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# A survey of radon level in underground buildings in China

Xiaoyan Li *, Baoshan Zheng, Yan Wang, Xue Wang

*Institute of Geochemistry, Chinese Academy of Sciences, GuiYang 550002, China*

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## Abstract

From 2003–2004, using solid state nuclear detectors, a survey of the air radon level in 234 underground buildings in 23 cities of China was carried out during spring as well as summer and winter. The annual radon concentrations in these underground buildings range from 14.9 to 2482 Bq m$^{-3}$, with an overall mean value of 247 Bq m$^{-3}$. When radon concentrations are averaged according to cities, Fuzhou and Baotou have the relatively higher radon levels, which are 714 and 705 Bq m$^{-3}$, respectively. Guangzhou and Shanghai have the relatively lower radon levels with 71.1 and 72.6 Bq m$^{-3}$. The annual effective dose by exposure to radon received by people working in these cities is concluded to be 1.6 mSv. The geological formation, coating level, decorating materials and ventilation situation all affect the radon concentration in underground buildings. The radon level in underground buildings has the lowest value in winter and the highest value in summer.

*Keywords:* Underground buildings; SSNTDs; Distribution; Radon

## 1. Introduction

Radon is a radioactive gas arising from the uranium decay chain, and is the largest single source of radiation exposure to population (Fovt et al., 1999). High radon exposures have been shown to cause lung cancer (Miles, 1988), and it is widely believed that the greater the exposure to radon, the greater the risk of developing lung cancer (Yang et al., 1999). Radon is a well-known natural hazard, which is why mitigation of the health risks due to exposure to radon and radon decay products is a problem of vital importance for human life (Iakovleva and Karataev, 2001).

The air radon comes mainly from the underground soil and construction materials. In general, $^{222}$Rn has the highest level in basements and underground spaces that are in contact with the soil (Anastasiou et al., 2003).

A large numbers of radon surveys have been carried out in spaces above the ground level in China and other countries (Jin et al., 1996; Koi and Kobayashi, 1996; Kies et al., 1996; Virk, 1999; Srivastava et al., 2001; Kullab et al., 2001).

In China, as the economy is developing and the population is expending, more and more underground buildings have been used as supermarkets, restaurants and entertainment places. So the radon level in underground buildings has become a hot issue (Yu et al., 1999; Yang et al., 2000; Yang and Zhang, 2004). However, large-scale surveys of radon in underground spaces were relatively insufficient. To take full advantage of the underground buildings, it is necessary to know the distribution of radon in underground buildings at first. In spring, summer and winter of 2003 and 2004, using solid state nuclear detectors, we performed a survey of the air radon level in 234 underground buildings in 23 cities of China. This paper described the distribution of radon in these underground buildings and in some of these cities. The factors causing high radon levels were analyzed as well.

## 2. Studied cities and sites selection

Studied cities were selected according to the following two factors. Firstly, the cities were selected if they were located in the zones of radioactive rocks or fractures. Secondly, some highly developed cities were also selected in this research. Therefore, the following 23 cities were chosen for the survey (shown in Fig. 1).

Well developed cities: Beijing, Shanghai
Granite region: Fuzhou, Quanzhou, Xiamen, Guangzhou,

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* Corresponding author.
*E-mail address:* lxyan421@hotmail.com (X. Li).

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Fig. 1. The studied cities on the map of China.

Shantou, Yangjiang, Wenzhou, Ningbo, Changsha, Qingdao
Karst region: Guiyang, Guilin
Capitals and other cities: Huhhot, Baotou, Jining, Erdos, Jinan, Nanchang, Shangrao, Zhengzhou, Wuhan.

Radon concentrations in approximately 10 underground buildings were measured in each city, and the geological formations, decorating materials, ventilation conditions and so on of each measured site were also recorded. The studied underground buildings include basements, parking garages and tunnels. Basements and parking garage of studied underground buildings were built under recently constructed high buildings and most basements are used as supermarkets, offices, hospitals, restaurants or entertainment places, where people are working. For tunnels, some were built during the war period (Before 1949, B.C.) as air-raid shelters and now most of them are closed and abandoned, while others were built for entertainment during the peace period (From 1949 to now).

