In order to explore the feasibility of an epidemiological study on lung cancer in areas with elevated indoor radon and thoron exposures, 202 residences including loess caves, brick caves, stone caves, and ordinary houses in twenty villages were selected from Yan'an and Luliang areas in the Chinese loess plateau, and indoor levels of thoron and its progeny as well as radon were determined with passive radon-thoron discriminative detectors and thoron progeny deposition rate devices. The exposure period covered from August 2001 through August 2002. The indoor radon concentration in loess cave ranged from 17 to 179 Bq m\(^{-3}\), with geometric means of 73 Bq m\(^{-3}\) and 71 Bq m\(^{-3}\) in Luliang and Yan'an, respectively. Geometric mean of EECT\(_n\) was estimated to be 1.6 Bq m\(^{-3}\) in Luliang and 2.2 Bq m\(^{-3}\) in Yan'an. The study also revealed that the air pollution in Yan'an was small compared with that in Luliang. Residential migration was very low in Yan'an area: 86% of the subjects had no migration; mean number of houses for the family master was estimated to be 1, ranged from 1 to 3. It would be expected to have several hundreds of lung cancer cases diagnosed with pathological evidences in 3–5 years. Yan'an and surrounding area are suitable for conducting an epidemiological study on residential exposure to radon, thoron and lung cancer risk.

KEY WORDS: cave dwelling, radon, thoron, epidemiology, lung cancer

1 INTRODUCTION

China conducted a nation-wide survey of \(^{222}\)Rn, commonly called radon, in early 1980s, and identified several radon-prone areas due to characteristics of building structure, e.g. low ventilation of the air in cave dwellings in Chinese loess plateau, or building materials.\(^1,2\) Cave dwelling, yao-dong or yao in Chinese, is a traditional and unique residence in the Chinese loess plateau, and most common in northern part of Shaanxi Province, western part of Shanxi Province, eastern part of Gansu Province, and western part of Henan Province. Cave dwelling can be classified into two grand categories, those excavated in a steep slope or cliff, kao-yao in Chinese, and those open cut underground, di-keng-yao in Chinese. Due to a low ventilation rate and a high exhalation rate of radon (loess wall not painted or not well painted), the radon level was reported to be high in such cave dwellings.\(^2\)

There have been two major case-control studies so far on the risk of lung cancer and residential radon in China.\(^3\) One was carried out in Shenyang City, where it was well-known for its heavy air pollution, another was in eastern part of Gansu Province. The latter was a large-scale population-based case-control study among cave dwellers in Pingliang and Qingyang areas of Gansu.\(^9\) It was concluded that the risk of lung cancer increased with increasing radon level. However, concentration of \(^{222}\)Rn, commonly called thoron, was not measured in the study though several studies have shown an existence of thoron in cave dwellings.\(^5,6\) The sample sizes, however, in these thoron studies were small, only 24 caves in a village in Pingli-
The area of Gansu and 18 brick houses and 32 caves in three
villages in Yan'an of Shaanxi were investigated.

The purpose of the present study was to measure indoor
thoron and radon in a large number of cave dwellings scattered
in a large area of the Chinese loess plateau and to explore the
feasibility to conduct an epidemiological study on lung cancer
among these cave dwellers. Concentrations of indoor thoron
and its progeny as well as the radon, and information on
tobacco smoking, migration, expected number of lung cancer
cases and its diagnosis, and other factors related with epidemi-
ological potentials were investigated and presented in this
paper.

II MATERIALS AND METHODS

The study was conducted in two well-known cave dwelling
areas, i.e., Luliang area of Shanxi Province and Yan'an area of
Shaanxi Province (Fig. 1). Twenty villages were first selected
from Yan'an and Luliang. Taking the type of residence into
account, i.e. loess cave dwelling, brick cave dwelling (actually
not a cave, but an arch-shaped brick house), stone cave dwell-
ing (an arch-shaped house constructed with stone), and ordi-
nary brick house, about 10 residences were investigated from
each village. From the viewpoint of residential change, the
loess cave dwelling was the prototype of all the cave dwellings,
then replaced with stone or brick cave dwelling, depending on
which building material was locally available, and followed by
ordinary house in recent years as local economy has grown up.

The cave dwelling usually consists of one room with a single
entrance and two windows at the front. Typical values of
length, width, and height of the loess cave dwelling are 8.0,
3.3, and 3.3 meters, respectively. The cave dwelling is tradition-
ally equipped with a bed-like place for residing and sleeping,
which is called kang in Chinese, piled up with sun-dried mud
bricks. There is a smoke ventilation system inside the kang
through the stove to the chimney outside. Thus the kang can be
heated by burning a variety of firewood, and the residences are
warmed in winter.

