Radioactivity level of the ambient environment of Anren bone-coal power station

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Abstract The radioactivity level of the ambient environment of Anren Bone-coal Power Station (BCPS) was investigated systematically. The γ radiation dose rate level in the environment, the content of ^{238}U and ^{226}Ra in the ambient soil and the farmland in the direction of downwind, the concentrations of ^{238}U, ^{232}Th, ^{226}Ra, ^{40}K and ^{222}Rn, as well as α potential energy in air, and the concentrations of natural U and Th in effluent are all higher than the corresponding values of the reference site. The additional annual effective dose equivalent to the residents living in the houses made of bone-coal cinder brick is 2.7 mSv.

Keywords Bone-coal power station, Environmental monitoring, Radioactivity level, Effective dose equivalent

CLC numbers X837

1 INTRODUCTION

It has been emphasized by recent international and domestic investigations and evaluation reports on the radioactive contamination to environment, and on the radioactity dose received by public, that the contaminating influence of the airborne radioactivities released from coal power station on the environment is much more severe than that from nuclear power station.[1-3] In respect of the "three sorts of wastes" problem of coal power stations, the project of "Nuclear Power, Energy Resources and Environment Evaluation" has been drawn up by the Safety Protection Bureau of the Chinese Nuclear Industry Corporation.

According to the requirement of this project, we have started the assessment of the environmental impact of the special power stations, which use bone-coal with higher content of radioactive nuclides as fuel, and of bone-coal mining, electricity generating and bone-coal cinder utilizing, we chose Anren bone coal power station (BCPS) located in Jiande County of Zhejiang Province as our object. Here in this report we evaluate the influence of its "three wastes" release on the ambient environment, and provide scientific basis for future bone-coal utilization, draft regional energy development policy and formulate the standard for environment protection measures.

Manuscript received date: 2001-02-14

Anren BCPS, located at 119° 36′E, 29° 40′N, is a pit head power station. Meiping village is to the west of the station and about 70 metre away from the station, and its topography is about 80 metre higher than the station and it is situated on leeward in summer, autumn and winter. The population of the village is around 300. There is a Panjiacun village, at the mountain foot, and around 1000 persons living in. This village is to the northeast of the station and about 300 metre away from the station, its topography is about 100 metre lower than the station, and situated on the leeward in spring. The waste water from the BCPS flows through the drains or seeps through the ground of the mining area and is converged in the mountain foot at the northeast of the BCPS, and then flows into Fuchunjiang River via the band shape farming areas of Wangjiacun village and Jinjiancun village, located between two chains of small hills.

The BCPS has a capacity of 750 kW, annual production is 2,500 M Wh and consumes 370,000 metric ton bone-coal each year. The chimney of the BCPS is 40 metre in height. It releases gas 27,000 m^3/h and dust 100 kg/h, most of which deposit within 30 metre around the chimney. The heaviest dust is deposited in Panjiacun village area in spring and in Meiping village area in other seasons. The bone-coal cinder from the BCPS is first piled in the nearby site and then distributed to the local cement factories to be used as an ingredient, ash in dust remover is used as raw material for refining V_2O_5, and the residue after the refinement is filled up in the waste-disposal site which is to the northeast of the BCPS.

2 INVESTIGATION ITEMS AND METHODS

In the course of the comprehensive utilization of bone-coal mining, electricity generating and V_2O_5 refining, the radioactive contaminants from Anren BCPS to the ambient environment mainly are bone-coal, bone-coal cinder, ash in dust remover between the boiler and chimney, chimney dust, gases discharged from the chimney, waste water from the BCPS and V_2O_5 refining workshop. So, the investigation items include γ dose rate in the ambient environment, concentration of ^{222}Rn and α potential energy in air, radionuclides in varied media and so on. The measuring and analytical methods and their lower level of detection (LLD) are listed in the Table 1.

