Global Scientific JOURNALS

GSJ: Volume 9, Issue 1, January 2021, Online: ISSN 2320-9186
www.globalscientificjournal.com

POTENTIAL RADIOLOGICAL DOSE OF ^{210}Po TO MARINE FISHES AND THEIR CONSUMER IN PENINSULAR MALAYSIA

Zal U'yun Wan Mahmood, Yii Mei Wo, Norfaizal Mohamed, Nooradilah Abdullah, Mohd Zuhair Mohd Sanusi, Nurrul Assyikeen Md. Jaffary and Kamarudin Samuding

Malaysian Nuclear Agency, Bangi, 43000 Kajang, Selangor, Malaysia
Correspondence email: zaluyun@nuclearmalaysia.gov.my

ABSTRACT

Potential radiological dose of ^{210}Po to common marine fishes and their consumer in Peninsular Malaysia was studied. The main objectives of this work are to quantify the activity concentration of ^{210}Po in fishes and evaluate the total dose rate of ^{210}Po to fishes using the ERICA Tool Assessment and annual effective dose to their consumer. Selected common fishes were obtained from around near shore in the east and west coast of Peninsular Malaysia either by using fishing rods or purchased from local fisherman. It is observed that the concentrations of ^{210}Po in the pelagic and demersal fishes in the ranges of 4.06 ± 0.18 Bq/kg fw. to 50.13 ± 2.24 Bq/kg fw. The pelagic fish of Yellowtail scad was identified to accumulate higher concentrations of ^{210}Po suggesting that they could serve as a locally bio-indicator of radionuclides in the Malaysian marine waters. Interestingly, the total dose rate for each fish was found to be well below the screening value of 10 µGy/hr as recommended by the ERICA Assessment Tool. This indicated that the ^{210}Po activity concentration in the Peninsular Malaysia marine environment was far below the screening value and this pose no risk to the marine living organism. Since higher concentration of ^{210}Po can contribute significantly the dietary dose of ionising radiation to high fish consumers, however such magnitude varies are considerably radiological safe for those consumers in Peninsular Malaysia. Ideally, before deciding the estimated dose value poses a risk to fish consumers, thus the volatility behaviour of ^{210}Po should be considered before ingestion.

Keywords: Annual effective dose, ERICA Assessment Tool, marine fish, ^{210}Po, Peninsular Malaysia

INTRODUCTION

Polonium-210 (Po-210, ^{210}Po) is a pure alpha emitting naturally occurring radionuclide (Bustamante et al., 2002) presents in the environment, including marine compartments as a result of its progeny (^{210}Pb-^{210}Bi) radioactive decay in the Uranium-238 (^{238}U) series. This radionuclide enters the marine environment *via* the natural radioactive decay of ^{222}Rn gas, ^{226}Ra in seawater and through wet and dry atmospheric deposition of ^{210}Bi and ^{210}Pb (Turekian et al., 1977). It is considered to have a great significance in the ocean in particular to marine organism due to it has a highly radiotoxic property and radiation exposure (Khan & Wesley, 2011). Moreover, ^{210}Po tends to reach its largest environmental concentrations within marine organisms (Yamamoto et al., 1994). It is strongly accumulated in a variety of marine organisms (Carvalho, 2011; Cherry & Shannon, 1974) *via* adsorption, absorption and ingestion (Alam et al., 2000). Polonium-210 is also strongly adsorbed onto the surfaces of the living marine organisms and is mostly accumulated in the organic structures or in the edible portions of marine organisms. The concentration of ^{210}Po in the edible portions of marine organisms may be many folds higher than that in the seawater because of biological re-concentration processes (Saiyad Musthafa & Krishnamoorthy, 2012).

Polonium-210 has a half-life of 138.377 + 0.002 days (Khan & Wesley, 2011). It is one of the most interesting and important radionuclides due to its relatively high activity concentrations in certain foods and its relatively high ingestion dose coefficient (IAEA, 2017). Its radio-toxicity through internal contamination which relates to a relatively high energy of about 5.3 MeV (Harisson et al., 2007; Jefferson et al., 2009) and it is concentrated in the soft tissues, such as muscle, liver, kidney, and haemoglobin (IAEA, 2004; Khan & Wesley, 2011; Matthews et al., 2007; Ŝtrok & Smodiš, 2010; UNSCEAR, 2000). Due to those properties, concerns are particularly acute if the natural radionuclides of ^{210}Po in human food items such as seafood. Furthermore, ^{210}Po is known to be a major contributor (90%) to the natural radiation dose received by most marine organisms (Cherry et al., 1989; Cherry & Shannon, 1974) and critical group doses in particular seafood consumption (CEC, 1990).

Though seafood is consumed widely by the people in coastal areas of Peninsular Malaysia, the pattern of consumption varies in different regions of the country. However, our knowledge of the radiation dose received by the population, mainly fisherman due to their potential impact is not well documented in Malaysia. It is therefore of interest to study the intake of ^{210}Po through specific dietary habit of this region, as the sand of the most coasts in Peninsular Malaysia is richly composed of monazite minerals which are high sources of uranium. Due to lack of study related to radiological dose of ^{210}Po on marine fish and its consumer, the eight different locations in Peninsular Malaysia were studied on its activity concentration and annual committed effective dose amongst the local people was also estimated. Therefore, such study on the ^{210}Po concentration in edible seafood and its estimation dose is very important for this country in order to assess the level of radiological safety to human in this region. With that, we have therefore calculated the radiation doses absorbed by diverse marine fish in which potential radiological risk was quantified to human consumes this species of fishes. The dose calculations should help the public quantitatively assess the risk associated with consumption of these common fishes. Thus, the aims of this study are to quantify the activity concentration of ^{210}Po in fishes and to evaluate the total dose rate of ^{210}Po to fishes using the ERICA Tool Assessment and annual effective dose to its consumer. This study is a part of the project “Levels, Trends and Effect of Natural and Anthropogenic Radionuclides in the Malaysian Marine Environment (Contract No. 22192)”, under the IAEA project “K41017 - Effects of Natural and Anthropogenic Radionuclides in the Marine Environment and Their Use as Tracers for Oceanography Studies”. Thus, this is not only additional information to enhance the existing radiological dose data for the nation but also to share it worldwide.

