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RESEARCH ARTICLE

Radon, Thoron and Natural Radioactivity Measurement of Thermal Power Plant of Punjab

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ABSTRACT

In the present study, some important parameters radon exhalation rate and thoron exhalation rate has been measured using BARC developed scintillation based Smart Radon Monitor (SRM) and Smart Thoron Monitor (STM) respectively. Natural radioactive component ^{226}Ra, ^{232}Th and ^{40}K measurement is carried out by NaI(Tl) detector using gamma ray spectrometry. Result obtained concludes that radiation from fly ash residues around the coal based power plants are within limits prescribed by the competent authority.

Key words: *Radon, Thoron, coal, fly ash, scintillation, power plant*

INTRODUCTION

Fly ash, a coal cumbustion product is one of the important sources of industrial intensifying exposure of occupational as well as general public from naturally occurred radionuclides. The radiation risk introduced by airborne emissions of coal-fired power plants has been cited as possible causes of degradation of public health. Assessment of the radiation exposure from the burning of coal is critically dependent on the natural radioactive contents in coal and fly ash. Coal is an important source of power generation in India. The country has at present 90,000 MW of electricity generation, of which coal combustion contributes to more than 70% of the power generation (Mishra, 2004). Fly ash which is the combustion of coal results in generation large amounts of ash, which is a major environmental problem. This problem is particularly important for Indian power plants since most of the power plants use poor quality coal with 55-60% ash content. This results in an average production of 100 million tons of ash per annum (Vijayan and Behera, 1999).

Human beings have always been exposed to ionizing radiation from various natural sources of radiation and one of the major routes of internal exposures is through inhalation of radioactivity present in the atmosphere. Radon and its progenies are proved to be a health hazard and their contribution is nearly about 50% to the total radiation population exposure, while the estimated contribution of thoron and its decay products to the annual effective dose from radon is about 8%. It is very important to assess the emission potential of radon and thoron for study of possible risk effect (United Nations Scientific Committee on the Effect of Atomic Radiation Source, 1993). According to UNSCEARE (1993), about 87% of the radiation dose received by mankind s due to natural radiation sources and the remaining is due to anthropogenic radiation. The external radiation exposure arises mainly due to cosmic rays and terrestrial radionuclide's occurring at trace levels in all soil. There are some regions in the world that are known for high background radiation areas (HBRAs), where the local geological controls and geochemical; effects causes enhanced levels of terrestrial radiation. (UNSCEARE2000). Wide ranging radiation studies have been carried out in the HBRAs in Brazil, in China, in India, in Iran and in USA and Canada and in some other countries to estimate risks and effect of long-term radiation exposure. High radiation above the earth is mainly due to naturally occurring radionuclide's ^{238}U, ^{232}Th and ^{40}K. High altitudes areas are also affected by cosmic radiation. All over the world, many works are being carried out to map radioelements in soil and environmental gamma dose rate. Radiogenic lung cancer is the oldest known radiation induced malignancy disease. It is now well established fact that radon when inhaled in large quantity causes lung disorders and is the second major cause of lung cancer after smoking (Committee on Health Risks of Exposure to Radon, National Research Council, 1999 and International Commission on Radiological Protection, 1993). The exposure of population to high concentrations of radon and its daughters for a long period lead to pathological effects like the respiratory functional changes and the occurrence of lung cancer .During recent years, radon monitoring has become a global phenomenon due to its health hazard effects on population (Radiation workers and public). Health effects of radon is noticed in human being as lung cancer, have been investigated from last few decades (International Commission on Radiological Protection, 1991) and UNSCEARE, 2000).

EXPERIMENTAL WORK

In this study, for measurement of radon exhalation from coal fired thermal power plant, samples were collected from different units of power plant from different locations of Guru Nanak Dev Thermal Plant. It is located at Bhatinda, Punjab with primary fuel as coal in present active state and operated by Punjab Government Power Corporation. A total of 18 samples have been collected from which 6 coal, 6 soil and 6 samples from Fly ash. Collected samples from different area are different in nature like coal, stone, sand, and soil type. After collection, all samples were crushed into form of fine powder by using Mortar and Pestle. Fine quality of the sample is obtained by using scientific sieve of 150 micron-mesh size. Samples were oven dried at 110°c for 24 h before measurement and then packed and sealed in an impermeable airtight PVC container to prevent the escape of radiogenic gases radon and thoron. An amount of 500 gram was taken as samples for SRM and STM based technique for measurement of radon exhalation rate and thoron exhalation rate (Gaware, *et. al.,* 2011).

