RADON LEVELS AND DOSE ESTIMATION IN SOME HOT SPRING HOTELS

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ABSTRACT
Guangdong is one of the provinces that have most hot springs in China. This paper presents the results of radon measurements in hot spring hotels of Guangdong province by using NR-667A(Ⅲ) continuous radon detector. Radon concentrations were measured in hotel rooms with attached bathrooms, tap waters and outdoors air. Radon concentrations were 53.4-292.5Bq/L in the hot spring water, and 17.2-190.9Bq/m^3 in outdoor air. In the bathrooms radon contents ranged from 29.3 to 911.6Bq/m^3 without using hot spring water, but after bathing 15 min and 30 min with hot spring water they reached 63.6-1917.8Bq/m^3 and 79.2-2710.7Bq/m^3 respectively. Radon concentrations in bedrooms ranged from 32.7 to 4337.8 Bq/m^3 without natural and mechanical ventilation, and they could reduce from the highest to 137.6-213.3Bq/m^3 after 1h ventilation. Indoor radon accumulation with bathing time was also presented. The effective dosages of radon to hotel workers and tourists are estimated.

INDEX OF TERMS
Radon, Hot spring, Hotel, Dose estimation, Indoors air pollution

INTRODUCTION
Radon originates from the decay of radium (^{226}Ra), which itself is a member of the uranium (^{238}U) decay series (J. G. Stark, H. G. Wallace;). ^{226}Ra occurs in virtually all type of rocks and soils, especially in granite. Typically higher radon concentrations might be expected in soil gas and the fracture-joint or fault-lineament related groundwater compared to the ambient air and surface water. Radon is a significant component of the groundwater that discharge in the springs (Przylibski et al., 2001; Choubey et al., 1997; Horvath et al., 2000; Das et al., 1998). Radon emanation and migration in the groundwater and in the air has been the subject of numerous studies, and indoor elevated radon concentration ranked the second in the leading causes of lung cancer, next to smoking (Hileman, 1983; Clarke, 1989; P. K. Hopke et al., 2000; Evans et al., 1981), it has long been a health problem of worldwide concern (ICRP 1987). Most areas of Guangdong province have granite bedrock; and Guangdong is one of the provinces that have most springs in China (HBRRG, 1980). Most of the hot springs are famous health resorts and tourist attraction. Radon has been regarded as a component

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beneficial to human health, and springs with the radon concentration higher than 110 Bq/L as having medical values. Many wonder if it has advantageous or disadvantageous healthy influence on the workers and tourists in these hot spring hotels. This paper determines the relation between the radon concentration in hot spring water and in the hotel indoor environment in selected hot spring resorts in Guangdong, China. The background information of the four measured springs are listed in Table 1. Radon in tap water of bathrooms, as well as in water from a spring discharging mouth, was measured. Radon in air was investigated indoor and outdoor.

Table 1. Background information of the four measured springs

Spring	Hydrochemical type	Discharge (m^3/d)	Temperature (°C)	Mineral (g/L)	H_2SiO_3 (mg/L)
Conghua	HCO_3-Na-K	1674	40-72	0.24-0.39	50-85
Zhongshan	Cl-Na	864	85	5.8	117
Nanshui	HCO_3-Na-K	150	48		
Taishan	Cl-Na	320	68	0.836	

ANALYTICAL METHODS

Radon in spring waters and air are measured by the Model NR-667A(III) (Song Gang et al, 2002) continuous real-time radon detector. Air is pumped into a counting chamber, and a semiconductor detector is used as an electrode to electrostatic gathering radon's first decay progeny RaA (^{218}Po) (Figure1). The detector counts the alpha particles, and can convert the alpha strength to radon concentration in predetermined intervals, and the results can be stored in the instrument's memory or be printed out directly. The detector is calibrated in the Research Institute of Uranium Mining (Hengyang, China), Department of Nuclear Energy of China in April 2001. The apparatus' constant is 1.72 Bq m^{-3}/(cp20m). While measuring radon concentrations in air, air is pumped into the counting chamber for 5 min, measured for 20 min, exhausted for 5 min.