MATERIALS AND METHODS

Study Area

A total of eight (8) sampling stations around near shore the east and west coast of Peninsular Malaysia was selected. These sampling stations are located in the coordinates range of 01^{o} 53.572′ – 06^{o} 5.151′ N latitude and 102^{o} 34.468′ – 104^{o} 19.075′ E longitude for the east coast and 04^{o} 12.973′ – 06^{o} 2.080′ N latitude and 100^{o} 07.211′ – 100^{o} 30.955′ E longitude for the west coast, respectively. The east coast stations are facing toward South China Sea while the west coast stations are situated in the Malacca Straits and facing towards the Indonesian archipelago (Table 1, Figure 1).

Table 1: Localities and water depth of sampling stations in Peninsular Malaysia

Zone	Location	Station ID	Latitude, N	Longitude, E	Sampling Date	Water Depth (m)
East Coast	Melawi	ML01	06° 5.151′	102° 34.468′	23 Sept 2017	22.1
	Kuala Terengganu	KT02	05° 32.467′	103° 13.211′	04 July 2018	42.9
	Marang	MG03	05° 08.557′	103° 26.703′	05 July 2018	41.8
	Cukai-Kemaman	CK01	04° 16.537′	103° 38.434′	09 April 2019	35.0
	Tanjung Sedili	TS03	01° 53.572′	104° 19.075′	11 July 2019	30.1
West Coast	Pulau Sembilan	PS01	04° 12.973′	100° 30.955′	14 March 2019	52.6
	Pulau Langkawi	PL01	06° 02.080′	100° 07.211′	03 July 2019	29.3
	Kuala Sepetang	KS03	04° 58.793′	100° 13.372′	02 Oct. 2019	25.0

All stations are relatively shallow with water depth between 22.1 – 52.6 m and basically situated about 20 km from mainland. These stations were selected by presuming that sources of natural radionuclides from most of the mainland of the neighbouring countries are able to accumulate or transfer into Malaysian waters. Moreover, many residential villages are situated along the same coast, which are active as fishermen with their fishing heritage, aquaculture and tourism activities that there has a greater consumption of seafood and potential to expose to radiological risk.

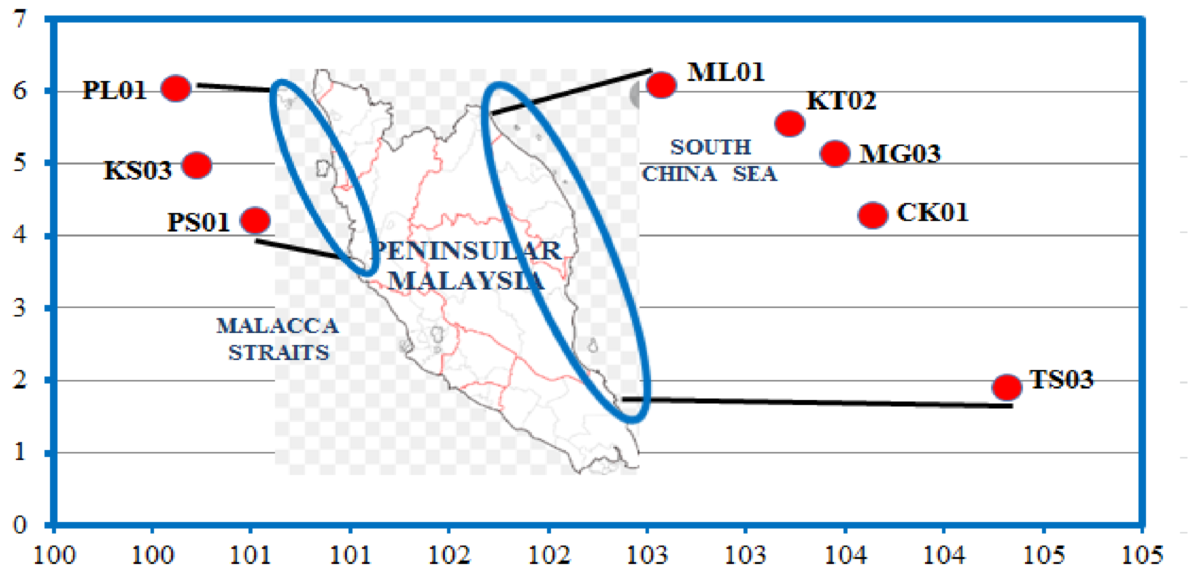


Figure 1: Location of the sampling stations in the east and west coast of Peninsular Malaysia

Sample Collection

Five species of marine fishes from two occupancy habitat of pelagic and demersal/benthic were chosen for this study in accordance to their availability at each station. Generally, these are the most common and highly demanded fishes to be consumed by Malaysian for protein source i.e. Yellowtail scad (*Atule mate*), Indian mackerel (*Scombridae rastrelliger* kanagurta) and Layang scad (*Decapterus macrosoma*) for pelagic fish and Delagoa threadfin bream (*Nimipterus delagoa* Smith) and Indian snapper (*Lutjanus madras*) for demersal fish, respectively (Photo 1). Two kilograms of these fishes was collected throughout 2017 - 2019 using fishing rods or purchased directly from local fisherman. All fish samples were transferred into a zipped plastic bag, stored in cold storage boxes which were covered by ice cube and transported to the laboratory.

