UNDERSTANDING OF HIGH RADON CONCENTRATIONS OBSERVED IN A WELL-VENTILATED JAPANESE WOODEN HOUSE

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ABSTRACT
Two nation-wide indoor radon surveys have been conducted in Japan. There was a significant difference between the two surveys. The first survey covered over 7000 houses using Karlsruhe passive radon detectors developed in Germany. The first survey provided relatively higher radon concentrations than expected though there are many well-ventilated wooden houses in Japan. The arithmetic mean was estimated to be 20.8 Bq m\textsuperscript{-3}. In the second survey, on the other hand, it was 15.5 Bq m\textsuperscript{-3}. In order to understand the inconsistency, passive radon detectors used in the first survey were placed in a traditional room at a Japanese wooden house. The concentration was functioned by the distance from the wall. Although passive radon detectors are designed to detect radon only effectively, a little contamination of thoron was often found in readings obtained from some detectors according to our experimental studies.

INDEX TERMS
Radon, Thoron, Ventilation, Soil wall.

INTRODUCTION
Many countries have experienced the nationwide indoor radon survey based on their social requirements. The indoor radon problem is still a large concern all over the world from the viewpoint of radiation protection research. This matter is supported by the fact that radon progeny inhalation makes a large contribution to radiation dose for general public. On the other hand, a lot of problems remain unsolved on the dose assessment due to radon. There is a difference on the estimate between two approaches for dose assessment: a dosimetric approach and an epidemiological approach. It has been pointed out that they differ by the factor of around 3. Various matters should be discussed so as to minimize the gap. More epidemiological studies should be conducted in naturally high background areas. In the epidemiological estimate, a long-term radon exposure is required. A passive radon detector is suitable for that purpose. However, a special attention must be accordingly paid to the presence of thoron. The presence of thoron has been ignored so far because its quantity is considered to be small. For more accurate dose assessment, however, radon concentration should be precisely estimated even though the thoron concentration is low.

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Two nationwide indoor radon surveys have been conducted in Japan (Fujimoto et al., 1997; Sanada et al., 1999). The first survey was commenced in 1985 and terminated in 1991. The survey covered over 7000 houses using Karlsruhe (KfK) passive radon detectors developed in Germany. The arithmetic mean was estimated to be 20.8 Bq m$^{-3}$. The first survey provided relatively higher radon concentrations than expected though there are many well-ventilated wooden houses in Japan. Many Japanese scientists pointed out the thoron contamination with the detector but no obvious evidence was shown at that time. The second survey was carried out using another track etched radon detector which is called the passive radon-thoron discriminative dosimeter (Doi and Kobayashi, 1994). The arithmetic mean was estimated to be 15.5 Bq m$^{-3}$. Table 1 summarizes the results on two nationwide surveys. In the present study, the detector used in the first survey was carefully examined from two approaches. In one approach, the detector was artificially exposed to high thoron atmosphere and was checked on readings. In another approach, the detector was placed in a Japanese wooden house and its performance was checked as well.

**Table 1. Differences between the two nationwide surveys in Japan**

<table>
<thead>
<tr>
<th>Item</th>
<th>First survey</th>
<th>Second survey</th>
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<tbody>
<tr>
<td>No. of house</td>
<td>&gt;7000</td>
<td>900</td>
</tr>
<tr>
<td>Thoron contamination</td>
<td>Yes</td>
<td>No (discriminative)</td>
</tr>
<tr>
<td>Arithmetic mean (Bq m$^{-3}$)</td>
<td>20.8</td>
<td>15.5</td>
</tr>
</tbody>
</table>

**MATERIALS AND METHODS**

Characteristics of the KfK detector are given by Urban and Piesch (1981). Polycarbonate foils are used as the alpha detecting material. Since the detectable energy range of the foil is small, the etching condition is optimized so as to detect alpha particles derived from radon effectively. In order to obtain the thoron sensitivity of the detector, our thoron facilities are set up as shown in Figure 1. Passive radon detectors are placed in the exposure chamber. Thoron gas is supplied with an external pump throughout the entire exposure period. A full description on the system can be given in other papers by Tokonami et al (2000, 2001). After six pieces of the monitor are exposed to thoron-rich air for 4 days, etching and data analysis are carried out. Grab air samples are taken for determination of both radon and thoron concentrations with scintillation cells (Pylon model 300A Lucas cell) three times a day throughout the exposure period. The measurement technique is described by Tokonami et al (2002).