We first explained the purpose of our survey to the selected
families, showed the interior of a sample detector and got their
consents, then interviewed them to collect information on
indoor air pollution including fuels of cooking and heating,
residential migration history of the family masters, and informa-
tion on age, sex, and working experience in cities as tempo-
rary worker, cigarette smoking, and medical exposure to

Fig. 1 Location of the study area in China.
diagnostic x-rays for each family member. Information on the current residence such as residence type, painting of the wall was also obtained. The size of residence was measured with a tape measure.

Newly designed passive integrating radon-thoron discriminative detectors were used in this study to determine annual concentration levels of radon and thoron. Briefly, the detector consists of two sets of radon detector, Radopot (Radosys Co., Ltd., Vegyez u. 17-25, H-1116 Budapest, Hungary), with two different air exchange rates. One of the two Radopots is modified so as to detect thoron more effectively. These passive detectors have been calibrated with the NIRS radon chamber and their performances have periodically been checked. They have also been participated in an annual NRPB intercomparison experiment to assure their qualities. The thoron progeny concentration was estimated with deposition rate measurement developed by Zhuo and Iida. CR-39 is used as the solid-state nuclear track detector in the above detectors.

These detectors were usually suspended from the wall in the middle of the residence. The distances from the wall and the ground floor were measured to be 0–30 cm and 150–300 cm, respectively. These passive devices were placed in residences for 6-month exposure and then were replaced with fresh ones for another 6-month exposure. The long-term measurement was made from August 2001 through August 2002. The concentrations of thoron and its progeny and radon used in this paper are the exposure-time-weighted averages.

### III RESULTS AND DISCUSSION

#### 1. Thoron and radon concentrations

Totally 202 residences with 601 persons in 20 villages of Luliang and Yan’an were measured and investigated. The cumulative exposure period of radon, thoron and its progeny ranged from 357 to 379 days, with an average of 366 days.

The concentrations of radon, thoron and its progeny in the investigated residences were shown in Table 1. The radon concentration ranged from 17 to 179 Bq m⁻³, with a geometric mean of 55 Bq m⁻³ for all types of residences in both areas. Twenty-five percent of the investigated residences exceeded 79 Bq m⁻³ of radon, 10% exceeded 105 Bq m⁻³, and 5% with radon concentration higher than 121 Bq m⁻³. The concentration of thoron gas was found to be high with a geometric mean of 148 Bq m⁻³, and ranged from 10 to 760 Bq m⁻³. For thoron progeny, its geometric mean of the equilibrium equivalent concentration of thoron (EECTₙ) was estimated to be 1.5 Bq m⁻³, ranged from 0.3 Bq m⁻³ to 6.1 Bq m⁻³. The percentiles of P₂₅, P₉₀ and P₉₅ were estimated to be 2.5, 3.1 and 3.7 Bq m⁻³, respectively.

As shown in Fig. 2, the loess cave was usually found to be with the highest concentration of radon, thoron or its progeny among four types of dwelling. There was no substantial difference between the stone cave dwellings and brick cave dwellings.

The loess cave dwelling was more common in Yan’an area, more than half (56%) of the current residences were loess cave. In Luliang area, the most common residence was the stone cave (58%), followed by brick cave (28%) and loess cave (11%). The proportion of the ordinary house was estimated to be 9% and 2% in Yan’an and Luliang, respectively.

It was clear that the exposure to radon was not high in the study area; only about 10% of the investigated cave dwellings exceeded 100 Bq m⁻³. The radon concentration showed a gradient: 50%, 75%, 90%, and 95% of the loess cave dwellings exceeded 73, 95, 116, and 133 Bq m⁻³ of radon, respectively.

