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On the Radiological Character of a Coal-Fired Power Plant at the Town of Çatalağzı, Turkey

Hüseyin AYTEKIN and Rıdvan BALDIK
Zonguldak Karaelmas University, Department of Physics, 67100, Zonguldak-TURKEY
e-mail: huseyinaytekin@gmail.com

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Abstract

This paper presents a study performed on the radiological character of the Çatalağzı Thermal Power Plant (ÇTPP/ÇATES), on the west Black Sea coast of Turkey. Natural radioactivity distribution of the terrestrial radionuclides ^{238}U, ^{232}Th, and ^{40}K of surface soil samples around the ÇTPP was analyzed. The average radioactivity concentrations for ^{232}Th, ^{238}U, and ^{40}K for soil samples were 39.7, 30.5, and 378.7 Bq kg^{-1}, respectively. ^{238}U and ^{40}K concentrations are lower than the world average values, 35 Bq kg^{-1} and 400 Bq kg^{-1}, respectively, and the ^{232}Th concentration is higher than the world average value, 30 Bq kg^{-1}.

Key words: Coal-fired power plant, Soil, Uranium, Thorium, Potassium

Introduction

With the increasing demand for electricity, coal is used as a fuel for electric power generation worldwide. As a result of coal combustion in a thermal power plant natural radionuclides and their products are released and distributed between gas and solid combustion products. The radionuclides such as ^{238}U, ^{232}Th, and ^{40}K are enriched in solid products, which are bottom and fly ashes. The fly ash is carried through the furnaces with gas flow toward the stack. Depending on the emission control system of the stack, most of the fly ash is collected, while the rest is released into the atmosphere and deposited on the soil around the coal-fired power plant. Beck and Miller observed that in most cases the activity released does not significantly impact the surrounding environment (Beck and Miller, 1980). However, recent publications have been concerned with the impact of environmental radioactivity in soil around coal-fired power plants (Flues et al., 2002; Papp et al., 2002; Papp and Dezsö, 2003).

Activity concentrations of the coals used in the ÇTPP and ash products, and radon concentrations in the plant were measured earlier (Bayata, 2007; Aytekin et al., in press). The annual average radon concentrations were 59.4 ± 21.6 Bq m^{-3} in the plant sections and 71.0 ± 33.4 Bq m^{-3} in dwellings in the plant (Aytekin et al., in press). The measured average activity concentrations of ^{238}Th, ^{232}U, and ^{40}K in the feed coals and in the bottom and fly ashes are shown in Table 1. This study is the second one performed on the radiological character of soil samples around the plant.

Generally, activity concentrations of natural radioactive isotopes in coal are of the same order as those in common rocks and soil, on average (35 Bq kg^{-1} for ^{238}U) (UNSCEAR, 2000). The radiological implication of these isotopes is due to the gamma ray exposure of the body and irradiation of lung tissue from inhalation of radon and its daughters. Therefore, the assessment of gamma radiation from soil samples is of particular importance in terms of the natural radiation to which the population is exposed around a coal-fired thermal power plant. There have been no experimental data about the gamma radia-

tion from soil samples around the ÇTPP. Since the construction of new coal-fired power plants is being considered in this region, the outcomes of this study will provide essential knowledge about the natural radioactivity concentrations of the soil around the ÇTPP. The present study includes the ^{232}Th, ^{238}U, and ^{40}K activity concentration measurements and dose estimations from surface soil samples around the ÇTPP. Analysis of the radiological influence of the plant in the wind direction and at long distances is the main subject of this study.

Table 1. Radionuclide emission characteristics of ÇTPP (Bayata, 2007).

Material	Radionuclides	Activity concentrations (Bq kg^{-1})
Bottom ash	^{238}U	96 ± 9
	^{232}Th	68 ± 8
	^{40}K	1064 ± 32
Fly ash	^{238}U	62 ± 7
	^{232}Th	58 ± 8
	^{40}K	800 ± 25
Coal	^{238}U	33 ± 5
	^{232}Th	31 ± 4
	^{40}K	329 ± 18

Materials and Methods

The study area

Zonguldak is the only basin where bituminous coals are produced in Turkey. Annually, about 2.5 million tons of coals are produced in this basin. Calories of these coals vary between 6200 and 7250 kcal/kg. Total reserve of the basin is estimated as 1.3 billion tons. About 66% of the produced coals are used in the ÇTPP. The middling products with ash content (45%-50%) of these coals are burnt in the ÇTPP.

The ÇTPP ($41^0 30' 48.4'' N$ and $0.31^0 53' 41.5''$E) is located ∼13 km northeast of the city of Zonguldak on the west Black Sea coast of Turkey and has been in operation since 1948. The ÇTPP is located near the sea, frosty fields, and dwellings, and covers a total area of 233,250 m^2, of which the plant area is 104,050 m^2. There are 2 units of 150 MW each. These units consume about 16 × 10^5 t of coal per year.

