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Potential Radiological Dose of ^{210}Po to Several Marine Organisms in Coastal Area of Coal-Fired Power Plant Tanjung Awar – Awar, Tuban

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Abstract

NORM (Naturally Occurring Radioactive Material) is a radionuclide element that naturally already exists in the earth. Its concentration can be increased by industrial activities, such as coal-fired power plant (CFPP). Coal-fired power plant activities produce fly ash and bottom ash which will be carried away by the wind and then can enter the CFPP environment, one of which is marine waters and can affect the existence of marine biota. The determination of the radiation dose rate is essential in assessing the risk of radionuclide exposure to the marine environment. This study aims to determine and evaluate the total dose rate of ^{210}Po to marine biota taken from the Karangsari fish market with catchment areas around the waters of CFPP Tanjung Awar – Awar, Tuban, East Java. This research was conducted in April 2021 in the waters of CFPP Tanjung Awar – Awar. ^{210}Po measurement activity was carried out using alpha ray spectrometry at the Marine Radioecology Laboratory of PTKMR-BATAN, then the radiation dose rate was calculated using the ERICA Tool software. The value of the total radiation dose of ^{210}Po on marine biota ranges from 2.70E-1 μGy.hr^{-1} to 39.70E+0 μGy.hr^{-1}. The radiation dose of ^{210}Po on marine biota measured in the waters of CFPP, has a lower value range than the research result carried out in other countries. Based on the Erica Tools software analysis, the total radiation dose measured on marine organisms in the waters of CFPP Tanjung Awar – Awar, does not give a negatively impact to the marine ecosystems and the sustainability of marine organisms in the study area.

Keywords: *Radiation dose rate, ^{210}Po, ERICA tools, marine biota, CFPP waters.*

Introduction

Globally, coal is one of the essential energy sources, especially in the power generation sector up to 39%, contributing the electricity production called coal-fired power plant (IAEA, 2010). In Indonesia, Presidential Regulation No. 71/2006 is the basis for constructing a coal-fired power plant (CFPP) known as the 10,000 MW CFPP Acceleration Project.

CFPP Tanjung Awar – Awar, Tuban, East Java is one of the coal-fired power plant included in the 10,000 MW Energy Diversification Acceleration Program (EDAP) Phase 1 with a capacity of 2 x 350 MW (Riadessy, 2015). The fuel used is low-calorie coal from Bontang, Kalimantan, with 160 tons.h^{-1} of coal consumption to produce 700 MW of electrical energy (Riadessy, 2015).

The use of coal as a power plant fuel can produce releases in fly ash and bottom ash containing natural radionuclides or Naturally Occurring Radioactive Material (NORM) with certain activities (Ozden *et al.*, 2018). In the coal combustion process at CFPP, there will be cracking, which causes natural radionuclides to come out with other emission gases through bottom and fly ash which contain NORM ten times higher than the original value (Hvistendahl, 2007). Natural radioactive elements are also concentrated in this processing and form a radioactive concentrate called TENORM (Pandit *et al.*, 2011).

According to Susiati (2005), the most dominant radioactive pollutants in coal samples are radioactive elements such as ^{210}Pb, ^{210}Po, ^{231}Pa, ^{226}Ra, ^{238}U, ^{232}Th, ^{14}C, ^{40}K (Table 1.). Radioactive pollutants numbers 1 to 6 belong to the group of heavy metals when it comes in the human body will follow the level route that negatively impacts human health.

^{210}Po is one of the natural radionuclides produced in CFPP processing ($T_{1/2}$ = 138.4 d) (Alam and Mohamed, 2011). ^{210}Po is an alpha-emitting

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natural radionuclide produced by the decay chain of ^{238}U through ^{210}Pb and ^{210}Bi, but can also be generated by the activation of the neutron ^{209}Bi (Gjelsvik *et al.,* 2012). Various marine organisms can accumulate ^{210}Po, it is the main contributor (90%) to the natural radiation dose from alpha-emitting radionuclides received by most marine organisms (Alam and Mohamed, 2011), which make it responsible for the majority of the absorbed dose received by a human from seafood ingestion (Makmur *et al.*, 2020). It may contribute almost 80% of the total dose received by humans (Makmur *et al.*, 2020). Alpha radiation that comes out of ^{210}Po is an internal-radiation hazard, which is very dangerous if it enters the human body through the consumption of marine biota because it has a large ionizing power (Gjelsvik *et al.*, 2012). Natural radionuclides in certain amounts can increase the risk of cancer if it enters the human body (Alam and Mohamed, 2011).