Sample Pre-Treatment and Preparation

In the laboratory, fish samples were removed from the ice and let them for a while until defrost. The whole body of the fish samples were weighed and recorded as total fresh weight in a preparation logbook. Fish physical size, i.e. individual whole body weight, length, height and width were measured for calculation of the total dose rate using the ERICA Assessment Tool. Then, the samples were dried at 60^{o}C in an electric oven to constant weight, re-weighed after cooling and their dry weight was recorded to estimate the water content for conversion factor calculation from dry weight to fresh weight. All dried samples were ground into powder form to homogeneity and then, the samples were kept in an airtight container.

Sample Digestion and Dissolution

Approximately 0.5 g of the grounded fish sample was spiked with 0.5 mL known activity concentration of ^{209}Po tracer and added 10 mL of conc. HNO_3, and 1 mL of H_2O_2. The mixture was let for a while until the reaction cease. The mixture of sample and acid was evaporated on a hot plate to almost dryness. If the samples were not totally digested, the procedure mentioned above was repeated until complete digestion. Then, added again 10 mL of concentrated HNO_3 and 1 mL of H_2O_2, let reaction cease and then evaporated to almost dryness and let it cool. Finally, 10 mL of concentrated HCl was added into the samples, then evaporated until almost dryness and the sample was let to cool (Zal U'yun et al., 2019; Zal U'yun et al., 2020).

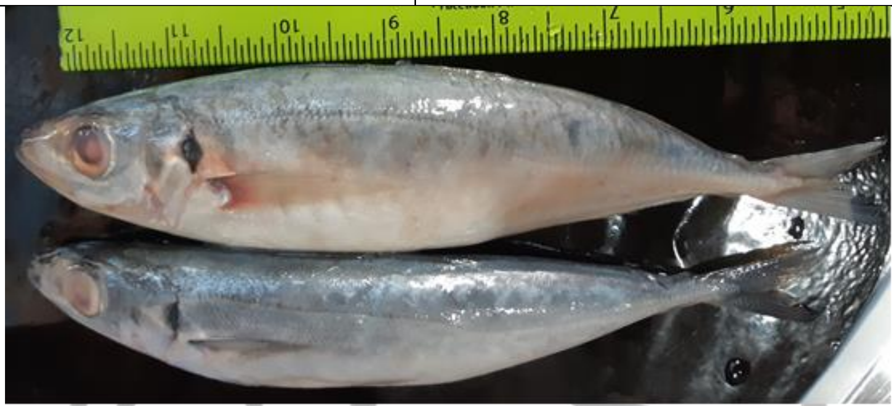
Spontaneous Auto-Deposition

3.3 mL of concentrated HCl was added to the dried sample until it was totally dissolved and dissolution. Then, the solution was transferred into the plating jar and added with distilled water up to a level of 80 mL. One (1) mL of stable Bi carrier (10 mg/g) solution and 1 g of hydroxylammoniumchloride (HAC) were added into the solution, then heated gently until all precipitate dissolve. A polished silver disc was mounted in the plating holder and put slowly and carefully into plating jar to avoid the solution splashed out. The plating jar was placed on a magnetic stirrer hot plate, then stirred and heated at a temperature of 85°C for four hours. After the plating process was completed, the plating holder was taken out, silver disc was washed with distilled water and rinsed with ethanol. Lastly, the disc was air dried and ready for counting (Zal U'yun et al., 2019; Zal U'yun et al., 2020).

Pelagic

Yellowtail scad (*Atule mate*)

Indian mackerel (*Scombridae rastrelliger* kanagurta)



Layang scad (*Decapterus macrosoma*)

Demersal

Delagoa threadfin bream (*Nimipterus delagoa* Smith)

Indian snapper (*Lutjanus madras*)

Photo 1: Pelagic and demersal fishes collected by fishing and purchased from local fisherman

Sample Counting Using Alpha Spectrometry System

The measurement of ^{210}Po particles was carried out by using an alpha spectrometry system (Ortec, Ortate Plus) for 24 hours. Polonium-210 activity concentration was corrected to the time of sample collection. The alpha spectrometry counting system was equipped with alpha Passivated Implanted Planar Silicon (PIPS) detectors with 450 mm^2 active area. The relative efficiency of each detector is about 25% for a detector-to-source distance less than 10 mm. The background count for each spectroscopy channel was less than one count per hour for energies above 3 MeV. The system was calibrated for energy and efficiency using multinuclide calibration standards comprising of ^{234}U, ^{238}U, ^{239}Pu and ^{241}Am supplied by Analytics, USA (SRS 67943-121) (Yii and Zal U'yun, 2011). The minimum detectable activity (MDA) for ^{210}Po in fish was quantified as 0.2 Bq/kg fw.

Estimation of Radiological Dose on Fishes

Radiological dose of ^{210}Po on marine fishes was estimated by using a tier 2 from the ERICA Assessment Tool. The purpose of tier 2 is to identify and screen out situations with low probability of significant radiological impact on non-human biota (Brown et al., 2008; Wood et al., 2008). It was therefore used for the calculation of the radiation exposure dose rate for marine fishes due to ^{210}Po presents in the marine environment around near shore on the east and west coast of Peninsular Malaysia. The total whole body of each fish species and sea water activity concentrations for ^{210}Po as well as average of three fish physical measurements were used in the calculation as an input data. Inputs of the best estimated radiological dose, measured activity concentrations of ^{210}Po for sea water and fish at each station are also input in the software. Due to in the software database was no data of such studied fish species and their occupancy factors; therefore, they were included in the software database. The screening confidence level for dose rate was set as 10 μGy/hr. Other parameters such as radiation weighting factors and uncertainty factors were left at their default values.