### Table 1 Concentration (Bq m⁻³) of indoor radon, thoron and thoron progeny (EECTₙ) in Luliang and Yan’an of China.

<table>
<thead>
<tr>
<th>Residence type</th>
<th>Luliang</th>
<th></th>
<th>Yan’an</th>
<th></th>
<th>Total</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>GM±GSD</td>
<td>Range</td>
<td>N</td>
<td>GM±GSD</td>
<td>Range</td>
</tr>
<tr>
<td>Radon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loess cave</td>
<td>33</td>
<td>73±1.5</td>
<td>26–162</td>
<td>81</td>
<td>71±1.5</td>
<td>17–179</td>
</tr>
<tr>
<td>Stone cave</td>
<td>45</td>
<td>32±1.4</td>
<td>18–67</td>
<td>10</td>
<td>50±1.3</td>
<td>31–78</td>
</tr>
<tr>
<td>Brick cave</td>
<td>16</td>
<td>43±1.6</td>
<td>26–142</td>
<td>5</td>
<td>50±1.2</td>
<td>43–63</td>
</tr>
<tr>
<td>Ordinary house</td>
<td>2</td>
<td>46±1.2</td>
<td>40–54</td>
<td>1</td>
<td>31</td>
<td>—</td>
</tr>
<tr>
<td>Total</td>
<td>96</td>
<td>45±1.7</td>
<td>18–162</td>
<td>97</td>
<td>67±1.5</td>
<td>17–179</td>
</tr>
<tr>
<td>Thoron</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loess cave</td>
<td>34</td>
<td>145±1.9</td>
<td>35–394</td>
<td>81</td>
<td>185±1.6</td>
<td>53–760</td>
</tr>
<tr>
<td>Stone cave</td>
<td>45</td>
<td>144±1.9</td>
<td>16–468</td>
<td>10</td>
<td>116±2.0</td>
<td>41–465</td>
</tr>
<tr>
<td>Brick cave</td>
<td>15</td>
<td>82±2.2</td>
<td>22–665</td>
<td>5</td>
<td>86±2.2</td>
<td>24–167</td>
</tr>
<tr>
<td>Ordinary house</td>
<td>2</td>
<td>26±4.0</td>
<td>10–68</td>
<td>1</td>
<td>421</td>
<td>—</td>
</tr>
<tr>
<td>Total</td>
<td>96</td>
<td>128±2.0</td>
<td>10–665</td>
<td>97</td>
<td>171±1.8</td>
<td>24–760</td>
</tr>
<tr>
<td>EECTₙ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loess cave</td>
<td>33</td>
<td>1.6±1.7</td>
<td>0.6–3.4</td>
<td>80</td>
<td>2.2±1.6</td>
<td>0.7–6.1</td>
</tr>
<tr>
<td>Stone cave</td>
<td>44</td>
<td>1.0±1.8</td>
<td>0.3–3.6</td>
<td>10</td>
<td>1.1±1.5</td>
<td>0.7–2.3</td>
</tr>
<tr>
<td>Brick cave</td>
<td>16</td>
<td>0.8±1.6</td>
<td>0.4–1.6</td>
<td>5</td>
<td>1.0±1.5</td>
<td>0.5–1.6</td>
</tr>
<tr>
<td>Ordinary house</td>
<td>2</td>
<td>0.7±2.5</td>
<td>0.4–1.3</td>
<td>1</td>
<td>1.2</td>
<td>—</td>
</tr>
<tr>
<td>Total</td>
<td>95</td>
<td>1.1±1.8</td>
<td>0.3–3.6</td>
<td>96</td>
<td>2.0±1.7</td>
<td>0.5–6.1</td>
</tr>
</tbody>
</table>

Note: GM denotes geometric means, GSD geometric standard deviation.
The EECTn was found to be high in loess cave dwellings with a geometric mean of 2.0 Bq m\(^{-3}\), and ranged from 0.6 to 6.1 Bq m\(^{-3}\). Using the data obtained in this survey, the annual average dose resulted from indoor exposure to radon and thoron was estimated to be 2.1 mSv. Taking thoron concentration into account, the concentrations of radon and progeny of thoron would be in a good gradient and high enough to explore relationship between the lung cancer risk and lifetime exposure to thoron and radon.

2. Low rate of residential migration and easy to estimate lifetime thoron and radon exposure

The local families have lived in the investigated areas over many generations. In the present survey, it was found that the residential migration rate was very low. Mean number of residences for family master was estimated to be 1.8 (ranged from 1 to 10) in Luliang area and 1.0 (ranged from 1 to 3) in Yan’an area, respectively. Family masters have lived in the current cave dwellings for, on average, 25 years. In Yan’an area, 86% of family masters had no residential migration: no stay in places other than their hometowns for longer than 12 months. Sixty percent of the family masters in Yan’an and 36% in Luliang have resided in the current cave dwellings since their births.

Usually local men lived in only two caves dwellings in their lifetime: the first was a cave where they were born in and had lived there until they got married; the second was a cave where they have lived since their marriages. For females, they usually married and moved to other villages. Among the investigated married women, 92% of them also resided in the current caves dwellings since their births.

It was noted that some of local farmers no longer resided in the traditional cave dwellings when they earned money enough to build an ordinary house; they used their own caves as storage rooms. However, elder people usually keep residing in loess cave dwellings.

