Evaluation of Vertical Distribution of $^{222}\text{Rn}$ Using a Ge Semiconductor Detector

T. Ichiji$^1$, T. Hattori$^1$ and T. Iida$^2$

$^1$Nuclear Energy Systems Department, Komae Research Laboratory, Central Research Institute of Electric Power Industry, 2-11-1, Iwado Kita, Komae-shi, Tokyo 201-8511, JAPAN
E-mail: ichiji@criepi.denken.or.jp

$^2$Department of Nuclear Engineering, Graduate School of Engineering, Nagoya University, Furoucho, Chikusa-ku, Nagoya-shi, Aichi 464-8603, JAPAN

Abstract. Environmental gamma radiation was measured using a Ge semiconductor detector for approximately 2 years during the period from July 2000 to August 2001 and from November 2002 to December 2003 in Tokyo. The vertical distributions of $^{222}\text{Rn}$ in air were estimated qualitatively using the ratios of the count rates of 1120 and 1765 keV gamma radiations to that of 609 keV emitted from $^{214}\text{Bi}$. Diurnal and seasonal variations of the ratios were investigated. In the case of diurnal variations, the ratios at the break of dawn were lower than at other times. This indicates that the difference in $^{222}\text{Rn}$ concentration in air in the vertical direction is significant at the break of dawn. As for seasonal variations, the ratios in summer were higher than those in winter. This indicates that the difference in $^{222}\text{Rn}$ concentration in air in the vertical direction is relatively small in summer.

1. Introduction

Variations of $^{222}\text{Rn}$ concentrations in air are caused by meteorological conditions, for example, air temperature, atmospheric pressure, humidity, insolation, wind direction and wind speed. In the global meteorological condition, $^{222}\text{Rn}$ concentrations in air increase because $^{222}\text{Rn}$ originating from the Asian continent is transported by wind and continental air masses. Hattori and Ichiji [1] reported a method of estimating seasonal variations of the $^{222}\text{Rn}$ originating from the Asia continent, using the correlation between $^{222}\text{Rn}$ and $^{212}\text{Pb}$ concentrations in air. One of the most important parameters of local meteorological conditions is the air mixture condition in the vertical direction. The vertical distribution of $^{222}\text{Rn}$ influences diurnal variations of $^{222}\text{Rn}$ in air. Nishikawa et al. [2] measured the height of the temperature inversion layer using acoustic radar and showed the relationship between $^{222}\text{Rn}$ in air and the height of the inversion layer. Kataoka et al. [3] observed $^{222}\text{Rn}$ concentrations and meteorological elements at different heights and compared them. Kataoka et al. [4, 5] measured vertical distributions of $^{222}\text{Rn}$ progeny concentrations in air on a meteorology tower at heights of 1, 10 and 100m above ground level. Nishikawa et al. [6, 7] estimated the gamma radiation dose rate due to atmospheric $^{222}\text{Rn}$ progeny, using the Monte Carlo calculation.

In order to estimate vertical distributions of $^{222}\text{Rn}$ in air, large-scale measurements with a high building or an airplane have been required. Continuous measurement is difficult when vertical distributions of $^{222}\text{Rn}$ in air are measured using an airplane. On the other hand, the coverage area is limited when vertical distributions of $^{222}\text{Rn}$ in air are measured on a high building. In this paper, an easy method of estimating the vertical distribution of $^{222}\text{Rn}$ in air using count rates of various gamma radiations emitted from $^{214}\text{Bi}$ is discussed.

2. Materials and methods

Environmental gamma radiation was measured using a Ge semiconductor detector during the period from July 2000 to August 2001 and from November 2002 to December 2003 at Komae Research Laboratory, Central Research Institute of Electric Power Industry in the suburbs of Tokyo. $^{222}\text{Rn}$ concentrations in air were simultaneously measured every hour. Hourly data of the $^{222}\text{Rn}$ concentrations were measured with an electrostatic monitor using the method reported by Iida et al. [8] The Ge semiconductor detector was installed outdoors at a height of 1 meter above the ground in a double-shielded tent. A schematic diagram of the gamma radiation measurement system is shown in
Fig. 1. The relative efficiency of the Ge semiconductor detector is 60%. In order to detect gamma radiation from the sky, a 1-m-diameter, 10-cm-thick Pb plate shield was placed under the gamma radiation measurement system and a 5-cm-thick Pb shield was placed around the detector. The atmosphere in the tent was kept at a temperature of about 20°C for stable operation of the detector, using an air conditioner. The gamma radiation energy spectra were automatically recorded on a hard disk of a personal computer every 10 minutes. The regions of interest (ROI) were set at 352 keV gamma radiation emitted from $^{214}$Pb and 609, 768, 1120, 1238, 1764 and 2204 keV gamma radiations emitted from $^{214}$Bi. The count rates of gamma radiation, the energy resolutions and the peak energy channels were simultaneously recorded on the hard disk. If problems arise, it is possible to check the energy resolutions and the drift of the peak energy channels. An electric refrigerator was used to cool the detector. It was not necessary to supply liquid nitrogen manually.

