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Coal An Impure Fuel Source: Radiation Effects of Coal-fired Power Plants in Turkey

İbrahim Uslu[1], Faruk Gökmeşe[2]*

[1]Selçuk University, Department of Chemistry Education, Konya, Turkey

[2]Hitit University, Department of Chemistry, Çorum, Turkey

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Abstract

Turkish coal is generally poor quality and the levels of chemical and radiological toxic trace elements in it are higher with respect to mean values of activity concentrations given in United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) Report. The main pathways through which the population living around soal-fired power plant (CFPP) is exposed to natural radionuclides are external and internal (ingestion and inhalation) dose and fly ash particles are the major component of the risk. It is estimated that the people working or living near the CFPP in Turkey receive a dose in between 0.1 mSv to 1 mSv extra from CFPP because nearly all the region of Turkey uranium (U) and thorium (Th) content in the coal are higher than 5 ppm to 7 ppm and around 25 ppm to 40 ppm respectively. Continuous monitoring is essential to determine occupational exposure levels in all stages of the coal fuel-cycle and proper measures should be taken to prevent direct contact of the ash pile with the top soil and local drainage systems.

INTRODUCTION

All stages of the coal fuel-cycle, including mining, combustion, and use and disposal of the bottom ash and fly ash cause exposure to the natural radiation. These radioactive elements in coal include potassium (^{40}K) and the decay series headed by uranium, thorium, as well as radium and radon as trace elements. The levels of chemical and radiological toxic trace elements in coal are receiving greater attention in the assessment of the environmental impact of electricity generation from Coal-Fired Power Plants (CFPPs) [1-5].

* Correspondence to: Faruk Gökmeşe
Hitit University, Department of Chemistry, Çorum, Turkey

Tel: +90364 227 7000/1632 Fax: +90364 227 7005
E-mail: farukgokmese@hitit.edu.tr

The emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon dioxide (CO_2), mercury and other organic and inorganic pollutants from CFPPs adversely affect the environment. Coal is also radioactive.

In this study, only radiological effect of coal combustion in Turkey is assessed; but, the evaluation of complete impact of a CFPP on environment assessment program should include both chemical and radiological toxicity.

MATERIALS AND METHODS

Natural radioactivity of coals in the world

Table 1 gives uranium (^{238}U), thorium (^{232}Th) and

Table 1. Natural radionuclide concentrations in various coals in the World.

State	Region	Calorific Value (kcal/kg)	Ash content	Concentration		
				^{238}U (ppm)	^{232}Th (ppm)	^{40}K (%)
Australia	DT	7070	9.6	0.80	2.1	0.097
	UL	6500	17.6	0.95	3.0	0.60
	BR	6330	18.4	1.8	6.5	0.15
Canada	CV	6360	9.2	1.1	2.0	0.66
China	FS	6390	21.4	1.7	5.5	0.16
Japan	HO	6420	20	0.96	3.9	0.45
	TH	6320	12.5	0.78	2.2	0.13
	HN	6280	20.8	0.53	1.9	0.17
	TS	5940	24.4	0.99	3.5	0.31
	ND	4420	40.5	0.93	3.8	0.42
S. Africa	EM	6510	13.7	1.7	4.8	0.87
	WB	6350	18.0	1.9	7.3	0.10
U.S.A.	CO	6430	14.3	0.31	0.49	0.0066

potassium (^{40}K) concentrations of coal from various regions of the world [1]. It is clear from Table 1 that natural radionuclide concentrations varies greatly among different kinds of coal and depends generally to ash content and calorific value.

In the UNSCEAR 1982 Report it is estimated the average concentration of ^{40}K, ^{238}U and ^{232}Th in coal is 50, 20, 20 Bq kg^{-1}, respectively. Although average uranium concentration in USA coal is given as 0.31 ppm in Table 1, according to U.S.G.S. Fact Sheets FS-076-01 [3], FS-163-97 [4] and FS-038-02 [5] coals containing more than 20 ppm uranium may also be used in CFPP. Coals containing more than 20 ppm thorium are extremely rare [4].