Fly ash has physical properties that are heavier than air (Lockwood and Evans, 2012). At a particular moment, it will fall into the environment around the power plant, which is usually dominated by sea waters (Alviandini *et al.,* 2019). Most radionuclides that accumulate in the marine environment contribute to external radiation sources. The higher the natural radionuclide content in the area is, the higher the radiation dose rate is (Júnior *et al.,* 2017).

Natural radionuclides released into marine waters will generally be spread through abiotic components (water and sediment). Through these components, there is also accumulation into the biota. Thus, this incident can slowly disrupt the life of biota and human life that consumes the marine biota (Suseno and Prihatiningsih, 2014).

Marine organisms risk exposure to internal and external radiation through radionuclide contamination mechanisms is found in the marine environment (Suseno and Prihatiningsih, 2014). External contamination occurs when the radionuclide attaches to the outside of the biota's body (ERICA, 2021). In contrast, internal contamination occurs when the radionuclide enters the biota's body through the respiratory tract (inhalation), ingestion, or absorption through the skin (Tsuchiya *et al.*, 2017). The concentration of ^{210}Po in the edible portions of marine organisms may be many folds higher than that in the seawater because of the biological reconcentration process (Musthafa and Krishnamoorthy, 2012). This is especially so with filter feeder mussels, which ingest detritus material with a high degree of radionuclide association. It has been recognized internationally that filter-feeding bivalve mollusks act as first-order biological indicators of radioactive pollution (Macklin Rani *et al.*, 2014).

Based on research (Alam and Mohamed, 2011) conducted at the coal-fired power plant industry in the Kapar coastal area of Malaysia, the biota that has potential for public consumption and the highest ^{210}Po activity when compared to other biota is *Anadara granosa,* it is included in mollusks and *Penaeus merguiensis*, which is included in crustaceans. Mishra *et al.* (2009), reported that ^{210}Po was non-uniformly distributed within the Mumbai coastal ecosystem. The highest values were associated with mollusks, the second-highest values with crustacea, and the lowest for fish.

According to Melawati (2003), radiation exposure from natural radionuclide up to 10.48 mSv/48 h resulted in disturbances in the larva stage (sensitive growth stage) of tiger prawn seeds in a mortality rate of as much as 50%. Thus, it is crucial to determine the radiation dose rate in the process of assessing the risk of radionuclide exposure to natural resources in the marine environment.

The ^{210}Po study related to CFPP operations has never been carried out in Indonesia. Many studies on NORM release from CFPP have been carried out, but only for environmental monitoring (Alviandini *et al.*, 2019; Anggarini *et al.*, 2018). Studies of its accumulation in several biotas have also been carried out in Malaysia (Abdullah *et al.*, 2015), Northern Arabian Gulf (Uddin *et al.*, 2017), Korea (Kim *et al.*, 2017), and Vietnam (Duong Van, 2020). On the other hand, the impact of CFPP operations on its accumulation in marine biota based on an increase in the concentration of ^{210}Po has been carried out in Malaysia (Alam and Mohamed, 2011).

A further study of radionuclide monitoring in the marine environment is to examine the impact on marine waters, including marine biota in the research area (Suseno and Prihatiningsih, 2014; Prihatiningsih et al., 2016). Several models have been developed to facilitate the assessment of the radiological impact of ionizing radiation on various species of biota, one of the most widely used models is the Erica Tool (Brown *et al.*, 2004; Brown *et al.*, 2008; Gjelsvik *et al.*, 2012; ERICA, 2021). The use of the Erica Tool has been widely applied in various environmental conditions (Brown *et al.*, 2004; Khan *et al.*, 2014). Using the Erica Tool, radiological studies on marine ecosystems have also been carried out to calculate the radiation impact of ^{134}Cs, ^{137}Cs, ^{90}Sr, and ^{110}Ag caused by the Fukushima nuclear reactor accident on Japanese marine biota (Yu *et al.*, 2015).