The method of measuring radon in spring water is shown in Figure 1. 100 ml of water was taken in a 250ml radon tight cylinder connected in a close circuit with the detector, with a glass tube containing sorbents to remove moisture before the air enters the detector. The air was pumped and circulated in a closed circuit for a period of time and the alpha activity was recorded. The concentration of radon in the thermal spring water can be calculated as:

$$C_{water} = (C_{Rn} \cdot V_{total}) / (e^{-\lambda_{Rn} t} \cdot V_{water}) \quad (1)$$

Where C_{water} (Bq/L) is the measured radon concentration of the water; C_{Rn} (Bq/L) is the measured air radon concentration by the detector; V_{total} (L) is the total volume of the air circulating, it includes the detector chamber (2L), the air interspaces upside of the diffuse ware and the coupling pipes; V_{water} is the volume of the water sample. $e^{-\lambda_{Rn} \cdot t}$ is the amendment factor

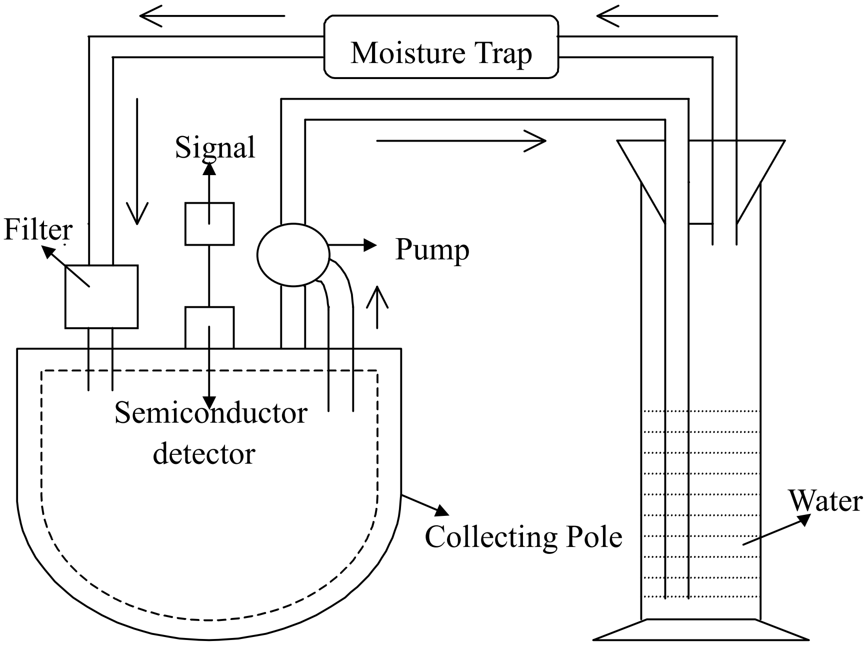

Figure 1. Sketch illustrating measurement method of radon in water

for the radon decay during the time interval t from sampling to measuring, λ_{Rn} is the radon decay constant (λ_{Rn}=0.000126 min^{-1} or 0.00756 h^{-1}).

RESULTS AND DISCUSSION

The results of radon measurements in spring water are presented in Table 2. Water samples in Nanshui were taken directly from the spring discharging mouth; others were tap water taken from the bathrooms. The radon concentration varied from 53.4 to 292.5 Bq/L, and the highest radon values were found in the Nanshui springs whereas the low values were recorded in the Taishan springs. Spring waters were firstly pumped into the sluice pools from the spring mouths, and then transported to every health resort or bathroom through pipeline; it could loss a relatively large portion of radon in midway transportation. This may be one reason for the higher radon concentrations in Nanshui samples than in other samples.