## 3. Surveying method

Above the ground level, the highest radon activity appears in summer and the lowest in winter, radon in autumn is similar to that in spring and they are close to the annual radon concentration (Wangxiehua, 1996). In consideration of this seasonal fluctuation, the radon concentrations in underground buildings of 12 cities, among which most are located in granite regions, were measured in spring, summer and winter. The sites in other cities were measured in summer and winter. The annual radon concentrations were obtained by averaging the concentrations in different seasons.

Solid state nuclear detectors (CR-39 detectors made in China) were used for the measurement. The main ingredient of CR-39 is Allyl Diethylene Glycol Carbonate, which is sensitive to α particles and is used widely in accumulating radon measurements.

The detectors of size 1 × 1 cm were mounted in a detector box with a filter film filtering radon daughters. The detector boxes were hung in underground buildings at a distance of

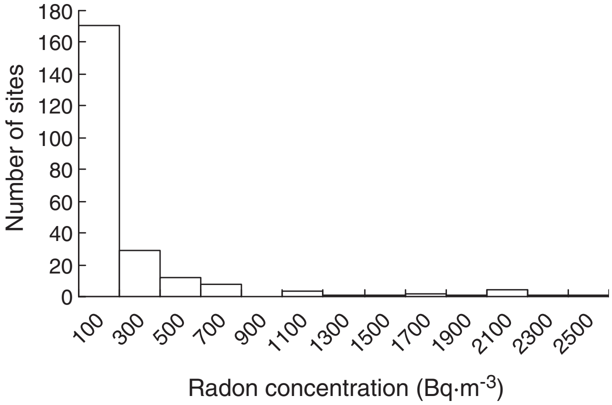

Fig. 2. The total distribution of annual radon concentration.

Table 1
The annual radon and corresponding data of cities (Bq m$^{-3}$)

| Cities | Number of cites | Ranges | Annual radon concentration | Standard deviation |
|---|---|---|---|---|
| Guangzhou | 11 | 22.9–267 | 71.1 | 75.7 |
| Yangjiang | 2 | 14.9–49.1 | 32.0 | 24.2 |
| Shantou | 12 | 39.9–504 | 195 | 167 |
| Xiamen | 13 | 32.7–498 | 142 | 120 |
| Quanzhou | 7 | 62.3–201 | 96.8 | 48.7 |
| Fuzhou | 16 | 80.3–2482 | 714 | 764 |
| Wenzhou | 10 | 27.3–639 | 170 | 188 |
| Ningbo | 10 | 40.5–548 | 120 | 157 |
| Shanghai | 9 | 41.3–148 | 72.6 | 35.3 |
| Shangrao | 11 | 29.0–676 | 90.3 | 187 |
| Nanchang | 9 | 34.5–233 | 123 | 68.5 |
| Guiyang | 24 | 26.9–2075 | 231 | 566 |
| Huhhot | 10 | 39.2–482 | 190 | 213 |
| Baotou | 16 | 76.1–2286 | 705 | 845 |
| Jining | 6 | 35.0–462 | 190 | 157 |
| Erdos | 4 | 64.1–387 | 276 | 167 |
| Beijing | 9 | 54.2–266 | 153 | 70.9 |
| Jinan | 7 | 31.1–1560 | 344 | 541 |
| Qingdao | 10 | 30.5–476 | 156 | 141 |
| Zhengzhou | 9 | 60.7–743 | 143 | 217 |
| Wuhan | 11 | 19.9–289 | 142 | 87.8 |
| Changsha | 8 | 47.4–1097 | 401 | 405 |
| Guilin | 10 | 38.2–344 | 130 | 94.2 |
| Total |  | 32.0–714 | 213 |  |

about 20 cm from any surface. Radon was diffused into the detector box and decay to its daughters and alphas, while radon daughters were filtered outside the detector box. The alphas originating from radon and its progenies were registering tracks in the detectors. The detectors were exposed in underground buildings for about 3 months before they were retrieved from all sites and sent back to lab for etching in 7N KOH at 70 °C for 6 h. At last, radon concentrations were obtained from the detectors using optical microscopes at a magnification of 630×.

