Survey of radon concentrations in bone-coal mining areas and inside BCCB houses in five provinces

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Abstract It was investigated that the radon concentrations in bone-coal mining areas, in outside and inside BCCB houses and ordinary red-brick (ORB) houses of the reference points in Hubei, Hunan, Jiangxi, Zhejiang and Anhui Provinces. It was shown that the average annual radon concentration inside BCCB houses in the bone-coal mining areas in the five provinces ranges from 85.7 to 303 Bq/m^3, with an average of 151 Bq/m^3, which is 3 times that inside ORB houses at the reference points. The average annual radon concentration outside BCCB houses in the bone-coal mining areas in the five provinces ranges from 12.0 to 73.8 Bq/m^3, with an average of 34.9 Bq/m^3, which is 1.5 times that outside ordinary ORB at the reference points. And the radon concentration in shafts of Hubei and Zhejiang Province is 9.51×10^3 Bq/m^3 and 965 Bq/m^3, respectively. This report also shows the changing patterns of radon concentrations with day, season, height, etc.

Key words Radon, Radioactivity, Bone coal, Bone-coal cinder brick (BCCB) house

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1 Introduction

According to the National Investigation of Natural Radioactive Level (abbreviated as "the investigation of levels" below) during 1983-1990, the specific activities of radionuclides in bone-coal are relatively high. It is a man-made activity which may significantly increase the radioactive level of environment and the public dose, when the local peasants spontaneously mine the bone-coal, produce bone-coal cinder bricks (BCCB, commonly called as carbide brick) with bone-coal cinder (BCC) on a small scale, and build dwelling houses with the carbide brick. Therefore, in 1991, the State Environment Protection Agency and the Safety Protection Bureau of the Chinese Nuclear Industry Corporation launched a project of "the study of effect of mining and utilizing radioactivity associated bone-coal mines on environment". The investigation covered five provinces, i.e. Hubei, Hunan, Jiangxi, Zhejiang and Auhui, and the content of the investigation includes: γ-radiation dose rate, natural radionuclides, non-radioactive elements, radon concentration, estimation and evaluation of public additional dose. One of the main contents is the survey of radon concentrations in bone-coal mining areas and inside bone-coal cinder bricks houses (abbreviated as "BCCB houses") in the five provinces. The project lasted more than two years, and was completed in 1993.

2 Surveyed items and methods

The investigation involved the average annual radon concentrations inside and outside BCCB houses in the bone-coal mining areas, those in bone-coal mining areas and pits; variation of radon concentration

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with days, seasons, years, floors of building, and vertical height; as well as the radon emanation rate in several media materials. The investigated sites include thirty rooms of BCCB houses in bone-coal mining areas and ten rooms of ordinary red-brick (ORB) houses as reference points in the five provinces. In this investigation, there were 166 indoor monitoring points and 22 outdoor points for radon concentration, while those in ordinary red-brick houses are 31 and 32, respectively. There were 308 indoor and outdoor measurement data for the radon concentration variation with days, seasons, years, while data for the variation with vertical height are 47.

In this investigation, the measurement methods and their lower level of detection (LLD) are listed in Table 1.

This investigation is conducted according to the technical specification given by Ref.[1]. All the measured results can be traced to the state metrology standard.

3 Results

3.1 Radon concentration

The average annual radon concentrations inside and outside various buildings in bone-coal mining areas in the five provinces are listed in Table 2.

Table 1 Measurement methods and instruments

	Methods	Frequency	Instruments	LLD
Concentration of ^{222}Rn	Track etch method	2-4/a	CSR detector	3.0 Bq/m^3
	Balloon method	2/a		2.5 Bq/m^3
α potential energy	Thomas method	2/a	FJ-13 α detector	20 nJ/m^3

Table 2 Average annual radon concentration inside and outside various houses and bone-coal shafts (height 1.5m) (Bq/m^3)

