EVALUATION OF EXTERNAL RADIOLOGICAL HAZARD IN BOTTOM AND FLY ASH FROM COAL FIRED POWER PLANTS.

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SUMMARY: Coal is the most important fossil fuel for non-nuclear power generation industries. The burning of coal generates ashes which contain natural radionuclides namely ^{238}U and ^{232}Th series including ^{40}K that are released into the environment. This study presents an evaluation of the radioactivity content found in the feed coal and ashes sampled from typical coal fired power plants. The sample was measured for activity concentration of the radionuclides and the results were used to evaluate the radiological hazard index of the sample.The findings revealed that the values of the external radiological hazard obtained were acceptable and safe to be reutilized.

Keywords—coal fired power plant, Natural Occurring Radioactive Material (NORM), coal combustion, radioactivity, Instrumental Neutron Activation Analysis.

INTRODUCTION

Coal like any other minerals found in nature contains trace amount of natural occurring radionuclides or Natural Occurring Radioactive Material (NORM) namely ^{238}U, ^{235}U, ^{232}Th including members of their decay series, trace quantities of ^{40}K and none of fission products.Enrichment of these radionuclides may occur in the bottom and fly ash residues as a results of combustion. Currently, NORM used in industries have received local and international attention due to its significant amount of residues or waste produced annually.Coal is widely available fossil fuel resources and with the uncertainty in nuclear power industry and the availability of other sources of fossil fuel decreases, it has lead coal remain to be relevant [1].Thus, coalcontinue to complementing some of renewable energy sources and capable to fill in the gaps in wind and solar powered electricity and become the most promising NORM industry compared to others. However, notwithstanding various benefit offers, electricity production may contribute to local environment degradation.The burning of coal may enhance the concentration level of natural radionuclides and potentially pose environmental, health and radiological impact.

This paper presents an investigation of radioactivity concentration level of NORM waste in bottom and fly ash from typical coal fired power plants. In addition, the analysis of the radioactivity concentration was also determined in the feed coal burned. The probable external radiological hazard and exposure, if any to the worker, public and the environment is presented based on systematic radiological hazard calculations.

2. MATERIALS AND METHODS

A grab sample of feed coal (FC), bottom ash (BA) and fly ash (FA) was taken from two CFPPs. Approximately 2 kg of material was collected and ground to fine powder form, homogenized and air dried for about 48 h in an air circulation oven at 110 °C in the laboratory and kept in polyethylene bags. Then, approximately 500 g of each sample was sealed and kept for a period of thirty days before radioactive counting for uranium and thorium in order to attain the radioactive equilibrium as well as to eradicate ^{222}Rn lost. The radioactivity content of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K in the sample were measured for their activity concentration by instrumental neutron activation analysis (INAA) combined with gamma spectrometry system. Sample was irradiated for 300 minutes at open pool type 1 MW Triga-Mark research reactor of Malaysia Nuclear Agency and counted sequentially after several days by using a gamma spectrometry detection system. All samples were counted twice with peak areas determined by computer code GENIE 2000 software. The blank sample was also treated following the same procedures where the final radioactivity content in the sample was determined minus from the blank.

3. RESULTS

3.1 Natural radionuclide content in coal and ashes

Table 1 presents the mean and the standard deviation of activity concentration of ^{238}U,^{226}Ra, ^{232}Th and ^{40}K in feed coal, bottom and fly ash from CFPP 1 and CFPP 2 using non-blended and blended coal as fuel, respectively.

3.2 Enrichment Factor (EF)

An enrichment of respective radionuclides with respect to feed coal is calculated by Eq.(1).

$$EF = (X)_{ash} / (X)_{coal} \quad (1)$$

Where X, is the activity concentration of an interest radionuclide divided to its activity concentration in the coal.

An EF $\geq$ 1.0 means that the radionuclide is enriched in the ash compared to coal.

Table 1: Measured radioactivity level (Bq kg^{-1})of natural radionuclides in collected sample from two CFPPs.