The detectors were calibrated in the Radon Laboratory, School of Nuclear Science and Technology, Nanhua University in Hengyang, China, which is Asia's regional coordination laboratory for international Radon Metrology Program (IRMP). 4.218 tracks cm$^{-2}$ (KBq m$^{-3}$ h)$^{-1}$ were obtained for $^{222}$Rn. Meanwhile, 17 duplicate measurements were produced and the variation coefficients were less than 20%. The measured limitation was 8.654 Bq m$^{-3}$ if the detectors were exposed for 3 months, and can meet the requirement of the survey.

Detectors were also calibrated for $^{220}$Rn in the same situation as for $^{222}$Rn, and obtained 0.159 tracks cm$^{-2}$ (KBq m$^{-3}$ h)$^{-1}$, which accounted for 3.8% of that of $^{222}$Rn. So the obtained data is mainly from $^{222}$Rn.

## 4. Results and discuss

### *4.1. The overall distribution of annual radon concentration*

Totally 674 detectors were exposed in the survey and 601 of them were sent back to the lab. For each site, its annual radon concentration is obtained by averaging its radon concentration in spring, summer and winter or in summer and winter. The highest annual radon concentration (2482 Bq m$^{-3}$) was detected at a site in Fuzhou, and the lowest one (14.9 Bq m$^{-3}$) was found in an underground office in Yangjiang. The average annual radon concentration of all 234 underground buildings was 247 Bq m$^{-3}$. The overall distribution of radon in these underground buildings was shown in Fig. 2.

The safe limitation of radon and its daughters is 200 Bq m$^{-3}$ in equilibrium equivalent concentration for type I underground buildings (constructed after 1979, meeting a public standard of China), and 400 Bq m$^{-3}$ for type II underground buildings (constructed before 1979, not meeting the public standard) (GB/T 17216—1998). From Fig. 2, it is found that most underground buildings have radon concentrations under 200 Bq m$^{-3}$. Among the 234 underground buildings, 200 buildings have annual radon concentrations below 400 Bq m$^{-3}$, and another 20 have annual radon concentration below 800 Bq m$^{-3}$. With the equilibrium factor at 0.5 (Wang, 1994), 85% of