Province	Mine name	BCCB houses in bone-coal mining areas						ORB houses in reference points						Shaft
		Indoor			Outdoor			Indoor			Outdoor			
		n[1]	$\overline{x}$	SD	n	$\overline{x}$	SD	n	$\overline{x}$	SD	n	$\overline{x}$	SD	$\overline{x}$
Hubei	Miaopu	23	91.9	68.5		16.3[2]	0.8		34.0[3]			16.7[3]		
	Zuantanyan[4]	44	125	13.0	2	12.4	8.3		34.0[3]			16.7[3]		9510
	Tangxiang	19	160	242		7.3	1.8		34.0[3]			16.7[3]		
	Average	3	126	34.0	3	12.0	4.5	3	34.0			16.7		9510
Hunan	Nijiangkou	16	56.0	45.0	9	42.6	15.3	2	26.3	17.2	5	22.7	11.8	
	Tianjingchong	7	117	52.4		42.6[5]	15.3	22	19.8	6.9	4	17.3	4.4	
	Average	2	86.5	43.1		42.6	15.3	2	23.0	4.6	2	20.0	3.8	
Jiangxi	Yushan	15	85.7			15.5[2]			46.8			15.5[2]		
	Shangrao	4	118			15.5[2]			46.2[6]			15.5[2]		
	Xiushui	14	53.4			15.5[2]			45.5			15.5[2]		
	Average	3	85.7	32.3		15.5			46.2	0.65		15.5		
Zhejiang	Anren	6	97.5	19.5	2	33.8	15.6	3	54.6	14.3	2	33.8[7]	15.6	
	Zhuge	6	273	36.4	3	45.5	58.5	2	91.0	16.9	2	31.2	10.4	965
	Shuangpai	6	538	186	2	13.0	8.4	2	101	10.4	21	27.2	7.8	
	Average	3	303	222	3	30.8	16.5	3	82.2	24.4	3	30.7	3.3	965
Anhui	Jixi	3	96.6	23.5	2	53.3			36[2]			35[2]		
	Yixian	3	207	66.6	2	94.2			36[2]			35[2]		
	Average	2	152	78.1	2	73.8	28.9		36			35		
Average of the five provinces		5	151	89.6	5	34.9	25.0	5	44.3	22.7	5	23.6	8.8	5238

1) n=Number of samples, $\overline{x}$ =Average of the measured values, SD=Standard deviations of the measured values. 2) Quoted from Ref.[2-4]. 3) The average is quoted from that of "the national investigation of level". 4) The buildings in bone-coal mining areas of Zuantanyan were made of ordinary red-bricks. 5) The same radon concentration as that in Nijiangkou is estimated. 6) The average of

Yushan and Xiushui is taken. 7) The same radon concentration as that outside BCCB house is considered.

The average annual radon concentration inside BCCB houses in the bone-coal mining areas ranges from 86.5 to 303 Bq/m^3, with an average of 151 Bq/m^3, which is 3.4 times that inside ORB houses. The maximum value inside BCCB houses accounts to 303 Bq/m^3 in Zhejiang Province, about 3.5 times that in Jiangxi Province (85.7 Bq/m^3).

The range of annual radon concentration outside BCCB houses in the bone-coal mining areas in the five provinces was between 12.0 Bq/m^3 and 73.8 Bq/m^3. Except for Hunan and Anhui Provinces, the average of annual radon concentration outside BCCB houses in other three provinces is lower than or close to the average value outside the ORB houses in the reference points.

The average of annual radon concentration in bone-coal shaft in Hubei and Zhejiang Province is 5.24 kBq/m^3, 24 times the corresponding average (214 Bq/m^3) inside BCCB houses in the bone-coal mining areas. The average of annual radon concentration in Zhuantanyan bone-coal pit, Zhushan County, Hubei Province is 9.51 kBq/m^3, which is 76 times that inside ORB houses in Zhuantanyan bone-coal mining areas. The average of annual radon concentration in Zhuge bone-coal pit in Zhejiang Province is 965 Bq/m^3, 3.5 times that inside BCCB houses in Zhuge bone-coal mining area.

3.2 Changing patterns of radon concentration

3.2.1 Diurnal variation

A diurnal variation curve of saddle shape for outside radon concentration in the bone-coal mining areas in Zhuantanyan is shown in Fig.1, with the changing formula of y=–0.0001x^5+0.0052x^4–0.0854x^3+ 0.5269x^2–0.8255x+0.5375. The pattern is the same as in other areas that the maximum value appears at about 6:00 to 7:00, and the lowest value at about 18:00 to 19:00. In the morning, the inversion layer appears above ground level, thus, the atmospheric diffusion condition becomes bad, and radon emanating from ground and bone-coal surfaces is accumulated in atmosphere nearly the ground surface, raising the radon concentration in the air. In the afternoon, the temperature nearby the ground goes up again so that the air convection is quickened and the atmospheric diffusion condition becomes good. And the radon concentration turns out to decrease.