Experimental technique

Surface soil samples were collected from 14 different locations around the ÇTPP (up to 6 km) in July 2006 (Figure). The coordinates of the locations were determined by GPS. Eleven samples (5 samples at short distances (HS05-HS09) and 6 samples at long distances (HS01-HS04, HS14, and HS15)) were collected at locations in the direction of the dominant wind. Three samples (HS11, HS12, and HS13) were collected from locations in the opposite direction. Four of the samples were collected at about 6000 km to analyze whether the plant has effects at long distances or not. Since the area has a rough and rocky structure the samples were collected from easily accessible locations.

Collected samples were crushed to about 100 μm size and dried for 24 h in an air circulation oven at 105 °C in the laboratory. Dried samples were mixed and prepared as homogeneous samples and put in polyethylene bags. About 150 g of each sample was sealed for 30 days before radioactive determination of uranium and thorium to attain radioactive equilibrium with their daughter products and to prevent radon loss. After attainment of secular equilibrium between ^{238}U, ^{232}Th, and their products, the samples were subjected to gamma-ray spectrometric analysis. Assaying was carried out at the Institute of Nuclear Science of Ege University, İzmir, Turkey.

The most widely used method for measuring ^{238}U in geological samples is scintillation gamma spectrometry based on the detection of high energy gamma rays of ^{214}Bi. There is an important problem due to ^{238}U and ^{226}Ra disequilibrium in geological materials. Therefore, the concentration determined through the product activities relies on the assumption that the ^{238}U decay series is in equilibrium and is called the equivalent uranium (eU) concentration (Ereeş et al., 2006; Bayata, 2007). This method was used for the determination of eU, eTh (equivalent thorium), and K (radioactive potassium) in the present study. Laboratory measurements of ^{238}U, ^{232}Th, and ^{40}K in soil of the region were obtained by gamma ray spectrometer using a 3" × 3" NaI (Tl) detector. Concentrations of ^{238}U and ^{232}Th were assessed from the intensity of gamma lines of ^{214}Bi (1.76 MeV) and ^{208}Tl (2.62 MeV), assuming all daughter products were in equilibrium with their parents. Concentration of radioactive potassium was measured from its 1.46 MeV peak. The samples were counted for 10,000 s with background measurements under the same condition.

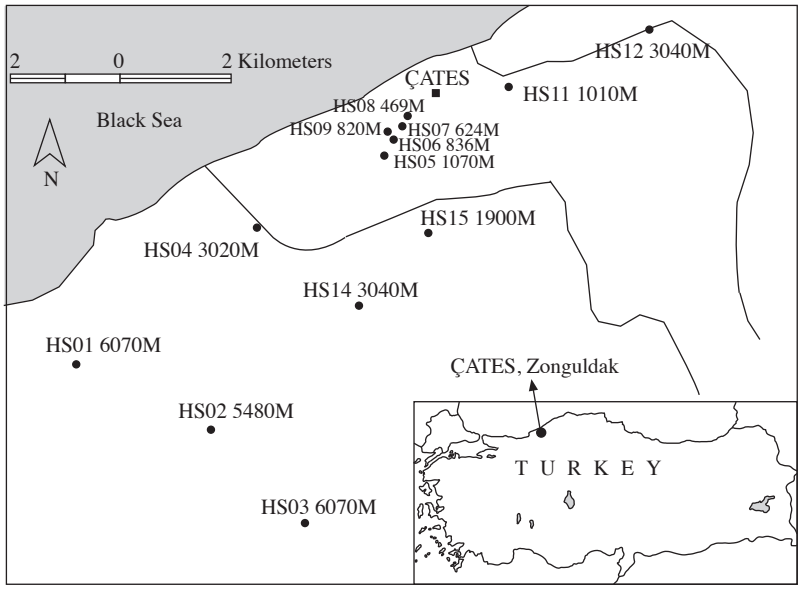

Figure. Map of Çatalağzı region, ÇTPP/ÇATES (square) and soil sampling points (circles).

In order to relate the concentrations of U, Th, and K in the samples, the following concentration equations were used (Ereeş et al., 2006):

$$eTh\ (ppm) = C(Th)/K_1, \tag{1}$$

$$eU\ (ppm) = (C(U) - \alpha C(Th))/K_2, \tag{2}$$

$$K(\%) = (C(K) - \gamma(C(U) - \alpha C(Th)) - \beta C(Th))/K_3. \tag{3}$$

where α, β, and γ are known as stripping ratios indicating the interaction among the K, U, and Th channels during counting. C(U), C(Th), and C(K) are the count rates to each channel of U, Th, and K in the samples. Determination of stripping rations was undertaken by accurately measuring count rates in all channels from pure series-equilibrium uranium and thorium sources. K_1, K_2, and K_3 are sensitivity factors for each channel and were determined by the measurement of standard (625 ppm eU, 150 ppm eTh, and 52% K) under appropriate conditions. Experimental values of stripping ratios α, β, and γ, and sensitivity factors K_1, K_2, and K_3 were 0.76, 0.86, and 1.31, and 33.52, 115.67, and 928.47, respectively.

