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Outdoor radon concentration in China

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Abstract. A nationwide survey was conducted in 2014 to investigate environmental outdoor radon level in 33 provincial cities across China. The radon detector used was a passive-type solid-state nuclear track detector, CR-39. Measurements were conducted under the same condition following the quality control programme. Outdoor radon concentrations in China ranged from 3 to 30.0 Bq·m^{-3}. The annual arithmetic and geometric mean radon concentration were 14 and 13.2 Bq·m^{-3}, respectively. The radon concentrations in the locations near or along coastline were lower than the average value, while those located in the inland area were higher. As a whole, the result showed no big difference from the data measured during the period 1983–1998. It demonstrated that the outdoor radon concentration level in China has not been changing remarkably for 20 years.

Key words: radon • CR-39 • passive-type radon monitor • outdoor • nationwide survey

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Introduction

The annual effective dose to Chinese population from natural radiation exposure is about 3.1 mSv/y, of which 1.56 mSv/y or 50% is due to the exposure from radon and its daughters [1]. The enhanced natural radiation level results mainly from indoor radon concentrations rising by 70%, compared to the previous data in 1990s [1, 2]. Based on the research, the increase in indoor radon concentrations was resulted from the building materials of the dwellers and the change in ventilation. Outdoor radon concentrations may also increase as rapid industrial development in China in the past 20 years. As a result, large amount of radon was released because of the consumption of coals, oil and gas, as well as exploitation of land.

During the period from 1983 to 1998, two national radon survey were carried out by the National Health Authority and the National Environmental Authority, respectively [3–6]. Three large-scale indoor radon survey were conducted by difference institutions, the first one in 26 cities from 2002 to 2005 [7], the second one in 5 provincial cities and 12 prefectural-level cities from 2006 to 2010 [8] and the third one in 11 provincial cities from 2013 to 2014. In addition, some local governments and institutes conducted radon concentration surveys too [9, 10]. In contrast to the work done on indoor radon concentration surveys, much less were done on nationwide outdoor radon concentration surveys. The survey conducted are feathered with limited measuring points, variation of measurement methods and different scale during 1983–1998 [3–6, 11]. Therefore, a one-year survey programme was launched in 2014 by the Department of Nuclear Safety Management of Ministry of Environmental Protection to investigate outdoor radon concentrations in 33 provincial cities across China.

Methodology and methods

Radon measurement detectors

Outdoor radon concentrations were measured with solid-state nuclear track detectors (SSNTD), or CR-39. For each batch of the detectors used, the factor of detectors was calibrated in the standard radon chamber, and it was around 3.8 tracks·cm^{-2}/kBq·m^{-3}·h. The measured detector background was less than 30 tracks/m^2.

For each batch of the measurement, the distribution, installation and retrieval of the radon detectors was managed in the same time by the local monitoring teams. All detectors in the same period returned from 33 cities were collectively etched and the etch-pits were counted under the same condition for the purpose of quality control.

Measuring points

There were two outdoor radon concentration surveys that are well accepted to be the typical cases. One was carried out in Japan during 1997–1999. Another was conducted in Germany during 2003–2006. Both were characterized with the utilization of same type of detectors during the programme and the sampling points distributed in same sampling space [12, 13]. In our survey programme, there are five measuring points in each provincial city, two points in the suburb and three points in urban area. For the two suburb points and two of the three urban points, each places one detector. The rest one of the three urban points places two detectors so as to check the consistency from two detectors. One detector is used as blank for background check. Totally seven detectors are used for each of the cities.

The detectors were exposed for about three months for both the first phase and the second phase and six months for the third phase, aiming to get more counts and improve statistic errors. The procedure in outdoor radon concentration measurement referred to standard method for radon measurement in environmental air (GB/T 14582-1993) [14]. Measuring points were suggested to locate in open areas, such as in weather station, in the park, or on campus in urban area, and in the areas far from buildings in the suburb for representative and reliable results. The detectors were protected from rain and strong wind with a plastic cover, installed at a height of 1.5–3 m (Fig. 1) or placed in the meteorological shelter box.

Fig. 1. Outdoor radon measuring method.