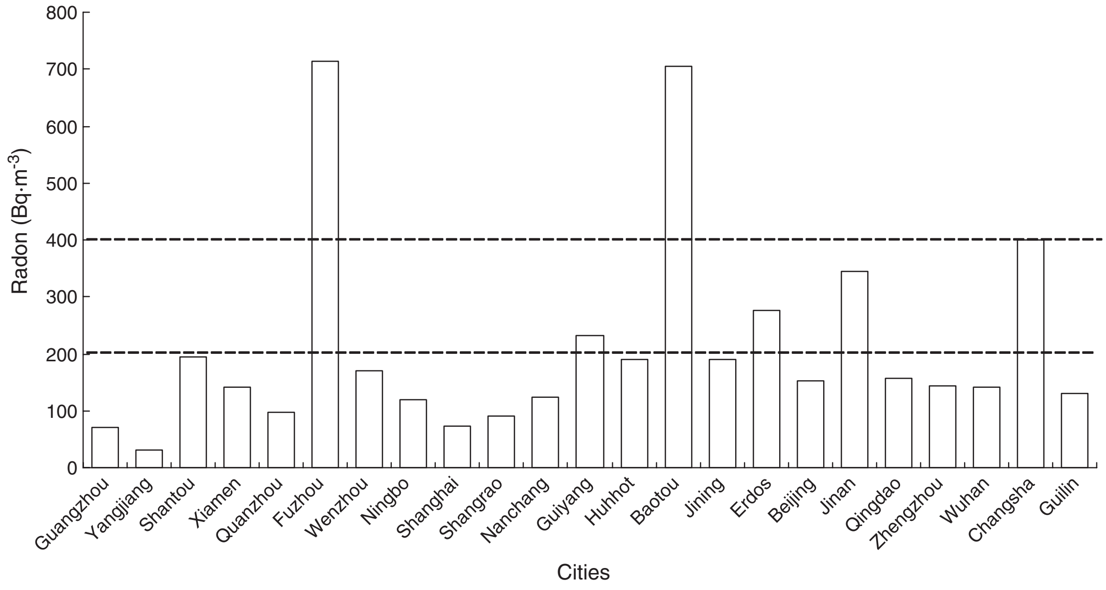

Fig. 3. The distribution of radon in underground cities.

Table 2
Radon in underground buildings in Fuzhou

| Sites | Primary decorating (coating) materials | Ventilation condition | Use condition | Radon concentration |
|---|---|---|---|---|
| 1 | Concrete | Forced ventilation | Fire control center | 80.3 |
| 2 | Concrete | Forced ventilation | Alleyway | 106 |
| 3 | Concrete | Nature ventilation | U | 247 |
| 4 | Calcareousness, ceramic tile | Nature ventilation | U | 239 |
| 5 | Concrete | Nature ventilation | Two people lived at night | 257 |
| 6 | Concrete | Forced ventilation | Bookstore | 130 |
| 7 | / | Forced ventilation | Water pump room | 276 |
| 8 | / | Nature ventilation | U | 755 |
| 9 | / | Nature ventilation | U | 2482 |
| 10 | / | Nature ventilation | U | 2016 |
| 11 | / | Nature ventilation | U | 1051 |
| 12 | Concrete | Nature ventilation | U | 432 |
| 13 | Concrete | Nature ventilation | U | 286 |
| 14 | Concrete | Nature ventilation | U | 1299 |
| 15 | / | Nature ventilation | U | 1660 |
| 16 | / | Forced ventilation | Office | 112 |

/ represents non-decorated and exposed to original rock; U represents unoccupied.

the studied buildings would have radon concentrations within the safe range for type I underground buildings, and 94% of the studied buildings would be within safe range for type II underground buildings.

### 4.2. Annual average radon concentrations of researched cities

The annual radon concentrations and its standard deviations of each city are listed in Table 1. The annual radon concentration of each city was obtained by averaging the data of all sites in the same city. The numbers of surveyed sites were shown as well. Fig. 3 showed the distribution of the annual radon of the researched cities.

The annual radon concentrations of these 23 cities ranged from 32.0 to 714 Bq m$^{-3}$, with an average value at 213 Bq m$^{-3}$. Among them, 17 cities have radon levels lower than 200 Bq m$^{-3}$, 20 are lower than 400 Bq m$^{-3}$, and all cities have radon levels below 800 Bq m$^{-3}$. It means that 87% of the surveyed cities have underground radon level below the safe limit for type I underground buildings, and data of all cities were below the limit for type II underground buildings.

From Fig. 3, it is shown that Fuzhou and Baotou have relatively high radon levels, which were 714 and 705 Bq m$^{-3}$, respectively. Without regarding Yangjiang (only two sites and the data could not represent the radon level of the whole city), Guangzhou and Shanghai have relatively low levels (71.1 Bq m$^{-3}$ of Guangzhou, 72.6 Bq m$^{-3}$ of Shanghai). This result is compatible with the research of radon above ground in China (Jin et al., 1996).

Radon in each site in Fuzhou and Baotou are shown in Tables 2 and 3. Fuzhou is located in a granite region. All studied underground buildings in Fuzhou were built in granite mountain and some of them are not coated completely. The underground building with the highest radon level (2482 Bq m$^{-3}$) in this survey is a tunnel in a granite mountain. The tunnel is not coated and surrounded with original granite rock, furthermore, there is an underground reservoir in it. The sampling site is near the underground reservoir.

In Baotou city, three sites(sites 3, 7, 12) which radon concentrations are higher than 2000 Bq m$^{-3}$ are unoccupied tunnels. There are four sites with radon concentrations below 100 Bq m$^{-3}$, among these, two sites have forced ventilation systems and among the other two sites, one is a sub-underground building, one is coated with concrete. The site with lowest radon concentration is a shop with forced ventilation.

