Radon Concentration in Two Largest Cities in Semitropical Taiwan

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Taiwan/radon/indoor/coal mines

Grab sampling either using the active charcoal method in combination with an ionization chamber or using a working level monitor was performed for the measurement of radon concentration in Taiwan's two largest cities Taipei and Kaohsiung. Long-term monitoring of radon concentration in dwellings and business buildings was also carried out with cellulose nitrate films as the alpha detectors. The average indoor radon concentration in these two cities is $17 \pm 6$ Bq m$^{-3}$. The outdoor radon concentration is about one-half of that on average. As assessed according to the model of UNSCEAR 1988, the induced effective dose equivalent is 0.67 mSv y$^{-1}$. Radon concentration in coal mines showed an average of $88.5 \pm 9.5$ Bq m$^{-3}$.

INTRODUCTION

The radon monitoring program in Taiwan can be traced back to 1979. It was to measure $^{222\text{Rn}}$ activity concentration in selected areas of Taiwan by sampling air through a filter paper and detecting the gross alpha counts of the filter paper with an alpha scintillation counter$^{1)\text{.}}$ The experimental results obtained from sampling in a radwaste plant, a storage room for uranium, a natural cave, a room using natural gas, etc. were just preliminary in nature. Later on emphases were given to the measurement of radon emanation rate in soil with thermoluminescent dosimeters (TLDs). Its principle is published elsewhere$^{2)\text{.}}$

Since the TLD reader and the TLDs themselves are expensive, the technique of using cellulose nitrate (CN) films and a spark counter came into our consideration. The CN films are very sensitive to alpha particles emitted from radon, and the spark counter is quick to count the tracks induced by the alpha particles and is easily fabricated in a laboratory. The spark counter$^{3)\text{}}$ was originally designed at the Oak Ridge National Laboratory of U.S.A. back in the early 1970. It was also used in France for the national indoor radon survey.

The CN films, therefore, were used to monitor the radon concentration in the present work. For the short-term monitoring of radon, grab sampling was used either with an ionization chamber or a surface barrier detector; the latter is attached to the sampling device.

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EXPERIMENTAL PROCEDURE

Methods of short- and long-term monitoring of both indoor and outdoor radon employed in our study are described as follows.

Grab sampling

A grab sampling employed in the present study is an instantaneous sampling which provides data on radon or radon daughter concentration at the time of sampling. In Taipei City, shown in Fig. 1, a working level monitor WLM-200 of Tracerlab Instrument* was used. It is a self-contained instrument with all elements of a data collection system and an alpha spectrometer including the membrane filter, silicon surface barrier detector, detector voltage generator, charge sensitive amplifier, multichannel analyzer, integrated flow meter, and microcomputer for data evaluation. In the $^{222}$Rn mode the WLM-200 operates in cycle times of 1 h. An automatic data evaluation is first done 15 and 30 min after starting the sampler. Later on the data is collected in time periods of 60 min.

In Kaohsiung City, also shown in Fig. 1, the active charcoal method was used. A charcoal trap (CP) was made of a copper U tube with 7 mm inside diameter and 1.7 m in length as shown in Fig. 2. Ten grams of active charcoal made by Merck** were placed at the bottom of the U

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* Tracerlab Instruments Horst Kelm, P. O. Box 1922, D-5020 Frechen 1, FR Germany
** Merck, Frankfurter Strasse 250, D-6100 Darmstadt 1, FR Germany.
The average diameter of active charcoal is 2.5 mm with an average density of 410 kg m$^{-3}$. The air flow rate during sampling was 2–5 L min$^{-1}$. During sampling the CP was placed inside a cooling box with dried ice and alcohol as the cooling agent. After sampling, argon gas was led to the CP for 2 min with a flow rate of 4 L min$^{-1}$ to replace air with argon. The CP was then heated at 350°C for 10 min. An ionization chamber of Ohkura*** was connected to the CP. Radon in the CP was forced to enter the ionization chamber by argon. The small ionization current induced inside the ionization chamber was read with a vibrating reed electrometer for 4 h in order to obtain the reading that equilibrium of radon and its daughters was reached.

The environmental conditions of grab sampling were as follows. The height of air inlet above ground was set at 1 m for both indoors and outdoors during office hours. Normally the sampling time was in the morning.

