Rn Concentration and Estimation of Annual Effective Dose in Xiazhuang Uranium Ore Field, Guangdong

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Abstract: FD-3017RaA instrument was used in the research to measure the radon concentration in soil of zhongdong area in Xiazhuang uranium ore field, Guangdong, and the radon concentration in the air 1m above ground surface was calculated using the earth-atmosphere radon exchange model. The research indicated that, the average values of radon concentration in soil and air were 2019.4 Bq•m$^{-3}$ and 56.22 Bq•m$^{-3}$, in range of 35-70000 Bq•m$^{-3}$ and 27.0-167.7 Bq•m$^{-3}$ respectively, and the annual effective dose caused by radon was 3.81 mSv, about 3 times higher than that in our country which is 0.88 mSv.

Keyword: radon gas survey; Rn concentration; annual effective dose

1. Introduction

Radon, colorless and tasteless radioactive inert gas, is the only gaseous element in the series of natural radioactive uranium. Radon and its decay products in the atmosphere are the most important contributors to human exposure from natural background radiation dose[1]. At the same time, radon is the second largest cause of lung cancer below smoking, and it has been classified as one of the 19 kinds of major environmental carcinogens by the World Health Organization[2]. Therefore, environmental radon research has been paid more and more attention.

Radon in the atmosphere comes mainly from soil and rock. Soil radon, moving into the atmosphere, is controlled by the uranium contents of soil and rock, the distribution of the faults and many other factors[3][4]. In the zhongdong area of Xiazhuang uranium ore field, Guangdong Province, 12 lines and 235 measurement points were disposed, FD-3017RaA instrument was used to research the soil radon concentration, and the radon concentration in the air 1m above ground surface was calculated according to the uranium contents in the soil, also, the annual effective dose caused by radon was estimated.

2 Geography and geology

Xiazhuang uranium ore field is in the north of Guangzhou city about 130 kilometers, and next to Quannan County of Jiangxi Province. The study section in the Zhongdong area of Xiazhuang uranium ore field was the landscape of Nanling hills and mountainous regions, and its climate was humid subtropical monsoon climate.

The area located in the intersection of east-west major dislocation and magmatite band in the early stage of Yanshan, north-west major dislocation and deep focus magmatite band in the advanced stage

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of Yanshan, and K2-E north-east major dislocation. Magma in deep Source actived strongly. From 140 Ma to 90 Ma, many deep source acidic, basic magma activities were appeared, with a north-west distribution, and lithology in the region was complicated, including acidic and medium-acidic granites, basic and medium-basic veins(dikes), and volcanic rocks, secondary volcanic rocks and so on.

A large number of granites whose average contents of radionuclides was relatively high had been distributed in the section, in addition, Xiazhuang ore field was the major one of the bases producing uranium, so the radionuclide contents was very high in some parts, after some decays, radon concentration was also high, therefore, it was necessary to study radon concentration in the soil and atmosphere and its harm to the human body.

3 Measurement instruments and methods

The radon activity concentration in the soil was measured by instantaneous measurement, using FD-3017 RaA instrument. FD-3017 RaA instrument was made by using the electrical properties of the first decay production of RaA (218Po) which was in the high-voltage electric field to improve the sensitivity of collecting α-particles. It could quantitatively measure radon concentration in the soil. It did not pollute detectors, eliminated the thorium-interference, had high sensitivity, operated simply, gained the measurement data in the field, and had become the main instrument measuring radon activity concentration in the soil.

3.1 the Quality Assurance of Field work

In order to obtain accurate data, the instrument used on the work had been calibrated, the instrument stability had been checked, and 10% of the field measurement points had been repeatedly measured.

3.1.1 Instrument Calibration

The instrument had been calibrated using standard liquid Ra source before working, and the conversion factor was 0.178 (Bq / L) / count.

3.1.2 The checkage of the instrument stability

In the Field work, the instrument was checked by plutonium source before starting work and finishing work every working day, and the results were shown in Fig 1. From Fig 1, the average value of the instrument was 7575.3, and the data were allowed to change in the range of 6817.7-8332.8, thus, the measurement data did not exceed the range of the changes, which meant that the instrument in the field was relatively stable, and the measurement data were reliable.

3.1.3 Instrument reading error

In the Work region, 12 lines with 235 points had been measured, and a total of 28 points had been randomly choosed to check the instrument reading error, which was more than 10 percent of the total workload. According to the formula in the "measurement norm of radon and its daughters ",
instrument reading error was 12.3%, less than 30% which was the max number requested in the norm.

Fig 1: The comparison of morning and evening measurement data in July-August, 2005

3.2 Work procedures and precautions

The survey was in Xiaoshui, Huziduishan, Huawu, Kengweitou in Zhongdong of Xiazhuang ore field in 2005, a total of 12 lines with 235 points. The line spacing of the lines was 40 m in one place, and the point-to-point distance of the line was 10 m.