Table 1. Dominant Radioactive Pollutants from Coal Burning

Number	Pollutant	Symbol	Radiation	Half Life
1	Timbal-210	^{210}Pb	Beta	19,4 Year
2	Polonium-210	^{210}Po	Alpha	138 Days
3	Protactinium-231	^{231}Pa	Alpha	3,43 x 10^4 Year
4	Radium-226	^{226}Ra	Alpha	1620 Year
5	Thorium-232	^{232}Th	Alpha	1,39 x 10^{10} Year
6	Uranium-238	^{238}U	Alpha	4,5 x 10Year
7	Karbon-14	^{14}C	Beta	5730 Year
8	Kalium-40	^{40}K	Alpha	1,28 x 10^9 Year

Source: (Susiati, 2005)

The same method would be used to assess the impact of ^{210}Po, which is thought to come from the CFPP flying ash release on marine biota in the waters of CFPP Tanjung Awar-Awar, Tuban, which is calculated using the Erica tool as the software. Study of radiation dose on biota can provide a complete picture of the effect of these natural radionuclides on the sustainability of natural resources in the marine environment (Brown *et al*., 2004; Brown *et al*., 2008; Khan *et al*., 2014; Mahmood *et al*., 2021; ERICA, 2021).

Therefore, such a study on the estimation ^{210}Po dose rate is crucial to assess the level of radiological safety to marine organisms. With that, we have therefore calculated the radiation doses absorbed by diverse marine organisms. Thus, this study aims to determine and evaluate the total dose rate of ^{210}Po to marine organisms using the ERICA Tools Assessment.

Materials and Methods

Sample collection

A sampling of marine biota was carried out in March 2021. The samples used are biota that has potential for public consumption. Referring to the researches (Alam and Mohamed, 2011; Suseno and Prihatiningsih, 2014; Kim *et al*., 2017), samples of popular seafood (fish, shrimp, cuttlefish, squid, and crab) were collected from fresh catch sold in the local fish market in the study area. The catch location was verified with the interviews by fishermen who carried out ship unloading activities near the local fish market. The research location can be seen in (Figure 1) samples were taken from the Karangsari traditional fish market, Tuban. There are ten (10) samples of biota were divided into four groups which are: crustaceans (shrimp, *Litopenaeus setiferus*; crab, *Portunus pelagicus*), molluscs (squid, *Loligo gahi*; cuttlefish, *Sepia aculeata*), demersal fish (grouper, *Epinephelus epistictus*; Japanese threadfin bream, *Nemipterus japonicus*; Indian halibut, *Psettodes erumei;* pink ear emperor, *Lethrinus lentjan*), and pelagic fish (anchovy, *Stolephorus commersonni;* yellowtail fish *Caesio cuning*). The samples were transported to the laboratory for further analysis.

Analysis of ^{210}Po

The method used to determine ^{210}Po in biota is based on *The International Atomic Energy Agency's Marine Environmental Laboratories* (IAEA-MEL) (Alam and Mohamed, 2011) with several modifications. The organism samples were dissected to obtain the edible part (muscle) and oven-dried at 60°C temperature. About 1 gram of the dried sample was digested with HNO_3 10 mL, heat until the sample was digested. Add H_2O_2 1 mL (drop by drop) and evaporate to dryness. Add HNO_3 6mL; H_2O_2 1mL and evaporate to dryness. Repeat this procedure twice. Add HCl 2 mL in residue and evaporate to dryness. Repeat this procedure twice. Then, the samples were dissolved in 0.1 M HCl with a pinch of ascorbic acid to reduce Fe (III), and ^{210}Po was spontaneously deposited on brightly polished silver discs (2 cm diameter) for 3-4 hours at a temperature of 70-90°C. The clamp with the silver disc was then removed from the solution, rinsed with deionized water and ethanol, and then aired. The discs were counted for ^{210}Po activities with an alpha spectrometer.

Sample counting using alpha spectrometry

The measurement of ^{210}Po was carried out by using alpha spectrometry for 24 hours. ^{210}Po activity concentration was corrected to the time of sample collection. The alpha spectrometry counting 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 ^{234}U, ^{238}U, ^{239}Pu, and ^{241}Am supplied by Analytics, USA (SRS 67943-121) (Mahmood *et al*., 2021).