Radon and its progeny concentrations in the spring hotel guest rooms and in outdoor air are presented in Table 2 and Table 3. Radon concentrations varied from 22.4 to 2855.2 Bq/m^3 in all measured rooms. Indoor radon concentrations were relatively higher in the Conghua and Nanshui spring hotels, especially in the bathrooms bathing with spring water. The highest radon values attained to 2855.2 Bq/m^3 in Nanshui. It was obvious that the indoor radon concentrations increased with the radon concentrations in spring water and the indoor spring water using via bathing. But as a special in the Conghua Spring Hotel, radon concentration in the bathroom was the highest after bathing 30 min and decreased to a lower level after 60 min

(Table 2). The guest room radon concentration in Conghua showed less variation with or without bathing, and maintained in a much higher level (>600Bq/m^3) which were beyond the guideline levels of USA (148 Bq/m^3) and WHO (200 Bq/m^3). The very significant influence of bathing activity on the indoor radon levels were observed in Nanshui.

Table 2. Radon concentrations in the spring waters and flats at different bathing times

Locations	Radon concentrations						
	Spring water (kBq/m^3)	Bathroom (Bq/m^3)			Double room (Bq/m^3)		
		15min	30min	60min	15min	30min	60min
Conghua	101.2-157.2	1011.4	1091.5	596.9	435.2	479.8	368.1
Nanshui	266.7-292.5	1917.8	2710.7	2855.2	753.4	1474.1	1615.1
Zhongshan	68.4-136.7	111.8	381.8	466.2	85.6	93	196.1
Taishan	53.4-59.8	63.6	79.2	297.7	39.6	56.8	72.4

Table 3. Indoor and outdoor radon and its progeny concentrations and radon dose estimation

Location		C_{Rn} (Bq/m^3)		C_{Pr} (mWL)		EEC_{Rn} (Bq/m^3)	Dose (mSv/y)
		Range	Mean ± S_d	Range	Mean ± S_d		
Conghua	Dr (NB)	615.7-720.3	676.5±54.9	166.2-194.5	182.7±15	270.6±22	11.3±0.9
	(B)	678.4-789.5	750.5±61.3	183.2-213.2	202.6±16	300.2±24	12.6±1.0
	Br (NB)	749.2-911.6	848.0±86.2	202.5-246.1	228.9±23	339.2±34	14.3±1.4
	(B)	850.6-1091	965.4±106.5	229.7-294.5	259.1±29	386.2±43	16.2±1.8
	Out	30.8-45.2	32.5±4.3	8.3-12.2	4.3±1.2	13±1.7	0.55±0.1
Nanshui	Dr (NB)	79.2-245.6	171.9±84.8	21.4-66.3	46.2±22.9	68.7±33.9	2.9±1.4
	(B)	1324-1909	1569.2±304	357.6-515.5	423.7±82	627.7±121	26.4±5.1
	Br (NB)	295.6-381.8	364.3±56.6	79.8-103.1	98.4±15.3	145.7±23	6.1±0.95
	(B)	753.4-2855	2144±696.4	203.4-770.9	578.9±188	857.6±278	36±11.7
	Out	79.2-190.9	135.5±50.2	21.4-51.5	36.6±13.6	54.2±20	2.3±0.8
Zhongshan	Porch	68.8-108.4	87.7±17.8	18.6-29.3	23.7±4.8	35.1±7.1	1.5±0.3
	Br (NB)	29.3-85.6	50.9±30.5	7.9-23.1	13.7±8.2	20.4±12.2	0.86±0.5
	(B)	91.2-466.2	232.6±137.2	24.6-125.9	62.8±37	93.1±54.9	3.9±2.3
	Out	24.6-37.8	28.6±4.5	6.6-10.2	7.7±1.2	11.4±1.8	0.5±0.08
Taishan	Dr (B)	22.4-32.7	27.5±3.8	6.0-8.8	7.4±1.0	11±1.5	0.46±0.1
	Br (B)	39.6-297.7	88.9±63.7	10.7-80.4	24±17.2	35.6±25.5	1.5±1.07
	Out	17.2-20.7	18.8±2.5	4.6-5.6	5.1±0.7	7.5±0.7	0.3±0.03

Note: DR—double room; GR—bathroom; Out—outdoor air; B—bathing; NB—no bathing; C_{Rn}—Radon concentration; C_{Pr}—Radon progeny concentration.