Field measurements were in accordance with the norm of radon measurement. In the measurement point, a 0.5-0.7 m deep hole was dug with drilling steel, and then sampler was inserted into the hole to exhaust the gas, at last measurer measured and noted the data. In the measurement process, the following points should be noted:

(1) The desiccant in the instrument should be changed frequently to ensure the dry level of the gas.

(2) The pores should be kept expedite to prevent soil particles from blocking pores to assure the same gas quantities.

(3) The measuring sheet surface should be clean and should not be contacted with the hands to ensure accurate count.

(4) Attention should be paid to sheet marks when put sheet and exchange sheet to prevent mixing the measurement results.

4 Soil radon concentration distribution

From the measurement results in the work area, the soil radon activity concentration in the area was in the range of 35-70000 Bq • m⁻³, some of which were eight times higher than the world average soil radon activity concentration [5]. The average value of radon activity concentration every line was shown in table 1.

From Table 1, the average value was higher only on the 7th line of the 12 lines, but all the average values were less than the world average value. The main reason of the higher average value was the
higher radon concentrations of individual measuring points on the line, which were caused by the uranium ore or structure beneath the measuring points.

Table 1: The average values of soil radon activity concentration every line in the work area

<table>
<thead>
<tr>
<th>Measuring Line numbers</th>
<th>Measuring Points</th>
<th>Average Radon Concentration/(Bq m⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>18</td>
<td>1050</td>
</tr>
<tr>
<td>1</td>
<td>18</td>
<td>970</td>
</tr>
<tr>
<td>2</td>
<td>17</td>
<td>2412</td>
</tr>
<tr>
<td>3</td>
<td>17</td>
<td>1666</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>1176</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
<td>1365</td>
</tr>
<tr>
<td>6</td>
<td>21</td>
<td>1526</td>
</tr>
<tr>
<td>7</td>
<td>21</td>
<td>6023</td>
</tr>
<tr>
<td>8</td>
<td>21</td>
<td>2507</td>
</tr>
<tr>
<td>9</td>
<td>21</td>
<td>1218</td>
</tr>
<tr>
<td>10</td>
<td>21</td>
<td>2489</td>
</tr>
<tr>
<td>11</td>
<td>21</td>
<td>1831</td>
</tr>
<tr>
<td>Total average</td>
<td></td>
<td>2019.4</td>
</tr>
</tbody>
</table>

5 Radon concentration in air and dose estimation

5.1 Theoretical calculation of radon concentration in the air

Soil radon activity concentration was affected by diffusion, convection, relay transmission, suction, pump and so on, so migration laws were very complicated. Convection and diffusion theories were used in the study, the air was as a no-radon layer, and soil radon moved into the the air only. On the ground, the radon flux from the soil was equal to it in the atmosphere. According to this, radon activity concentration in the air was calculated as following:

\[
C = \frac{A}{\lambda \eta} \left( \sqrt{V_1^2 + 4\lambda D_i} \eta - V_1 \right) \exp\left(-\sqrt{\frac{V_1^2 + 4\lambda D_i}{2D_2}} \eta \right) \cdot \sqrt{\frac{V_2^2 + 4\lambda D_2}{2D_2}} \eta
\]

In the formula

- \( A = 2.64 \times 10^{-4} \cdot \rho \cdot w(U) \cdot K_p \cdot \alpha \)
- \( C \): radon Activity concentration in the air (Bq m⁻³);
- \( D_i, \eta, v_i \): radon diffusion coefficient (cm²/s) and convection velocity (cm/s) in the rock or soil respectively;
- \( D_2, v_2 \): radon diffusion coefficient (cm²/s) and convection velocity (cm/s) in the air respectively;
- \( \lambda \): Radon decay constants (s⁻¹);
- \( K_p \): Uranium-radium equilibrium coefficient;
- \( \alpha \): emanation coefficient from Rock or soil;
η: Rock or soil porosity;
X: height above the ground (negative number) (cm);

According to the results from previous studies [7], and data from work area, some parameters were:
\[ \begin{align*}
D_1 &= 1.25 \times 10^2 \text{ cm}^2/\text{s}, \quad v_1 = 1.5 \times 10^3 \text{ cm/s},
D_2 &= 0.2 \text{ cm}^2/\text{s}, \quad v_2 = 5.5 \times 10^3 \text{ cm/s},
\rho &= 1.5 \text{ g/cm}^3, \quad K_P = 1,
\alpha &= 0.15, \quad \eta = 0.35, \quad X = -100 \text{ cm}.
\end{align*} \]

The radon activity concentrations in the air by the formula (1) were shown in Table 2.