Type of CFPP	Sample	Activity concentration (Bq kg^{-1})			
		^{238}U	^{226}Ra	^{232}Th	^{40}K
CFPP 1	FC	5.9 $\pm$ 0	3.9 $\pm$ 1.4	2.7 $\pm$ 0.6	14.5 $\pm$ 4.9
	BA	34.7 $\pm$ 9.5	41.1 $\pm$ 5.9	31.3 $\pm$ 6.4	136.4 $\pm$ 26.3
	FA	47.7 $\pm$ 8.3	48.4 $\pm$ 7.7	44.3 $\pm$ 1.5	299.0 $\pm$ 52.7
CFPP 2	FC	9.0 $\pm$ 0	10.8 $\pm$ 2.8	10.3 $\pm$ 0.6	40.9 $\pm$ 12.3
	BA	63.7 $\pm$ 2.5	83.6 $\pm$ 11.3	71.7 $\pm$ 2.3	318.9 $\pm$ 52.3
	FA	77.7 $\pm$ 3.2	87.5 $\pm$ 13.1	77.3 $\pm$ 1.5	355.3 $\pm$ 60.2

Note: FC = Feed coal; BA = Bottom ash; FA = Fly Ash

Table 2 presents the calculated value of EFs for all samples which showed the mean and standard deviation of EF for ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K in bottom and fly ash.

Table 2: Calculated Enrichment Factor (EF) in collected sample from two CFPP

Type of CFPP	Sample	Enrichment Factor (EF)			
		^{238}U	^{226}Ra	^{232}Th	^{40}K
CFPP 1	BA	6 $\pm$ 1.9	3.6$\pm$ 2.0	12 $\pm$ 3.5	9 $\pm$ 3.7
	FA	8 $\pm$ 2.1	12 $\pm$ 4.9	16 $\pm$ 3.7	20 $\pm$ 7.9
CFPP 2	BA	7 $\pm$ 1.3	7 $\pm$ 3.6	7 $\pm$ 1.1	8 $\pm$ 3.2
	FA	9 $\pm$ 0.4	8 $\pm$ 2.5	8 $\pm$ 2.1	9 $\pm$ 4.5

Note: FC = Feed coal; BA = Bottom ash; FA = Fly Ash

3.3 Radium Equilibrium (Ra_{eq}) and External Radiological Hazard Index (H_{ex}).

The radiological hazard based on Ra_{eq} and H_{ex} is primarily assessed. $Ra_{eq}$is strongly related to external dose (gamma) and internal dose (radon and its daughters).The Ra_{eq} and H_{ex} are calculated using Eq.(2) and Eq.(3) [2].

$$Ra_{eq}= C_{Ra} + 1.43C_{Th} + 0.077C_{K} \quad (2)$$

$$H_{ex} = C_{Ra}/370 + C_{Th}/259 + C_{K}/4810 \quad (3)$$

Where, C_{Ra}, C_{Th} and C_{K} are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}, respectively.It has been assumed that the same gamma dose rate is produced by 370 Bq kg^{-1} of ^{226}Ra or 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K [3]. H_{ex} is determined from Ra_{eq}, by assuming that the maximum value allowed (equal to unity) as to corresponds to the upper limit of Ra_{eq}, 370 Bq kg^{-1} [2], for the safe use. H_{ex} limit is reported as unity in order to keep the external radiological hazard insignificant.Table 3 presents the calculated Ra_{eq} and H_{ex} value for the samples which showed the Ra_{eq} and Hex in FC, BA and FA.

Table 3. Calculated Radium equivalent concentration (Ra_{eq}) and External hazard indices (H_{ex}) in coal and ashes.

Sample	CFPP 1		CFPP 2	
	Ra_{eq} (Bq kg^{-1})	H_{ex}	Ra_{eq} (Bq kg^{-1})	H_{ex}
FC	8	0.02	29	0.08
BA	96	0.30	211	0.57
FA	135	0.40	225	0.61

Acceptable Hex value < 1.0.

4.DISCUSSION

Table 1 showed that the measured activity concentrations for each radionuclide in ashes was found much higher than those in feed coal. The results obtained were clearly observed that after the coal burn up, the radionuclides accumulated much higher in ashes. The findings illustrate that CFPP using blended coal results a higher radioactivity due to higher inorganic content compared to non-blended coal. Generally, the activity concentration of natural radionuclides found in ashes (residues) do not exceed the waste clearance limit of 1000 Bq kg^{-1} for both ^{238}U and ^{232}Th; and 10000 Bq kg^{-1} for ^{226}Ra [4].

The EF value in Table 2depends on the enrichment and volatilization behaviour of these radioactive trace elements in coal combustion. It is mostly influenced by the physicochemical properties of the specific elements, chemical compounds in coal and ashes, the nature of combustion process and the mechanism criteria that occur at the emission control devices. Enrichment in ashes in every radionuclide is also related to the particle size.

As in Table 3, fly ash was found to record the highest Ra_{eq} and H_{ex} compared to feed coal and bottom ash which concur with the enrichment factor of the activity concentration as in Table 1. This indicates the ashes are enriched in radioactivity than the feed coal. Nevertheless, the findings suggest that the calculated Ra_{eq} and H_{ex} for the samples were acceptable and safe to be reutilized.

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