Estimation of the Annual Effective Dose to Fish Consumer

The annual effective dose of ^{210}Po from fish consumption by an adult was estimated from the ^{210}Po activity concentrations measured in pelagic and demersal fishes collected in this study. The average yearly consumption of marine fish per adult in Peninsular Malaysia as reported by Ministry of Health Malaysia was 44.78 kg/yr (FCSM, 2014). The annual committed effective dose for an individual from seafood consumption was calculated using the following equation (Connan et al., 2007).

$$AED = DF \times MF \times \Sigma (A_i \times C_i \times f_i)$$

where AED is the annual effective dose (μSv/yr); DF is the ingestion dose coefficient, 1.2×10^{-6} Sv/Bq for an adult (EPA, 1988); MF is a weighted factor of 0.6 to account for the time elapsed between catch and consumption, owing to the 138 days half-life of ^{210}Po (Aarkrog et al., 1997; UNSCEAR, 2000). A_i is the ^{210}Po concentration (Bq/kg fresh weight); C_i is seafood consumption (kg/yr), per capita of marine fish consumption and taken as 44.78 kg/yr as described earlier (FCSM, 2014) and f_i is the assumption that 60% real fraction of the fishes being consumed (Zal U'yun et al., 2020).

RESULTS AND DISSCUSSION

Activity Concentrations of ^{210}Po in Fishes

Activity concentrations of ^{210}Po in fishes collected from eight sampling stations situated along near shore the east and west coast of Peninsular Malaysia are summarized in Table 2. The range activity concentrations of ^{210}Po in the whole-body of pelagic fishes i.e. Yellowtail scad), Indian mackerel and Layang scad were 16.12 ± 0.72 – 50.13 ± 2.24 Bq/kg fw. (average: 30.87 Bq/kg fw.), 4.14 ± 0.18 – 10.21 ± 0.46 Bq/kg fw. (average: 7.18 Bq/kg fw.) and 20.38 ± 0.91 – 41.21 ± 1.84 Bq/kg fw. (average: 30.80 Bq/kg fw.), respectively. While for each demersal fish of Delagoa threadfin bream and Indian snapper, it was ranged between 4.16 ± 0.19 – 18.70 ± 0.84 Bq/kg fw. (average: 10.93 Bq/kg fw.) and 4.06 ± 0.18 – 27.41 ± 1.23 Bq/kg fw. (average: 15.74 Bq/kg fw.), respectively. Clearly, those values of ^{210}Po in the five species of fish were found to be many folds higher than that in the seawater (0.36 ± 0.02 – 1.84 ± 0.08 Bq/m^3). These were due to both pelagic and demersal specially ingesting detritus material with a high degree of ^{210}Po association (Rani et al., 2014). Moreover, the ranges of ^{210}Po concentration showed a significant difference between species, and this could be related to their trophic level where the higher trophic level of these species likely facilitated bioaccumulation of ^{210}Po. In other word, the variation of ^{210}Po concentration in those fishes could be due to the different living or geographical characteristic habitats, location and environmental condition, feeding metabolism, habit and pattern of the species, biological processes, size and seasonal changes (Alam & Mohamed, 2011a). Aközcan & Uğur (2013) agreed with us that the mechanism of uptake of ^{210}Po by fish depends on those factors which are discussed above as biological variables.

Consequently, the degree of ^{210}Po accumulation in the fishes can be arranged in the following order of Yellowtail scad > Layang scad > Indian snapper > Delagoa threadfin bream > Indian mackerel. The relatively highest activity concentration of ^{210}Po found in Yellow scad because it is well known as a very active and freely movement fish in the seawater column resulted more chances to uptake more food and suspended particles or any other small marine organisms as a food with high content of ^{210}Po that are abundant at the surface seawater. Whilst, such condition is not happening in Indian mackerel because it is a passive fish which only getting foods or any other materials in the surrounding area. Additionally, the most likely explanation for the lower of ^{210}Po in Indian mackerel is the reported decline in seawater activity concentrations of this radionuclide in the sampling location caught off the east coast of Peninsular Malaysia. Interestingly, Yellowtail scad can be suggested locally as a bio-indicator of ^{210}Po radioactive pollution in Malaysia.

Generally, the result showed that the concentrations of ^{210}Po in pelagic fishes of Yellowtail scad and Layang scad were relatively higher than those in demersal fishes. This indicated that pelagic fishes live in the upper water column or the pelagic zones of the ocean that were taken more ^{210}Po from seawater owing to their freely moving about within the water column. Other than that, they were also fed a suspended matter and food particles which are available in the water column. Since polonium is absorbed from water and incorporated into the suspended particles, it is suggested that the high concentration in the body tissues of both fishes might be due to the feeding habits of the marine organisms and its transfer factor to the higher trophic level (Kulsawat & Porntepkasemsan, 2016). Ŝtrok and Smodiš, (2011) was strictly supported that the pelagic environment contributes significantly to ^{210}Po accumulation that is aligned with these fishes which are accumulated high concentration of ^{210}Po. While, demersal species is not so much accumulated of ^{210}Po from seawater as this radionuclide is a strong particle reactive and tendency to associate with suspended particle which is easily and rapidly removed into bottom water column by scavenging process and lastly deposited onto sediment in the seabed resulted low accumulation of ^{210}Po in demersal fish.

Table 2: Estimation of the total dose rate to fish and annual effective dose to fish consumer