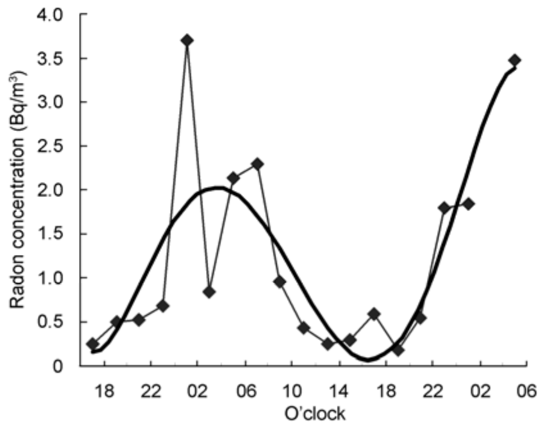

Fig.1 Diurnal change of outdoor radon concentration in Zhuantanyan bone-coal mining area in Hubei Province (Octorber 28-29, 1991).

Fig.2 shows a change of alpha potential energy of radon daughter. This was a three-day continuous measurement with windows and doors opening in December 1991 and June 1992 respectively. It is indicated that the changing curve of indoor alpha potential energy tends to be a saddle shape either in summer or in winter. During a day, the maximum peak value appears within several hours before or after midnight, while the minimum within several hours before or after 13:00. At 7:00 to 8:00 and 18:00 to 19:00, the measured value is close to the day average value.

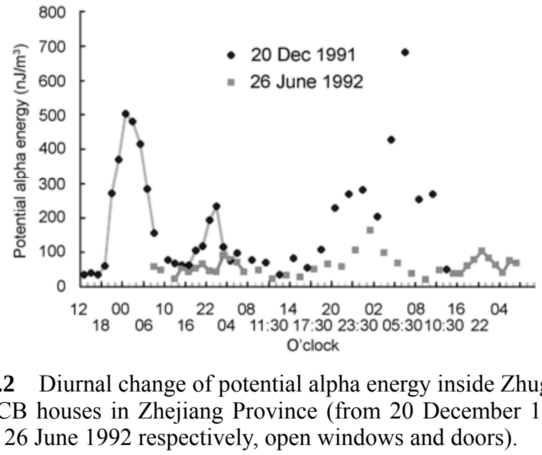

Fig.2 Diurnal change of potential alpha energy inside Zhuge's BCCB houses in Zhejiang Province (from 20 December 1991 and 26 June 1992 respectively, open windows and doors).

Fig.3 gave the change of alpha potential energy of radon daughter, which was also a three-day continuous measurement but with windows and doors closed in December 1991 and June 1992 respectively. In comparison with Fig.2, the maximum and minimum value, and the daily average value of alpha potential energy always appear with one to three hours delay correspondingly.

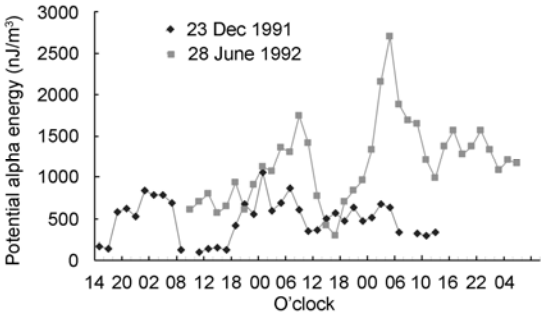

Fig.3 Diurnal change of potential alpha energy inside Zhuge's BCCB houses in Zhejiang Province (from 23 December 1991 and 28 June 1992 respectively, closed windows and doors).

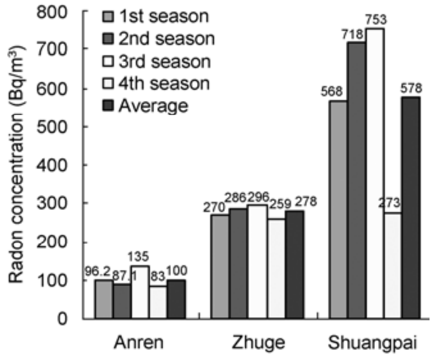

Fig.4 Seasonal change of the radon concentrations inside BCCB houses at three mining areas in Zhejiang Province.

3.2.2 Seasonal variation

The seasonal statistics of radon concentrations inside BCCB houses in Zhejiang's Anren, Zhuge and Shuangpai bone-coal mining areas are shown in Fig.4. It is seen that the radon concentration in four seasons is 0.97, 1.05, 1.24 and 0.74 times of the annual average value, respectively. During a year the maximum value is at 3rd season, the minimum is at 4th, and the 1st and 2nd are close to the annual average.

