The effect of coal-fired power plant (CFPP) operations on food transfer Polonium-210 (210Po) in coastal ecosystem

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Abstract. A coal-fired power plant (CFPP) is an option to cover a requirement of supply electrical energy, but in the process of operating, it can release several radionuclides. One of the radionuclides is 210Po which is one of the most radiotoxic natural radionuclides. 210Po radionuclides can move into the food web in marine ecosystems. The transfer of 210Po to marine ecosystems can be determined using a method of impact radiation doses on components of marine ecosystems such as plankton, coral, fish, molluscs, and crustacea. The results show that external and internal doses of 210Po were still below the screening level determined by International Atomic Energy Agency (IAEA), thus does not have an impact on the marine organism ecosystem.

1. Introduction
The 10,000 MW Acceleration Program is one of the important in preparing for national energy availability in the future. Government regulation number:71/2006 became the basis for the construction of power plants in Indonesia known as the 10,000 MW Coal-Fired Power Plant (CFPP) acceleration project. The construction of the power plant project is to pursue electricity supply and support the energy diversification program of power plants using non-petroleum fuels by utilizing low-calorie coal whose reserves are abundantly available in the country [1].

The use of coal as a fuel power plant can produce loose in the form of fly ash and bottom ash containing natural radionuclides with a certain concentration of activity [2]. When coal-burning there will be cracking that causes natural radionuclide elements to come out along with other emission gases and have 10 times higher levels of radioactivity [3]. In the processing of coal, natural radioactive elements are concentrated and form radioactive concentrates called TENORM [2].

Fly ash that comes out alongside other gas emissions will fall into the environment around the power plant which is usually dominated by sea waters [4]. Natural radionuclides that are released into the ocean waters will generally spread through abiotic components (water and sediment) through these components also occur hoarding to biota tissues so that this occurrence can interfere with biota life and can interfere with the life of humans who consume marine biota [5].

One of the natural radionuclides produced in the processing of CFPP is 210Po [3]. 210Po is an element produced from the decay chain of 238U through 210Pb and 210Bi, but can also be produced by the activation of neutron 209Bi [6]. 210Po is an alpha transmitter radioactive element that delivers the highest dose to humans through the intake of marine biota consumed [6].

Studies on Naturally Occurring Radioactive Material (NORM) from CFPP release have been widely conducted, but only environmental monitoring [4]. Studies of its accumulation in several biotas...
have also been conducted in Indonesia [7], Malaysia [8], and Korea [9]. In addition, the impact of CFPP operations on their accumulation in marine biota based on an increase of $^{210}$Po has been carried out in Malaysia [3]. Similar research in Indonesia is very limited. $^{210}$Po research related to CFPP operations has never been conducted in Indonesia. This paper will discuss natural radioactive pollution due to the process of burning coal. In addition, it will discuss the activity of $^{210}$Po in biota, and its displacement in the food chain in marine ecosystems. Radionuclide data is obtained from existing publications.

2. Methodology
The activity of $^{210}$Po and NORM are obtained from existing publications. Determination of radiological doses in marine biota can be known by using the erica tool. Determination of the dose level of radiation exposure in marine biota is carried out because $^{210}$Po is assumed to present in the marine environment. The activity of $^{210}$Po in biota is used as a calculation in data input. The dose rate is set as 10 Gy/h [8].

3. Result and discussion
3.1. Natural radionuclides produced from power plants
Natural radioactive exposure of Coal-Fired Power Plants (CFPP) in general is greater than exposure to nuclear power plants [3]. This is contrary to the common assumption that only nuclear power plants can produce radioactive waste that is harmful to the environment.

According to [10], 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 number 1 to 6 belong to the group of heavy metals when it come in the human body will follow the level route that negatively impacts human health. Alpha radiation that comes out from $^{210}$Po to $^{238}$U is a danger of internal radiation, which is very dangerous if it enters the human body because it has a large ionization power [10].

