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TECHNICAL REPORT

Radon Levels in China

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This paper reviewed and summarized the results and problems of a nation-wide environmental radon survey which was carried out from 1984 to 1990 in China. Indoor radon concentrations were measured in 10,811 dwellings, and which covered 26 provinces and cities all over China. The range of indoor radon concentrations was <LLD-386.8 Bq·m^{-3}, the average was 22.5 Bq·m^{-3} and 19.6 Bq·m^{-3} for arithmetic mean and geometric mean, respectively. Both outdoor radon concentrations and indoor radon progeny concentrations were also reported. Even though the grab sampling was taken as the main method of the survey, it was still a valuable reference.

KEYWORDS: radon, radon 222, survey, survey monitors, concentration, radioactivity, China

I. Introduction

The inhalation of radon (^{222}Rn) and its progeny in dwellings is one of the most important sources of natural radiation exposure to the public. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), about half of the annual effective dose received by human beings living in radiation normal background areas of the world is contributed from the inhalation of ^{222}Rn and its progeny.[1)]

There are great changes in China with the country-wide development both in economy and in the lifestyle in recent years, such as living situation, dwelling construction, composition change of building materials and the use of air condition. As a consequence, the exposure from natural radiation to the general population is supposed to be growing,[2,3)] especially the exposure concerning indoor radon levels. And today a nation-wide investigation on public exposure due to natural radiation, especially on the increase of the exposure is planning at present.

It is necessary and important to know the accurate radon levels in the early years when we evaluate the increase of the exposure today. There was a nation-wide environmental radon survey in the period from 1984–1990 was ever carried out under the coordination of the Laboratory of Industrial Hygiene, Ministry of Health (LIH), but still no general conclusion has been given out for some reasons until now. One of the reasons, for example, is that grab sampling was taken as the main method throughout the radon survey. Even though the radon survey introduced by this paper was not enough both in the number of dwellings and in the duration in some areas, as a preparative work of the investigation planning now, all the results reported by local individuals, who participated in the radon project during 1984–1990 were reviewed and summarized, and it is still a valuable reference.

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II. Methodology

1. Principles of Selecting Sampling Sites

The nation-wide radon survey was coordinated by LIH, carried out by all the institutions that belong to the Chinese National Environmental Radioactivity Monitoring Network (CNERMN), located in provinces, municipal region or city all over the country. Sampling sites were selected by local investigators based on principles of representative in the feature of both geographical, architecture characteristics and living custom, as well as the population factor in each area. The number of sampling sites were determined by the ability and resources of local institution, however, a minimum number, not less than 1 site per half million population, was requested by LIH for statistical concern.

Normally two indoor samplings in different measurement points, which at least one in bedroom, were chosen at each site. Usually, the sampling points were at a height of 1.5 m above floor and with distances larger than 0.5 m from walls.

2. Sampling and Measurement Methods

(1) Grab Sampling and Measurement

For the limited measurement condition at that time, most of the institutions in local province took a grab sampling during the survey, but not integrating measurement that applied for environmental evaluation at the present time. There were three kinds of grab sampling and measurement methods were made use of for radon and its progeny measurements during the nation-wide survey, as listed in **Table 1**. The dual-filter environmental radon monitors used had a decay volume of 15 *l* with a filter-tank length of 1.04 m. The flow rate of sampling was 30 *l*·min^{-1}, and the filter was measured by FJ-13 alpha radiation detector (made in China) after sampling. Its lower limit of detection (LLD) with 95% reliability was about 2.3 Bq·m^{-3} of radon for 30 min sampling time. The second grab sampling technique used was a scintillation flask radon monitor with a volume of 0.7 *l* and background of about 0.06 counts per min. Its LLD was about 3.6 Bq·m^{-3} of radon. Another grab method used by some institutions was plastic balloon,[4)] which was evolved from the dual-filter monitor.

Table 1 Measurement methods and instruments used during the survey

Methods	Instruments and equipment	Lower limit of detection	
		Radon ($Bq\cdot m^{-3}$)	PAEC (mWL)
Grab sampling			
(a) Dual-filter	FT620 radon monitor	2.3	2.1
(b) Scintillation flask	ZYW-8501 radon monitor	3.6	
(c) Balloon	FDT-84 radon monitor	3.7	2.1
Integrating measurement			
Activated carbon	γ-spectrometer	4.4	

The decay volume of the balloon was of 1 m^3, and it was also detected by FJ-13 alpha radiation detector. The LLD with 95% reliability was 3.7 $Bq\cdot m^{-3}$.