Being low migration rate and stable residing history, the estimation of lifetime radon and thoron exposures for the cave dwellers especially for the elder people would be facilitated. In the present survey, for 90% of the investigated families, all the cave dwellings where they have resided for more than 12 months were available for our measurements.

The investigation revealed that the low migration of local people had been changed since the open policy in early 1980s especially among the young generations. They left their hometowns for cities as temporary workers including cooks, waiters/waitresses, builders to earn more money. As shown in Table 2, the proportion of those migrated out as temporary workers was 17% and 5% in males and females, respectively. The proportion for the males increased first with age, and reached a peak at the age of 20 – 24 years, then decreased. In females, the highest percentage was seen at the age of 15 – 19 years; the proportion was low in other age groups. For those who migrated out as temporary workers, they usually returned for a family reunification during the Chinese New Year. No sizable difference was observed between Yan’an and Luliang.

3. Tobacco smoking rate

Fifty-six percent of the investigated males was current tobacco-smoker. The smoking rate increased sharply with age (Table 2). There was a rapid increase of the smoking rate, from 7 percent in age group of 15 – 19 years to about 60 percent in age group of 20 years and more. The smoking rate in the female was found to be very low, only 4% of the women were current smokers in the present survey, all of them were aged 50 years and over. No sizable difference of tobacco smoking rate was observed between Yan’an and Luliang. The local smokers usually smoked homemade roll cigarettes or pipes. Only can...
they buy ready-made cigarettes in local markets and smoke them in recent years.

4. Medical exposures

About twenty percent of the investigated family members was self-reported to have been exposed to diagnostic x-rays including fluoroscopy and roentgenography. The percentage increased first with age, and reached a peak at age of 50–59 year-old, then decreased with age (Table 2). No sizable difference of the medical exposure was observed between Yan’an and Luliang. The exposure frequency distribution was comparable with the national figure in China.10 In the study area, fluoroscopy was still a very common medical practice though the dose resulted from this practice was higher than that from roentgenography.

5. Air pollution

Neither major industry nor industrial air pollution exists in the investigated areas. Taking the fuel of cooking as an index of indoor air pollution, it was found that air in Luliang Prefecture of Shanxi Province, the major coal production province in China, was heavily polluted due to coal burning for cooking; 68% of the families in Luliang burnt coals for cooking, compared with only 11% in Yan’an. In Yan’an area, most of the families burnt biomass or firewood for cooking. The local farmers used kang with burning of biomass or coal to warm the residence in winter. There was a similar trend with that of cooking fuel: heavy air pollution observed in Luliang due to coal burning. From the viewpoint of air pollution, it will be better and more suitable to conduct an epidemiological study on lung cancer and residential exposure to radon and thoron in Yan’an area than in Luliang area.

6. Expected number of lung cancer cases and its diagnosis

Lung cancer was not a leading cancer in the study area though its incidence rate increased in the recent years throughout the whole China.11 The major sites of cancer were reported to be esophagus, stomach and liver in Yan’an area, which accounted for 70% or over of all deaths from cancer.12, 13 There are 2 million people living in Yan’an area. Suppose that the incidence rate of lung cancer is 10/100,000. It was expected that about 200 cases of lung cancer would be ascertained every year in Yan’an area. Based on the local medical records, 30% of lung cancer cases were diagnosed with pathological evidence (mainly by bronchoscope or surgery) in advanced hospitals located in Yan’an or capital of Shanxi Province. The pathological evidences including embedded paraffin blocks were available for further laboratory work when requested. The diagnosis was substantially improved in the recent years due to a rapid progress of the local economy. However, the surgical rate was still low, only 10%, due to no medical insurance system covering the local farmers and the prohibitive expense of surgery and hospitalization.

IV CONCLUSION

A feasibility study of indoor thoron and radon and lung cancer was carried out in twenty villages in Yan’an and Luliang in the Chinese loess plateau. It was shown that local farmers have been exposed to an elevated indoor thoron and radon. The residential mobility was low, mean number of residences was one, and air pollution was small in Yan’an area. It would be expected to have several hundreds of lung cancer cases diagnosed with pathological evidences in 3–5 years. Yan’an area was considered to be one of the suitable places for conducting an epidemiological study on lung cancer risk and residential exposure to thoron and radon.

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REFERENCES


2) Z. WANG and F. STEINHAUSLER; Elevated indoor exposure in Chinese carbon brick and cave dwellings, Health...


UNSCEAR; Sources and effects of ionizing radiation, Annex D, Table 12, Table 15, (2000), United Nations, New York.


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