The parameters of Turkish CFPPs

Coal (lignite) plays an important role within the electric power system of Turkey. Share of coal use in energy production is decreasing by the years due to increase in share of imported natural gas in total electricity generation. Turkey has hard coal (anthracite and bituminous) reserves of around 1.1 billion tons, plus lignite reserves around 8 billion tons. 40% of Turkey's lignite is located in the Afsin-Elbistan basin of southeastern Anatolia, while hard coal is mined only in one location Zonguldak basin of northwestern Turkey [6-11].

Descriptive parameters of Turkish CFPP's such as installed capacity as MW, and calorific value & consumption capacities are given in Table 2 [8-11]. According to this table lowest quality (i.e. highest ash percent) coal is used in Manisa-Soma CFPP where as highest quality coal is used in Afşin-Elbistan.

Natural radioactivity in Turkish coal

Turkish coal, which is used mainly for power generation, is generally of poor quality and highly polluting. Almost 85% of lignite production is used in power plants. As it is seen from Figure 1, 66 % of the coal has calorific value of 1000-2000 kcal/kg. According to Table 1 and Table 3, trace elements, U, Th, and K contents are higher in high ash or low calorific value coal as expected [8-11].

Afşin-Elbistan coals have lowest thorium and potassium content (Table 3). In a different study U, Th, K contents of Ankara-Çayırhan (Beypazarı) lignites are given as 1 to 24 ppm, 1 to 18 ppm and 0.1 to 0.96%, respectively [12].

The percentage of transference of U, Th and K of

Table 2. The parameters of Turkish Coal Fired Power Plants (CFPP).

CFPP Name	Installed Capacity (MW)	Consumption Capacity (x1000 t/y)	Calorific Value of the Coal	Ash %
Afşin-Elbistan	1.360	17.000	2670	35
Ankara-Çayirhan	620	4.300	2905	50
Bursa-Orhaneli	210	1.560	2580	41
Çatalagzı	300	1.800	4141	56
Kütahya-Seyitömer	600	5.500	2403	50
Kütahya- Tunçbilek (A+B)	429	2.720	4977+2381	23+53
Manisa-Soma (A+B)	1.034	8.300	4588+2490	26+44
Manisa-Soma (C)	600	3.350	1368	64
Mugla-Yatagan	630	5.150	3048	39
Mugla- Yeniköy	420	3.860	1835	56
Sivas-Kangal (1,2,3)	458	5.400	3503	37
TOTAL	6.691	62800		

Turkish coals from five regions is given in Table 4 [13-16]. The percent transference of trace elements of the coal into the atmosphere depends mainly on the burning conditions. The coal particle size, burning temperature and duration of burning are important parameters controlling transference. Percent transference of U into atmosphere is very low since it is the heaviest nuclide. But this is not the same for Th. Percent transference of Th and K are almost the same and higher than U.

Coal combustion eliminates organic components causing an increase in ash radioactivity compared to coal radioactivity. During combustion, heavier portion of ash, together with incompletely burned organic matter, fall to the bottom of the furnace known as bottom ash. Fly ash, the lighter portion, is carried through the boiler. Most of the fly ash is collected with electrostatic filters while rest is released to the atmosphere. In big CFPP's fly ash to bottom ash ratio is 5 to 1 [17]. Analysis of natural radionuclides showed that they have approximately 50% higher concentrations in fly ash relative to bottom ash [18]. Fly ash is primarily composed of non-combustible glassy compounds melted during combustion. Among the CFPP's used throughout the world, older ones release about 10% of the fly ash whereas more modern ones provided with sophisticated retention devices, release less than 1% of the fly ash [19]. According to Table 5 [8-11], the fly ash is enriched in uranium several times over the original uranium concentration in the coal since uranium, and thorium, content does not decreased as the volume of coal decreases.

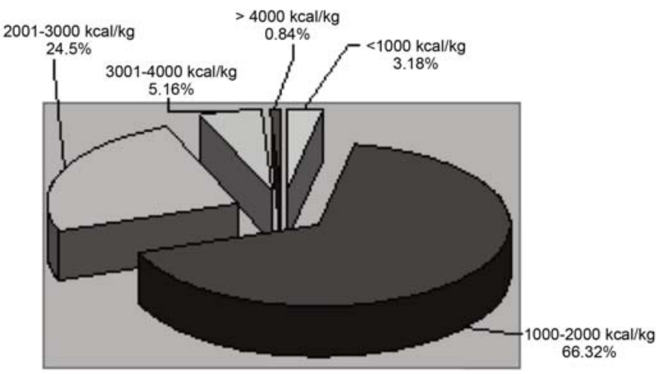

Figure 1. Quality of Turkish lignites [6].