The indoor radon concentration in terms of equilibrium-equivalent radon concentration (EEC_{Rn}) and the annual effective dosage can be calculated as the following:

$$EEC_{Rn} = A_{Rn} \cdot F_1 \qquad (2)$$

$$Dose = EEC_{Rn} \cdot K \cdot F_2 \qquad (3)$$

Where A_{Rn} is the measured indoor radon activity and F_1 is the equilibrium factor (F_1=0.40). K is the dose conversion coefficient (K=6 nSv/(Bqhm^{-3}), UNSCEAR 1996); and F_2 is the annual total irradiation time (7008 h/yr). The results are listed in Table 3. The average annual effective inhalation doses of radon and its progeny for the workers should pay attention to, especially in the Conghua and Nanshui hotels. The radiation exposure levels for tourists who occasionally reside in these hotels may be negligible.

Accumulating radon concentrations with time in the closed guest rooms with no other disturbing factors are presented in Figure 2. The radon concentrations increased with the closed time in the Nanshui and Conghua spring hotels, but showed a slightly decrease in the Zhongshan and Taishan spring hotels. This indicated that there might exist sources of radon other than hot spring water application in Nanshui and Conghua hotels. Also from Figure 2 we can see that after about 1h ventilation by opening all windows and doors, radon concentration dropped from the highest values to the ordinary levels.

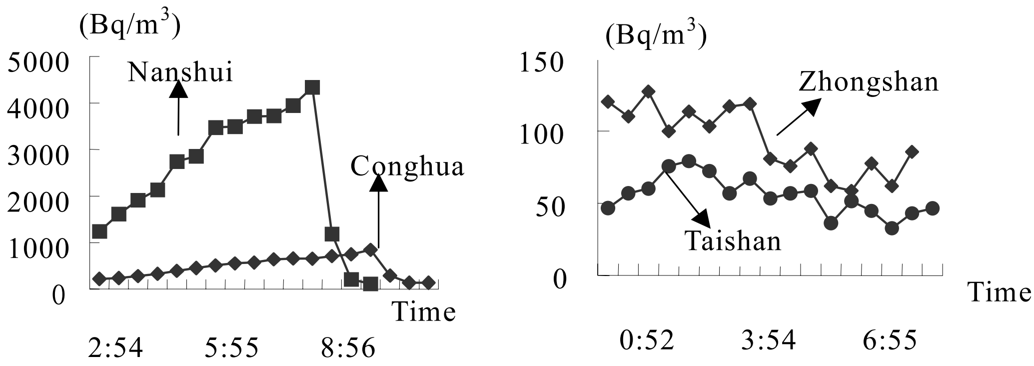

Figure 2. Accumulating curve of radon concentration with time in spring hotels

CONCLUSION

It has long been a debatable issue whether the higher radon concentration in hot spring water leads to health risks from higher occupational (like hot spring hotel workers) and occasional (like tourists) exposure to radon in hot spring resorts. The measured results in the four hot spring resorts in Guangdong indicated that applying hot spring water in hotels contributed to the elevated indoor radon levels in hotel indoor environment, especially in the bathrooms; The indoor radon concentration may exceed the relative guideline values, thus resulted in added irradiation exposure for hotel workers as well as tourists and recuperate personals. Technical or management measures (like enhancing ventilation) should be taken to avoid the accumulation of radon to higher levels in indoor environment in these hot spring resorts.

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