Table 1. Dominant Radioactive Pollutants from Coal Burning [10].

| 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$^5$ Year |

Based on the data activity of radioactive elements resulting from coal burning in the research ACARP (Australian Coal Association Research Program) in [11], have been shown in Table 2.

Table 2 shows that the activity of each radionuclide from coal combustion is highly dependent on the mineral content of coal, the mining site, and the area from which the coal originated [11]. $^{210}$Po is one of the most dominant radioactive pollutants in coal samples and highly radiotoxic with a specific activity of 166 TBq/g [6].
Table 2. Natural Radionuclide Activities of Coal Burning Products (ACARP-Australian Coal Association Research Program [11])

| Coal Description | U (mg/kg) | Th (mg/kg) | Th-232 (Bq/kg) | Po-210 (Bq/kg) | Rn-222 (Bq/kg) | Total of Radioactivity (Bq/kg) |
|------------------|-----------|------------|----------------|----------------|----------------|--------------------------------|
| USA 1            | 1.3       | 2.6        | 28             | 23             | 25             | 714                            |
| USA 2            | 1.2       | 3.2        | 32             | 48             | 33             | 1105                           |
| USA 3            | 1.3       | 3.0        | 27             | 23             | 23             | 850                            |
| South Afrika 1 A | 1.7       | 7.3        | 46             | 42             | 42             | 986                            |
| South Afrika 1 B | 2.3       | 6.7        |                |                |                |                                |
| South Afrika 2 A | 1.8       | 5.4        | 19             | 16             | 18             | 740                            |
| South Afrika 2 B | 2.0       | 6.6        |                |                |                |                                |
| South Afrika 3   | 1.8       | 6.6        | 62             | 55             | 56             | 1325                           |
| South Afrika 4   | 2.1       | 7.7        |                |                |                |                                |
| Indonesia A      | 0.2       | 0.67       | 19             | 19             | 21             | 560                            |
| Indonesia B      | 0.1       | 0.5        |                |                |                |                                |
| Colombia A       | 0.45      | 0.9        | 19             | 16             | 16             | 447                            |
| Colombia B       | 0.34      | 0.85       |                |                |                |                                |
| China A          | 3.1       | 12.2       | 37             | 37             | 35             | 977                            |
| China B          | 2.4       | 10.6       |                |                |                |                                |
| Venezuela 1      | 0.64      | 1.8        | 15             | 20             | 12             | 436                            |
| Polandia A       | 2.2       | 2.8        | 18             | 15             | 16             | 573                            |
| Polandia B       | 1.8       | 2.5        |                |                |                |                                |

Table 2 is coal ash containing total radioactivity with ranges (0.1 – 12.2) mg. kg⁻¹ and (15 - 62) Bq. kg⁻¹. The highest radioactivity content in becquerel units is found in African and the lowest in Venezuela; 62 Bq.kg⁻¹ and 15 Bq.kg⁻¹, respectively. Indonesian coal ash contains radioactivity with a total of 560 Bq.kg⁻¹.

Based on calculations by [12], at the CFPP Lestari Energi Banten, Indonesia. The result of setting voltage 40 KV DC, after performing the calculation process obtained particle migration speed 4 m/s, then the particle collection efficiency by ESP (Electrostatic Precipitator) 98.71%, this indicates that there is 1.29% of flying ash particles coming out into the environment around the power plant which is usually dominated by seawater. In addition [12], conducted a simulation of actual voltage and current for the determination of optimum voltage ESP, where the result of voltage setting performance if given input of 40KV DC, using calculations will be obtained particle collection efficiency by ESP only 81.98 %. These results indicate that 18.02% of flying ash which contains natural radioactive comes out into the environment and can contaminate the sea waters.