Experiments

Outdoor radon mostly releases from the surface of the earth. The radon concentrations may change with heights [15]. In order to obtain the variations from the radon detectors installed at different measurement height in the same location, a test was carried out on the campus in the Tsinghua University in Beijing. The time when radon detectors installed and retrieved in the test was the same as in each city. Table 1 presents the result of the test conducted in the Tsinghua University. The results show that there is no significant variation when the radon detectors installed at a height of 1–3 m in the same location. Therefore, in this programme, no correlation was made for the measurements at the height between 1.5 and 3 m from the surface.

Detector background

Detector background consists of materials of CR-39 or detectors exposed when they were stored in laboratory for time consuming and during transportation from distribution and return.

A few of detectors for each period were saved in lower radiation level lead box for about three months, then together with the detectors from provincial cities were etched and the etch-pits were counted in the same conditions for back-

Table 1. Radon concentrations at different height [Bq·m^{-3}]

Measuring height [m]	Mean	Standard deviation
1.0	10	2
1.5	12	2
2.0	11	1
3.0	12	2

The detectors were installed at different height on the campus of the Tsinghua University.

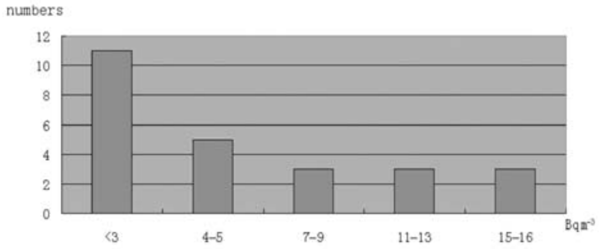

Fig. 2. Detector background from transportation and material.

ground values. The background of CR-39 detector etched pits after three months was mostly less than 30 tracks/m^2. The calibrated factor of detectors was 3.8 tracks·cm^{-2}/kBq·m^{-3}·h as mentioned earlier. Therefore, detector background from materials was <30 tracks·m^{-2} for three months, or the background equivalent radon concentration for exposure of three months is <1000*(30/3.8)/90 days/24 h or 3.6 Bq·m^{-3}.

The detector background from material and additional exposure of transportation was determined by counting the etched pits of the detector remained and returned from each city after the completion of other detectors installed in the city. The time of transportation for detectors generally took two weeks. Figure 2 gives the distribution of detector background from transportation and material for first period. Most of them are less than 3 Bq·m^{-3}. But some of them are greater than 5 Bq·m^{-3}. The higher detector background might be attributed to inappropriate seal in radon-proof bags during transportation, or improper storage. However, the addition of detector background from transportation was not significant.

Table 2. Outdoor radon concentrations in China [Bq·m^{-3}]

Administrative regions	Cities*	Annual mean	Range	Arithmetic mean**	Geometric mean***
North China	Beijing	9.3	BG-12	–	–
	Tianjing	11.6	BG-17	–	–
	Shijiazhuang	14.2	5–21	–	–
	Taiyuan	15.6	11–22	–	–
	Huhehaote	16.1	6–27	13.3	11.8
Northeast China	Shenyang	21.5	11–33	–	–
	Changchun	29.7	13–47	–	–
	Haerbin	11.1	BG-15	20.8	19.7
East China	Shanghai	3.0	BG-3	–	–
	Hangzhou	8.3	BG-17	–	–
	Jinan	6.2	BG-12	–	–
	Nanjing	8.5	BG-23	–	–
	Hefei	5.4	BG-6	–	–
	Fuzhou	11.8	7–19	–	–
	Xiamen	10.9	5–17	–	–
	Nanchang	15.7	13–17	8.7	7.1
South-center China	Zhengzhou	8.9	BG-18	–	–
	Wuchang	12.0	BG-26	–	–
	Changsha	17.6	BG-40	–	–
	Guangzhou	15.2	BG-28	–	–
	Shenzhen	18.5	3–37	–	–
	Nanning	25.8	17–37	–	–
	Haikou	10.7	BG-26	15.5	15.6
Southwest China	Chengdu	15.7	5–26	–	–
	Chongqing	15.2	4–29	–	–
	Guiyang	21.2	5–31	–	–
	Kunming	24.6	12–34	–	–
	Lasa	24.7	12–50	20.2	17.0
Northwest China	Xian	7.3	BG-12	–	–
	Lanzhou	17.0	12–24	–	–
	Xining	13.8	8–24	–	–
	Yinchuand	13.1	5–26	–	–
	Wulumuqi	11.9	5–28	12.6	11.2
Annual arithmetic mean		14.3	BG-50	annual geometric mean	13.2

BG – Background, BG < 3.6 Bq·m^{-3}. * The population of 33 cities accounts for about 20% of the population in China. ** The annual arithmetic mean radon concentration was calculated from all radon concentrations divided by measuring points. *** The annual geometric mean radon concentration was calculated from weighted population in a city.