![Diagram](image)

**FIG. 1.** Schematic diagram of gamma radiation measurement system.

### 3. Results and discussions

Environmental gamma radiation was measured continuously for approximately 2 years during the period from July 2000 to August 2001 and from November 2002 to December 2003. Environmental gamma radiation increases if it rains, since $^{222}$Rn progeny, which come from the air and clouds and are contained in rainwater, accumulate on the ground. Data from the beginning of rainfall until three hours after the end of rainfall were excluded, since the increase in gamma radiation level due to rain is not the subject of our study. The diurnal variations of $^{222}$Rn concentrations in air and count rates of gamma radiation emitted from $^{214}$Bi in autumn are shown in Fig. 2. Diurnal variations of count rates of main gamma radiation emitted from $^{214}$Bi showed a similar tendency to those of $^{222}$Rn concentrations in air. Transition probabilities of each occurrence of gamma radiation emitted from $^{214}$Bi and the detection efficiencies of the Ge semiconductor detector are shown in Table I. Rn-222 concentrations in air and the count rates of gamma radiation emitted from $^{214}$Bi were high at the break of dawn and low during the
daytime. Typical vertical distributions of $^{222}$Rn in air are shown in Fig. 3. Rn-222 is accumulated at low altitude at the break of dawn because a temperature inversion layer is formed. Rn-222 diffuses to high altitude during the daytime as the temperature inversion layer disappears after dawn. The difference in $^{222}$Rn concentration in air in the vertical direction is larger at the break of dawn than during the daytime.

![Graph showing diurnal variations of $^{222}$Rn concentrations in air and count rates of gamma radiation of $^{214}$Bi in autumn.]

**Table I.** Transition probabilities of gamma radiation from $^{214}$Bi and detection efficiencies of Ge semiconductor detector.

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>Transition probability (%)</th>
<th>Detection efficiency (cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>609</td>
<td>44.8</td>
<td>9.7E-02</td>
</tr>
<tr>
<td>768</td>
<td>4.8</td>
<td>8.5E-02</td>
</tr>
<tr>
<td>1120</td>
<td>14.8</td>
<td>6.8E-02</td>
</tr>
<tr>
<td>1238</td>
<td>5.9</td>
<td>6.4E-02</td>
</tr>
<tr>
<td>1764</td>
<td>15.4</td>
<td>5.2E-02</td>
</tr>
<tr>
<td>2204</td>
<td>4.9</td>
<td>4.6E-02</td>
</tr>
</tbody>
</table>
Ratios of the count rates of gamma radiation of 1120 keV and 1765 keV to that of 609 keV were calculated. Vertical distributions of $^{222}$Rn in air were estimated qualitatively using the ratios. The ratios of the count rates of high-energy gamma radiation to that of 609 keV are relatively high, if the difference in $^{222}$Rn concentration in air in the vertical direction is relatively low, because low-energy gamma radiation is more easily absorbed by air than high-energy gamma radiation.

The diurnal variations of ratios in winter season are shown in Fig. 4. In the case of diurnal variations, the ratios at the break of dawn (at around 5 or 6 o’clock) were lower than at any other time. This indicates that the difference in $^{222}$Rn concentration in air in the vertical direction is relatively large at the break of dawn. The seasonal variations of ratios at 6 o’clock are shown in Fig. 5. As for seasonal variations, the ratios in summer were higher than those in winter. This indicates that the difference in $^{222}$Rn concentration in air in the vertical direction is relatively small in summer.
FIG. 4. Diurnal variations of ratios of gamma radiation in winter season.

FIG. 5. Seasonal variations of ratios of gamma radiation at 6 o’clock.
4. Conclusion

Environmental gamma radiation was measured using a Ge semiconductor detector over a period of approximately 2 years in Tokyo. Vertical distributions of $^{222}\text{Rn}$ in air were estimated qualitatively using the ratios of the count rates of 1120 and 1765 keV gamma radiations to that of 609 keV emitted from $^{214}\text{Bi}$. Diurnal and seasonal variations of the ratios were investigated. The ratios of the count rates of high-energy gamma radiation to that of 609 keV are relatively high, if the difference in $^{222}\text{Rn}$ concentration in air in the vertical direction is relatively low, because low-energy gamma radiation is more easily absorbed by air than high-energy gamma radiation. In the case of diurnal variations, the ratios at the break of dawn were lower than at any other time. This indicates that the difference in $^{222}\text{Rn}$ concentration in air in the vertical direction is relatively large at the break of dawn. As for seasonal variations, the ratios in summer were higher than those in winter. This indicates that the difference in $^{222}\text{Rn}$ concentration in air in the vertical direction is relatively low in summer. The vertical distributions of $^{222}\text{Rn}$ in air could be estimated qualitatively using gamma radiation measured with a Ge semiconductor detector at ground level.

References

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4. Kataoka, T., Yunoki, E., Michihiro, K., Sugiyama, H., Matsunaga, K., Tanimoto, H., Ishida, T. and Mori, T., $^{222}\text{Rn}$ concentration in outdoor air and some meteorological elements at different heights of the ground level above sea level, Atmospheric radon families and environmental radioactivity II, 143-149 (1990)