Station ID	Species of Fish	Occupancy Habitat	Individual Fresh Weight of Fish (g)	Activity Concentration of ^{210}Po in Fish (Bq/kg fw.)	Total Dose Rate of ^{210}Po per Organism (μGy/hr)	Annual Effective Dose of ^{210}Po to Consumer (μSv/yr)
ML01	Yellowtail scad (*Atule mate*)	Pelagic	72.28	50.13 ± 2.24	1.530	969.76
	Indian snapper (*Lutjanus madras*)	Demersal	60.62	4.06 ± 0.18	0.124	78.54
KT02	Layang scad (*Decapterus macrosoma*)	Pelagic	41.80	41.21 ± 1.84	1.260	797.21
	Indian snapper (*Lutjanus madras*)	Demersal	51.52	27.41 ± 1.23	0.837	530.25
MG03	Indian mackerel (*Scombridae rastrelliger* kanagurta)	Pelagic	77.95	10.21 ± 0.46	0.312	197.51
	Delagoa threadfin bream (*Nimipterus delagoa* Smith)	Demersal	117.46	18.70 ± 0.84	0.571	361.75
CK01	Yellowtail scad (*Atule mate*)	Pelagic	102.1	24.48 ± 1.09	0.748	473.56
	Delagoa threadfin bream (*Nimipterus delagoa* Smith)	Demersal	98.52	15.39 ± 0.69	0.470	297.72
TS03	Indian mackerel (*Scombridae rastrelliger* kanagurta)	Pelagic	80.00	4.14 ± 0.18	0.127	80.09
	Delagoa threadfin bream (*Nimipterus delagoa* Smith)	Demersal	89.23	5.21 ± 0.23	0.159	100.79
PS01	Layang scad (*Decapterus macrosoma*)	Pelagic	68.34	20.38 ± 0.91	0.623	394.25
	Delagoa threadfin bream (*Nimipterus delagoa* Smith)	Demersal	65.27	13.30 ± 0.59	0.406	257.29
PL01	Yellowtail scad (*Atule mate*)	Pelagic	39.71	32.76 ± 1.46	1.001	633.74
	Delagoa threadfin bream (*Nimipterus delagoa* Smith)	Demersal	60.96	4.16 ± 0.19	0.127	80.48
KS03	Yellowtail scad (*Atule mate*)	Pelagic	120.44	16.12 ± 0.72	0.493	311.84
	Delagoa threadfin bream (*Nimipterus delagoa* Smith)	Demersal	92.71	8.88 ± 0.40	0.271	171.78

The content of protein in fish also plays an important role in accumulation of ^{210}Po, it is suggested that this radionuclide is primarily associated with proteins in living organisms (Alam & Mohamed, 2011a). Since the content of protein in the body of Yellowtail scad (18.76 g) and Layang scad (22.72 g) is relatively higher than Indian snapper (7.83 g) and Delagoa threadfin bream (17.76 g) (http://www. Fatsecret.co.id, 2020), therefore both pelagic fishes accumulated more ^{210}Po in their bodies. In the context of the whole-body size of fish, there has a relationship with accumulation of ^{210}Po. This exhibited that the weight of pelagic fish has a negative correlation to ^{210}Po accumulated in their whole-body with the Pearson's correlation coefficient, r = 0.6818 (Figure 2). This can be explained that the small fishes are living and freely moving within the water column which can be fed much detritus suspended particles and materials are contained a high concentration of ^{210}Po. Moreover, the small fishes have a large surface area per volume, which could accumulate much ^{210}Po in their body as compared to the bigger size of fish. Whilst, demersal/benthic fish has a positive correlation with r = 0.7058 between fish weight and their ^{210}Po content. This due to small fishes is dominant to live in the water column which low content of ^{210}Po as compared to the bottom or sediment interface which is many big fishes as their enemy. Furthermore, the high concentration of ^{210}Po in the tissues of the big fishes suggested that the feeding habits and mechanisms of this fishes. This also could be probably high protein toward to increasingly and rapidly associate and transfer ^{210}Po to their body. This also indicated that there are many deposited suspended and food particles as well as invertebrates and other species of small fishes containing ^{210}Po at the water-sediment interface as a source of food for big size of fishes living there.

Clearly, the finding showed that the activity concentration ranges of ^{210}Po in all fish species (4.06 – 50.13 Bq/kg fw.) were generally higher as compared to worldwide ranges of 0.08 – 12 Bq/kg ww. reported by UNSCEAR (2000). This indicated that Malaysia, which is one of the countries that has a high content of mineral consisting ilmenite, zircon, rutile, and monazite in the soil and beach sands, progressively enhances natural radionuclides such as ^{210}Po into the marine water. Furthermore, the Malaysian coastal are mostly enclosed by the landmasses particularly the west coast of Peninsular Malaysia, this consequently received large input of soil which high content of ^{210}Po. This supply of radionuclide that attached to eroded soil move into the marine environment by rain water flow or flood from the mainland of neighbouring countries and surrounding islands particularly during the monsoon season (Zal U'yun et al., 2020). Furthermore, there are a few regions in the world, including Malaysia which is known for high background radiation areas (HBRAs). These are due to their local geological controls and geochemical effects, cause enhanced levels of terrestrial radiation (UNSCEAR, 2000) and indirectly will be affected radiation level in the marine environment.

Total Dose Rate of ^{210}Po in Fish

The ^{210}Po concentration in seawater and five species of fishes together with other of their physical data (size and weight) were used to estimate the total dose using ERICA Assessment Tool (software for the assessment of impacts of radiation on non-human biota) which can be downloaded from the free open source. The default value of 10 µGy/hr was used as the screening confidence level, below which radiological risks are negligible (Anderson et al., 2009) for risk assessment to fish. Thus, estimation of the total dose rate of ^{210}Po per each fish was presented in Table 2. The total dose rates of ^{210}Po in the whole-body of pelagic and demersal fishes were varied from 0.127 – 1.530 µGy/hr and 0.124 – 0.837 µGy/hr, respectively. Absolutely, the finding showed that the total dose rates of ^{210}Po in pelagic fishes were higher compared to demersal fishes. This relatively difference related to the depth profile indicated an increase of ^{210}Po to mid-water, which almost pelagic fishes live in this zone and the decreasing again of ^{210}Po to lower levels at greater depths (Fowler, 2011) whereas demersal fishes live and feed. Furthermore, this indicated that ^{210}Po in fishes is most probably contributed by seawater and less from the sediments. It is strictly proven by Carvalho and Fowler (1993) that the ingestion of food also plays a major role in the accumulation of ^{210}Po toward contributing such value of the total dose rate to fish.

