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Radiological characteristics of pulverized fly ashes produced in Turkish coal-burning thermal power plants

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ABSTRACT

The objective of this study is to determine radiological characteristics of pulverized fly ash (PFA) collected from the 15 coal-burning thermal power plants (TPPs) in operation by means of gamma spectrometric technique and to assess the radiological impacts from the utilization of PFA samples examined as filling and cover material in earthwork applications. Also, the annual effective doses received by workers handling PFA and members of the public living in a house near the PFA pile/landfill were estimated using methods specified in the Radiation Protection 122. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K measured in PFA samples were tabulated for each TPP. The activity results show that Turkish PFA may have relatively high natural radioactivity content, depending on its origin reaching in the case of Kangal PFA 2720 Bq kg^{-1} of ^{226}Ra. The values of external exposure indexes (radium equivalent activity index and gamma index) calculated for PFA samples are within the recommended safety limits. As well, the highest mean total annual effective doses estimated as 7.3×10^{-5} Sv y^{-1} for workers and 1.5×10^{-4} Sv y^{-1} for members of the public are significantly lower than the annual limit of 1.0×10^{-3} Sv y^{-1}.

1. Introduction

Turkey is greatly dependent on fossil fuel (natural gas, coal, petroleum, fuel oil) to meet the electric power requirement. About 83% of the total electricity in Turkey is generated thermal power plants (66% of the total installed electricity generation capacity) [1]. Coal plays an important role in electric generation in Turkey because it is an essential domestic source. Lignite coal recoverable reserves are estimated to be about 8300 million tons (Mt) while hard coal reserves are about 1330 Mt [2]. Turkish lignite coal has a very low calorific value and high sulphur, dust and ash content. The ash content of the Turkish coal ranges from 16% to 50% [3]. Therefore, majority of the lignite coal is consumed by the electricity sector. Coal (lignite, hard and imported coal) accounted for about 24% (of which 81% is from lignite and 19% is from hard coal and imported coal) of the total installed electricity generation capacity of 42,000 megawatt (MW) in 2008 [1]. Coal-burning thermal power plants (TPPs) consumed 72.6 Mt of pulverized coal in 2008 [1].

Coal contains trace quantities of the naturally occurring primordial radionuclides including uranium–radium (^{238}U–^{226}Ra) and thorium (^{232}Th) and their decay products and the radioactive isotope of potassium (^{40}K). Earlier work by MTA (General Directorate of Mineral Research and Exploration) indicates that Turkish coals contain on average 12.5 mg kg^{-1} of ^{238}U and 6.6 mg kg^{-1} of ^{232}Th [4]. These values are higher than the worldwide mean values of elemental concentration of ^{238}U (2 mg kg^{-1}) and ^{232}Th (4 mg kg^{-1}) measured in worldwide coal [4]. Besides, pulverized fly ash (PFA) which is a combustion residue of pulverized coal blown into a fire furnace at a coal-burning TPP becomes up to 3–5 times more enriched in radionuclides mentioned above than the pulverized coals.

The 15 coal-burning TPPs listed in Table 1 produce a total of over 15 Mt of PFA annually [5]. Depending on the emission control systems the largest fraction of PFA is collected and usually stored in piles, or dumped or deposited on the land in the vicinity of the TPP. The growing production of PFA has long caused on environmental problem with technological and economic effects in the world. Also, the amount of PFAs accumulated at power stations or stored in piles or ponds can contribute to environmental radiological problems through its dispersal into atmosphere and its handling or disposal [6]. PFA contains enhanced concentration of the natural radionuclides ^{226}Ra, ^{232}Th, and their decay products and ^{40}K. These radionuclides emit alpha particles, beta particles, and gamma rays. Therefore PFA piles or ponds considered an ionizing radiation source can lead to the exposure of workers and members of the general public to ionizing radiation via three pathways: (i) external exposure of local workers and people living in a house

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Table 1
Parameters of Turkish coal-burning thermal power plants in operation.

Power plant	Location	Unit number	Total power (MW)	Gross generation (GW h)	Coal type	Fuel (ton/y)	Ash (%)
Afşin-Elbistan A	K. Maraş	4	1360	4198	Lignite	10,970,167	36–42
Afşin-Elbistan B	K. Maraş	4	1440	7241	Lignite	–	20–51
Çan	Çanakkale	2	320	2192	Lignite	1800,000	32
Çatalağzı	Zonguldak	2	300	1882	Hard	1658,630	41–48
Çayırhan	Ankara	4	620	3100	Lignite	3696,266	36–42
Çolakoğlu-2	Kocaeli	1	190	950	Hard	–	–
Kangal	Sivas	3	457	1811	Lignite	5194,456	19–24
Kemerköy	Muğla	3	630	3411	Lignite	4563,781	31–36
Orhaneli	Bursa	1	210	1332	Lignite	1413,436	25–31
Seyitömer	Kütahya	4	600	4051	Lignite	5384,720	32–37
Soma (A + B)	Manisa	6	1034	5482	Lignite	8948,501	25–50
Sugözü	Adana	2	1320	6050	Hard (imported)	3300,000	–
Tunçbilek (A + B)	Kütahya	5	429	1607	Lignite	1907,753	16–51
Yatağan	Muğla	3	630	3981	Lignite	5538,297	26–36
Yeniköy	Muğla	2	420	1929	Lignite	3412,505	32–40