Results and discussions

Table 2 presents the result of outdoor radon concentration survey in China. There are 165 measuring points in 33 provincial cities. The population of these cities accounts for about 20% of the population in China. Outdoor radon concentration in China ranged from 3 to 30 Bq·m^{-3}. The annual arithmetic and geometric mean radon concentrations were 14 and 13.2 Bq·m^{-3}, respectively.

As a whole, the result was similar to the previous data measured from 1983 to 1998. But it was higher than that of the world (10 Bq·m^{-3}) [1]. China is geographically regionalised into six administrative regions. The annual arithmetic mean radon concentration for each administrative region was 13.3 Bq·m^{-3} for North China, 20.8 Bq·m^{-3} for Northeast China, 8.7 Bq·m^{-3} for East China, 15.5 Bq·m^{-3} for South-center China, 20.2 Bq·m^{-3} for Southwest China and 12.6 Bq·m^{-3} for Northwest China. The annual geometric mean radon concentration for each administrative division was 11.8 Bq·m^{-3} for North China, 19.7 Bq·m^{-3} for Northeast China, 7.1 Bq·m^{-3} for East China, 15.6 Bq·m^{-3} for South-center China, 17.0 Bq·m^{-3} for Southwest China and 11.2 Bq·m^{-3} for Northwest China.

Distribution of outdoor radon concentration

China is situated in the eastern part of Asia, on the west coast of the Pacific Ocean. The territory of China extends about 5200 km from west to east, 5500 km from north to south. China topographically slopes down from west to east in a three-step staircase (Fig. 3). Most of China is situated in the temperate zone. Some parts of South China are located in tropical and subtropical zones, while the northern part is near the frigid zone. In the north part of China, summer is warm and short and winter is long and cold. The eastern and southern coastal regions of China are warm and humid. The temperatures in the interior areas of China change greatly during the daytime.

Figure 3 and Table 2 present outdoor radon concentrations distributed topographically in China. Outdoor radon concentrations were low, or most of them are lower than nationwide average in East China. The reason is thought that it was influenced by marine air with lower radon. Outdoor radon concentrations in North China were similar trends to those in East China. They increased with the distance from coastline. For example, radon concentrations were lower in Beijing and Tianjin, and higher in Shijiazhuang, Taiyuan and Huhehaote. Higher outdoor radon concentrations in Northeast China might result from continental climate. In Northwest China, arid climate theoretically facilitates radon release from the soil. But lower annual temperature affects on radon release in a certain extent. In addition, convection and dispersion of air affected by annual strong wind resulted in lower outdoor radon concentrations. In Southwest China, humid climate restricts radon release from the soil. Lower outdoor radon concentrations were measured in Chongqing and Chengdu. But arid climate in Kunming and Lasa resulted in higher outdoor radon concentrations. Distribution