The improved Tsivoglou and Markov methods[4] were used for measuring radon progeny by most institutions. LLDs for radon progeny are also listed in Table 1.

(2) Integrating Measurement

Passive integrated activated carbon radon monitors, with LLD of about 4.4 $Bq\cdot m^{-3}$ for an exposure period of 3 to 4 d, were used during the survey in Beijing area.[5] There were 506 dwellings were measured by the integrating monitors and the result is given in **Table 2**.

(3) Quality Assurance

Several quality assurance measures on radon and its daughters measurements were taken during the whole process of the nation-wide radon survey:

(a) All the measurement methods employed were tested and intercompared before applying to practice.

(b) All the measurement instruments were calibrated with standard sources which were able to trace back to national standard. Many of the instruments were calibrated at LIH radon laboratory regularly.

(c) Three inter-laboratory intercomparisons on grab radon sampling-measurements were organized by LIH during the course of survey. Results showed that the differences with the LIH reference values were within one standard deviation band for 80% of the participants and were within two standard deviation for all the participants.

(d) The Laboratory of Industrial Hygiene, Ministry of Health (LIH) participated four times international intercomparisons on grab sampling with its scintillation flask from 1987–1988. It indicated that 90% of the LIH results were agreeable within ±8% and 100% with ±10% with the reference values given by EML (Environmental Measurements Laboratory, USA), ARL (Australian Radiation Laboratory, Australia) and SNIRP (Sweden National Institute of Radiation Protection, Sweden).

III. Results and Discussions

1. Indoor Radon Concentrations

Table 2 listed up all the data of indoor radon concentrations which were reported by local individuals, who participated in the radon project. There were 10,811 dwellings located in 26 provinces or cities were concerned totally. For your convenience, **Fig. 1** gives the map of China and all the names and locations of each province are shown clearly.

The results was shown in Table 2. The range of all the radon concentrations measured was from <LLD to 386.8 $Bq\cdot m^{-3}$ (in Shanxi Province). The reported province-averaged concentrations varied from province to province as listed in Table 2. Based on the data of Table 2, the nation-wide average indoor radon concentration was estimated to be 22.5 $Bq\cdot m^{-3}$ for the arithmetic average and 19.6 $Bq\cdot m^{-3}$ for the geometric average, respectively.

2. Outdoor Radon Concentrations

Radon concentrations in outdoor air were measured at 4,302 sites by the network in the nation-wide survey, totally. The range of outdoor radon concentrations was from <LLD to 163.0 $Bq\cdot m^{-3}$ (in Fujian Province). According to the mean value of each province in **Table 3**, it was calculated that for the whole country, the arithmetic average was of 10.0 $Bq\cdot m^{-3}$ and the geometric average was of 8.1 $Bq\cdot m^{-3}$ as shown in Table 3.

3. Indoor Radon Progeny Concentrations

Indoor radon progeny concentrations, in terms of potential alpha energy concentration, were investigated in 4,788 sites, and the results was listed in **Table 4**. The measured range of indoor progeny concentrations was from <LLD to 55.2 mWL. Based on the province-averaged data, the nation-averaged indoor radon progeny concentration can be estimated to be 3.2 mWL for the arithmetic average and 2.1 mWL for the geometric average as shown in Table 4.

4. Geographical Distribution

It was showed that the province-averaged indoor radon concentrations had a obviously geographical variation. The highest province-averaged value of 51.8 $Bq\cdot m^{-3}$ (geometric mean) was found in Fujian Province, the next was 36.1 $Bq\cdot m^{-3}$ in Hunan Province, about 2.6 and 1.8 times of the country-average value, respectively. A survey of natural radionuclide contents in soil in China was carried out in the period of 1983–1990, according to the results of the project, ^{226}Ra contents in soil nation-wide showed a trend of higher in the South and lower in the North.[31] However, the indoor radon concentrations did not show a good correlation with ^{226}Ra contents in soil in general. This can be explained that the hot climate of the South made windows or doors keeping open all the year, and the 'open' status resulting to much higher ventilation rates of dwellings. As a result, on general,

