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Status of ^{137}Cs concentrations in sea water at the inlets of the Indonesian Through Flow (ITF)

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HIGHLIGHTS

- Within ITF equatorial Pacific water was transported to the Indian Ocean.
- The ITF is one of the distribution channels of ^{137}Cs from Fukushima.
- There was limited data of ^{137}Cs passing through the ITF.
- The marine monitoring at the ITF ocean passage have been performed.

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ABSTRACT

There is a lack of available data on ^{137}Cs water concentrations at the Indonesian Through Flow (ITF). The data is required for evaluation of the possible impact of the Fukushima accident in Indonesia's marine environment. ^{137}Cs monitoring at inlets of ITF were conducted in order to address this possible impact. Monitoring was performed by the Baruna Jaya III research vessel during the Sail Morotai campaign of 2012. Surface sea water (0–10 m depth) samples were collected at 7 stations. The AMP (Ammonium molybdophosphate) method was used for separating radiocesium from seawater. The radiocesium were measured by a HPGe detector of gamma spectrometer system. The measured concentrations of ^{137}Cs in the Flores Sea ranged between 0.29–0.30 Bq m^{-3}. At another inlet of the ITF in the Halmahera Sea which the concentration of ^{137}Cs were founded varied between 0.20–0.38 Bq m^{-3}. The water concentrations of ^{137}Cs in the Lifamatola Passage, at the Eastern of Sulawesi, ranged between 0.20–0.30 Bq m^{-3}. There was no detection of ^{134}Cs at any of the monitoring stations. The result showed that the input ^{137}Cs from the Pacific Ocean to Indonesian Seas was not from Fukushima but was characteristic of global fallout in the Pacific Ocean.

1. Introduction

Indonesia is an archipelago with approximately 78% of which is covered by water, and it lies between the Pacific and the Indian oceans. The nuclear accident in Fukushima has become a public concern in Indonesia requiring information about its possible impact on the marine waters of Indonesia. The two main sources of radioactive contamination from the nuclear accident in Fukushima are the radioactive liquids which are discharged directly into the sea (containing ^{137}Cs, ^{134}Cs, and various other radionuclides) and atmospheric deposition on the surface of the sea (Bailly du Bois et al., 2012). As a substance that dissolves easily in water, ^{137}Cs can travel to great distances by ocean currents.

According to You et al. (2005), the Kuroshio branch transports water to North Pacific Intermediate Water (NPIW) and it contributes to the global ocean circulation via the Mindanao Current (MC) and the Indonesian Through Flow (ITF). Within the Indonesian Through Flow (ITF), approximately 10–15 Sv of equatorial Pacific water is transported to the Indian Ocean (Gordon et al., 2010). The Upper thermocline of the NPW is a major component of the ITF that it is transported into the Indonesian Seas through the Makassar strait (Ding et al., 2013; Sprintall et al., 2009). According to Mayer et al. (2010), there are three main routes of the ITF. The first is a western route where the Mindanao Current (MC) flows to

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the Celebes Sea, along the Makassar Strait, into the Flores Sea and the Lombok Strait or the Ombai Strait into the Indian Ocean. The second is the South Pacific subthermocline water from the South Equatorial Current (SEC) through the Maluku Sea and the Lifamatola Strait into the Banda Sea and furthermore through the Ombai Strait or the Timor Passage into the Indian Ocean. The third is a route which transports water through the Halmahera and the Seram Seas before joining waters of the second route in the Banda Sea.

The Indonesian Through Flow is one of the channels for the distribution of contaminants from Fukushima to the Pacific Ocean, and finally into the Indian Ocean. However there is no available data on the ITF to permit evaluation of the possible impact of the Fukushima accident in the Indonesia marine environment. In order to address the possible impact of the Fukushima nuclear accident, the samplings were conducted on various coastal and deep sea waters by the Indonesian National Nuclear Energy Agency. The coastal monitoring of radiocesium has been previously reported by Suseno and Prihatiningsih (2014). Additionally the deep sea monitoring has been previously conducted in the Indian Ocean waters off West Sumatra (Suseno et al., 2015) and eastern Indonesia marine water (Hoir et al., 2013). Recently, no data has been generated at the inlet of ITF. In this paper, we report on the levels of ^{134}Cs and ^{137}Cs radioactivities at the inlet areas of ITF based on the samples taken for monitoring on aboard of the RV Baruna Jaya III during Sail Morotai 2012 campaign. This campaign was a maritime international event which was organized by the Indonesian government. Some oceanographic researches such as the radioactive monitoring has been performed during the sail Baruna Jaya III from the Java island to the Morotai Island.