Table 3. Uranium (U), Thorium (Th) and Potassium (K) content of coals used in coal-fired plants in Turkey.

CFPP Name	U in coal µg/g	Th in coal µg/g	K %
Afşin-Elbistan	12	1.5	0.2
Ankara-Çayırhan	6.5	9.4	0.8
Bursa-Orhaneli	10	8.8	0.4
Çatalağzı	20	27	1.6
Kütahya-Seyitömer	5.9	13	1.1
Kütahya-Tunçbilek (A+B)	(10+19)	(12+49)	(0.4+0.8)
Manisa-Soma (A+B)	(41+31)	(12+15)	(0.4+0.7)
Manisa-Soma (C)	21	30	0.8
Muğla-Yatağan	82	24	0.7
Muğla- Yeniköy	20	6.8	1.1
Sivas-Kangal (1,2,3)	25	1.3	0.4

Table 4. Percentage transference of elements into ash.

Element	Çayırlı	Çilli	Alpagut	Beypazarı	Seyitömer	Muğla-Yatağan
U	99.3	99.7	91.2	97.4	92.1	
Th	77.3	86.3	78.1	76.3	80.3	
K	80.5	86.0	78.9	70.6	81.8	

In Table 6, the estimated mean values of activity concentrations in coal and fly ash given in UNSCEAR Report [2] are shown. These values are consisting with the values given in Table 5. According to Table 6, an enrichment of a factor about 5 to 10 is found from coal to fly ash. Therefore, the goal of this study was to estimate the influence of the CFPP on the environment and their contribution to the workers of CFPP and to the population exposure to the radiation in their vicinities.

Dosimetric calculations

The main pathways through the population, living around CFPP is exposed to natural radionuclides, are external and internal (ingestion and inhalation) dose.

Natural radionuclides contained in coal come mainly from the three main decay chains; the uranium-radium chain (^{238}U series), the uranium-actinium chain (^{235}U series) and the thorium chain (^{232}Th series) as well as ^{40}K. Natural uranium consists of 99.3% (weight) ^{238}U and 0.72% (weight) ^{235}U. In this study calculation the ^{235}U series has ignored because of the small portion of ^{235}U, although Corbett (19) suggests that this may not be justified. The isotopic abundance of ^{40}K is small, only 0.012% of naturally occurring potassium, which gives a specific activity of 31.3 Bq/g of natural potassium. The relationship between the number of atoms of a certain species, N, and its activity, A is defined as [20]:

Table 5. Fly ash content of coal-fired plants in Turkey.

CFPP Name	U in fly ash μg/g	Th in fly ash μg/g	K %
Afşin-Elbistan	85	9.2	0.5
Ankara-Çayırhan	18	21	1.4
Bursa-Orhaneli	29	9	0.4
Çatalağzı	25	42	3.5
Kütahya-Seyitömer	12	27	1.8
Kütahya- Tunçbilek (A+B)	45+58	38+50	1.2
Manisa-Soma (A+B)	202+106	43	1.1
Manisa-Soma (C)	124	113	1.2
Muğla-Yatağan	129	44	2.3
Muğla- Yeniköy	57	11	1.6
Sivas-Kangal (1,2,3)	58	7.5	1.2

Table 6. Activity concentration in fly ash vs coal (Bq/kg).

Radionuclides	U-238	Th-232	K-40
Coal	20	20	50
Fly ash	200	70	265

$$N = \frac{T_{1/2}A}{\ln 2} \quad (1)$$

where $T_{1/2}$ is the half-life of the radionuclide. Using Eq. 1 the relationship between the concentration of uranium, thorium, and potassium in coal site and fly ash disposal site, and corresponding activities of ^{238}U, ^{232}Th, and ^{40}K are calculated as follows [21]:

$$1 \text{ ppm eU} = 12.35 \text{ Bq kg}^{-1} \text{ of } ^{238}U \quad (2)$$

$$1 \text{ ppm eTh} = 4.06 \text{ Bq kg}^{-1} \text{ of } ^{232}Th \quad (3)$$

$$1\%K = K_{pct} = 313 \text{ Bq kg}^{-1} \text{ of } ^{40}K \quad (4)$$

Dose limits in this chapter will be calculated as external and internal dose and total effective dose will be the some of external and internal effective dose. The sum of total effective dose to the relevant critical groups of members of the public shall not exceed 1 mSv in a year [22].