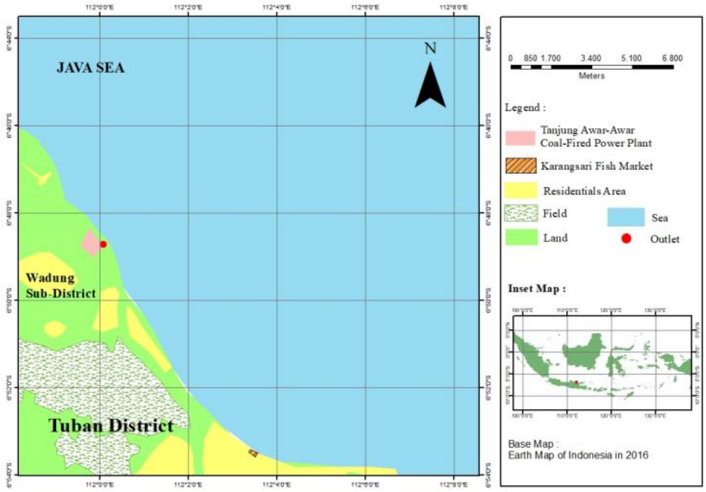

Figure 1. Sampling locations at the Tanjung Awar – Awar, Tuban Coastal Area.

Data analysis

The concentration of ^{210}Po was determined by using the following equation (Makmur *et al*., 2020). With notes, N_{net} is the net count area, f_1 is a correction factor for tracer decay during sample counting, f_2 is a correction factor for tracer decay between a separation start date and counting start date, and f_3 is a correction factor tracer decay between sampling and separation date.

Calculation of total dose rate using the Erica Tool

The radiation dose rate was calculated using the Erica Tool (software used to assess radiological impacts on non-human biota) (Brown *et al*., 2008). The value of the total radiation dose to marine organisms was determined by the concentration ratio between the environmental concentration and the concentration absorbed by the organism (Abbasi *et al*., 2021). Various studies have recorded a range of concentration ratios in various aquatic organisms called concentration factors (CF) recorded in the Erica Tool database (ERICA, 2021). In addition, radionuclides dissolved in water can be adsorbed in suspended sediment particles until they finally settle in the bottom sediments of the waters due to the movement of currents, wind, or dispersion (Suseno and Prihatiningsih, 2014). The Kd is the ratio of the concentration of an element on a solid phase (soil or sediment) divided by the equilibrium concentration in the contacting liquid phase (water) (Sheppard *et al*., 2011). The factor concentration equation (CF) and distribution coefficient (Kd) are respectively described by ERICA (2021).

Radionuclide concentrations can be converted into radiation exposure values for each aquatic organism produced by a radionuclide. Exposure to radiation dose to organisms is divided into two pathways: internal dose (DCC_{int}) and external dose (DCC_{eks}) (Abbasi *et al*., 2021b). Internal dose is the value of radiation dose absorbed by the organism from the radionuclide concentration that the body has absorbed. In contrast, external dose illustrates the value of radiation exposure from the concentration of radionuclides in the environment that is not absorbed in the organism's body (Ciesielski *et al.,* 2015). The total dose rate can then be calculated by ERICA, (2021) and Table 2.

Results and Discussion

^{210}Po activity results in organisms consisting of crustaceans (shrimp, *Litopenaeus setiferus*; crab, *Portunus pelagicus*), mollusks (squid, *Loligo gahi*; cuttlefish, *Sepia aculeata*), demersal fish (grouper, *Epinephelus epistictus*; Japanese threadfin bream, *Nemipterus japonicus*; Indian halibut, *Psettodes erumei;* pink ear emperor, *Lethrinus lentjan*), and pelagic fish (anchovy, *Stolephorus commersonni;* yellowtail fish, *Caesio cuning*), were used as input data in the Erica Tool software. The results of ^{210}Po measurement in the marine biota samples use a spectrophotometer Alpha shown in Table 4.

Based on the monitoring results, in moving contaminants in the food chain, transfer factor data is used in the ERICA tool database (Brown *et al*., 2008; ERICA, 2021). The database comes from experimental results in various countries and has been published in reputable international journals. The movement of contaminants in the food chain is illustrated in Figure 2. In Figure 2, if the radionuclide concentration value is known in one component, the radiation dose can be predicted in the other components (ERICA, 2021).