Table 1 Detection items, methods, instruments

Media	Items	Methods	Instruments	LLD
Environment	γ radiation	Scintillation method	SG-102 X-γ dose rate meter	10 nGy/h
Atmosphere	Concentration of ^{222}Rn	Track etch method	CSR detector	3.0Bq/m^3
	α potential energy	Thomas method	FJ-13 α detector	20nJ/m^3
	^{238}U, ^{40}K	γ spectrometry	HPGe γ spectrometer	0.3Bq/sample
	^{226}Ra, ^{232}Th	γ spectrometry	HPGe γ spectrometer	0.1 Bq/sample
Liquid	Natural Uranium	Laser spetrography	JU-1 laser detector	0.05 μg/L
	Natural Thorium	N-235 extraction	721 spectrophotometer	0.07 μg/L
	^{226}Ra	Precipitate of barium sulfide	FJ-2603 low background detector	0.5mBq/L
	^{40}K	Atomic absorption spectrophotometry	AA-670 spectrophotometer	0.6mBq/L
Solid	^{238}U, ^{40}K	γ spectrometry	HPGe γ spectrometer	0.9Bq/kg
	^{226}Ra, ^{232}Th	γ spectrometry	HPGe γ spectrometer	0.3Bq/kg

3 INVESTIGATION RESULTS AND DISCUSSION

The monitoring results of the radioactivity level in the ambience of Anren BCPS are listed in Tables 2–7 according to items of γ radiation dose rate, concentration of ^{222}Rn and α potential energy, and content of nuclides in the media. The monitoring result in Hangzhou Huapu Nursery, which is taken as a reference point, is also listed in these Tables.

Table 2 γ radiation dose rate in ambient environment of the BCPS$^{(1)}$ (nGy/h)

Measured sites	Field			Road		
	n	$\overline{x} \pm s$	Range	n	$\overline{x} \pm s^{(2)}$	Range
Bone-coal	59	466±86	263-616	-	-	-
Ash in dust remover	25	359±33	280-418	-	-	
Bone-coal cinder	33	240±54	158-355	-	-	
BCPS area	23	301±88	180-481	21	260±48	183-381
Bone-coal mine area	23	289±97	165-506	21	264±80	158-489
Meiping village	20	222±57	135-412	20	264±29	221-312
Paijiacun village	13	97±20	63-127	16	217±42	140-324
Farmland area	17	97±33	58-174	16	167±29	137-247
Reference point	37	42±10	26-61	19	57±6	44-68

Note: $^{(1)}$These values in the table has been subtracted the background value of cosmic ray, $^{(2)}$ n=Number of samples, $\overline{x}$=Average of the measured values, s=Standard deviations of the measured values

Table 3 γ dose rate, the concentration of ^{222}Rn, and α potential energy in indoor and outdoor

Measured sites	Kind of house	γ dose rate ($nGy \cdot h^{-1}$)		Concentration of ^{222}Rn indoor ($Bq\ m^{-3}$)$^{(1)}$	α potential energy in Outdoor ($nJ\ m^{-3}$)$^{(2)}$
		indoor$^{(1)}$	outdoor		
Panjiacun village	I$^{(3)}$	105	97	42	112
Reference point	I$^{(3)}$	115$^{(5)}$	42	25$^{(5)}$	85
Meiping village	II$^{(4)}$	212	222	75	253
Panjiacun village	II$^{(4)}$	212	97	75	253

Note: $^{(1)}$Quoted from Ref.[4], $^{(2)}$Estimated values, $^{(3)}$The I kind house is the house made of normal red brick, $^{(4)}$The II kind house is the house made of bone-coal cinder brick, $^{(5)}$Quoted from Ref.[5]

Table 4 Concentration of ^{222}Rn and α potential energy in outdoor

Measured sites	Concentration of ^{222}Rn ($Bq \cdot m^{-3}$)		α potential energy ($nJ\ m^{-3}$)	
	Winter	Summer	Winter	Summer
Panjiacnn village	7.9±1.6	7.0±4.1	27.3±5.5	28.9±17
Meiping village	17.7±8.7	18.4±6.8	69.3±23	76.3±28
BCPS	23.6±4.3	17.8±3.3	102±28	74.1±14
Reference point	12.3±4.5	7.6±2.1	40.7±18	26.6±8.8

Table 2 shows the γ radiation dose rate level, the order from high to low is as follow: bone-coal > ash in dust remover > bone-coal cinder, respectively. The average values of γ radiation dose rates in the field of Meiping village, bone-coal mine area, and BCPS area are 4.3, 5.9 and 6.2 times higher and in road is 3.6 times higher than the reference point, respectively.

