A STUDY OF ENVIRONMENTAL RADON LEVELS IN RAMMED EARTH DWELLINGS IN THE SOUTH WEST OF WESTERN AUSTRALIA

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ABSTRACT

Indoor radon and thoron progeny Equilibrium Equivalent Concentrations (EEC) were measured with a portable “Radon Sniffer” in 10rammed earth dwellings and 10conventional dwellings in Margaret River in the South West of Western Australia. Natural background gamma radiation was also measured within the dwellings. The results of this study show that the mean indoor radon progeny concentrations in rammed earth and non-rammed earth dwellings was 24 Bq m⁻³ EEC and 9.3 Bq m⁻³ EEC respectively. The mean indoor thoron progeny concentrations in rammed earth and non-rammed earth dwellings was 3.9 Bq m⁻³ EEC and 0.8 Bq m⁻³ EEC respectively. The ranges of combined indoor radon and thoron progeny concentrations in rammed earth and non-rammed earth dwellings were between 2.1 and 76 Bq m⁻³ EEC and 2.0 and 27 Bq m⁻³ EEC respectively. The mean annual effective radiation dose equivalents from combined indoor radon and thoron progeny concentrations EEC using UNSCEAR’s (1982) conversion factors in rammed earth and non-rammed earth dwellings were 4.1 mSv y⁻¹ and 2.2 mSv y⁻¹ respectively.

INTRODUCTION

Radon is believed, as a result of epidemiological studies, to be carcinogenic to humans (1,2,3). Exposure to radon decay products is recognized as a hazard for the development of lung cancer in humans (2). The United States Environmental Protection Agency (EPA) estimates that approximately 14,000 lung cancer deaths, with an uncertainty range of 7,000 to 30,000, occur in the US annually due to exposure to radon in homes (4). The International Commission on Radiological Protection (ICRP) estimates that indoor radon contributes approximately 50% of the total annual radiation dose to the population of the United Kingdom (5). Residents of the Perth Metropolitan Area in Western Australia area also receive on average approximately 50% of their total annual environmental radiation dose due to exposure to indoor radon-222 (²²²Rn) and radon-220 ("Thoron") (²²⁰Rn) progeny (6).

In the Perth study it was found that there was a significant correlation between the concentrations of ²²²Rn and ²²⁰Rn progeny found in dwellings assessed and the type of soils and geological structure in the ambient environment (7,8). For soils composed of granite and laterite, which are known to have relatively high uranium and thorium contents (7), it was concluded that this geological feature could have caused the elevated concentrations of ²²²Rn and ²²⁰Rn progeny as these radioactive gases are the decay products of the uranium-238 (²³⁸U) and thorium-232 (²³²Th) radioactive decay series (7).

More recently in the Margaret River area of the South West of Western Australia a particular form of building construction, namely rammed earth, has become a popular choice for both residential and commercial construction. Rammed earth dwellings are predominately constructed from laterite, which is more commonly known as gravel.

Laterite is formed by the chemical breakdown of older granitic rock (9) as a result of being exposed to weathering processes, particularly rainfall (9,10) and the work of groundwater (10) over millions of years. The hardening concrete like properties of laterite were recognized early and consequently it has been utilized in road construction and as a building material around the world (9,10). The significance of laterite is that it can be radioactive, i.e., the material emits enhanced levels of gamma radiation (11,12,13,14). According to the Western Australian Department of Mines (1989) a mineral is considered to be radioactive if it contains more that 0.02% of uranium and 0.05% of thorium (14). Previous studies in the Perth metropolitan area have indicated that soils in the Darling Scarp
(hills), are mildly radioactive due to relatively high levels of thorium (7,8,15) and uranium in the soils and rocks which are predominately comprised of laterite, clay and granite (7). Studies in North America have also revealed that clay soils, which cover most of that country, are also radon prone (16).

METHODS

The instrument used to carry out indoor radon and thoron measurements was a Radon Sniffer working level meter manufactured by Thomson and Nielsen Electronics Ltd of Canada (17). The Radon Sniffer contains an air pump, a filter holder and a liquid crystal display. Accessories include a rechargeable battery pack and 12 volt 400 mA voltage adapter utilized to convert mains 240 volt AC electricity to charge the battery. An anemometer is also utilized to adjust the air-flow rate and measure pump output. The heart of the instrument is the detector system, which is based on silicon dosemeter chips. The Radon Sniffer is operated by sampling air from the environment at a constant rate of 1 litre per minute for a period of 2 hours through a standard 0.8 mm millipore filter, when the pump was operating. Radon and thoron progeny decay products are collected on the filter paper and alpha particles emitted are counted by the detector and displayed as "ALPHA COUNTS". This is the total integrated alpha count over the whole counting period not the alpha activity (7,17).