Fig.5 indicated the radon concentration in BCCB houses and ORB houses in Hunan's gold, coal and uranium mines under the usual living condition in spring-summer and autumn-winter. On an average, there is 17% decrease of radon concentration values in spring-summer for all eight kinds of BCCB houses and ORB houses as compared with those in autumn-winter, except for BCCB houses in Chenxi coal mine and uranium mine B.

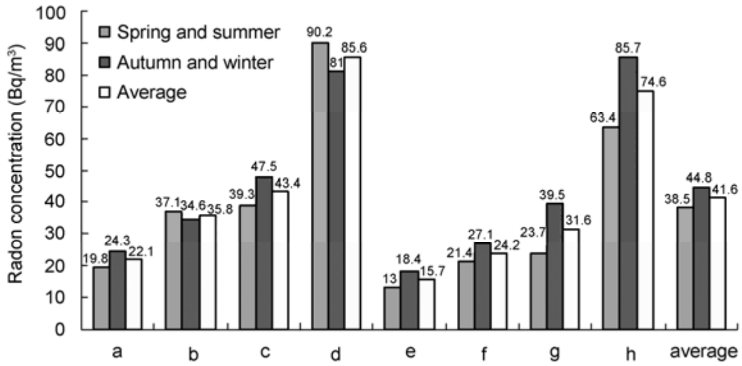

Fig.5 Indoor radon concentration in 8 kinds of houses in Hunan Province.
a) Cinder-mixing brick houses in Xiangxi gold mine; b) BCCB houses of Chenxi coal mine; c) BCCB houses of uranium mine A; d) BCCB houses of uranium mine B; e) ORB houses of reference points; f) BCCB houses A (<200 nGy • h^{-1}); g) BCCB houses B (200nGy • h^{-1}~300 nGy • h^{-1}); h) BCCB houses C (>300 nGy • h^{-1}).

3.2.3 Floor variation

The indoor radon concentrations of the 1st to 3rd floor in ORB houses and BCCB houses in Hunan's bone-coal mining areas are shown in Fig.6. It's known that the indoor radon concentrations of the first floor in ORB houses and BCCB houses are 41% and 15% higher than those of the second floor, respectively, and the indoor radon concentrations of the second floor and the third floor in ORB houses are about the same, because the indoor radon concentration of the first floor is related not only to the building material, but also to the ground material.

3.2.4 Vertical variation

In the investigation of radon concentration, the detector placed either indoors or outdoors is always hung at more than two meters high above the ground to ensure the recovery rate of CSR track detectors. As a result, the measurement is not accurate to represent the average radon concentration indoors and outdoors in 1.5-meter-height respiratory zone. Therefore, it is better to introduce two factors for the height- correction: one for indoor radon concentration (k_1) and the other for outdoor one (k_2).

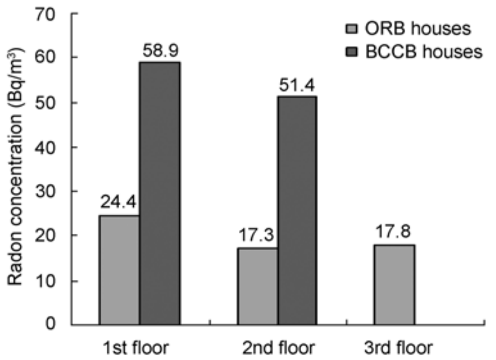

Fig.6 Radon concentrations on various floors of buildings in Hunan Province.

According to Ref.[5], if the indoor radon concentration at 2.4 m height is converted into the average indoor value of radon concentration, then k_1 should be equal to 1.3; and if the dose equivalent accepted by the public staying indoors is assessed according to the average radon concentration at 2.4 m height, k_2 should be 1.5.

From 0.3 to 10 m height, the outdoor radon concentration changes obviously, and decreases with the raising of height. With the radon concentration in 1.5 m height as a reference point, the correction coefficients k_h change from 0.41 to 4.31 for the height range. Relationship of k_h and the measured height (x) is clearly shown in Fig.7, with the formula of k_h=0.40x+0.29. So the correction coefficient for the height of 2.4 m ($k_{2.4}$) is equal to about 1.3.