Accumulation chamber technique was used to measure the radon and thoron exhalation rate. Radon mass exhalation and Thoron surface exhalation measurements were performed using BARC developed Smart Radon and Thoron Monitor respectively. About 500 grams of sample was taken in the accumulation chamber for carrying out measurements. For Radon mass exhalation rate measurement, radon build up in the accumulation chamber is sampled into the scintillation cell (150cc) of the Smart Radon Monitor through a "progeny filter" and "thoron discriminator" eliminating radon progenies and thoron. The thoron discriminator based on "diffusion time delay" does not allow the short lived thoron ^{220}Rn (half-life 55.6 sec) to pass through. The alpha scintillations from radon and its decay products formed inside the cell are continuously counted for a user programmable counting period by the PMT and the associated counting electronics. The alpha counts obtained are processed by a microprocessor unit as per a look back algorithm to display the concentration of radon. The build-up radon concentration was measured at a time intervals of 1 hour till to attain saturation of radon concentration. On the other hand, thoron concentration was measured at a regular time interval of 15 minutes till equilibrium is reach for thoron concentration (Sahoo, *et. al.*, 2007).

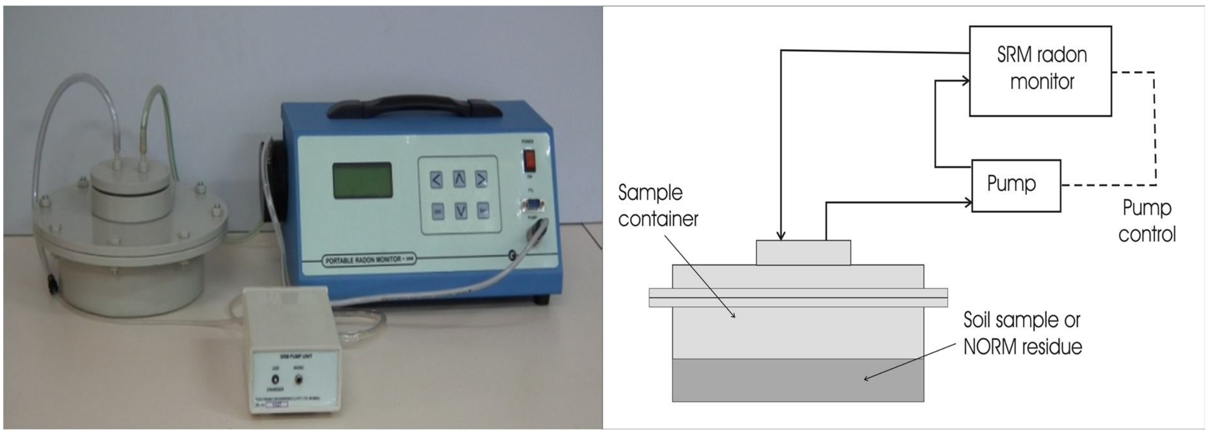

Fig.1: Photograph and schematic diagram of the radon/thoron exhalation measurement set up

CALCULATION METHODOLOGY

The radon concentration C (Bq m^{-3}) at time t inside the chamber can be written as

$$C(t)= \frac{J_m M}{V\lambda_e}\left[1-e^{-\lambda_e t}\right]+C_0 e^{-\lambda_e t} \quad \text{……..(1)}$$

Where,

J_m is the ^{222}Rn mass exhalation rate (mBq kg^{-1} h^{-1}), V is theeffective volume (m^3) i.e. Volume of the container + volume of the detector- volume of sample, C is radon concentration per unit volume of air (Bq m^{-3}), C_0 is the ^{222}Rn concentration (Bq m^{-3}) present in the chamber volume at t = 0. M is the mass of the sample (kg), λ_e is the effective decay constant for ^{222}Rn, which is sum of the leak rate (if existing) and the radioactive decay constant of ^{222}Rn (h^{-1}).

Upon least square fitting the experimentally measured radon build up data to the exponential growth equation available in the software origin

$$Y(x)= Y_0 + A_1 e^{-\frac{x}{t_1}} \quad \text{…….. (2)}$$

We get fitting parameters Y_0, A_1 and t_1. Comparing Eq. (1) and Eq. (2), we can get radon mass exhalation rate $J_m= Y_0 V\lambda_e$ / M and effective decay constant $\lambda_e= 1/t_1$. A typical plot of radon build up inside the closed chamber is given in Fig. 2.