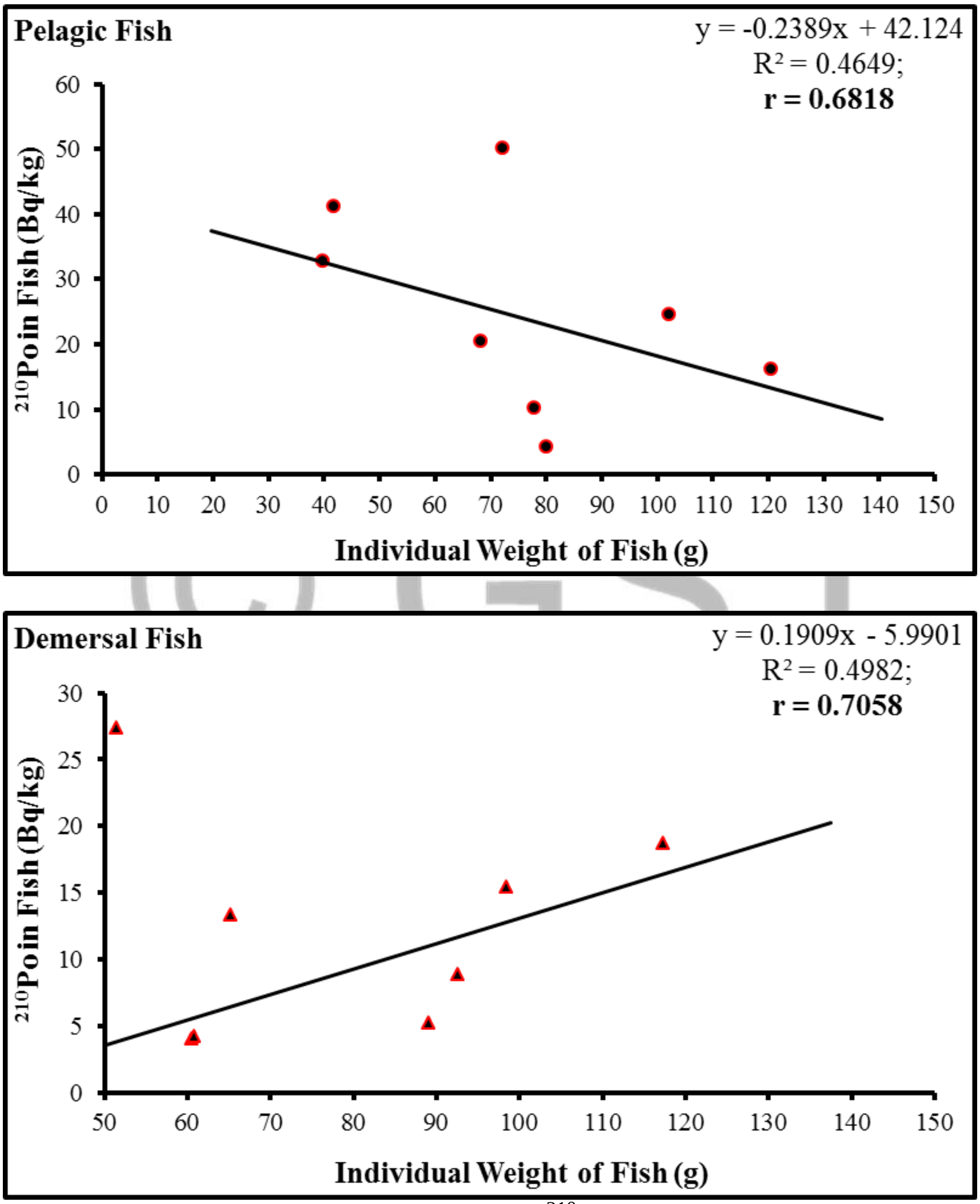


Figure 2: Relationship of fish weight (fresh; g) and ^{210}Po activity concentration (Bq/kg fw.) in fish

Additionally, the result revealed a clear relationship between ^{210}Po accumulation in fishes and the ecological niche of fishes, where the accumulation decreases with depth (Alam

& Mohamed, 2011b) aligns to decrease the dose received by fish which live at the sea bottom. In another context, the low total dose rate of ^{210}Po in demersal fish may be a factor of the reported rapid depuration of ^{210}Po by this species. The lack of total dose rate of Delegoa threadfin bream is also due to their body size are relatively larger compared to pelagic fish such as Yellowtail scad and Indian mackerel. Thus, this can be related to the factor of the smaller surface area per volume for this species of fish to receive an internal and external dose from accumulated ^{210}Po or other radionuclides. In other hand, Ŝtrok & Smodiš (2011) was reported that the larger animals (eg. fish) have the lower ^{210}Po activity concentration. According to them, this could be related to the slower metabolism for the larger, older, and heavier animals. Additionally, this may probably depend on the factors of the physical and chemical properties of the ambient water, behaviour of fishes and related to their species; and geographical regions. This elevation of the total dose rate is also associated with ^{210}Po level in fish that their influence factors were more detail discussed in the above section.

However, the results showed that the probability of exceeding the selected screening dose rate for each fish was well below the probability selected and no further assessment was needed. This indicated that the ^{210}Po activity concentration in the Peninsular Malaysia marine environment was far below the screening value, this pose no risk to the living organism.

Annual Effective Dose of ^{210}Po to Fish Consumer

Generally, the ingested dose of ^{210}Po from the consumption of fish from the east and west coast of Peninsular Malaysia was estimated to be in the range of 78.54 – 969.76 μSv/yr (Table 2). This indicated that the effective doses of ^{210}Po for Yellowtail scad (311.84 – 969.76 μSv/yr) were comparatively higher than Layang scad (394.25 – 797.21 μSv/yr), Indian snapper (78.54 – 530.25 μSv/yr), Delegoa threadfin bream (80.48 – 361.75 μSv/yr) and Indian mackerel (80.09 – 197.51 μSv/yr) owing to the relatively higher ^{210}Po activity concentration in Yellowtail scad. The dose for ^{210}Po from the ingestion of five common species of fishes estimated in this study found to be many folds higher as compared to the radiation exposure of adult populations from ingestion of natural radionuclides of 0.11 mSv/yr. This estimation is large portion contributed by ^{210}Pb/^{210}Po (UNSCEAR, 2000).