3.2. Polonium activity in marine biota
Based on research by [13] have been shown in Table 3. The results of the analysis showed that the highest activity of the \(^{210}\text{Po}\) in marine biotas was noted for green mussels and the lowest for tuna,
which represent different values among marine biota species. The highest activity of $^{210}\text{Po}$ in green mussels can be caused green mussels are bivalves that have habitats associated with sediment, their feeding habits as filter-feeders, and their ability to accumulate contaminants [14]. Its high bioaccumulation capability causes a previously undetectable concentration of pollutants in sea waters to be found in Bivalvia's [15].

**Table 3.** $^{210}\text{Po}$ activity in marine biotas from the Jakarta Bay [16].

| Sample (Local Name) | Sample (Scientific Name) | Lokasi       | $^{210}\text{Po}$ Activity (Bq/Kg) |
|---------------------|--------------------------|--------------|------------------------------------|
| Tuna                | *Thunnus albacares*      | Jakarta Bay  | 9.05 ± 3.05                        |
| Mackerel            | *Scomberomorus commerson*| Jakarta Bay  | 67.34 ± 13.82                      |
| Red Snapper         | *Lutjanus campechanus*   | Jakarta Bay  | 35.03 ± 12.41                      |
| Shrimp              | *Litopenaeus setiferus*  | Jakarta Bay  | 9.12 ± 2.80                        |
| Green Mussel        | *Perna viridis*          | Jakarta Bay  | 137.37 ± 25.49                     |

3.3. Polonium activity in marine biotas from Korean coastal waters

Based on research by [9], polonium-210 was determined from twelve marine biota species, including two plankton, one planktivorous fish (anchovy, *Engraulis japonicus*), four pelagic carnivorous fish (chub mackerel, *Scomber japonicus*; largehead hairtail, *Trichiurus lepturus*; Japanese horse mackerel, *Trachurus japonicus*; and red tilefish, *Branchiostegus japonicus*), one demersal fish (olive flounder, *Paralichthys olivaceus*), one crustacean (red-banded lobster, *Metanephrops thomsoni*), four molluscs (Far eastern mussel, *Mytilus coruscus*; oyster, *Crassostrea gigas*; abalone, *Nordotis discus*; Japanese common squid, *Todarodes pacificus*). Results are presented by muscle in Table 4.

Polonium-210 concentration in the whole body of anchovy (*Engraulis japonicus*) collected in May 2014 was 392 ± 2 Bq kg$^{-1}$, several times higher than in the plankton that comprises their main diet. This value was the highest among the fish in this study. In 2015, $^{210}\text{Po}$ concentration in anchovy was determined for a sample collected in another location. Polonium-210 concentration in the whole body in June 2015 was 59.0 ± 4.6 Bq kg$^{-1}$, slightly higher than the values from plankton. The difference in $^{210}\text{Po}$ concentrations in anchovy collected in May 2014 and in June 2015 may be due to habitat differences. In anchovy studied from a single region of the Black Sea, the whole-body $^{210}\text{Po}$ concentration differed by a factor of two within the space of one month [16]. Assuming fish obtain most or all of their $^{210}\text{Po}$ burden from the plankton they ingest, the higher $^{210}\text{Po}$ concentrations in anchovy, compared to those in plankton, suggest that $^{210}\text{Po}$ is biomagnified up the food web to anchovy [9].

According to [17], the mechanism of absorption of $^{210}\text{Po}$ by fish depends on biological variables such as feeding habit and location, based on radionuclide research in some fish in Izmir, shows that measurable activity in fish species that prey on plankton such as anchovies has high radionuclide activity. According to [18], the larger biota the lower value of $^{210}\text{Po}$, this can be caused by the metabolism of biota that has a larger body will be slower than small-bodied biota.
Table 4. $^{210}$Po activity in biota from Korean Coastal Waters [9].