### 4.3. The received annual effective dose by exposure to radon

Among these studied underground buildings, there are 87 underground working places where people are working for 8 h in working days. The annual radon concentrations are in a range from 14.9 to 498 Bq m$^{-3}$ with an overall arithmetic mean value of 107 Bq m$^{-3}$. There are about 115 holidays in 1 year, so there are about 250 working days without considering working overtime. If people have to work 8 h every day, and 0.8 and 0.2 are elected to be the factor that people stay in a room and out of the room, the time that people spent staying in underground spaces, indoor above the ground level and outdoor above the ground level, is 2000, 5008 and 1752 h, respectively.

Table 3
Radon in underground buildings in Baotou

| Sites | Primary decorating (coating) materials | Ventilation condition | Use condition | Radon concentration |
|---|---|---|---|---|
| 1 | Granite | Forced ventilation | Electricity store | 94.1 |
| 2 | Granite, wood | Forced ventilation | Furniture store | 148 |
| 3* | Gneiss | Nature ventilation | U | 2133 |
| 4* | Concrete, wood | Nature ventilation | U | 181 |
| 5* | Concrete | Nature ventilation | U | 762 |
| 6 | Concrete | Nature ventilation | Office | 357 |
| 7* | Gneiss | Nature ventilation | U | 2286 |
| 8 | Concrete | Nature ventilation | U | 189 |
| 10* | Gneiss, concrete | Nature ventilation | U | 1635 |
| 11 | Concrete | Nature ventilation | U | 619 |
| 12* | Gneiss | Nature ventilation | U | 2187 |
| 13 | Concrete | Nature ventilation | U | 189 |
| 14 | Concrete | Sub-underground, nature ventilation | Hospital room | 87.4 |
| 15 | Concrete | Nature ventilation | Machine room | 115 |
| 16 | Concrete | Nature ventilation | Machine room | 97.4 |
| 17 | Granite | Forced ventilation | Shop | 76.1 |

U represents unoccupied. *Represents tunnels.

With equilibrium factor at 0.5, transfer factor $9\,\mathrm{nSv}(\mathrm{Bq\,h\,m^{-3}})^{-1}$ (Pan, 2003) is elected, the annual effective dose by exposure to radon is obtained by the formula below:

$$H_{\mathrm{Rn}} = C_{\mathrm{EEC}} \times K \times T,$$

| | |
|---|---|
| $H_{\mathrm{Rn}}$ | the annual effective dose (mSv) |
| $C_{\mathrm{EEC}}$ | equilibrium equivalent radon concentration ($\mathrm{Bq\,m^{-3}}$) |
| $K$ | transfer factor |
| $T$ | occupied hours (h) |

The indoor and outdoor equilibrium equivalent radon concentration in China is 12, 8 $\mathrm{Bq\,m^{-3}}$, respectively (Pan, 2003). Accordingly the average radon concentration is 107 $\mathrm{Bq\,m^{-3}}$ in underground working places. The annual effective dose by exposure to radon received by people working in underground working places in China is concluded to be 1.6 mSv. The max value of 498 $\mathrm{Bq\,m^{-3}}$ appears in Xiamen where the indoor and outdoor radon concentration in China is 51.8, 48.7 $\mathrm{Bq\,m^{-3}}$ (Pan, 2003), respectively. The annual effective dose by exposure to radon received by people working in this underground working place is concluded to be 6.0 mSv.

### 4.4. The factors affecting radon concentration

From comparing the condition of underground buildings of cities, it is found that geological formation, decorating (coating) materials and ventilation condition are main factors affecting the radon concentration in underground buildings.

Geological formation is one of the main factors affecting the radon concentration in underground buildings. Most non-coated underground buildings of Fuzhou have radon concentrations above 1000 $\mathrm{Bq\,m^{-3}}$ because they are exposed to original granite rock (Table 2). Shanghai is in a deposited plain formed with silt from upper and middle reaches of the Changjiang River (Wu et al., 1998), so underground buildings in Shanghai have a relatively lower radon concentration though some of them are non-coated.