Table 2. Equation of radiation value per unit of radionuclide concentration

Organism Group	F Equation
Phytoplankton	$F = [DCC_{int} \,.\, CR + DCC_{eks}]$
Macroalgae	$F = [DCC_{int} \,.\, CR + 0{,}5 \,.DCC_{eks} \,.\, (1 + K_d)]$
Vascular plant	$F = [DCC_{int} \,.\, CR + 0{,}5 \,.DCC_{eks} \,.(1 + K_d)]$
Zooplankton	$F = [DCC_{int} \,.\, CR + DCC_{eks}]$
Polychaeta	$F = [DCC_{int} \,.\, CR + DCC_{eks} \,.\, K_d]$
Mollusks dan Bivalves	$F = [DCC_{int} \,.\, CR + 0{,}5 \,.DCC_{eks} \,.(1 + K_d)]$
Crustacea	$F = [DCC_{int} \,.\, CR + 0{,}5 \,.DCC_{eks} \,.(1 + K_d)]$
Demersal Fish	$F = [DCC_{int} \,.\, CR + 0{,}5 \,.DCC_{eks} \,.(1 + K_d)]$
Pelagic Fish	$F = [DCC_{int} \,.\, CR + DCC_{eks}]$
Bird	$F = [DCC_{int} \,.\, CR + DCC_{eks}]$
Sea Mammal	$F = [DCC_{int} \,.\, CR + DCC_{eks}]$
Reptile	$F = [DCC_{int} \,.\, CR + DCC_{eks}]$
Anemone dan Reef	$F = [DCC_{int} \,.\, CR + 0{,}5 \,.DCC_{eks} \,.(1 + K_d)]$

R = Concentration Ratio (Bq.kg^{-1} fresh weight per Bq.kg^{-1}); Kd = Distribution Coefficient (1 kg^{-1}); DCC = Dose Conversion Coefficient (µGy.h^{-1} per Bqkg^{-1}).
Source : (ERICA, 2021).

Tabel 3. Risk Degree: Criteria of risk measurement (Risk characterization)

Dose Rate (D)	Risk Degree	Effect
D > 100 mGy hr^{-1}	Extremely High Risk	High mortality of roe; acute lethal of fish; decrease in diversity
10 mGy hr^{-1}< D < 100 mGy hr^{-1}	High Risk	Mortality of roe and plankton; fish die within a few days
400 µGy hr^{-1} < D < 10 mGy hr^{-1}	Medium Risk	Some organisms such as zooplankton will be affected
10 µGy hr^{-1} < D < 400 µGy hr^{-1}	Low Risk	Some sensitive organisms at embryonic and larval stages will be affected
< 10 µGy hr^{-1}	No-Risk	Safe

Source: (Ye *et al*., 2017)

Table 4. The activity of ^{210}Po in Marine biota

Marine Biota	Concentration average of Po-210 (Bq.kg^{-1})
Pelagic Fish	103.86
Demersal Fish	42.79
Mollusks	107.87
Crustaceans	354.85

The radiation dose level of marine biota was calculated using the Erica Tool software. The study results of external and internal radiation doses on marine biota in the waters of CFPP Tanjung Awar-Awar Tuban are shown in Table 5.

Based on the Erica Tool software calculations, total radiation dose rate received by marine organisms in the waters of CFPP Tanjung Awar – Awar, Tuban ranges between 2.70E-1–39.70E+0 µGy.hr^{-1}. Gray (Gy) is an international unit used to express the amount of radiation dose received by a material (Brown *et al*., 2008). The highest value of total radiation dose obtained by biota was found in true corals - colony (39.70E+0 µGy.hr^{-1}), and the lowest for macroalgae (2.70E-1 µGy.hr^{-1}). Some marine organisms have a total radiation dose value above the screening level (10E+0 µGy.hr^{-1}), including (crustaceans, phytoplankton, true corals – colony, and true corals – polyp) (11.00E+0; 13.30E+0; 39.70E+0; 21.00E+0) µGy.hr^{-1}, respectively. Based on Ye *et al*. (2017), the dose rate value under screening level 10E+0 µGy hr^{-1} is safe, and under chronic irradiation of 400E+0 µGy.hr^{-1}, which is the screening dose rate used in biota, there will be no significant effect observed on organisms in coastal areas.