**Long-term monitoring**

A passive method using CN films, LR 115 Type 2 films of Kodak**** as solid state alpha-track detectors, was used for long-term monitoring of indoor radon. The thickness of this type of CN film is 12 μm, which is specially designed for the registration of alpha particles. The tracks detected by these CN films are not directly visible but have to be intensified by processing the films in an alkaline bath.

The CN film was cut into 30 mm × 45 mm and adhered to a plastic cup of about 1.1 × 10$^{-3}$ m$^3$ in volume. The cover of the plastic cup was drilled into several small holes to let the air go through. A 0.45-μm filter of glass fiber was adhered to the inside of the cover to prevent the dust

*** Ohkura, Tokyo, Japan
**** Kodak, 75594 Paris Cedex 12, France
and the radon daughters from going through. The plastic cup is shown in Fig. 3.

The exposure time for indoor radon was 4 weeks. The tracks due to alpha particles from radon that enters the air space at the cup were registered in the CN film.

The films were etched in a solution consisting of $10^{-3}$ m$^3$ pure CO$_2$-free water and 0.1 kg NaOH. After the solution was left for 1 h until the temperature was in equilibrium with the water bath, films were immersed in the solution at a constant temperature at 60°C for 70 min, and then washed for about 10 min with running water.

To avoid wrinkles in the etched films, the wet film was dried in an oven at 60°C. Care was exercised in handling the wet film to avoid damage.

There are two ways to count the number of alpha tracks registered. One is to use a microscope for manual counting, and the other is to use a spark counter. Both of these two methods were used in the present study. The microscope used is a Nikon Model SMZ-2T for industrial use. A magnification of 60 is sufficient for the present study. The etched film was placed on the manual stage. For each view with naked eyes an area of $(1/36) \times 10^{-4}$ m$^2$ was used. The number of alpha tracks in each sample under examination should reach 20 at least. Ten readings were required for each sample, and 100 readings were required to determine the background.

Spark counting is a simple technique for automatic counting and for magnification of etched perforation in thin film track-etch detector. The dried CN film was placed on the metal electrode and covered with aluminized Mylar with the aluminum side toward the track-etch film. When a

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**Nikon, Tokyo, Japan**
high voltage was applied, a spark passed through one of the holes and evaporated a large hole in the thin aluminum electrode. The spark then jumped from one hole to another until it passed through all holes. The number of sparks indicates the number of etched holes. The only source of error displayed is due to counting statistics. Consistent data were obtained only after trying several counting procedures and sparking voltages. It was found that at 600 V two sparks for each track would enlarge the etched holes and polarize the film. The counts at 450 V were used to determine the actual signal level.

Letters were sent to the residents who are interested in knowing radon or science study. Then CN films were mailed to those people in total of 50 families and business buildings. The CN films enclosed in a plastic cup were placed in their living rooms, bed rooms or in the offices where they go to work. The CN films were processed when mailed back after exposure to radon for 2 months.

*Calibration*

The WLM-200 uses a mathematical calibration method without relying on standard radon chamber. The radon chamber is referred to a chamber in which known activity of radon is generated for calibration purpose. The sampling and the decay of the filter activity are described by a set of 4 differential equations. For the calibration of CN films, they were placed in a radon environment with a concentration of at least 100 Bq m\(^{-3}\). The radon environment was created in an enclosure in which radium was used as the source of radon. We have also participated in the international intercomparison program sponsored by the Australian Radiation Laboratory in Victoria. The reported radon concentration ratio for our 2 rounds is 1.04±0.04 (mean± standard deviation) with a standard error of mean (SEOM)=0.02 and significances of t-statistic (T)=1.

**RESULTS AND DISCUSSION**

*Outdoor radon*

The outdoor radon measured in Kaohsiung City with the charcoal method varied from 2.2 to 20 Bq m\(^{-3}\) in 1982–1988. It depends on time and location during sampling. On average the radon concentration outdoor at Kaohsiung City was 8.8 Bq m\(^{-3}\). The diurnal variation reached the highest in the afternoon from 1 to 4 PM. A typical diurnal variation for outdoor radon concentration measured with WLM method at Kaohsiung City is shown in Fig. 4.

*Indoor radon*

The dwellings surveyed with CN films in Kaohsiung City were mostly constructed with concrete. A few of them were constructed with red bricks or wood. The average concentration of indoor radon in 1987–1988 was 17±6 Bq m\(^{-3}\) (1σ). In addition, TLDs were used simultaneously to measure the gamma dose rate indoors which was 97±13 nGy h\(^{-1}\) on average.