Table 2 Indoor radon concentrations in China (1984–1990) (Bq·m^{-3})

Provinces or areas	Dwelling number	Range	Arithmetic mean	Geometric mean	Equilibrium factor (F-value)	Reference
Beijing	506	<LLD-259.0	30.3	20.6		5)
Hebei	73		22.3		0.37	6)
Shanxi	204	<LLD-386.8	27.5	18.5	0.50	7)
Neimeng	277	3.8-335.4	31.5	22.3	0.31	8)
Liaoning	397	<LLD-244.2	29.6	19.0	0.49	9)
Jilin[a)]	51		8.7±1.0		0.50	10)
Heilongjiang[a)]	413		20.8±20.1	13.3±2.3	0.44	11)
Shanghai	148	2.4–31.5	9.2	7.5	0.50	12)
Jiangsu	486	3.2–80.0	16.0	13.0	0.42	13)
Zhejiang	351		17.2			14)
Anhui	856	<LLD-151.5	16.2	12.0		15)
Fujian	338	3.5–318.0	52.7	51.8	0.49	16)
Jiangxi	343	4.6–78.1	20.7	19.1	0.54	17)
Shandong	46	8.5–36.5	18.7	18.0	0.45	18)
Henan	346	3.4–111.8	21.5	16.7		19)
Hubei	380	3.7–377.9	22.5		0.53	20)
Hunan[a)]	78		42.8±27.0	36.1±1.0	0.51	21)
Shenzhen	69	3.3–54.0	16.0	14.0	0.20	22)
Sichuan	2,686	<LLD-374.0	20.8	15.5	0.58	23)
Guiyang	224	15.6–73.2	31.9			24)
Tibet	160	<LLD-75.0	9.6	7.1	0.57	25)
Shanxi	837	2.9–189.7	43.3	36.5	0.60	26)
Gansu	1,213	<LLD-274.1	24.4	20.3	0.38	27)
Qinghai	162	<LLD-105.3	20.9	17.6	0.43	28)
Ningxia	149	2.7–91.2	21.3	16.8	0.48	29)
Haikou	18	12.1–20.7	16.1	15.7	0.52	30)
Total	10,811	<LLD-386.8	22.5	19.6	0.47±1.0	

[a)] The results of radon concentrations of these provinces were only reported as Mean±SD, but no ranges.

Fig. 1 Locations of each province in China

Table 3 Outdoor radon concentrations (1984-1990) (Bq·m^{-3})

Provinces or areas	Site number	Range	Arithmetic mean	Geometric mean	Equilibrium factor (F-value)	Reference
Beijing	15		8.1±4.1	6.7±2.4		5)
Shanxi	65	<LLD-32.5	8.8	7.5	0.7	7)
Liaoning	71	<LLD-103.5	9.6	7.5	0.61	9)
Jilin[a)]	19		5.8±0.2		0.67	10)
Heilongjiang[a)]	319		11.3±11.1	6.7±3.1	0.54	11)
Shanghai	119	<LLD-11.5	5.0	4.3	0.7	12)
Jiangsu	311	3.0–46.0	12.0	9.9	0.49	13)
Zhejiang[a)]	166		12.7			14)
Anhui	453	<LLD-74.5	9.9	7.7		15)
Fujian	169	3.6–163.0		48.7±3.2	0.53	16)
Jiangxi	216	<LLD-13.9	9.3	8.8	0.61	17)
Shandong	148	<LLD-12.3	5.1	4.8	0.6	18)
Henan	96	2.6–76.3	16.4	12.4		19)
Hubei	70	6.7–30.5	12.4	10.6	0.62	20)
Hunan[a)]	73		26.3±16.9	21.4±2.0	0.56	21)
Shenzhen	10	2.8–35.9	13.7	10.4	0.17	22)
Sichuan	856	<LLD-82.1	14.7	11.9	0.62	23)
Guiyang	224	5.4–25.5	13.2			24)
Tibet	102	<LLD-23.7	3.9	3.1	0.64	25)
Shanxi	335	<LLD-76.7	26.2	22.2	0.75	26)
Gansu	217	<LLD-105.4	22.2	17.0	0.54	27)
Qinghai	161	<LLD-43.1	8.0	6.5	0.63	28)
Ningxia	69	3.7–60.0	13.7	11.0	0.64	29)
Haikou	18	11.2–18.6	14.3	14.0	0.59	30)
Total	4,302	<LLD-163.0	10.0	8.1	0.59	

a) The results of radon concentrations of these provinces were only reported as Mean±SD, but no ranges.