Based on (ERICA, 2021), each marine organism has a certain effect on the value of the radiation dose received on each biota. The total radiation dose obtained in crustaceans is 11.00E+0 µGy.hr^{-1}. This value exceeds the screening level set by the Erica Tool (10 µGy.hr^{-1}). Still, based on ERICA (2021) the interval value, 0 – 50E+0µGy.hr^{-1} on crustaceans, has no significant effect statistically on DNA chain damage. According to (Harshitha *et al*., 2016), the crustacean is an important part of coastal ecosystems in maintaining the balance of ecosystems in the marine environment. Including in

Tabel 5. The estimated value of the total radiation dose rate ^{210}Po on marine biota in the waters of CFPP Tanjung Awar – Awar, Tuban was calculated using the ERICA Tool

No	Marine Organism	Exsternal Dose Rate ^{210}Po (µGy.hr^{-1})	Internal Dose Rate ^{210}Po (µGy hr^{-1})	Total Dose Rate ^{210}Po (µGy hr^{-1})
1	Bird	3.83E-11	8.78E+0	8.78E+0
2	Benthic Fish	1.39E- 4	3.87E+0	3.87E+0
3	Benthic Mollusks	1.45E- 4	3.34E+0	3.34E+0
4	Crustacean	1.32E- 4	11.00E+0	11.00E+0
5	Macroalgae	1.51E- 4	2.70E-1	2.70E-1
6	Mammal	2.01E- 11	5.12E+0	5.12E+0
7	Pelagic Fish	4.02E- 11	3.22E+0	3.22E+0
8	Phytoplankton	2.83E- 5	13.3E+0	13.30E+0
9	Polychaeta worm	2.96E- 4	5.87E+0	5.87E+0
10	Reptile	2.10E- 11	5.96E+0	5.96E+0
11	True corals - colony	1.32 E- 4	39.70E+0	39.70E+0
12	True corals - polyp	1.48E- 4	21.00E+0	21.00E+0
13	Vascular plant	1.45E- 4	3.1E-1	3.1E-1
14	zooplankton	4.47E-11	5.08E+0	5.08E+0

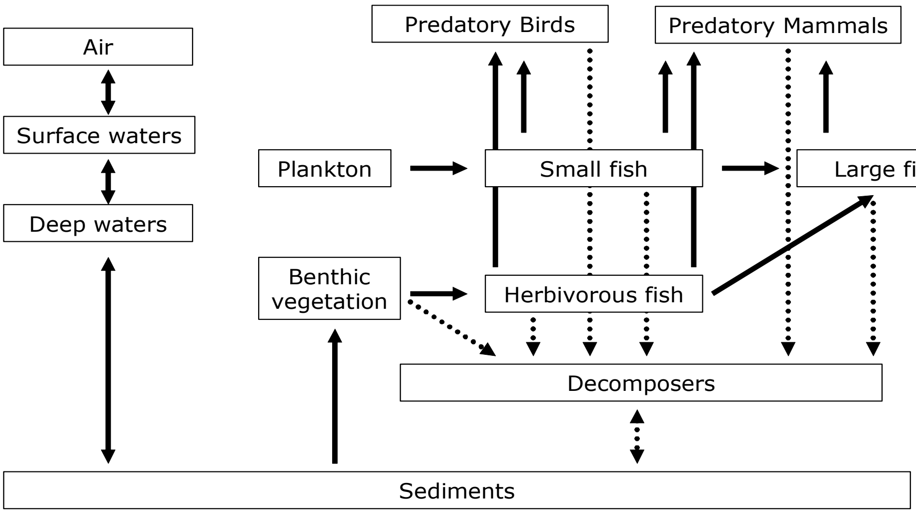

Figure 2. Schematic illustration of the measurement model of the radiation dose rate on natural resources in the marine environment by the ERICA Tool software (ERICA, 2021).

dead corals (Ulfah *et al.,* 2019). One of them, crustaceans alive by making a hole in the substrate nest of sediment. This activity can improve air circulation sediment to prevent and reduce the formation of phytotoxin, such as H_2S that can harm marine organisms (Handayani *et al.*, 2016). Thus, based on the total radiation dose value in crustaceans, it will not harm the sustainability of crustacean life, which can maintain the balance of ecosystems in the marine environment (ERICA, 2021).