The thoron (^{220}Rn) concentration in the chamber will reach equilibrium in a short time period and the equilibrium thoron concentration (C_T) is given by the formula

$$J_T = C_T\, V \lambda \,/\, A \quad \text{…….. (3)}$$

Where V is the residual air volume of the set up (m^3). A is surface area of the sample (m^2). λ is the ^{220}Rn decay constant (0.0126 s^{-1}). Hence by knowing the value of equilibrium thoron concentration, the thoron surface exhalation rate can be estimated using Eq. (3).

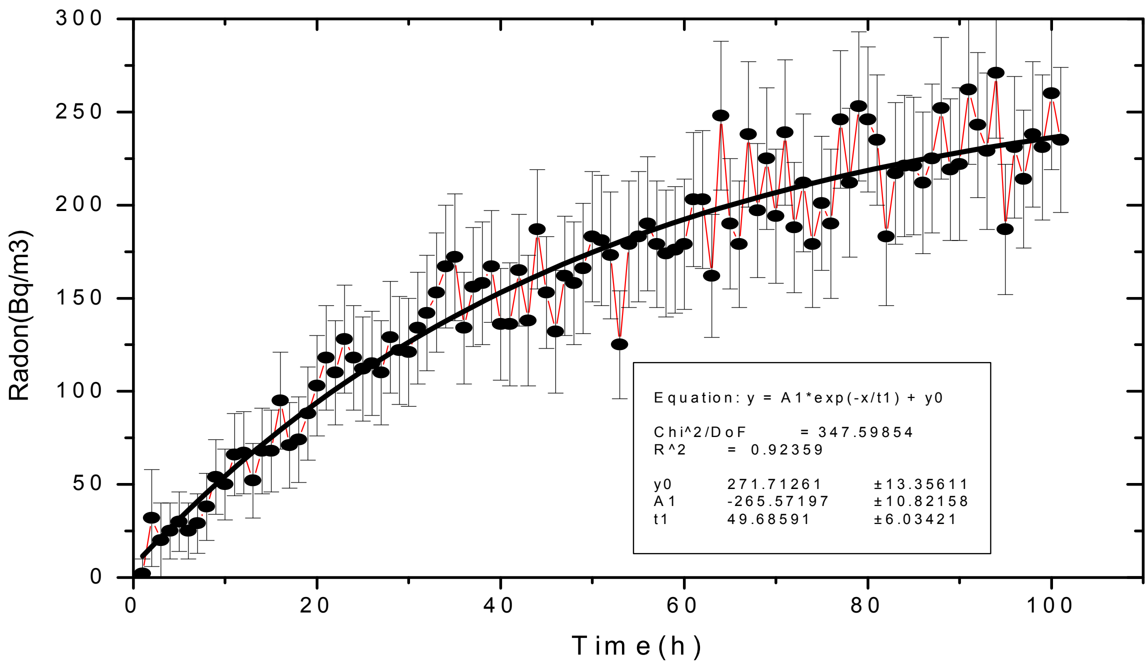

Fig. 2: Least square fitting of Eq. (2) to data plotted between radon concentrations in chamber with time

Equation 2 and 3 were used for calculating radon exhalation rates and thoron exhalation rate for coal and flyash samples (Sahoo and Mayya, 2010).

RESULT AND DISCUSSION

Radon mass exhalation and thoron surface exhalation rate using active techniques (SRM based) are summarized in Table 1.

Table 1: Radon/Thoron Exhalation Rate, ^{226}Ra, ^{232}Th, ^{40}K and radium equivalent activity in samples of Guru Nanak Dev Thermal Plant, Bhatinda, Punjab

S.No	Sample code	Type of sample	Radon Mass Exhalation Rate in $mBqkg^{-1}h^{-1}$	Thoron Surface Exhalation Rate in $mBqkg^{-1}h^{-1}$	^{226}Ra in $Bqkg^{-1}$	^{232}Th in $Bqkg^{-1}$	^{40}K in $Bqkg^{-1}$	radium equivalent activity Ra_{eq} in $Bqkg^{-1}$
1	GDC1	COAL	69.3	1202	48.18	55.42	532.3	168.41
2	GDC2	COAL	97.6	1159.5	51.23	59.03	547.12	177.77
3	GDC3	COAL	86.0	1331.6	41.17	31.05	493.21	123.54
4	GDC4	COAL	87.8	985.5	37.95	27.66	466.88	113.45
5	GDC5	COAL	147.1	1102.9	55.3	32.67	503.7	140.80
6	GDC6	COAL	383.5	1139.3	53.11	51.55	497.09	165.10
7	GDF1	FLYASH	81.5	655.6	46.65	31.79	562.1	135.39
8	GDF2	FLYASH	14.7	576.7	50.02	42.11	832.11	174.30
9	GDF3	FLYASH	56.2	514	43.79	33.1	897.9	160.26
10	GDF4	FLYASH	36.3	544.3	55.4	56.11	534.07	176.76
11	GDF5	FLYASH	69.8	633.4	41.59	42.11	576.03	146.16
12	GDF6	FLYASH	95.6	603	47.76	62.65	602.34	183.72
13	GDS1	SOIL	81.5	655.6	49.88	46.2	492.1	153.83
14	GDS2	SOIL	14.7	576.7	35.2	12.8	501.2	92.09
15	GDS3	SOIL	56.2	514.0	41.88	27.55	544.61	123.21
16	GDS4	SOIL	36.3	544.3	39.77	29.1	602.55	127.77
17	GDS5	SOIL	69.8	633.4	47.22	31.02	577.09	136.01
18	GDS6	SOIL	95.6	603.0	49.91	39.43	609.32	153.21
Average			87.7	776.3	46.44	39.51	576.20	147.32