near a piles/landfill to gamma radiation emitted from the members of the ^{226}Ra and ^{232}Th series along with ^{40}K; (ii) internal exposure of the respiratory tract to alpha and beta particles due to inhalation of the radioactive inert gas radon (^{222}Rn, a daughter product of ^{226}Ra) and its short-lived decay products; (iii) internal exposure due to inhalation and/or ingestion of PFA particles.

These problems have led to the implementation of various alternative utilizations, in which PFA is considered as a value-added product. Approximately 33% of the total PFA produced in Europe is used as cement raw materials, as constituent in blended cements and as an addition for the production of concrete [7], while an estimated 1% of the total PFA produced in Turkey is used for cement, concrete and brick production, and earthwork applications (highway backfill, road stabilization, road pavement, embankments, etc.) [8].

From a radiological point of view, it is very important to study in detail the radiological characteristics of PFAs for accurately assessing the radiation exposure of the occupational and members of the public and developing standards and guidelines for the use and management of these materials. By this time a few studies concerning to the radioactivity of Turkish PFA collected some TPPs were published in the literature [8–13]. However the detailed information on the radiometric characterization of PFAs obtained from all coal-burning TPPs in operation in Turkey and the radiological impacts of the utilization of PFAs as filling and cover material in earthwork applications is not available in literature. In the present study, the radiological characteristics of PFA samples collected from the 15 coal-burning TPPs were determined using gamma ray spectrometer connected with HPGe detector. Elemental concentrations of ^{238}U, ^{232}Th and ^{40}K were calculated using the results of the activity concentrations of these radionuclides measured in the PFA samples. Radium equivalent activity (Ra_{eq}) and gamma index (I_1 and I_2) was calculated to assess radiological impacts of the utilization of PFA in earthwork applications (road construction, roadbeds, road pavement, landfill, landscaping, embankments, etc.). In addition, the total annual effective doses, which are the sum of the effective doses of external gamma radiation, inhalation and ingestion received by for workers and members of the public (adults) were estimated using methods given in the Radiation Protection 122 in various exposure scenarios (outdoor storage, transportation and road construction for workers and residence in a house near the PFA pile/landfill for adults) [14].

2. Material and methods

2.1. PFA sampling

A total of 317 PFA samples analyzed in this study were collected from the 15 coal-burning TPPs widely distributed, with the majority in the West region of Turkey as shown in Fig. 1. The samples were dried in a temperature-controlled furnace at 110 °C for 4 h to remove moisture. After moisture removal, these samples were cooled in moisture-free atmosphere. The samples were transferred to containers and weighed. Each container was hermetically sealed to prevent escape of radon gas. Before counting each sample was stored for more than 4 weeks to allow ^{226}Ra and its short-lived decay products to reach the secular equilibrium because of the

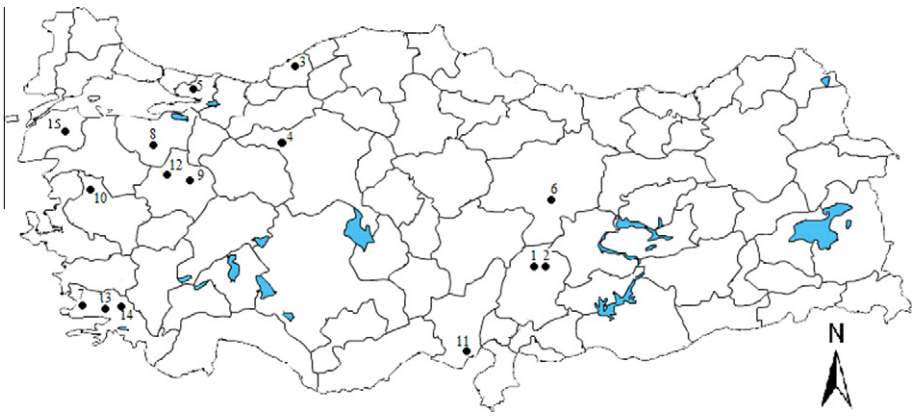

Fig. 1. Locations of the coal-burning TPPs [(1) Afşin-Elbistan A, (2) Afşin-Elbistan B, (3) Çatalağzı, (4) Çayırhan, (5) Çolakoğlu-2, (6) Kangal, (7) Kemerköy, (8) Orhaneli, (9) Seyitömer, (10) Soma, (11) Sugözü, (12) Tunçbilek, (13) Yatağan, (14) Yeniköy, (15) Çan] sampled in the study.