Table 4 shows the concentrations of ^{222}Rn and α potential energy in outdoor air at Panjiacun Village, which are about the same level as those at the reference point. The concentrations of ^{222}Rn in the outdoor air at the BCPS and Meiping village is about one times higher than that at the reference point, and the α potential energy is about 2 times higher than that at the reference point.

Table 5 Specific activities of radionuclides in solid media (Bq·kg^{-1}, dried weight)

Sample	n	^{238}U			^{226}Ra			^{232}Th			^{40}K		
		$\overline{x}$	s	Range	$\overline{x}$	s	Range	$\overline{x}$	s	Range	$\overline{x}$	s	Range
Bone-coal cinder	7	741	179	519-1109	701	187	490-1095	17.9	4.2	14.0-25.5	360	45	272-411
Bone-coal	8	1056	381	720-1947	959	169	740-1317	22.0	5.0	11.0-28.8	485	125	370-754
Ash in dust remover	4	1728	614	710-2300	1685	613	640-2200	45.0	18	29.0-76.0	790	72	700-900
Dust of chimney	3	2100$^{(2)}$			1810	171	1670-2000	50.0	16	40.3-68.0	747	136	590-835
Soil of farmland	4	245	106	173-428	144	52	94-222	54.2	6.1	43.8-59.4	710	93	569-817
Soil of BCPS	5	641	309	317-1100	607	319	280-1100	46.0	11	35.0-66.0	735	161	550-996
Soil of Meiping	4	728	182	440-940	793	326	390-1300	41.0	5.0	32.0-45.0	663	129	490-850
Soil of reference	4	37	10	24-48	38	7	28-46	49.0	8.0	36.0-56.0	278	62	200-370

Note: $^{(1)}n$=Number of samples, $\overline{x}$=Average of measured values, s=Standard deviation of measured values, $^{(2)}$There was only one sample

Table 6 Specific activity of radionuclides in outdoor air (10^{-4}Bq/m^3)

Sampling sites	n	^{238}U		^{226}Ra		^{232}Th		^{40}K	
		$\overline{x}$	Range	$\overline{x}$	Range	$\overline{x}$	Range	$\overline{x}^{(1)}$	Range
Panjiacun village	2	1.38	0.33-2.44	0.67	0.54-0.80	2.55	0.92-4.19	0.55	0.33-0.77
BCPS	2	5.81	3.72-7.91	4.07	3.26-4.88	2.68	1.06-4.30	1.73	0.72-2.74
Meiping village	2	5.52	3.72-7.33	6.28	3.49-9.07	1.26	0.20-2.33	1.80	0.42-3.17
Reference point	2	0.62	0.16-1.08	0.61	0.05-1.16$^{(2)}$	0.82	0.63-1.01	0.53	0.31-0.74

Note: $^{(1)}n$=Number of samples, $\overline{x}$=Average of measured values, $^{(2)}$If the measured value of one of the samples is lower, the *LLD* value was used instead for calculation

Table 5 shows that the content of ^{238}U, ^{226}Ra in the bone-coal used by the BCPS is 20 times and 27 times higher than that in ordinary coal, respectively. It is evident that the bone-coal is a kind of fuel of which the content of radionuclides is quite high. The farming fields, located outside the power station and the bone coal mining area, are irrigated directly by the water discharged from the mining area, therefore, the content of ^{238}U and ^{226}Ra in the field soil have been risen 5.6, 2.8 times than that in the soil of the reference point, respectively. Because of bone-coal mining, transporting and the ash release from the chimney of the BCPS, the contents of ^{238}U and ^{226}Ra in the soil at Meiping village and the BCPS are 15–20 times higher than those in the soil of the reference point. So that the radioactive contamination to the soil at the mining area is obvious.