2. Methods

Seawater samples for ^{134}Cs and ^{137}Cs analysis were collected on board of the Baruna Jaya III from 6 to 10 September 2012. Fig. 1 show the location of seven sampling stations at the inlets of the Indonesian Through Flow, i.e. the Flores Sea, the Buru Sea, the Celebes Sea and the Halmahera Sea. Approximately 200L of surface seawater samples were collected at the each sampling station. The preparation of water sample of ^{137}Cs determination followed the methodologies outlined in Yamada and Wang (2007) with some modifications. Briefly, the seawater was acidified by concentrated nitric acid to a pH of 1–2. Radiocesium was separated from seawater by coprecipitation by adding 200 g of Ammonium Molybdophosphate (AMP) and an aliquot of CsCl solution containing 0.2–0.4 g cesium as a carrier. After standing for 24 h, the supernatant was separated out from the precipitate. Finally, the AMP/Cs precipitates were dried and placed into a plastic container before gamma counting. ^{137}Cs was determined by gamma ray at the photopeak of 661 keV. Each sample was measured for 259 200–345 600 s. Three unit of HPGe detectors was used with counting efficiency of 20%–25% and FWHM of 1.8 keV for a peak of 1332 keV of ^{60}Co. The type of gamma spectrometers employed were Canberra type GX2018, Canberra type GC2020 and Ortex type GMX 25P4-76. The method consisted of detector calibration, determination of detector counting efficiency, cumulative counts of both background and samples at regular intervals of time counted, photopeak smoothing and linear regression.

3. Result and discussions

Radiocesium has dispersed to the world ocean after released from the Fukushima Dai-ichi Nuclear Power Plant. In the first years after the accident, ^{137}Cs rapidly moved and spread from the Fukushima coast to the east and over the north western (NW) Pacific Ocean (Nakano and Povinec, 2012). The North Equatorial Current (NEC) in the NW Pacific Ocean is a broad westward stream found between 8°N and 18°N. This current splits into two branches at 13°N where most of the Mindanao Current (MC) water flows eastward to form the North Equatorial Counter Current (NECC). The Mindanao current transport 9.2 Sv (Sv $= 10^6$ m^3 s^{-1}) of surface water to the upper thermocline of the NEC and into Indonesian seas through the Makassar Strait. This is known as the Indonesian Through Flow (Gordon, 2005; Du and Qu, 2010; Sprintall et al., 2009; Schiller et al., 2010). Before entering the Makassar Strait, some MC must upwell into surface layers and then spread to southward within the surface Ekman layer (Gordon, 2005).

The Flores Sea receives upper thermocline water (5.0 Sv) which then flows to eastward to the Banda Sea, or to a small portion (∼1.7 Sv) which directly exits into the Indian Ocean via Lombok Strait (Ding et al., 2013; Gordon et al., 2010). We monitored at two stations in the Flores Sea (SM6: 121°8.3694′E 05°42.7846′S; SM7:118°59.77′E 05°54.07′S). The concentration of ^{137}Cs at SM6 and SM7 stations were 0.29 Bq m^{-3} and 0.30 Bq m^{-3} respectively. These water concentrations were lower than for the ^{137}Cs data previously reported for the Pacific ocean (Kaeriyama et al., 2013; Kamenik et al., 2013). Kaeriyama et al. (2013) reported that the concentrations of ^{137}Cs in surface seawater collected from the western and central North Pacific in July 2011, October 2011 and July 2012 were more than 10 mBq kg^{-1}. Furthermore, Kaeriyama et al. (2013) reported that ^{134}Cs was also detected at 94 sampling locations. In contrast, Kamenik et al. (2013) reported that the concentrations of ^{137}Cs to the north of Hawaii Island (March and May 2011) were within the range of 1.2–1.5 Bq m^{-3}.

According to Sprintall et al. (2009) and Gordon et al. (2010), the Makassar strait received most of its water from the North Pacific (9,2 Sv). The Halmahera sea received saltier water from lower thermocline of subtropical the South Pacific. We undertook ^{137}Cs monitoring at 3 stations (SM1:1°30.18′E, 0°15.066′N; SM2: 129°31.01′E, 01°7.09′N and SM3:127°1.05′E, 02°3.86′N) in the Halmahera Sea to investigate another possible input of ^{137}Cs from the Pacific Ocean. The concentrations of ^{137}Cs at SM1, SM2 and SM3 were 0.38 Bq m^{-3}, 0.20 Bq m^{-3} and 0.25 Bq m^{-3} respectively These results were comparable with the concentration of ^{137}Cs in the Flores Sea and also lower than those from the Pacific Ocean.