| Sample (Local Name) | Sample (Scientific Name) | Location | $^{210}$Po Activity (Bq/Kg) |
|---------------------|--------------------------|----------|-----------------------------|
| Anchovy             | Engraulis japonicas      | Korean Coastal | 392 ± 2.2                  |
| Largehead hairtail  | Trichiurus lepturus       | Korean Coastal | 5.56 ± 1.23                |
| Chub mackerel       | Scomber japonicas        | Korean Coastal | 0.8 ± 0.03                 |
| Japanese horse mackerel | Trachurus japonicas    | Korean Coastal | 5.26 ± 0.13                |
| Red tilefish        | Branchiostegus japonicas | Korean Coastal | 3.08 ± 0.94                |
| Olive Flounder      | Paralichthys olivaceus   | Korean Coastal | 0.51 ± 0.12                |
| Abalon              | Nordotis discus          | Korean Coastal | 2.93 ± 0.86                |
| Far eastern mussel  | Mytilus coruscus         | Korean Coastal | 47.8 ± 5.9                 |
| Oyster              | Crassostrea gigas        | Korean Coastal | 46.3 ± 7.1                 |
| Red-banded lobster  | Metanephrops thomsoni    | Korean Coastal | 2.84 ± 0.23                |
| Japanese common squid | Todarodes pacificus     | Korean Coastal | 8.61 ± 2.01                |
| Plankton [20-300 mm] | -                       | Korean Coastal | 137 ± 51                   |
| Plankton [>300 mm]  | -                       | Korean Coastal | 113 ± 2                    |

3.4. Polonium activity in marine biotas from peninsular Malaysia

Activity concentrations of $^{210}$Po in fishes collected from eight sampling stations situated along near shore the east and west coast of Peninsular Malaysia have been researched by [8], are summarized in Table 5.

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$^{-1}$ (Average: 30.87 Bq.kg$^{-1}$), 4.14 ± 0.18 – 10.21 ± 0.46 Bq.kg$^{-1}$. (Average: 7.18 Bq.kg$^{-1}$) and 20.38 ± 0.91 – 41.21 ± 1.84 Bq.kg$^{-1}$. (Average: 30.80 Bq.kg$^{-1}$), 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$^{-1}$ (Average: 10.93 Bq.kg$^{-1}$) and 4.06 ± 0.18 – 27.41 ± 1.23 Bq.kg$^{-1}$ (average: 15.74 Bq.kg$^{-1}$) respectively. The ranges of $^{210}$Po concentration showed a significant difference between species it can be caused by different living habitats or geographical characteristics, environmental location and conditions, feeding habits, species habits and patterns, biological processes, size, and seasonal changes [3]. According to [17], the mechanism of absorption of $^{210}$Po by fish depends on biological variables such as diet, habitat, and location.

In general, the results showed that the concentration of $^{210}$Po in pelagic fish Yellowtail scad and Layang scad were relatively higher than those in demersal fishes. This suggests that pelagic fish live in water columns or sea pelagic zones that get more than $^{210}$Po of seawater because they move freely within the water column. In addition, pelagic fish also consume suspended substances and food particles available in the water column [19]. According to [18], the pelagic environment contributes significantly to $^{210}$Po accumulation that is aligned with these fishes which are accumulated high concentrations 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 tend to associate with a suspended particle which is easily and rapidly removed into the bottom water column by scavenging process and lastly deposited onto sediment in the seabed resulted in low accumulation of $^{210}$Po in demersal fish.
3.5. Total dose rate of $^{210}$Po in marine biota
Polonium activity 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. The default value of 10 µGy/hr was used as the screening confidence level, below which radiological risks are negligible [20], for risk assessment to fish. Thus, the estimation of the total dose rate of $^{210}$Po per fish was presented in Table 5. 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.