Table 6 shows the average concentration of radionuclides of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K in out door air at the BCPS and Meiping village are 5.67×10^{-4}Bq/m^3, 5.18×10^{-4}Bq/m^3, 1.97×10^{-4}Bq/m^3 and 1.77×10^{-4}Bq/m^3, respectively. In comparison with the reference point, these values are obviously higher.

Table 7 Content of natural radionuclides in the water samples

Sampling sites	n	Natural U (μg·L^{-1})		^{226}Ra (mBq L^{-1})		Natural Th (μg·L^{-1})		^{40}K (mBq·L^{-1})	
		$\overline{x}$	Range	$\overline{x}$	Range	$\overline{x}$	Range	$\overline{x}^{(1)}$	Range
Up of the pour-in-point$^{(2)}$	2	0.23	0.16-0.30	2.34	0.7-3.97	$< LLD$		52.4	50-54.8
Down of the pour-in-point$^{(3)}$	2	0.26	0.21-0.30	1.41	0.8-2.02	$< LLD$	-	52.6	50-55.3
Drain$^{(4)}$	2	46.1	38.4-53.9	12.1	3.1-21.2	0.58	0.25-0.9	56.5	50-63.0
Rivers and lakes$^{(5,6)}$	30	0.30	0.05-1.23	3.02	0.9-12.2	0.05	0.01-0.2	98.6	14-462
Qiantangjiang River$^{(6)}$	9	0.50	0.08-1.23	4.06	0.9-12.2	0.06	0.02-0.2	88.4	25-167

Note: $^{(1)}n$=Number of samples, $\overline{x}$=Average of measured value, $^{(2)}$Up 100 meters from the pour-in-point in Fuchunjiang, $^{(3)}$Down 100 meters from the pour-in-point in Fuchunjiang, $^{(4)}$Up 50 meters from the pour-in-point at the drain, $^{(5)}$These are rivers and lakes of Zhejiang Province, $^{(6)}$ Quoted from Ref.[5].

The water discharged from the BCPS, including from V_2O_5 refining workshop and bone-coal mining area, seeps through the ground and gets into drain at the mountain foot nearly the Panjiancun village to the northeast of BCPS. It flows through band shape farming fields, such as Wangjiacun village and Jinjiacun village, and gets directly into Fuchunjiang River and there is no other branch to dilute it. The average conent of natural uranium, ^{226}Ra, ^{40}K in the water samples collected from Fuchunjiang River at the up and down streams of the pour-in-point, is 0.25 μg/L, 1.88 mBq/L, and 52.5 mBq/L (see Table 7), respectively. It is lower than that in rivers of Zhejiang Province including. Qiantangjiang River system. This means that the BCPS's discharged water doesn't severely pollute the Fuchunjiang River. But the average contents of natural uranium and thorium in the water samples collected in the drain about 50 meter up stream from the pour-in-point are 46.1 μg/L and 0.58 μg/L, respectively, and those for ^{226}Ra and ^{40}K are 12.1 mBq/L and 56.5 mBq/L, respectively (see Table 7). It is obvious that the drain water is contaminated by radionuclides.

4 PUBLIC DOSE ASSESSMENT

The total annual effective dose equivalent H_E is equal to the sum of effective dose equivalent of internal irradiation and external irradiation. The additional annual effective dose equivalent is the difference between the total annual effective dose equivalents of the resident living in the houses made of bone-coal cinder brick and that of the resident living in the reference point.

According to the dose estimation formulas provided by the UNSCEAR report (1993), and based on the data on the γ radiation dose rate and concentration of ^{222}Rn in indoor and outdoor, the radioactivity of nuclides in air on ground (Tables 3, 4 and 6), the annual effective dose equivalents of the internal irradiation and the external irradiation are listed in Table 8.