In Taipei City the average radon concentration measured with WLM for 4-story concrete apartments in 1987–1988 varied from 5.5±0.4 to 18.9±3.0 Bq m\(^{-3}\) depending on the ventilation
condition. The lower values were obtained from houses with good ventilation condition while the higher values from the poor ventilation condition. For a 15-story building, similar radon concentration was detected except in the basement of building where concentration of $66.4 \pm 3.0$ Bq m$^{-3}$ was detected.

Coal mines

The coal mines in Taiwan are mainly situated in the northern part of Taiwan as shown in Fig. 1. Within a 20 km width in the middle part of North Taiwan, the coal mine extends to a 120

Table 1. Indoor, outdoor and coal mine radon concentrations in Taiwan

<table>
<thead>
<tr>
<th>Sampling locations</th>
<th>Radon concentration (Bq m$^{-3}$)</th>
<th>Sampling method</th>
<th>No. of sampling points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaohsiung outdoors</td>
<td>2.2–20 (8.8)</td>
<td>Air sampler</td>
<td>7</td>
</tr>
<tr>
<td>Kaohsiung indoors</td>
<td>1.5–51.5 (17 ± 6)</td>
<td>CN films</td>
<td>Concrete 16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Brick 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wood 1</td>
</tr>
<tr>
<td>Kaohsiung indoors</td>
<td>$97 \pm 13$ nGy h$^{-1}$ (gamma radiation)</td>
<td>TLDs</td>
<td>23</td>
</tr>
<tr>
<td>Taipei indoors</td>
<td>5.5–18.9</td>
<td>WLM</td>
<td>4-story houses 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15-story houses 2</td>
</tr>
<tr>
<td>Coal mines</td>
<td>$89 \pm 10$</td>
<td>CN films</td>
<td>First mine</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1st tunnel 16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2nd tunnel 12</td>
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<td></td>
<td></td>
<td></td>
<td>3rd tunnel 12</td>
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<td></td>
<td></td>
<td></td>
<td>5th tunnel 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Second mine</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1st tunnel 16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2nd tunnel 16</td>
</tr>
</tbody>
</table>

Remarks: Numerals in parentheses are the average radon concentrations.
km distance. The ventilation in mines under regulatory control is quite similar to that practiced in the U.S. The radon concentration depends on the depth of the coal mine. On average radon concentration in Taiwan coal mine was found to be 88.5±9.5 Bq m⁻³ with CN films.

A summary of indoor, outdoor and coal mine radon in Taiwan is presented in Table 1. This table includes sampling locations, radon concentration, sampling method and number of measured points.

Dose assessment

The radon dose assessment can be found in such publications by the International Commission on Radiological Protection and the United Nations Scientific Committee on the Effects of Atomic Radiation. It is assumed that 19 h is spent for indoor activity by men and women and 5 h spent for outdoor activity. Using the effective dose equivalent factor of 10 nSv h⁻¹ per Bq m⁻³ (EEC), then the effective dose equivalent (HE) and the equilibrium equivalent radon concentration (Xeq) can be calculated. Based on the radon concentration detected in Kaohsiung City, the ratio of HE to Xeq is 0.069 mSv y⁻¹ Bq⁻¹ m⁻³ indoor and 0.018 mSv y⁻¹ Bq⁻¹ m⁻³ outdoor. The ratio of Xeq to the real radon concentration is called the equilibrium factor (F) which is assumed to be 0.5. Then the indoor Xeq radon concentration is 8.5 Bq m⁻³ while that of outdoor is 4.4 Bq m⁻³. The radiation dose due to indoor radon is thus 0.59 mSv y⁻¹ and that due to outdoor radon is 0.08 mSv y⁻¹ with a total of 0.67 mSv y⁻¹.

Since the average indoor radon concentration is 17±6 Bq m⁻³, it is far below the action level of 150 Bq m⁻³ given by the U.S. Environmental Protection Agency. The radiation dose thus induced is 0.67 mSv y⁻¹ which is close to the natural background γ radiation in Taiwan.

The average concentration of indoor radon in Taiwan is lower than that obtained by other countries which have the similar monitoring program. Taiwan is situated in the semitropical zone. The island always has the sea breeze; there are no unusual distribution of naturally occurring radionuclides in soil and rocks. All these factors mentioned above have attributed to the low concentration of indoor radon in Taiwan.

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REFERENCES

and magnification of etched holes in cellulose nitrate films. Nucl. Tracks and Radiat. Measure. 11: 115–
121.
Nations, New York.