From the Halmahera Sea, water (1.5 Sv) transfers to the Lifamatola Passage, East of Sulawesi with a spillover of deep water into the depths of the Banda Sea (Gordon et al., 2010). We performed monitoring at SM4 (123°36.24′E 0°3.302′N) and SM5 (123°56.94′E 02°32.02′S) in order to determine the ^{137}Cs concentration in the Buru Sea and the Celebes Sea which also received ^{137}Cs from the Pacific Ocean. The concentrations of ^{137}Cs at SM4 and SM5 were 0.30 and 0.20 Bq m^{-3} respectively. Vertical dynamic processes (e.g., upwelling and entrainment) are known to occur in water that enters into the Banda Sea (Guilderson et al., 2009). Unfortunately, we did not perform sampling at this area so data were not available for ^{137}Cs in surface water to permit any evaluation of ^{137}Cs movement in this region.

In general, the concentrations of ^{137}Cs in surface waters at inlets of the Indonesia Through Flow were lower than for waters from the Pacific Ocean. All monitoring data on ^{137}Cs concentration was presented in Table 1. The CTD data measurements of all monitoring stations were showed in Fig. 2 (Hoir et al., 2013). According to results of the CTD data, the thermocline layer occurred at 150 to 400 m depth and its temperature was constant at 5 °C until a greater depth. This result indicated that thermocline layer occurred at a shallow depth. According to Duran et al. (2004), radiocesium is retained in surface or near-surface layer and significantly decreased at depth because it is only bound to about ≤1% of particulates. Furthermore, the vertical profile in the water column in the Asia sea region shows that most of the radiocesium occurs in surface or near-surface sea water (Duran et al., 2004).

Fig. 1. Sampling locations.

Table 1
Concentration of ^{137}Cs on surface water on inlet area of Indonesia Through Flow.

Sample code	Sampling date	Latitude	Longitude	^{137}Cs (Bq m^{-3})
SM 1	17-Sep-12	0°15.0657′N	131°30.1852′E	0.38 ± 0.04
SM 2	16-Sep-12	1°7.0989′N	129°31.0074′E	0.20 ± 0.02
SM 3	11-Sep-12	2°3.8591′N	127°1.0448′E	0.25 ± 0.04
SM 4	09-Sep-12	0°3.3019′N	123°36.2432′E	0.30 ± 0.03
SM 5	08-Sep-12	2°32.0168′S	123°56.9417′E	0.20 ± 0.02
SM 6	06-Sep-12	5°42.7846′S	121°8.3694′E	0.29 ± 0.04
SM 7	05-Sep-12	5°54.0658′S	118°59.773′E	0.30 ± 0.04

Table 2
Comparative ^{137}Cs concentrations in the Pacific and Indian oceans.

Location	^{137}Cs (Bq m^{-3})	^{134}Cs (Bq m^{-3})	Reff
North west Pacific	0.41–0.47	MDA–2.7	Men et al. (2015)
North west Pacific	2–35 000	0.01–0.8	Povinec et al. (2011)
Northwestern Pacific Ocean	2.67 ± 0.18	0.97 ± 0.09	Kumamoto et al. (2013)
Hawaii island and Guam	1.2–1.5	MDA	Kamenik et al. (2013)
Indonesia Coast	<MDA–0.13	MDA	Suseno and Prihatiningsih (2014)
Indian Ocean, Indonesia area	<MDA–0.28	MDA	Suseno et al. (2015)
Eastern Indonesia marine water	0.14–0.43	MDA	Hoir et al. (2013)

MDA: Minimum detectable activity.

Our study showed that from all monitoring stations ^{134}Cs was under detection limit. This result confirms that there were been no input of ^{137}Cs from the Fukushima release, as labeled by the ratio of ^{134}Cs/^{137}Cs in seawater samples being close to 1 (Povinec et al., 2013). The absence of ^{134}Cs indicated that the source of ^{137}Cs in Indonesian surface water was derived from global fallout. On the other hand, this should be shown by the similarity between ^{137}Cs characteristics in the Pacific Ocean that is the source of the Indonesia Through Flow waters. According to Hirose and Aoyama (2003), anthropogenic radionuclides in sea water of the Pacific Ocean and its marginal are mainly sourced from global fallout and also partly from the release or dumping of nuclear wastes from nuclear facilities. Although the data on ^{137}Cs concentrations in the sea around Indonesia is very limited, some other studies can be used as a reference. Yamada et al. (2006) reported the concentration of ^{137}Cs in surface water that was collected in Sulu and Indonesian seas to be about 2.42 m Bq m^{-3}. Furthermore, to compare our study, we use the figure of Pacific Ocean zoning based on the global fallout of anthropogenic radionuclides on latitudinal and longitudinal distributions that described by Hirose and Aoyama (2003). Indonesian waters lie in the region of Box 6 (down stream of the South Equatorial current) and 8 (down stream of the part of the weak South Equatorial current). The ^{137}Cs concentrations in surface waters in the area of BOX 6 and 8 were