Table 4 Indoor radon progeny concentrations (1984–1990) (mWL)

Provinces or areas	Dwelling number	Range	Arithmetic mean	Geometric mean	Reference
Hebei	73		3.8		5)
Shanxi	105	<LLD-10.8	2.6	2.1	6)
Neimeng	45	<LLD-11.4	3.1	2.2	7)
Liaoning	397	<LLD-55.2	3.9	2.6	8)
Jilin[a)]	51		<LLD		9)
Heilongjiang[a)]	40		6.2 ± 9.3[b)]	2.6 ± 3.9[b)]	10)
Shanghai	120	<LLD-4.4	<LLD	<LLD	11)
Jiangsu	491	<LLD-11.1	2.1	2.1	12)
Zhejiang[a)]			2.1		13)
Fujian	338	<LLD-52.4	11.4	6.49	15)
Jiangxi	337	<LLD-16.1	3.3	2.9	16)
Shandong	46	<LLD-3.9	2.4		17)
Hubei	1,920	<LLD-40.2	2.7	2.1	19)
Hunan[a)]	78		5.6±3.3	4.7±1.8	20)
Shenzhen	42	<LLD-2.4	<LLD	<LLD	21)
Sichuan	502	<LLD-10.4	2.4	2.1	22)
Tibet	140	<LLD-6.4	<LLD	<LLD	24)
Shanxi	849	<LLD-25.5	6.9	5.5	25)
Gansu[a)]	201		4.0		26)
Qinghai	162	<LLD-9.1	2.4	2.1	27)
Ningxia	155	<LLD-15.5	2.8	2.3	28)
Haikou	18	<LLD	<LLD	<LLD	29)
Total	4,788	<LLD-55.2	3.2	2.1	

a) The results of radon concentrations of these provinces were only reported as Mean±SD, but no ranges.
b) The data of Heilongjiang province was reported to have a large range of variety and only Mean±SD was given.

except for Fujian and Hunan Provinces, the geographical distribution of indoor radon concentrations is lower in the South of China and higher in the North of China.

5. Indoor and Outdoor Radon Progeny Equilibrium Factors

Indoor and outdoor radon progeny equilibrium factor (F-value) were obtained during the survey, as listed in relevant columns of Tables 2 and 3, respectively. The province-averaged indoor F-values were in the range of 0.2–0.6 and the nation average estimated to be 0.47 ± 0.10, similar with the world indoor average values 0.4.[32,33] The nation average F-value for outdoor environment, based on the province-averages, is 0.59 ± 0.12. It seemed to be smaller than the world outdoor average values, which is estimated to be 0.8.[32,33] However in UNSCEAR 2000 Report, the world average F-value of 0.6 is recommended for the outdoor environment.

6. Problems and Discussion

As introduced at the beginning of this paper the nation-wide radon survey was carried out in the duration of 1984–1990, but the measuring period in detail, *i.e.* the season, of each local institution was not accordant. Furthermore, since most of the local institutions had no continuous or integrating measuring techniques at that time, grab sampling was adopted during the survey. Even though the works on quality assurance was done well in the prophase of the radon project, the insufficiency of the project design made the results difficult to compare each other and also less of representative.

IV. Conclusions

(1) Totally, radon concentrations at 10,811 indoor and 4,302 outdoor sites were surveyed from 1984–1990 coordinated by the Laboratory of Industrial Hygiene, Ministry of Health (LIH).

(2) Based on province-averaged data reported in literature, the estimated nation-averaged values (arithmetic mean) of radon concentrations were $22.5\,\mathrm{Bq\cdot m^{-3}}$ and $10\,\mathrm{Bq\cdot m^{-3}}$ for indoor and outdoor air, respectively. The nation-averaged radon progeny concentration of indoor air was 3.2 mWL based on 4,788 dwellings survey.

(3) The radon survey so far in China are not enough both in number of dwellings and the measurement duration, and using integrating or continuous measuring techniques are necessary.

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