**Table 2: The radon activity concentrations in the air of every line**

<table>
<thead>
<tr>
<th>Line numbers</th>
<th>Measuring Points</th>
<th>Average Radon Concentration in the Air (Bq m(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>18</td>
<td>29.2</td>
</tr>
<tr>
<td>1</td>
<td>18</td>
<td>27.0</td>
</tr>
<tr>
<td>2</td>
<td>17</td>
<td>67.1</td>
</tr>
<tr>
<td>3</td>
<td>17</td>
<td>46.3</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
<td>32.8</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
<td>38.0</td>
</tr>
<tr>
<td>6</td>
<td>21</td>
<td>42.5</td>
</tr>
<tr>
<td>7</td>
<td>21</td>
<td>167.7</td>
</tr>
<tr>
<td>8</td>
<td>21</td>
<td>69.8</td>
</tr>
<tr>
<td>9</td>
<td>21</td>
<td>33.9</td>
</tr>
<tr>
<td>10</td>
<td>21</td>
<td>69.3</td>
</tr>
<tr>
<td>11</td>
<td>21</td>
<td>51.0</td>
</tr>
<tr>
<td>Average value</td>
<td></td>
<td>56.22</td>
</tr>
</tbody>
</table>

From Table 2, the radon activity concentrations in the air were in the range of 27.0-167.7 Bq \(\cdot\) m\(^{-3}\), with an average value 56.22 Bq \(\cdot\) m\(^{-3}\), compared with the value 15.4 Bq \(\cdot\) m\(^{-3}\) [8] in Guangdong province and 14 Bq \(\cdot\) m\(^{-3}\) [8] in China, it was higher.

**5.2 The annual effective dose calculation**

When then radon activity concentrations in the air were known, dose caused by radon could be estimated. equilibrium equivalent radon concentration, \(C_{eq}(Rn)\), could be calculated by equilibrium factors of 0.4 indoors and 0.6 outdoors multiplying radon concentration, then the annual effective dose could be calculated as follows [9][10]:

\[ H_E = C_{eq}(Rn) \times Q \times N \]  \( (2) \)

In the formula:
- \(H_E\): the annual effective dose, mSv;
- \(C_{eq}(Rn)\): equilibrium equivalent radon concentration, Bq \(\cdot\) m\(^{-3}\);
- \(Q\): dose conversion factors, nSv \(\cdot\) m\(^3\)/Bq \(\cdot\) h;
- \(N\): hours of 1760 h/a outdoor, 7000 h/a indoor;
Indoor and outdoor equilibrium equivalent radon concentration multiplying dose conversion factor (9 nSv • m³ / (Bq • h)) represented the effective dose per hour indoor and outdoor respectively. According to reference [10], the average indoor radon concentration of Xiazhuan uranium ore field was 130 Bq • m³, so the annual effective dose caused by radon in the study area could be calculated as follows:

\[ H_i = (130 \text{ Bq} \cdot \text{m}^{-3} \times 7000 \text{h} \times 0.4 + 56.22 \text{ Bq} \cdot \text{m}^{-3} \times 1760 \text{h} \times 0.6) \times 9 \text{nSv} \cdot \text{m}^3 / (\text{Bq} \cdot \text{h}) \]
\[ = 3.81 \text{mSv} \]

According to the formula (2) and the indoor and outdoor radon concentration in the Guangdong Province presented in reference [8], the annual effective dose caused by radon of Guangdong Province could be calculated, and the calculation results were shown in table 3.

The results compared the annual effective dose caused by radon in the study area with it in Guangdong Province, the China, the World were shown in Table 3. From Table 3, we could see that the annual effective dose caused by radon in the study area was much higher than it in Guangdong Province, the China, and the world.

Table 3: The annual effective dose caused by radon

<table>
<thead>
<tr>
<th></th>
<th>The annual effective dose caused by radon / (mSv·a⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Indoor</td>
</tr>
<tr>
<td>The study area</td>
<td>3.28</td>
</tr>
<tr>
<td>Guangdong Province</td>
<td>0.48</td>
</tr>
<tr>
<td>China</td>
<td>0.75</td>
</tr>
<tr>
<td>World</td>
<td>1.0</td>
</tr>
</tbody>
</table>

6 Conclusion

Radon in soil and in air had been studied in Xiazhuan uranium ore field through a great deal of field measurements and indoor calculations, and several recognitions had been gained:

(1) The average soil radon concentration in world was 7400 Bq • m³, and the soil radon concentrations in the study area were in the range of 35-70000 Bq • m³, with an average value 2019.4 Bq • m³. Several values were over the average soil radon concentration in world, which were caused by the uranium ore or structure beneath the measuring points.

(2) The radon concentration in the air 1m above ground surface was in the range of 27.0-167.7 Bq•m³, with an average value 56.22 Bq•m³, which was three times higher than the normal value in China, and the outdoor annual effective dose was up to 0.53 mSv, also higher than 0.13 mSv, which was the average value caused by radon in China, so radon radiation in the air would hurt the staff health who worked in the mine area, thus, supervision and management should be strengthened in all taches.
The indoor and outdoor annual effective dose in the study area caused by radon was 3.81 mSv, which was higher than 0.88 mSv in China. It would harm the residents health who lived in such circumstances long time, so the relevant departments should take effective measures to reduce indoor and outdoor radon activity concentrations in the study area, and make radon radiation in the scope of the limit which was stipulated in the norm.

References