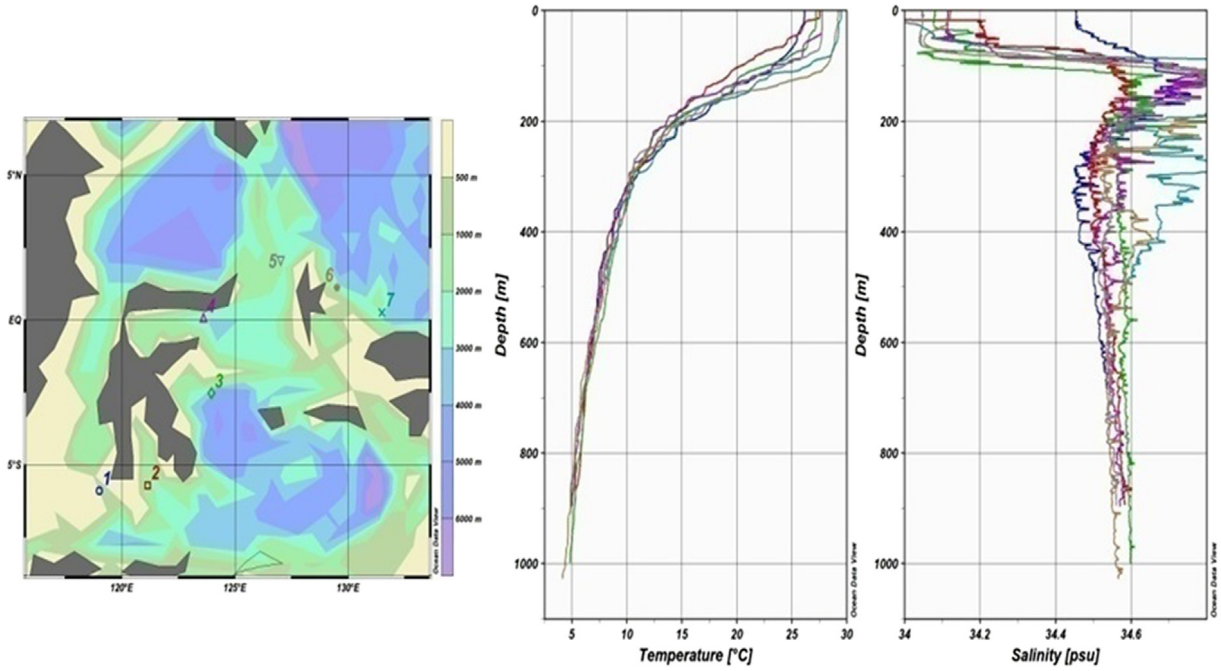

Fig. 2. Some CTD data measurement.

2.5 Bq m^{-3} and 1.7 Bq m^{-3}, respectively. Nakano and Povinec (2012) predicted that during the first year following the Fukushima release ^{137}Cs rapidly moved and spread from the Fukushima coast to the east over the north western (NW) Pacific Ocean. Moreover, by using the LAMER calculation code, Nakano and Povinec (2012) predicted for single releases 1 PBq of ^{137}Cs from Fukushima will move relatively slowly to reach the North Pacific Ocean and in 2016 will reach some Indonesian waters but its concentration would be below 0.1 Bq m^{-3}. On the other hand, the result of previous monitoring has shown that concentration of ^{137}Cs in Indonesia coastal area were 0.12–0.32 Bq m^{-3} (Suseno and Prihatiningsih, 2014). Furthermore, the concentration of ^{137}Cs in deep waters off West Sumatra and Southern Java (Indian Ocean) were below the minimum detectable activity (MDA) of 0.28 Bq m^{-3}. The comparison of our measurement with other authors (Men et al., 2015; Povinec et al., 2011; Kumamoto et al., 2013; Kamenik et al., 2013; Suseno et al., 2015; Suseno and Prihatiningsih, 2014) after Fukushima accident was shown at Table 2. The data of ^{137}Cs water concentration at Indonesia coasts and those at Indian Ocean as part of Indonesia marine areas showed comparable with data at the recent study.

4. Conclusion

The concentration of ^{137}Cs in the Flores Sea (input from Makassar that was the main inlet of ITF) ranged from 0.29–0.30 Bq m^{-3}. Another inlet of ITF is the Halmahera Sea where its concentration of ^{137}Cs varied between 0.2–0.38 Bq m^{-3}. The concentrations of ^{137}Cs in the Lifamatola Passage, east of Sulawesi, ranged from 0.20–0.30 Bq m^{-3}, respectively. The result has shown that input of ^{137}Cs from the Pacific Ocean to the Indonesia Sea was not from Fukushima but characteristic of global fallout in the Pacific Ocean.

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