Results and Discussion

The measured radionuclide concentrations for the uranium and thorium series range from <1 to 85 Bq kg^{-1}, while ^{40}K concentrations range from <129 to 691 Bq kg^{-1} (Table 2). Mean values of radioactivity concentrations for ^{232}Th, ^{238}U, and ^{40}K were 39.7, 30.5, and 378.7 Bq kg^{-1}, respectively. The measurement results show that the activity concentrations of the samples collected in the wind direction are higher than those of samples collected in the opposite direction. ^{238}U and ^{40}K concentrations are lower than the world average values, 35 and 400 Bq kg^{-1} for ^{238}U and ^{40}K, respectively (UNCEAR, 2000; Merdanoğlu and Altınsoy, 2006). The concentration of ^{232}Th is higher than the world average value, 30 Bq kg^{-1}.

The outdoor air-absorbed rates due to terrestrial gamma rays 1 m above the ground were calculated for ^{226}Ra (^{238}U), ^{232}Th, and ^{40}K concentration values in soil. The measured ^{226}Ra concentration is the same as the ^{238}U concentration. The coefficients for conversion of activity concentration to absorbed dose rates for ^{226}Ra, ^{232}Th, and ^{40}K in air were 0.462, 0.604, and 0.0417 nGy h^{-1} per Bq kg^{-1} respectively, and the formula for the absorbed dose rate is given as (UNCEAR, 2000; Veiga et al., 2006):

$$D(nGyh^{-1}) = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K. \tag{4}$$

The comparison of calculated dose rates with the world average dose rates is seen in Table 3. The calculated average dose rate to which the population is exposed is 53.85 nGy h^{-1}. This is within the world range 18-93 nGy h^{-1}, the average rate of which is 60 nGy h^{-1}.

Table 2. Concentrations of ^{232}Th, ^{232}U, and ^{40}K in soil samples collected around the ÇTPP, Turkey (Bq kg^{-1}). Samples locations were defined by CPS.

Sample no.	Direction	Distance (m)	^{232}Th (Bq kg^{-1})	^{238}U (Bq kg^{-1})	^{40}K (Bq kg^{-1})
HS 01	SW	6070	32.5 ± 5.7	22.5 ± 4.7	277.3 ± 16.6
HS 02	SW	5480	41.6 ± 6.5	24.2 ± 4.9	577.0 ± 24.0
HS 03	SW	6070	67.5 ± 8.2	85.0 ± 9.2	293.8 ± 17.1
HS 04	SW	3020	33.9 ± 5.8	49.3 ± 7.0	170.0 ± 13.0
HS 05	SW	1070	53.7 ± 7.3	65.1 ± 8.1	570.6 ± 23.9
HS 06	SW	836	50.6 ± 7.1	< 13	606.3 ± 24.6
HS 07	SW	624	49.0 ± 7.0	34.6 ± 5.9	323.1 ± 18.0
HS 08	SW	469	57.4 ± 7.6	< 19	691.1 ± 26.3
HS 09	SW	820	53.4 ± 7.3	23.1 ± 4.8	312.6 ± 17.7
HS 11	E	1010	21.2 ± 5.0	< 1	346.5 ± 19.0
HS 12	NE	3040	< 4	25.8 ± 5	290.9 ± 17.0
HS 13	NE	6000	13.7 ± 3.7	22.0 ± 4.7	270.9 ± 16.5
HS 14	SW	3040	42.9 ± 6.6	23.3 ± 4.8	456.5 ± 21.4
HS 15	S	1900	25.8 ± 5.1	26.6 ± 5.1	128.9 ± 11.4
Mean			39.7 ± 16.7	30.5 ± 21.2	378.7 ± 166.1

Table 3. Average activity concentration of natural radionuclides in soil and calculated absorbed dose rate in air 1 m above the ground.

Nuclide	World average		Çatalağzı (study area)	
	Concentration (Bq kg^{-1})	Dose rate (nGy h^{-1})	Concentration (Bq kg^{-1})	Dose rate (nGy h^{-1})
^{232}Th	30	18.12	40	23.97
^{238}U	35	16.17	31	14.09
^{40}K	400	16.68	379	15.79
Total				53.85
World range (UNSCEAR, 2000; Merdanoğlu and Altınsoy, 2006)				18-93

Conclusion

This paper presents the ^{232}Th, ^{238}U, and ^{40}K activity concentration measurements and dose estimations from surface soil samples around the Çatalağzı Thermal Power Plant, Turkey. The average concentration value of ^{232}Th is higher than the world average value while ^{238}U and ^{40}K concentrations are lower. The average absorbed dose rate is 53.85 Bq m^{-3}. This is within the range of world total dose rate 18-93 Bq m^{-3}.

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