Decorating (coating) materials are also a main factor affecting the radon concentration in underground buildings, which is very clear from discussing radon concentrations in underground buildings in Baotou. Observing Table 3, sites 3, 4, 5, 7, 10, and 12 are tunnels all located in a metamorphic rock region and with nature ventilation. Sites 3, 7, 10, and 12 are coated with gneiss, which also has high radionuclide activities, so the average radon of the 4 tunnels is 2060 $\mathrm{Bq\,m^{-3}}$. Site 5 is coated with concrete and its radon concentration is 762 $\mathrm{Bq\,m^{-3}}$. Site 4 is coated with concrete and wood and its radon concentration is only 181 $\mathrm{Bq\,m^{-3}}$.

Ventilation condition is an important factor affecting the radon concentration in underground buildings (Li et al., 2005). Guangzhou is also located in granite region, but its radon in underground buildings is lower than that in other cities. The main reason is that most of underground buildings in Guangzhou adopted forced ventilation. Comparing the ventilation condition of 87 underground working places, it is found that the average radon concentrations in 40 underground working places with forced ventilation is obviously lower than that in 47 underground working places with nature ventilation (Fig. 4).

Furthermore, there are many other factors affecting radon concentration of underground buildings, and all factors combine together to form a mutual effect. Therefore, even in the same city, radon concentrations of different underground buildings may be different.

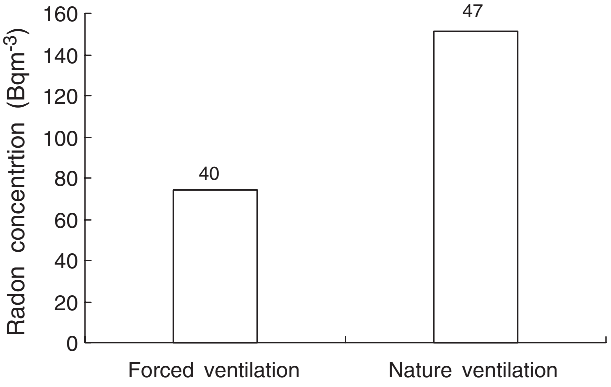

Fig. 4. Radon concentration in different ventilations.

### 4.5. The radon seasonal variation

The survey also shows a seasonal radon variation. Similar to reports from other scholars (Muramatsu et al., 2002; Perrier et al., 2004), underground buildings have the highest radon level in summer and the lowest in winter (Li et al., 2006). The number of cities with radon levels lower in winter and higher in summer is 21, which is 91% of the total number of the survey cities.

## 5. Conclusions

The annual radon concentrations in 234 underground buildings in China range from 14.9 to 2482 $\mathrm{Bq\,m^{-3}}$, with a overall mean value 247 $\mathrm{Bq\,m^{-3}}$. When radon concentrations are averaged according to cities, Fuzhou and Baotou have the relatively higher radon levels, which are 714 and 705 $\mathrm{Bq\,m^{-3}}$, respectively. While Guangzhou and Shanghai have the relatively lower radon levels which were 71.1 and 72.6 $\mathrm{Bq\,m^{-3}}$. The annual effective dose exposure to radon received by people working in these cities is concluded to be 1.6 mSv. In the underground working places with max radon value in Xiamen, the annual effective dose received by people is 6.0 mSv. The geological formation, decorating materials and ventilation situation are the main factors affecting the radon concentration in underground buildings. For most underground buildings, the radon level in summer is higher than that in winter.

## References

Anastasiou T, Tsertosa H, Christofides S, Christodoulides G. Indoor radon ($^{222}$Rn) concentration measurements in Cyprus using high-sensitivity portable detectors. Journal of Environmental Radioactivity 2003;68: 159–69.

Fovt LL, Baixeras C, Domingo C, Fernandez F. Experimental and theoretical study of radon levels and entry mechanisms in a Mediterranean climate house. Radiation Measurements 1999;31:277–82.