Table 8 shows the total annual effective dose equivalents for the residents living in the normal brick houses (the I kind) at the reference point and Panjiacun village, that is, 1.38, 2.30 mSv, respectively, and those for the residents living in the bone-coal cinder brick houses (the II kind) at Paijiacun village and Meipin village are 3.90, 4.18 mSv, respectively. For all residents living in these houses, the dose equivalent caused by α potential energy due to daughters of ^{222}Rn in indoor and outdoor, are 51%, 63%, 65% and 63% of the total dose equivalent, respectively, with an average of 61%. The dose caused by α potential energy due to daughters of ^{222}Rn in indoor, are 46%, 60%, 63% and 59% of the total dose, respectively, with an average of 57%. This analysis shows that, no matter where the residents live, in normal brick houses at the reference point and Panjiacun village or in bone-coal cinder brick houses at Panjiacun village and Meiping village, the main part of their annual effective dose equivalent is caused by α potential energy due to daughters of ^{222}Rn indoors, which contribute more than half of the total doses. So, the gross effective dose equivalent can be greatly decreased by effectively decreasing the concentration of ^{222}Rn indoors only. The annual additional effective dose equivalent to the residents living in the bone-coal cinder brick houses at Panjiacun village and Meiping village are 2.52 and 2.80 mSv. It has exceeded the national standard "Regulations for Radiation Protection"(GB8703-88), according to which the annual additional effective dose equivalent is 1 mSv to public.

Table 8 Annual effective dose equivalent (mSv)

Place	Kinds of house	External irradiation dose: γ radiation $H_{E,\gamma}$ Indoor	Outdoor	Sum	Addition	Internal irradiation dose: α potential energy $H_{E,Rn}$ Indoor	Outdoor	Sum	Addition	Natural radionuclides(1) D Dose	Addition	Sum	Addition	Total dose H_T Sum	Addition
Reference point	I(2)	0.56	0.05	0.61	–	0.63	0.08	0.71	–	0.06	–	0.77	–	1.38	
Panjiacun village	I(2)	0.52	0.12	0.64	0.03	1.38	0.06	1.44	0.73	0.22	0.16	1.66	0.89	2.30	0.92
Panjiacun village	II(3)	1.04	0.12	1.16	0.55	2.46	0.06	2.52	1.81	0.22	0.16	2.74	1.97	3.90	2.52
Meiping village	II(3)	1.04	0.27	1.31	0.70	2.46	0.16	2.62	1.91	0.25	0.19	2.87	2.10	4.18	2.80

Note: (1)Due to natural radionuclides in air near ground, (2)The I kind house is the house made of normal red brick, (3)The II kind house is the house made of bone-coal cinder brick.

5 CONCLUSIONS AND SUGGESTIONS

From the analyses above, we can reach the following conclusions.

(1) In the ambient environment of Anren BCPS, the γ radiation dose rate level, the content of ^{238}U and ^{226}Ra in soil, the radioactivities of ^{238}U, ^{232}Th, ^{226}Ra, ^{40}K in air, the concentrations of the ^{222}Rn and it's α potential energy, all are higher in comparison with the reference point. The average contents of natural uranium and thorium in the drain water of BCPS ambience are 154 times and 12 times higher than the normal values for rivers in Zhejiang Province.

(2) The additional annual average effective dose equivalent to the residents living in the bone-coal cinder brick houses is 2.7 mSv. In order to benefit the development and comprehensive utilization of Anren bone-coal mine, and reduce the influence of the

"three wastes" from the BCPS on its ambient environment, the following measures are suggested:

(I) Prevent the scattering of bone-coal and bone-coal cinder during transportation.

(II) Prohibit using bone-coal cinder with high radioactivity content to pave the road or fill the house bases.

(III) Enhance the ventilation of the rooms in order to decrease the concentration of ^{222}Rn in houses made of bone-coal cinder and decrease the total dose. The houses of bone-coal cinder brick with high concentration of ^{222}Rn should not be used as living room.

(IV) Use wet (dust removing) method to improve the dust removing efficiency and decrease the radioactive contamination of dusts to the ambient environment.

(V) Prohibit use primitive methods of burning bone-coal to make bone-coal cinder which is used as a ingredient in cement. Strengthen the regulation of primitive methods in burning bone-coal to decrease the environmental contamination and the spread over of radioactive materials.

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