (UNDP). The purpose of the development of ASPAMARD are to characterize the transportation and fate of essential radioactive contaminants in the regional oceans; to provide a reference or benchmark levels of key anthropogenic radionuclides in the regional seas against which the impact of future man-made contributions can be evaluated; to better understand transport processes and the fate and behavior of radionuclides and analog pollutants in the marine environment; and to assess dose associated with the ingestion pathway for seafood [20]. ASPAMARD under the project IAEA and published literature collected data of marine radioactivity contributed by Philippines, Indonesia, Australia, China, Bangladesh, India, Republic of Korea, Pakistan, Malaysia, Sri Lanka, Vietnam, and Thailand.

Over more than ten years ago, Indonesia has not been contributed to any data to the ASPARMAD. Since National Radioactivity Monitoring Program was held, Indonesia has become one of several limited countries that significantly contributed to the ASPARMAD from several publications [11,12,13,14,15]. The recent contribution of $^{137}$Cs in seawater from countries in the Asia Pacific Region, including Indonesia to the ASPARMAD [21], shows in Figure 3.

![Figure 3. $^{137}$Cs distribution in the Asia Pacific region by ASPAMARD [21]](image)

Bases on ASPAMARD, seawaters, sediments, and biota from the regional seas of Asia Pacific extending from 50° N to 60° S latitude and 60° E to 180° E longitude and Indonesia was included [20]. $^{137}$Cs in seawater after Fukushima accident from Figure 3 shows in the range 0.02-1.5 Bq m$^{-3}$. This data is comparable with the condition before the Fukushima accident, which means no contaminated marine area by $^{137}$Cs in the Asia Pacific marine region after ten years.

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