In order to examine the detection response in an actual environment, they are placed in a Japanese traditional room with a relatively high thoron concentration (Ma et al., 1997). A high thoron exhalation from the wall of the house is found in other measurements, because the wall is covered with relatively thorium-rich soil and its surface is scarcely treated. Five pieces of KfK detector each are placed at 10, 20, 40, 80 and 140 cm distance from the wall for 120 days.
Figure 1. Experimental setup for thoron sensitivity test.

RESULTS AND DISCUSSION
In the experimental work, 6 pieces of the KfK detector were exposed to thoron-rich air with the thoron concentration of $2.5 \times 10^3$ Bq m$^{-3}$ and the radon concentration of $2.3 \times 10^2$ Bq m$^{-3}$. Since the sensitivity of radon has already been determined with another experiment with pure radon atmosphere, the thoron sensitivity was given by this experiment. Table 2 summarizes the sensitivity of thoron and radon on the KfK detector. Since the radon detector is usually designed to detect radon only effectively, little attention has been paid to the presence of thoron in the environment. However, radon concentrations might be overestimated and consequently the dose would be far from the accurate one with wrong instructions even though excellent detectors are used. A single use of the detector will not be able to provide two pieces of information on radon and thoron in an unknown environment. In fact, if the track density obtained is regarded to consist of radon only, the radon concentration might be overestimated to be $2.3 \times 10^3$ Bq m$^{-3}$ with the thoron exposure condition.

When five pieces of the detector were placed with the above manner in an actual dwelling, a high thoron exhalation was observed with another test and its exhalation rate was estimated to be $1.8$ Bq m$^{-2}$ s$^{-1}$, which was equivalent to that from soil surface (Tokonami, in press). Figure 2 illustrates the detection response of the KfK detector in an actual environment. The radon concentration at the distance of 10 cm far from the wall was 32.3 Bq m$^{-3}$ as an arithmetic mean. On the other hand, the radon concentration in the center of the room (140 cm distance far from the wall) was 21.2 Bq m$^{-3}$. Using these data, statistical analyses were carried out on significance of the difference among their readings. The ANOVA test was conducted to examine a hypothesis that radon concentrations at different distances from the wall are equal. It was consequently found that they were not equal ($F=13.1$ with 4 and 24 degrees of freedom; the p-value is $<0.0001$). Then, the Duncan’s test was done so as to understand how different they are. It is concluded that: (1) The radon concentration at 10 cm distance from the wall is the highest; (2) Radon concentrations at 10 and 20 cm distances from the wall are significantly different. In addition, they are higher than those at further points from the wall. (3) Radon concentrations at further points than 40 cm are not significantly different. Eventually, the radon concentrations between 10 and 140 cm distances from the wall are significantly different ($T=8.9$, degrees of freedom=8, $p<0.0001$). This implies that the result in
the first survey might be affected by the presence of thoron. For accurate measurements of radon, a special attention must be paid to placement of the detector in such circumstances. Because the detector is usually placed on furniture or is suspended on the wall in a house when considering activities of residents. It will be difficult to place the detector in the center of the room so as to avoid thoron contamination on the radon detector. Alternatively, another detector with a different ventilation rate should be placed in parallel with an ordinary one.

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Radon</th>
<th>Thoron</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>(tracks cm⁻² kBq⁻¹ m³ h⁻¹)</td>
<td>(tracks cm⁻² kBq⁻¹ m³ h⁻¹)</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>8.5 x 10⁻¹</td>
<td>7.0 x 10⁻¹</td>
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**CONCLUSION**

In order to understand high radon levels observed in a well-ventilated Japanese house, some detector was examined using thoron. It was actually used in the nation-wide survey in Japan. With our thoron facilities, the sensitivity for thoron was given. In addition, performance of the detector was examined with an actual thoron exposure in a Japanese house. Since soil walls are often used as our Japanese architectural method, it implies that radon concentrations will be overestimated in such circumstances. A special attention should be paid to placement of the detector accordingly when radon concentrations are precisely measured.

**Figure 2.** Detection response of the KfK detector in an actual environment.
REFERENCES