From the data listed in Table-1 radon mass exhalation rate vary from 14.7mBqkg^{-1}h^{-1} to 383.5mBqkg^{-1}h^{-1} with an average of 102.1mBqkg^{-1}h^{-1} and thoron surface exhalation rate varies from 514Bqm^{-2}h^{-1} to 1331.6 Bqm^{-2}h^{-1} with an average of 870.6 Bqm^{-2}h^{-1} for coal and flyash samples collected from Guru Nanak Dev Thermal Plant, Bhatinda, Punjab using Active technique.

RADIUM EQUIVALENT ACTIVITY

To represent the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K by a single quantity, which takes into account the radiation hazards associated with them, a common radiological index has been introduced. The index called radium equivalent activity (Ra_{eq}) is used to ensure the uniformity in the distribution of natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K and is given by the expression

$$Ra_{eq}=1.43C_{Th} + C_{Ra}+ 0.077C_{K} \quad \text{........ (4)}$$

Where C_{Th},C_{Ra} and C_K are the activities concentration in (Bqkg^{-1}) of ^{226}Ra(U series), ^{232}Th and ^{40}K respectively. It was assumed that 370 Bqkg^{-1} of ^{226}Ra, 259 Bqkg^{-1} of ^{232}Th and 4810 Bqkg^{-1} of ^{40}K produce the same gamma-ray dose rate. The maximum dose Raeq in building materials must be less than 370 Bqkg^{-1} for safe use, i.e., to keep the external dose below 1.5 mSvy^{-1}.

ABSORBED GAMMA DOSE RATE AND THE EFFECTIVE DOSE RATE

The absorbed dose rates due to (radiation in air at 1m above the ground surface for a uniform distribution of the naturally occurring radionuclides (^{226}Ra, ^{232}Th and ^{40}K) were calculated based on guidelines provided by UNSCEAR reports. We assumed that the contributions from other naturally occurring radionuclides, such as ^{235}U, ^{87}Rb, ^{138}La, ^{147}Sm and ^{178}Lu, to actual dose rates were insignificant. The D((nGyh^{-1}) inair was calculated using the expression below:

$$D_R = 0.0417C_K + 0.621C_{Th}+ 0.462C_{Ra} \quad \text{........(5)}$$

Where D_R is the absorb dose rate (nGy hr^{-1}), and K_K, K_{Th} and K_{Ra} are the conversion factors (or dose rate coefficient) for potassium (0.043), Thorium (0.662) and Radium (0.427) respectively measured in nGy $hr^{-1}BqKg^{-1}$.

ESTIMATION OF ANNUAL EFFECTIVE DOSE

To estimate the effective dose rates, the conversion coefficient from absorbed dose in air to effective dose (0.7 $SvGy^{-1}$) and indoor occupancy factor (0.8) proposed by UNSCEAR 2000 and 2008 reports are used. The annual effective dose, E was calculated from the expression

$$AEDIndoor\ (mSvy^{-1}) = D(\ (n\ Gyh^{-1}) \times 10^{-6} \times 8760 \times 0.8 \times 0.7$$

For outdoor occupancy factor (0.2)

$$AEDOutdoor\ (mSvy^{-1}) = D(\ (n\ Gyh^{-1}) \times 10^{-6} \times 8760 \times 0.2 \times 0.7 \qquad \text{........(6)}$$

Where, D(($nGyh^{-1}$) is the total absorbed dose rate due to gamma radiations from materials containing radionuclides of ^{226}Ra, ^{232}Th, and 0.7 $SvGy^{-1}$ is the conversion coefficient from absorbed dose in air to effective dose.