Outdoor effective external dose

The air absorbed dose rate of coal site and fly ash disposal site (assuming they are distributed homogenously on the ground) can be converted to effective dose (1 m above the ground) using conversion factors presented by the UNSCEAR Report [23]. These conversion factors are shown in Table 7 and were originally calculated by Saito and Jacop [24].

The total gamma dose rate in air at 1 m above the ground at each location in the coal site and ash pond are calculated using dose coefficients (nGy. h^{-1}/$Bq.kg^{-1}$) of 4.62×10^{-1}, 6.04×10^{-1}, 4.17×10^{-2} for ^{238}U, ^{232}Th and ^{40}K, respectively [22,23].

Using the relationships between activity vs. concentration and external exposure rate conversion factors, and conversion factors between effective dose and absorbed dose (Table 7) [22,23], the annual effective dose E in at a height of 1 m of the coal site and fly ash disposal site from U, Th, and K concentrations can be calculated using equation 4 [20]:

$$E_a = 33.6 \times eU_{ppm} \times 14.9\, eTh_{ppm} \times 81.1 \times K_{pct} \quad (5)$$

The results of air absorbed (external) effective dose of a worker who live or work on the coal site & fly ash disposal site are shown in Table 8. In the calculation the fraction of time of workers at the site (outdoor) is assumed as 0.2 [23]. Using dose conversion factors given in Table 7 the same calculation can be repeated for children and infant.

Table 7. Conversion factors between effective dose and absorbed dose for U, Th, K distributed homogeneously in the ground.

Nuclide	Effective dose conversion factors Sv Gy^{-1}		
	Infants	Children	Adult
^{238}U	0.899	0.766	0.672
^{232}Th	0.907	0.798	0.695
^{40}K	0.926	0.803	0.709
Average	0.91	0.79	0.69

As it is seen from the results the workers receive highest external dose from Manisa, Soma, and Yatagan CFPP but 1 mSv is a public dose and these values are close to this limit [22].

Internal exposure

Possible internal exposure dose to the population is calculated using Yatağan CFPP as a source. Internal exposures of the critical group of the public arise from the intake of naturally occurring radionuclides released from CFPP by inhalation and ingestion. Doses by inhalation result from the presence in air of fly ash particles containing mainly radionuclides of the ^{238}U and ^{232}Th decay chains. Doses by ingestion are mainly due to ^{40}K and to the ^{238}U and ^{232}Th series radionuclides present in drinking water and foods. Tables 9 and 10 give effective dose conversion factors from ingestion and inhalation. In these tables infants are defined as baby with the age of 1-2 years, children with the age of 7-12 years and adults which is higher than 17 year [22]. More detailed dose conversion factors can be found from IAEA-BBS-115 [22]. Moderate absorption from the lung is assumed for the dose conversion factors for inhalation. A dose conversion factors infant via inhalation of ^{238}U for moderate absorption is 9.4 μSv, if slow absorption of ^{238}U from the lung is assumed than the value will be 25 μSv, which is three times higher than moderate absorption.

Table 8. Air absorbed (external) effective dose of adult.

CFPP Name	Effective Dose, coal site mSv	Effective dose, Fly ash disp. site mSv
Afşin-Elbistan	0.09	0.61
Ankara-Çayırhan	0.08	0.21
Bursa-Orhaneli	0.10	0.23
Çatalağzı	0.24	0.35
Kütahya-Seyitömer	0.10	0.19
Kütahya- Tunçbilek	0.29	0.56
Manisa-Soma (A+B)	0.26	1.50
Manisa-Soma (C)	0.24	1.19
Muğla-Yatağan	0.63	1.04
Muğla- Yeniköy	0.17	0.44
Sivas-Kangal (1,2,3)	0.18	0.43

Table 9. Effective dose conversion factors from ingestion.