However, the results of this study could not be compared to other findings because this study is based on the radionuclide concentration in the whole-body of fish and different species with other studies. Most other studies elsewhere were reported the total doses for seafood consumption, which consisting of fishes, crustaceans, molluscs etc., while this study was a specific dose for individual fish. Furthermore, ^{210}Po from the consumption of these fishes may depend also on the timeframe the fishes were caught, prepared, storage and cooking methods before ingestion (Kim et al., 2017). Since ^{210}Po has a short half-life and it is easily volatile at high temperature, so it may be only minimally present in these five of fishes as typically how Malaysian cuisines were prepared and cooked (Zal U'yun et al., 2020). Absolutely, these elevated variations of fish ingestion dose of ^{210}Po when compared to other values reported elsewhere may be related to several factors such as species, season and region. Thus, in the execution to estimate the dose of ^{210}Po from fish needs to be more precisely assessed for the next time. The ^{210}Po concentrations in the edible portions of fishes or other marine organisms were used to assess the effect of natural variations of ^{210}Po on the estimation of effective dose to seafood consumers.

CONCLUSION

This study of activity concentrations of ^{210}Po in five species of fishes from the east and west coast of Peninsular Malaysia were determined their respective current ranges. The ^{210}Po was present in all fish samples and was quite higher predominantly in pelagic fish as compared to demersal/benthic fish and that detected concentrations was also in different variations. The concentration of ^{210}Po in Yellowtail scad showed a large range from 16.12 Bq/kg fw. to 50.13 Bq/kg fw. and the ranges of ^{210}Po concentrations in other fish species tended to be less diverse. This elevated concentration of ^{210}Pb in Yellowtail scad suggested that the ^{210}Po present is primarily accumulated through the diet and other factors of biological variables, size etc. as discussed above. However, the results showed that the probability of exceeding the selected screening dose rate for each fish was well below the recommended value (10 µGy/hr) by the ERICA Assessment Tool. This indicated that the ^{210}Po activity concentration in the Peninsular Malaysia marine environment was far below the screening value, this pose no risk to the living organism. Since higher concentration of ^{210}Po can contributes significantly the dietary dose of ionising radiation to high fish consumers, however such magnitude varies are considerably radiological safe for those consumers in Peninsular Malaysia. These needs to take into account of fish species and its body size as well as the timeframe of catching the fish, preparation, storage and cooking methods before ingestion.

AKNOWLEDGEMENT

The authors are grateful to International Atomic Energy Agency (IAEA) for providing funds to execute the CRP 41017 project (IAEA Research Contract No.: 22192). The authors would also like to thank to Malaysian Nuclear Agency (Nuklear Malaysia) for continuous supporting and encouraging as well as all personnel and project members, i.e. Mr. Tarmizi, Mr. Noh, Mr. Izzat, Mr. Salahuddin and Ms. Dainee which are involved in the implementation of the research project, sampling and sample analysis.

REFERENCES

Aarkrog, A., Baxter, M.S., Bettencourt, A.O., Bojanowski, R., Bologa, A., Charmasson, S., Cunha, I., Delfanti, R., Duran, E., Holm, E., Jeffree, R., Livingston, H.D., Mahapanyawong, S., Nies, H., Osvath, I., Pingyu, Li, Povinec, P.P., Sanchez, A., Smith, J.N. and Swift, D. (1997). A comparison of doses from ^{137}Cs and ^{210}Po in marine food: a major international study. Journal of Environmental Radioactivity, 34 (1): 69-90.

Aközcan, S. and Uğur, A., (2013). Activity levels of ^{210}Po and ^{210}Pb in some fish species of the Izmir Bay (Aegean Sea). Marine Pollution Bulletin, 66:234-238.

Alam, M.N., Chowdhury, M.I., Kamal, M., Ghose, S., Matin, A.K.M.A. and Ferdousi, G.S.M. (2000). Radionuclide concentrations in mussels collected from the southern coast of Bangladesh. Journal of Environmental Radioactivity, 47(2): 201-212.

Alam, L. and Mohamed, C.A.R. (2011a). A mini review on bioaccumulation of ^{210}Po by marine organisms. International Food Research Journal, 18: 1-10.

Alam, L. and Mohamed, C.A.R. (2011b). Natural radionuclide of Po-210 in the edible seafood affected by coal-fired power plant industry in Kapar coastal area of Malaysia. Environmental Health, 10: 43-53.

Anderson, P., Garnier-Laplace, J., Beresford, N.A., Copplestone, D., Howard, B.J., Howe, P., Oughton, D. and Whitehouse, P. (2009). Protection of the environment from ionizing radiation in a regulatory context (protection): proposed numerical benchmark values. Journal of Environmental Radioactivity,100: 1100-1108. doi: 10.1016/j. jenvrad.2009.05.010.

Bustamante, P., Germain, P., Leclerc, G. and Miramand, P. (2002). Concentration and distribution of ^{210}Po in the tissues of the scallop *Chlamys varia* and the mussel *Mytilus edulis* from the coasts of Charente-Maritime (France). Marine Pollution Bulletin, 44: 997-1002.

Brown, J.E., Alfonso, B., Avila, R., Beresford, N.A., Copplestone, D., Prohl, G. and Ulanovsky, A. (2008). The ERICA Tool. Journal of Environmental Radioactivity, 99: 1371-1383. doi: 10/1016/j. jenvrad.2008.01.008.

Carvalho, F.P. (2011). Polonium (^{210}Po) and lead (^{210}Pb) in marine organisms and their transfer in marine food chains. Journal of Environmental Radioactivity, 102: 462-472.

Carvalho, F.P. and Fowler, S.W. (1993). An experimental study on the bioaccumulation and turnover of polonium-210 and lead-210 in marine shrimp. Marine Ecology Progress Series, 102: 125-133.