The results showed that the total dose level of $^{210}$Po in pelagic fish was greater when compared to demersal fish. Differences in these results related to the depth of the water column profile showed an increase of $^{210}$Po in the mid-water area where this area is pelagic fish habitat and there was a decreased activity of $^{210}$Po to a lower level at a deeper depth which is the habitat of demersal fish [21]. The feeding habit of a biota plays a major role in the accumulation of $^{210}$Po to the contribution of values such as the total dose rate for fish biota [22].

| Station ID | Species of Fish | Occupancy | Individual Fresh Weight (g) | $^{210}$Po Activity in Fish (Bq/Kg) | Total Dose Rate $^{210}$Po per Organisme (µGy/hr) |
|------------|----------------|-----------|-----------------------------|-----------------------------------|-----------------------------------------------|
| ML 01      | Yellowtail scad (Atule mate) | Pelagic   | 72.28 | 50.13 ± 2.24 | 1.530 |
|            | Indian snapper (Lutjanus madras) | Demersal | 60.62 | 4.06 ± 0.18 | 0.124 |
|            | Layang scad (Decapterus macrosoma) | Pelagic | 41.80 | 41.21 ± 1.84 | 1.260 |
|            | Indian snapper (Lutjanus madras) | Demersal | 51.52 | 27.41 ± 1.23 | 0.837 |
| KT 02      | Indian mackerel (Scombridae rastrelliger) Delagoa threadfin bream (Nimipterus delagoa) | Pelagic | 77.95 | 10.21 ± 0.46 | 0.312 |
|            | Delagoa threadfin bream (Nimipterus delagoa) | Demersal | 117.46 | 18.70 ± 0.84 | 0.571 |
| MG03       | Yellowtail scad (Atule mate) | Pelagic | 102.1 | 24.48 ± 1.09 | 0.748 |
|            | Delagoa threadfin bream (Nimipterus delagoa) | Demersal | 98.52 | 15.39 ± 0.69 | 0.470 |
| CK01       | Indian mackerel (Scombridae rastrelliger) Delagoa threadfin bream (Nimipterus delagoa) | Pelagic | 80.00 | 4.14 ± 0.18 | 0.127 |
|            | Delagoa threadfin bream (Nimipterus delagoa) | Demersal | 89.23 | 5.21 ± 0.23 | 0.159 |
| TS03       | Layang scad (Decapterus macrosoma) | Pelagic | 68.34 | 20.38 ± 0.91 | 0.623 |
|            | Delagoa threadfin bream (Nimipterus delagoa) | Demersal | 65.27 | 13.30 ± 0.59 | 0.406 |
| PS01       | Yellowtail scad (Atule mate) | Pelagic | 39.71 | 32.76 ± 1.46 | 1.001 |
|            | Delagoa threadfin bream (Nimipterus delagoa) | Demersal | 60.96 | 4.16 ± 0.19 | 0.127 |
| PL01       | Yellowtail scad (Atule mate) | Pelagic | 120.44 | 16.12 ± 0.72 | 311.84 |
|            | Delagoa threadfin bream (Nimipterus delagoa) | Demersal | 92.71 | 8.88 ± 0.40 | 171.78 |
Additionally, the result revealed a clear relationship between $^{210}\text{Po}$ accumulation in fishes and the ecological niche of fishes, where the accumulation decreases with depth [3], aligns to decrease the dose received by fish that live at the sea bottom. In another context, the low total dose rate of $^{210}\text{Po}$ in demersal fish may be a factor in the reported rapid depuration of $^{210}\text{Po}$ 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 (Yellowtail scad and Indian mackerel). According to [18], the larger biota the lower value of $^{210}\text{Po}$, this can be caused by the metabolism of biota that has a larger body will be slower than small-bodied biota.

4. Conclusions

Based on the results of data collection and information related to coal-burning and its impact on the marine environment and biota, can be concluded that: Burning coal will produce natural radioactive, one of natural radioactive is $^{210}\text{Po}$ and will increase in the area and its surroundings. The activity of $^{210}\text{Po}$ in fish biota depends on biological variables such as diet, habitat, and location of each species. External and internal radiation from $^{210}\text{Po}$ is still below the screening level determined by the International Atomic Energy Agency (IAEA) than it does not have an impact on the marine ecosystem.

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