Radionuclide	Effective dose coefficient μSv/Bq		
	Infants	Children	Adults
^{238}U	0.12	0.068	0.045
^{232}Th	0.45	0.29	0.23
^{226}Ra	0.96	0.80	0.28
^{40}K	0.042	0.013	0.006

Table 10. Effective dose conversion factors from inhalation.

Radionuclide	Effective dose coefficient μSv/Bq		
	Infants	Children	Adults
^{238}U	9.4	4	2.9
^{232}Th	50	26	25
^{40}K	0.017	0.0045	0.0021

Ingestion drinking water

Ingestion intake of the critical group of the public of natural radionuclides released from CFPP depends on the consumption rates of drinking water and food and on the radionuclide concentration. Annual intake of drinking water is given as 150, 350, and 500 kg/year for infants, children and adults respectively [23].

Water composition in the region of Seyitömer CFPP is given as 2.5-22.6, 0.8-8.5, 6.4 for the waters from the fountains of the Seyitömer region, Kınık Stream, and Porsuk River respectively [25]. According to regulation of Ministry of Health [11], maximum acceptable concentration of potassium is 12 ppm. The waters from the fountains of the Seyitömer region exceed the limits for drinking water for potassium. But in radiological point of view using Eq. 5 and Table 9, an adult gets 2 μSv from ^{40}K which is well below the annual public effective dose limit of 1 mSv.

^{226}Ra, which is one of the daughter products of ^{238}U can be detected in the environment near Yatagan CFPP [23,26]. Table 11 and 12 give the ^{226}Ra content of the water and soil samples measured near the villages of Yatagan CCFP.

If we compare the ^{226}Ra values in drinking water in Yatagan region with respect to other countries, it is seen that values are in the range of very foreign countries data.

Using effective dose conversion factors given in Table 9 [22,23] and appropriate drinking water consumption rate, effective dose from ingestion of drinking water from villages of Yatağan can be calculated. The highest ^{226}Ra activity is found near the well close to ash disposal site of Yatağan CFPP. Even if one consume the water near ash disposal site with a 718.91 mBql^{-1} ^{226}Ra activity, effective dose from ingestion is calculated as one order of magnitude lower than public dose limit (1 mSv).

Table 10 gives the values ^{226}Ra in soil near the villages of Yatağan CFPP and these values are also in the range of many countries compared at the same table.

Inhalation

Combustion of coal disperses the radioactivity in the coal over large areas in the vicinity of CFPP through fly ash emissions from the stacks. The quantity of radionuclides emitted to the atmosphere depends on the concentration in the coal, the method of combustion, and the efficiency of the fly ash recovery. Under normal conditions, when electro filters in CFPPs operate with high efficiency, a minor portion of ash produced is released through the chimney into the atmosphere due to high efficiency of electrostatic filters amounting up to 99.5%. Depending on the chimney height, the ash is deposited from the plum at a closer or further distance from CFPP. However, in the case of coal having high ash content like Turkish lignite, electro filters can frequently blocked, and, therefore, temporarily turned off. During such episodes, enormous amounts of fly ash are released into the atmosphere. This is the frequent case with CFPPs in Turkey, which use low calorific lignite. It is also well

Tablo 11. ^{226}Ra in drinking water samples near villages of Yatagan CCPP.

Village name	mBq/l	Villiage name	mBq/l	Countries	mBq/l
Kadıköy	65.49	Eskihisar	245.31	USA	0.4-1.8
Şeref	81.77	Cazgırlar	16.28	China	0.2-120
Bozarmut	179.82	Yaylaköy	32.56	Finland	10-49000
Çatak	179.82	Kapıbağ	228.66	France	7-700
Kavaklıdere	147.26	Şahinler	114.33	Germany	1-1800
Menteşe	147.26	Hisarardı	65.49	Italy	0.2-1200
Çakırlar	114.33	Yava	32.56	Poland	0.7-21
Derebağ	114.33	Turgut Beldesi 1	14.33	Romania 0.5-130	
Mesken	114.33	Katrancı	212.38	Switzerland	0.1-1500
Akgedik	147.26	Hacıveliler	245.31	Spain	<20-4000
Kavak	16.28	Köklük	114.33	UK	0.1-180
Desdin	16.65	Ash disposal site	718.91		

known that the specific activity in the fly ash increases with decreasing particle size, so the escaping fly ash has higher concentration than the fly ash captured by the electro filters. According to UNSCEAR [2], for a fly ash particle size of 17 μm ^{238}U Enrichment factor is 1.3. But it is increased to 2.8 enrichment factor if the fly ash particle size decreased to 2 μm. It should be noted here that fly ash whose particle size is smaller than 10 μm are considered to be within the respirable range.