CEC (1990). The radiological exposure of the population of the European Community from radioactivity in North European marine wasters- Project ‘Marina’. Commission of the European Community. Report No. EUR 12483, Luxembourg.

Cherry, R.D., Heyraud, M. and James, A.G. (1989). Diet prediction in common clupeoid fish using Polonium-210 data. Journal of Environmental Radioactivity, 10: 47-65.

Cherry, R.D. and Shannon, L.V. (1974). The alpha radioactivity of marine organisms. Atomic energy review 1974, 12: 3-45.

Connan, O., Germain, P., Solier, L. and Gouret, G. (2007). Variations of Po-210 and Pb-210 invarious marine organisms from Western English Channel: contribution of Po-210 to the radiation dose. Journal of Environmental Radioactivity, 97: 168-188.

Database makanan dan penghitung kalori, http://www. Fatsecret.co.id, 2020. Access on 24 March 2020.

EPA (1988). Limiting values of radionuclide intake and air concentration and dose conversion factors for inhalation, submersion and ingestion. Oak Ridge National Laboratory, Oak Ridge, TN; US, EPA, Washington, DC; Federal Guidance Report No. 11, EPA-520/1-88-020.

Food Consumption Statistic of Malaysia (FCSM) (2014). National health and morbidity survey 2014: Malaysian adult nutrition survey. MOH/S/IKU/46.15(PR), Institute for Public health, Ministry of Health Malaysia.

Fowler, S.W. (2011). ^{210}Po in the marine environment with emphasis on its behaviour within the biosphere. Journal of Environmental Radioactivity, 102: 448-461.

Harrison, J., Leggett, R. Lloyd, D. Phipps, A. and Scott, B. (2007). ^{210}Po as a poison. Journal of Radiology Protection, 27: 17-40.

IAEA (2004). Sediment distribution coefficients and concentration factors for biota in the marine environment. Technical Reports Series No. 422. International Atomic Energy Agency (IAEA), Vienna, Austria.

IAEA (2017). The environmental behaviour of polonium, Technical Reports Series No. 484, International Atomic Energy Agency (IAEA), Vienna, Austria.

Jefferson, R.D., Goans, R.E., Blain, P.G. and Thomas, S.H. (2009). Diagnosis and treatment of polonium poisoning. Clininal Toxicology (Phila), 47: 379-392 and Erratum in: Clinical Toxicolology (Phila) 47, 608.

Khan, M.F. and Wesley, S.G. (2011). Assessment of health safety from ingestion of natural radionuclides in seaoods from a tropical coast, India. Marine Pollution Bulletin, 62(2): 399-404.

Kim, S.H., Hong, G.H., Lee, H.M. and Cho, B.E. (2017). ^{210}Po in the marine biota of Korean coastal waters and the effective dose from seafood consumption. Journal of Environmental Radioactivity, 174: 30-37.

Kulsawat, W. and Porntepkasemsan, B. (2016). Distribution of ^{210}Po in some marine biota of a Samut-Sakhon region: evaluation of dose to consumers. KKU Engineering Journal, 43(x): xx- xx.

Matthews, K.M., Kim, C.K. and Martin, P. (2007). Determination of ^{210}Po in environmental materials: a review of analytical methodology. Applied Radiation Isotope, 65(3): 267-279.

Rani, L.M., Jeevanram, R.K., Kannan, V. and Govindaraju, M. (2014). Estimation of polonium-210 activity in marine and terrestrial samples and computation of ingestion dose to the public in and around Kanyakumari coast, India. Journal of Radiation Research and Applied Sciences, 7: 207-213.

Saiyad Musthafa, M. and Krishnamoorthy, R. (2012). Estimation of 210-Po and 210-Pb and its dose to human beings due to consumption of marine species of Ennore Creek, South India, Environ. Monitoring Assessment, 184(10): 6253-6260.

Ŝtrok, M. and Smodiš, B. (2010). Levels of ^{210}Po and ^{210}Pb in fish and molluscs in Slovania and the related dose assessment to the population. Chemosphere, 82(7): 970-976.

Turekian, K.K., Nozaki,Y. and Benninger, L.K. (1977). Geochemistry of atmospheric radon and radon products, Annual Revision Earth Planet Science, 5: 227-255.

UNSCEAR (2000). Sources and effects of ionizing radiation. United Nations Scientific Committee on the Effects of Atomic Radiation United Nations, New York; Report to the general assembly with scientific annexe.

Wood, M.D., Marshall, W.A., Beresford, N.A., Jones, S.R., Howard, B.J., Copplestone, D. and Leah, R.T. (2008). Application of the ERICA Integrated Approach to the Drigg coastal sand dunes. Journal of Environmental Radioactivity, 99: 1484-1495. doi:10.1016/j. jenvrad.2008.03.008.

Yii, M.-W. and Zal U'yun, W.M. (2011). Radioactivity of plutonium isotopes, ^{137}Cs and their ratio in sediment, seawater and biota from the east coast of Peninsular Malaysia. Journal Radioanalytical Nuclear Chemistry, 289: 819-833.

Zal U'yun Wan Mahmood, Nooradilah Abdullah, Norfaizal Mohamed @ Muhammad, Mohd Tarmizi Ishak and Muhammad Izzat Muammar Ramli (2019). Distribution of Po-210 in seawater, biota and sediment in the east coast of Peninsular Malaysia. Jurnal Sains Nuklear Malaysia, 31(2): 59-68.

Zal U'yun Wan Mahmood, Norfaizal Mohamed, Yii Mei Wo, Nooradilah Abdullah, Mohd Tarmizi Ishak, Mohamad Noh Sawon and Muhammad Izzat Muammar Ramli (2020). ^{210}Po in marine fish: estimation of the effective dose to consumers in Peninsular Malaysia. Global Scientific Journals, 8(3): 2051-2062.