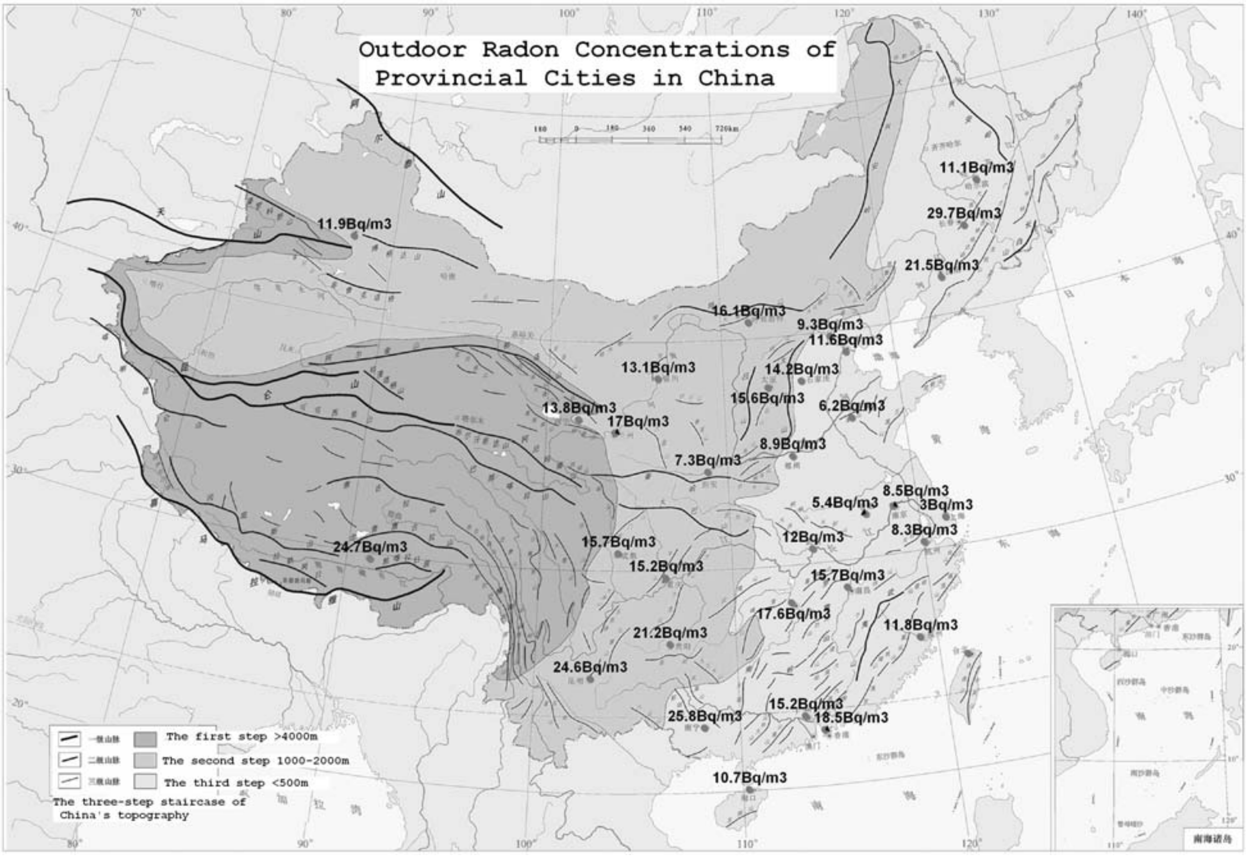

Fig. 3. Outdoor radon concentration distribution on topography.

of outdoor radon concentration in South-center China was complex. It was related to the geographical locations. Marine or coastal climate in southern area, outdoor radon concentration in Haikou was lower, but higher in Guangzhou and Shenzhen, which is thought to be related to geological conditions.

Discussion

Table 3 gives the outdoor radon concentrations compared with the result measured before 2000 by the Ministry of Public Health and the Ministry of Environmental Protection, respectively. In this programme, all radon detector were a passive-type detector (CR-39), same measuring points and method were adopted in each city in China. All detectors of each period were installed and retrieved in the same time. Therefore, the results are expected to be more reliable. While the previous surveys were conducted at different measuring points and scale. Various devices were used in the investigation, of which most were grab sampling measurement methods, such as double filter method, scintillation method and balloon method, and some were integrated measurement methods, for example, track etch method and activated charcoal method. Grab sampling measurements were performed in daytime of certain seasons. The results of grab sampling measurement were obviously influenced by weather, or meteorological conditions, as daily and seasonal variation of outdoor radon concentration were observed [3, 12, 16, 17]. The daily and seasonal variation might be balanced, as outdoor radon concentrations in random sample from grab sampling methods measured at different time and in different season, and sufficiently high number of measuring points.