For the calculation of inhalation dose we should use an example CFPP, for example Yatagan CCFP. This CCFP consume annually 5.2 x 10^{6} kg of coal (Table 2) with an ash content of 0.39%. It should be note that for large power stations, 20% of the ash collected as bottom ash. Assuming electrostatic filter efficiency as 99.2% [29] and assuming fly ash activity of ^{238}U, and ^{232}Th both as 100 Bq/kg^{-1}, we can calculate the release rate from the stack as 0.4 kg fly ash×s^{-1} (40 Bq×s^{-1} for ^{238}U, and ^{232}Th) when filters operate and 50 kg×s^{-1} (5000 Bq×s^{-1} for ^{238}U, and ^{232}Th) when the filters shut down.

Tablo 12. ^{226}Ra in soil.

Region	Bq/kg	Other Countries	Bq/kg
Cazgırlar	41.11	Algeria	5-180
Madenler	62.59	China	2-440
Hisarardı	185.93	Denmark	9-29
Turgutlar	114.81	Estonia	6-310
Katrancı	83.70	Germany	5-200
Hacıbayramlar	45.93	Iran	8-55
Kırıkköy	57.77	Switzerland	10-900

Yatağan CFPP is very close to the city center. Ground level air concentration at downwind distance X in sector p, C_A (Bq x m^{-3}) is calculated using Eqn 6 [29].

$$C_A = \frac{P_P F Q_i}{u_a} \quad (6)$$

where P_p is the fraction of time during year that the wing blows towards the receptor of interest in sector p, (default value P_p=0.25),

U_a is the geometric mean of the wind speed at the height of release representative of one year, Default value (2 m/s), Q_i is the annual average discharge rate for radionuclide i (Bq/s); F is the gaussian diffusion (dilution) factor appropriate for the height of release and the downwind distance X being considered, for 1000 m from the stack the F is given as [29] 1 x 10^{-5} 1/m^{2}.

Using the default values from Eq 6, ground level concentration C_A of ^{238}U and ^{232}Th can be calculated as 5 x 10^{-5} Bq/m^{3}. If electrostatic filter are shut ground level concentration will be calculated as 6.3 x 10^{-3} Bq/m^{3}.

The effective dose conversion factors from inhalation given in Table 13 used for the calculation of effective dose from inhalation, assuming breathing rates: infants 1.900 m^3/year, children 5.600 m^3/year, adults 7.300 m^3/year [23]. If electrostatic filter works properly all the year, annual effective dose for adult is calculated as 1 µSv for ^{238}U and 9 µSv for ^{232}Th. If the filters are shutdown, the annual effective dose from inhalation is calculated as 0.13 µSv for ^{238}U and 1 mSv for ^{232}Th.

^{222}Rn and ^{220}Rn (thoron) are the gaseous radioactive products of the decay of the radium isotopes ^{226}Ra and ^{224}Ra, which are present in all terrestrial materials such as coal and ash. Aycık and Ercan [27] measured the average ^{226}Ra concentration of lignite samples taken from Yatağan CFPP as 0.30 Bq/kg and they estimate the annual ^{226}Ra release from this CFPP as 3.7 x 10^{11} Bq. Yaprak [28] measured time integrated ^{222}Rn concentrations in the houses near the Yatagan CFPP ranging from 10 to 120 Bq/m^3. The arithmetic mean of the ^{222}Rn concentration is given as 45 Bq/m^3. If we assume equilibrium factors of 0.4 indoors, occupancy, and dose conversion factor for inhalation of radon as 9 nSv (1/Gq.h.m^3) [23], the following annual effective doses are derived:

$$45 \text{ Bq/m}^3 \text{ x } 0.4 \text{ x } 7000 \text{ h x } 9 \text{ nSv } 1/\text{Bq.h.m}^3 = 1.1 \text{ mSv} \quad (6)$$

According to IAEA-BSS-115 [26] the estimated average doses to the relevant critical groups of members of the public that are attributable to practices shall not exceed in a special circumstances, an effective dose of up to 5 mSv in a single year provided that the average dose over five consecutive years does not exceed 1 mSv per year. But especially annual effective dose of radon exceed the average dose of 1 mSv for public and also if filters are shutdown than the annual effective doses are also goes to critical values.