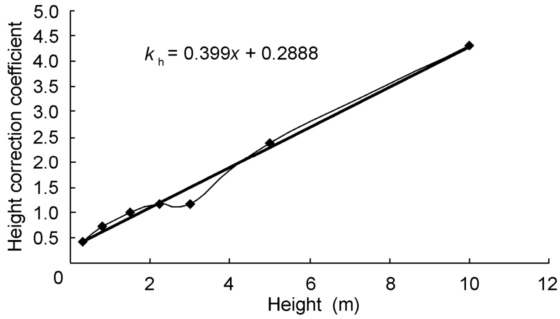

Fig.7 Height correction coefficient vs outdoor radon concentration.

3.3 Radon emanation quantity

Table 2 shows the radon emanation quantity in bone-coal mining areas in Hunan, Zhejiang and Anhui Provinces. The annual radon emanation quantity is about 2.3×10^{12} Bq from open mining areas of bone-coal, cinder piling areas of lime-factory, cinder piling areas of bone-coal power station and ambience near chimney of the bone-coal power station of Nijiangkou in Hunan.

In bone-coal and bone-coal cinder piling areas, bone-coal pits, etc., in three bone-coal mining areas in Zhejiang, the total of the annual radon emanation quantity is 2.1×10^{11} Bq.

The emanation quantity from two bone-coal cinder piling areas in Jixi and Yixian County, Anhui Province, is estimated to be about 1.7×10^{10} Bq.

Table 2 Radon emanation quantity of bone-coal mining areas in three provinces

Province	Areas	Annual radon emanation quantity (Bq)
Hunan	Open mining areas	7.5×10^{11}
	Cinder piling areas of lime-factory	10.4×10^{11}
	Cinder piling areas of bone-coal power station	4.2×10^{11}
	Ambience near chimney of bone-coal power station	0.9×10^{11}
	Sum	2.3×10^{12}
Zhejiang	Open mining areas	1.8×10^{10}
	Bone-coal and bone-coal cinder piling areas	1.1×10^{11}
	Bone-coal pits	8.0×10^{10}
	Sum	2.1×10^{11}
Anhui	Bone-coal cinder piling areas	1.7×10^{10}
Sum of the three provinces		2.5×10^{12}

4 Conclusion

4.1 Radon concentration

The range of average annual radon concentration in BCCB houses mentioned above in the investigated bone-coal mining areas is between 85.7 Bq/m^3 and 303 Bq/m^3, with an average of 151 Bq/m^3, which is 3.4 times that in the ordinary red-brick houses in the reference point. The radon concentration is given in decreasing order as follows: Zhejiang (303 Bq/m^3), Anhui (152 Bq/m^3), Hubei (126 Bq/m^3), Hunan (86.5 Bq/m^3) and Jiangxi (85.7 Bq/m^3).

The average annual radon concentration in bone-coal mining areas is from 12.0 Bq/m^3 to 73.8 Bq/m^3, with an average of 34.9 Bq/m^3, which is 1.5 times that in the reference point. The order of radon concentration is as fallows: Anhui (73.8 Bq/m^3), Hunan (42.6 Bq/m^3), Zhejiang (30.8 Bq/m^3), Jiangxi (15.5 Bq/m^3) and Hubei (12.0 Bq/m^3).

The radon concentration in the pits of Hubei and Zhejiang is 9.51×10^3 Bq/m^3 and 965 Bq/m^3 respectively, with an average of 5.24×10^3 Bq/m^3.

4.2 Radon emanation quantity

The annual radon emanation quantity in total released from the investigated mining areas in Hunan, Zhejiang and Anhui Provinces is about 2.5×10^{12} Bq.

4.3 Indoor radon level in BCCB houses

According to the regulations of ICRP65 publication[6], the action-intervention level of radon is 200 to 600 Bq/m^3 equilibrium equivalent concentrations, i.e. the level is 200 Bq/m^3 for new-built buildings and 600 Bq/m^3 for other buildings. The corresponding value, according to the State Standard of China[7], is 200 and 400 Bq/m^3 respectively.

According to this investigation, the radon concentration in BCCB houses is relatively high (from 85.7 to 303 Bq/m^3). Except Hunan, the indoor radon concentration in most BCCB houses in the mining areas in other four provinces amounts to more than 200 Bq/m^3. The average of indoor radon concentration in BCCB houses in Zhuge and Shuangpai mining areas is 406 Bq/m^3. Especially in Shuangpai, the maximum value is up to 1076 Bq/m^3 and the equilibrium equivalent radon concentration is 430 Bq/m^3. Therefore, one should pay great attention to considerable indoor radon concentration in BCCB houses, which contributes most to the additional effective dose.

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