GB/T 17216. Hygienic standard for peacetime utilization of civil air defence works; 1998.

Iakovleva VS, Karataev VD. Radon levels in Tomsk dwellings and correlation with factors of impact. Radiation Measurements 2001;34:501–4.

Jin Y, Wang Z, lida T, lkebe Y, Abe S, Chen H, et al. A new subnationwide survey of outdoor and indoor $^{222}$Rn concentrations in China. Environment International 1996;22(Suppl. 1):657–63.

Kies A, Biell A, Rowlinson L, Feider M. Radon survey in the Grand-duchy of Luxembourg—indoor measurements related to house features, soil, geology, and environment. Environment International 1996;22:805–8 [Suppl].

Koi M, Kobayashi S. Survey of concentration of radon isotopes in indoor and outdoor air in Japan. Environment International 1996;22:649–55 [Suppl].

Kullab MK, Al-Bataina BA, Ismail AM, Abumurad KM. Seasonal variation of radon-222 concentrations in specific locations in Jordan. Radiation Measurements 2001;34:361–4.

Li Xiaoyan, Zheng Baoshan, Wang Yan, Wang Xue. A study of daily and seasonal variations of radon concentrations in underground buildings. Journal of Environmental Radioactivity 2006;87:101–6.

Li Xiaoyan, Wang Yan, Zheng Baoshan, Wang Xue. A study of reducing radon level by ventilation in underground space. Nuclear Techniques 2005;28:954–6.

Miles Jon. Development of maps of radon-prone areas using radon measurements in houses. Journal of Hazardous Materials 1988;61:53–8.

Muramatsu H, Tashiro Y, Hasegawa N, Misawa C, Minami M. Seasonal variations of $^{222}$Rn concentrations in the air of a tunnel located in Nagano city. Journal of Environmental Radioactivity 2002;60:263–74.

Pan Ziqiang. Exposure resulted from radon and its decay products in air in China. Radiation Protection 2003;23:134–7.

Perrier Frédéric, Richon Patrick, Crouzeix Catherine, Morat Oierre, Mouël Jean-Louis Le. Radon-222 signatures of natural ventilation regimes in an underground quarry. Journal of Environmental Radioactivity 2004;71:17–32.

Srivastava A, Zaman MR, Dwivedi KK, Tamachandran TV. Indoor radon level in the dwellings of the Rajshahi and Chuadanga regions of Bangladesh. Radiation Measurements 2001;34:497–9.

Virk HS. Indoor radon levels near the radioactive sites of Himachal Pradesh, India. Environment International 1999;25:47–51.

Wang Wuan. Methods for determination of equilibrium ratio between radon daughters and radin (*f* value). Uranium Mining and Metallurgy 1994;13:126–9.

Wangxiehua. Radon level in air environment. Chinese Journal of Radial Health 1996;5:139–41.

Wu Shuilong, Zhang Yuqing, Zhu Yongkang, Lu Jing, Chen Beihua. The concentration and distribution of radionuclides in soil in Shanghai area. Chinese Journal of Radiological Medicine and Protection 1998;8:46–50.

Yang Shouming, Zhang Puling. A survey of the radon and its daughters in underground public spaces. Jingsu Preventive Medicine 2004;15:43–4.

Yang Wenjie, LeiYang, Lu Yufeng, Liu Hongtao, ShuangWang, Lu Yanhua, Li Weiquan. Measuring $^{222}$Rn level in underground space by SSNTD'S. Chinese Journal Health 1999;3:93.

Yang Juanjuan, Guan Qingchao, Chen Yue, Zhang Lianping, Song Gang, Wen Jihui, Liu Shiming. Analysis of radon concentration in underground supermarket of Shandong Province. Chinese Journal of Radial Health 2000;9:18–9.

Yu Shui, Wang Gongpeng, Luo Yisheng, Fan Feiyu, Liu Guolian. Survey of radon concentration and mitigation techniques in some dwellings and galleries. Radiation Protection 1999;19:195–9.