RESULTS AND DISCUSSION

A large quantity of trace elements is released annually into the atmosphere from coal combustion. Therefore, it is essential for effective control measures to have sound understanding of the transport routes of the natural radionuclides from CFPP to the various components of the environment, and of the uptake and accumulation of the radionuclides by workers, public and the ecosystem concerned.

Coal data (Table 1) from China indicate that because of higher-than-average concentration of natural radionuclides in coal and relatively low filter efficiencies (90%) and high population densities around the plants, the collective effective doses arising from atmospheric releases of radioactive materials from CFPP's there is approximately 50 man Sv/GW year [23]. If the same assumption is true for Turkish CFPP, according to Table 2, 62.8×10^9 kg of coal is required to produce 6.7 GW year of electrical energy. The collective effective dose per year of burning coal in Turkey is therefore estimated to be (50 man Sv/Gw year) × 6.7 (GW year) = 335 man Sv. The annual per caput dose is obtained by dividing the annual collective effective dose (335 man Sv) by the population of Turkey (70 x 10^6); the result is 5 µSv.

Table 13 shows the maximum whole-body radiation doses caused to an individual at a distance of about 500 m from a CFPP, as calculated by different investigators. The original values were normalized for a CFPP of 1000 MW. Table 13 shows that even taking into account the differences in the uranium and thorium contents of coal as assumed by the various investigators, the results of their evaluations of the individual radiation doses are very consistent. For example 1 ppm U content gives a a dose of 0.04 mSv/y by Mc.Bride et. al [31] and if the uranium content of the coal is increased to 25 ppm, than the

Table 13. Maximum individual radiation doses resulting from a 1000 MW CFPP [30].

Radionuclide ppm	Mc. Bride et al.	Cooper and Dakik	US EPA	
		S. Texas	Worst Case	
U	1	5	25	1-9
Th	2	7	40	5
	Whole body maximum individual doses mSv/y			
Collective Doses	0.04	0.1	1	0.4

dose also increased to 1 mSv/y which is 25 times higher dose. From this result we can estimate that the people working or living near the CFPP in Turkey receive a dose in between 0.1 mSv to 1 mSv extra from CFPP because nearly all the region of Turkey U and Th content in the coal are higher than 5 ppm to 7 ppm and around 25 ppm to 40 ppm respectively.

CONCLUSION

In this study, we considered the radiological effects of coal combustion on environment. A complete impact assessment should also include chemical contaminants.

Low quality, high ash and U, Th and K contening lignites should be considered as a source of radiation to the population living in the vicinity of CFPPs. It is suggested that the radioactivity content of the coal supply to CFPPs should be monitored and use of high uranium and thorium containing coals should be avoided.

The main radiological impact on the population living around CFPPs is inhalation of natural radionuclides during the passage of the cloud. The major component of the risk is due to the fine release of fly ash particles. To eliminate the risk, either the stack height should be increased or better electrostatic filters should be used. For the fine structure the risks are eliminated only when the height of the stack is increased. The increase height reduces the individual inhalation dose significantly.

During mining, coal preparation and ash disposal site operations, dust control or use of personal respiratory protective equipment are very important to assure “as low as reasonably achievable” inhaled concentrations. Since respirable fly ash has the highest concentration of radionuclides in ash disposal sites operators must be trained.

Continuous monitoring is essential to determine occupational exposure levels in all stages of the coal fuel-cycle, including mining, combustion, and use and during disposal of the bottom and fly ash.

Fly ash is used as an additive in construction materials. In the use of fly ash in building materials radioactivity levels and pathways should be considered to protect population.

Bottom and fly ash disposal sites around CFPPs are the primary environmental concern for groundwater contamination. Proper measures should be taken to prevent direct contact of the ash pile with the top soil and local drainage systems.

Measure should be also taken to check the release of radionuclides from ash pond and subsequent mixing with river.

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