EXTERNAL AND INTERNAL HAZARD INDICES

To limit the external (radiation dose from building materials to 1.5 $mSvy^{-1}$ per practice, the external hazard index (H_{ex}) was calculated as

$$H_{ex} = C_{Ra}/370 + C_{Th}/259 + C_K/4810 \qquad \text{........(7)}$$

In addition to the external hazard, radon and its shortlived products are also hazardous to the respiratory organs. To account for this threat the maximum permissible concentration for ^{226}Ra must be reduced to half of the normal limit (185 $Bqkg^{-1}$). The internal exposure to carcinogenic radon and its short lived progeny is quantified by the internal hazard index (H_{in}) given by the expression

$$H_{in} = C_{Ra}/185 + C_{Th}/259 + C_K/4810 \qquad \text{........(8)}$$

For the safe use of a material in the construction of dwellings and to keep the radiation hazard to be insignificant, this index value must be less than unity. The value of radium equivalent in Bq kg^{-1}, representative level index, internal hazards and external hazards of soil, fly ash and soil sample are listed in table 2 (Mahur, *et. al.*, 2008).

Table 2: Absorbed gamma dose, Internal hazards index, External hazard index, Annual effective dose of Coal and flyash samples collected from Guru Nanak Dev Thermal Plant, Bhatinda, Punjab

S.No.	Sample code	Type of sample	absorbed gamma doses D($nGyh^{-1}$)	internal hazards index (H_{in})	external hazards index (H_{ex})	Annual effective dose (indoor) ($nGyh^{-1}$)	Annual effective dose(outdoor) ($nGyh^{-1}$)
1	GDC1	COAL	78.87	0.5851	0.4549	0.3869	0.0967
2	GDC2	COAL	83.14	0.6186	0.4801	0.4079	0.1020
3	GDC3	COAL	58.86	0.4450	0.3337	0.2888	0.0722
4	GDC4	COAL	54.17	0.4090	0.3064	0.2658	0.0664
5	GDC5	COAL	66.84	0.5298	0.3803	0.3279	0.0820
6	GDC6	COAL	77.27	0.5895	0.4459	0.3791	0.0948
7	GDF1	FLYASH	64.73	0.4918	0.3657	0.3176	0.0794
8	GDF2	FLYASH	83.95	0.6060	0.4708	0.4119	0.1030
9	GDF3	FLYASH	78.22	0.5512	0.4328	0.3838	0.0959
10	GDF4	FLYASH	82.70	0.6271	0.4774	0.4057	0.1014
11	GDF5	FLYASH	69.38	0.5072	0.3947	0.3404	0.0851
12	GDF6	FLYASH	86.08	0.6253	0.4962	0.4223	0.1056
13	GDS1	SOIL	72.25	0.5503	0.4155	0.3545	0.0886
14	GDS2	SOIL	45.11	0.3439	0.2488	0.2213	0.0553
15	GDS3	SOIL	59.16	0.4460	0.3328	0.2903	0.0726
16	GDS4	SOIL	61.57	0.4526	0.3451	0.3020	0.0755
17	GDS5	SOIL	65.14	0.4950	0.3674	0.3196	0.0799
18	GDS6	SOIL	72.95	0.5487	0.4138	0.3579	0.0895
Average			70.02	0.5234	0.3979	0.3435	0.0858

CONCLUSION

Gamma ray spectrometry has been used to determine the radioactivity concentration ^{226}Ra, ^{232}Th and ^{40}K in the studied sample collected from various locations of power plants. From results, average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were 46.44, 39.51 and 576.20 Bq kg^{-1} respectively. The absorbed gamma doses (D) in air due to naturally occurring radionuclide's in the sample varied from 45.11 to 86.08 nGyh^{-1} with an average value of 70.02 nGyh^{-1}. The radiological parameters such as radium equivalent activity (Ra_{eq}) and activity index shows that internal dose due to natural radioactivity in the samples used not exceed the dose criteria. Also internal hazard index and external hazard index are less than the international average mean value. The radon exhalation rate of the coal, fly ash and soil samples from Guru Nanak Dev Thermal Plant, Bhatinda, Punjab are under the limit prescribed by Radiation Protection Agencies. Effect on nearby areas locality around thermal power plant can be neglected and under the limit prescribed by regulatory board. Thus flyash appears to be safe and brick made from fly ash can be used as building materials without imposing significant radiological hazards to public. In future study on radon and natural radioactivity measurment in power plants of other parts of country will definitly give a strong correlation between fly ash commercial and its healrh effects on humane being.

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