The total radiation dose on true corals–colony and polyps were 39.70E+0 and 21.00E+0 Gy.hr^{-1}. These values exceeded the screening level set by the Erica Tool (10 µGy.hr^{-1}). In contrast, based on (ERICA, 2021), the interval value was 0–85E+0 µGy.hr^{-1} on true corals–colony and polyp where there were no significant effects on growth inhibition. The assessment (ERICA, 2021) indicates no negative impact on the balance of the marine ecosystem around the waters of the CFPP Tanjung Awar – Awar, Tuban. Consider coral reefs have a high conservation value function (ecological-process supporting, coastal-life supporting, coastal-sediment sources, and beach protecting from the abrasion threat) (Hoegh-Guldberg *et al.*, 2017).

Phytoplankton has a total radiation dose value (external + internal) of 13.30E+0 µGy.hr^{-1}. The total radiation dose (external + internal) obtained by phytoplankton exceeds the screening level set by the Erica Tool (10 µGy.hr^{-1}) but based on (ERICA, 2021), the total radiation dose with an interval of 0 – 50E+0 µGy.hr^{-1} on phytoplankton only gives small stimulatory effect on phytoplankton growth. Thus, it will not interfere with the growth and sustainability of phytoplankton life. Referring to (Effendi *et al*., 2016), phytoplankton has a crucial role in the food chain because these organisms are a food source for pelagic fish, so the abundance is often associated with these organisms the quality of aquatic fertility.

The relationship among individuals in the marine environment is complex and mutually influences each other (reciprocity). The reciprocal relationship among biological elements forms an ecosystem's ecological system (Kwak and Park, 2020). In ecosystems, there are food chains, energy flows, and biogeochemical cycles (Kwak and Park, 2020). The food chain is the transfer of energy at its source (plants) through a series of prey-predatory organisms (Trites, 2003). The food chain that occurs in marine ecosystems in the form of phytoplankton as primary producers is considered as trophic level I, zooplankton eating phytoplankton as trophic level II, carnivores eating zooplankton as trophic level III, and so on (Trites, 2003). The growth process of phytoplankton is influenced by the availability of nutrients, while zooplankton is a predator, its growth is influenced by the availability of phytoplankton, and so on (Trites, 2003). The function of the food chain is to maintain the number of an organism in an ecosystem (Kwak and Park, 2020). An ecosystem imbalance will occur if one experiences extinction due to pollution in the sea (Islam and Tanaka, 2004). One of the pollutants that can be released into marine bodies is natural radionuclide ^{210}Po which can be produced from CFPP (Alam and Mohamed, 2011). Natural radionuclides released into marine waters will generally be spread through abiotic components (water and sediment). Through these components, there is also accumulation into the biota network so that this incident can slowly disrupt the life of biota and human that consumes the marine biota (Suseno and Prihatiningsih, 2014).

The value of the total radiation dose in this study was compared with the total radiation dose to marine biota in other countries, Norwegian waters, which was carried out by (Brown *et al*., 2004). The comparison results based on the diversity of marine biota species show that the total radiation dose in the waters of CFPP Tanjung Awar - Awar, Tuban, Indonesia is smaller than in Norwegian waters. Variations in the value of the total radiation dose can be influenced by several factors such as the type and size of the biota, feeding habits, input of pollutants, and location (Štrok and Smodiš, 2011; Aközcan, 2013;).

Based on the assessment (ERICA, 2021), the total radiation dose of ^{210}Po on the biota in the study area shows that there is no significant hazard impact from the operation of the coal-fired power plant (CFPP) on the biota in the waters. Thus, it will not harm marine ecosystems and the sustainability of marine life in the waters of CFPP Tanjung Awar - Awar, Tuban.

Table 6. Comparison of total radiation doses from Norwegian coastal waters (Brown *et al*., 2004)

Marine Organism	Total Dosis Radiasi ^{210}Po (μGy.hr^{-1})
Benthic Fish	9.00
Benthic Mollusks	37.00
Crustacean	50.00
Macroalgae	2.10
Mammal	20.00
Pelagic Fish	11.00
Phytoplankton	2.50
zooplankton	25.00

Conclusion

The radiation dose of ^{210}Po was non-uniformly distributed in marine organisms, variations in the value of the total radiation dose can be influenced by several factors such as the type and size of the biota, feeding habits, input of pollutants, and location. The Erica Tools software analysis showed that the probability of exceeding the selected screening dose rate for each marine organism was well below the chronic irradiation value. This indicates that the ^{210}Po activity concentration in the waters of CFPP Tanjung Awar - Awar, Tuban was far below the screening value. This poses no risk to the marine ecosystems and the sustainability of marine biota.

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