Table 3 reveals that the range of outdoor radon concentrations in this programme was smaller than that measured before the year 2000. The reason was thought that long-term measurement of integrated method resulted in less statistic errors. Outdoor radon concentration in Shanghai was the lowest, and similar to the previous data [6, 10, 18], while outdoor

Table 3. Outdoor radon concentrations compared with the results measured before the year 2000

Cities	Previous measurements (before 2000)				2014 data		Deviation* [%]
	Samples	Range [Bq·m^{-3}]	Mean 1 [Bq·m^{-3}]	Method	Range [Bq·m^{-3}]	Mean 2 [Bq·m^{-3}]	
Beijing	15	0.6–14.1	8.10	Grab sampling	BG-12	9.3	13
Tianjing			9.36	Continuous	BG-17	11.6	19
Shijiazhuang					5–21	14.2	–
Taiyuan	253	0.7–79.8	14.1		11–22	15.6	10
Huhehaote	25	3.7–32.8	11.5	Grab sampling	6–27	16.1	29
Shenyang	227	1.3–103.5	9.7	Grab sampling	11–33	21.5	55
Changchun	19		5.8	Grab sampling	13–47	29.7	80
Haerbin	319		11.3	Grab sampling	BG-15	11.1	–2
Shanghai			5.1	Integrated	BG-3	3.0	–70
Hangzhou	34	4.8–11.0	8.4		BG-17	8.3	–1
Jinan	15	1.6–6.8	4	Grab sampling	BG-12	6.2	–
Nanjing	311	3.0–46	13	Grab sampling	BG-23	8.5	–53
Hefei	856	0.7–14.5	9.9	Grab sampling	BG-6	5.4	–83
Fuzhou	367	1.5–214.2	40.8		7–19	11.8	–246
Xiamen					5–17	10.9	–
Nanchang	216	1.3–13.3	9.3	Grab sampling	13–17	15.7	41
Zhengzhou	96	2.6–76.3	16.4	Grab sampling	BG-18	8.9	–84
Wuchang	70	2.2–32.7	12.4	Grab sampling	BG-26	12.0	–3
Changsha	73		26.3	Grab sampling	BG-40	17.6	–49
Guangzhou	25	6.8–26.5	14.5		BG-28	15.2	5
Shenzhen	18		13.4	Grab sampling	3–37	18.5	28
Nanning					17–37	25.8	–
Haikou	18	11.2–18.6	14.3	Grab sampling	BG-26	10.7	–34
Chengdu					5–26	15.7	–
Chongqing	208	3.7–44.3	14.4	Grab sampling	4–29	15.2	5
Guiyang	51	6.3–25.9	15.7		5–31	21.2	26
Kunming	16	10.5–52.7	28	–	12–34	24.6	–14
Lasa	50	1.5–29.2	7		12–50	24.7	72
Xian	335	2.1–76.7	26.2	Grab sampling	BG-12	7.3	–259
Lanzhou	217	0.2–105.4	22.2	Integrated	12–24	17.0	–31
Xining	161	1.8–43.11	8.01	Grab sampling	8–24	13.8	42
Yinchuang	69	3.7–60.6	13.7	Grab sampling	5–26	13.1	–5
Wulumuqi					5–28	11.9	–
Arithmetic mean			14.0		BG-50	14.3	2

BG – Background; BG < 3.6 Bq·m^{-3}. * Deviation [%] = (Mean 2 − Mean 1)/Mean 2.

radon concentration in Changchun was the highest, and at variance with the previous data. Significant variance with the previous data can be found in Xian and Fuzhou. This may be the reason that average value of previous data might represent the provincial data, not just a city. Further measurement is needed to clarify the reason behind.

As higher outdoor radon level in Fuzhou was reported in previous measurement, it has been widely concerned. An agreement result was found that a mean outdoor radon concentration was 9.5 ± 1.9 Bq·m^{-3}, ranging from 5.4 to 15.4 Bq·m^{-3} in Fuzhou and 11.2 ± 3.0 Bq·m^{-3}, ranging from 7.3 to 20.5 Bq·m^{-3} in Xian, respectively [18].

Summary

The nationwide outdoor radon concentration survey in this programme was conducted for one-year period of time in 33 provincial cities across China. The passive-type detector (CR-39) was emplaced in the suburb and urban area of each city. The annual arithmetic and geometric mean outdoor radon concentrations in China were 14 and 13.2 Bq·m^{-3}, respectively. The radon concentrations in the locations near or along coastline were lower than the average value. This might be due to the influence of marine air. The result in this programme was similar to the previous annual average measured 20 years ago. No significant change in outdoor radon occurred in the past 20 years.

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