Prior to carrying out individual indoor radon and thoron measurements the Radon Sniffer was calibrated with a 10 nCi (370 Bq) custom-mounted Am-241 alpha emitter supplied by the manufacturer, to guard against systematic errors. The calibration source was previously checked by the Radiation Health Branch of the Health Department of Western Australia to confirm its activity.

Indoor radon and thoron levels were measured in ten (10) rammed earth and ten (10) non-rammed earth dwellings. Radon and thoron counts were computed in milli-working levels and converted to equivalent equilibrium radon and thoron progeny concentrations (EEC) in Bq m⁻³. These concentrations were converted to a radiation dose equivalent in millisierverts using conversion factors of 0.061 mSv Bq⁻¹ m⁻³ for radon-222 progeny and 0.29 mSv Bq⁻¹ m⁻³ for radon-220 (thoron) progeny as recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (19).

The instrument used to measure background gamma radiation levels was a Berthold LB 1200 radiation dose rate meter. This is a portable instrument that can be used to measure beta, gamma or X-ray radiation. Its design centres around a Geiger-Muller-type ionization chamber that has a 27 mm diameter opening and movable sliding shield on the underside of the instrument. The shield is opened to measure beta radiation and closed to measure gamma radiation. The instrument is energized by 2 nickel cadmium batteries, which can be recharged using an external power source. Prior to carrying out background radiation measurements, the Berthold LB 1200 was calibrated with a Cs-137 source for environmental radiation by a NATA (National Association of Testing Authorities) registered laboratory, to guard against systematic errors. The Berthold LB 1200 instrument was used to measure background gamma radiation levels within the rammed earth and non-rammed earth dwellings located in Margaret River and also externally in the laterite soils, which surrounded all the dwellings.

THEORY

To measure indoor radon and thoron progeny working levels a flexible version of the two-count method was used (7). Prior to applying this method to analyse the field data, the Radon Sniffer was calibrated and tested using standard samples prepared and checked in the laboratory. Air was then sucked through a filter paper for 2 hours (6,7,18). By observing the integrated alpha counts for a period of 0 to 30 minutes and 300 to 600 minutes after sampling, the radon and thoron progeny working levels were calculated utilizing a computer program developed at Murdoch University (7). The delay period of observation of integrated alpha counts, 300 minutes after sampling, is intended to eliminate radon progeny from the determination of thoron progeny working levels as the relatively short-lived radon progeny will have almost all decayed during that period (7,18).

Using this method (7), radon progeny working levels may be computed as:

$$WL(Rn) = (1.044 \ N_1 + 5.150 \ N_2 + 3.805 \ N_3) \times 10^{-3}$$

$$N_1 = \frac{\lambda_c}{\lambda_a} N_3 \quad , \quad N_2 = \frac{\lambda_c}{\lambda_b} N_3$$

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actual radon (and thoron) gas concentration, which is normally assessed in most studies (22) and stated as the international and national action levels. Is worth noting that 1 Bq m⁻³ EEC is equivalent to approximately 3 Bq m⁻³ of actual radon (and thoron) gas concentration assuming secular equilibrium applies.

Table 1 shows the mean concentration of indoor radon progeny measured in rammed earth and non-rammed earth dwellings in Margaret River. The mean concentrations in these dwellings were 24 Bq m⁻³ EEC (73 Bq m⁻³) and 9.3 Bq m⁻³ EEC (27.8 Bq m⁻³) respectively. The mean concentrations from both types of dwellings were found to be higher than the total mean radon concentration value for Australia (12 Bq m⁻³) previously obtained by the Australian Radiation Laboratory (ARL) in 1996 (21). These concentrations were also higher than the mean radon concentration recently found in 1,267 Western Australian homes (17 Bq m⁻³) (15). The mean concentration in rammed earth dwellings was also higher than the mean concentrations found in 104 Perth homes in 1991-1992 (17.4 Bq m⁻³ EEC) (7). Two of the rammed earth dwellings had mean radon gas concentrations of 163 Bq m⁻³ (54 Bq m⁻³ EEC) and 197 Bq m⁻³ (66 Bq m⁻³ EEC) which exceeded the US EPA (148 Bq m⁻³) action level (4). The higher level was also just under the national (200 Bq m⁻³) (2) and State (200 Bq m⁻³) action levels (15). The highest radon gas concentration measured in the non-rammed earth dwellings was 80 Bq m⁻³ (27 Bq m⁻³ EEC).

It is conceivable that the higher mean indoor radon progeny concentration found in the rammed earth dwellings, particularly in comparison to the non-rammed earth dwellings also located in Margaret River, is due to an enhanced emanation rate of radon derived from uranium present in the laterite within the rammed earth walls. 60% of rammed earth dwellings compared to 20% of non-rammed earth dwellings exceeded the public exposure limit of an annual effective dose equivalent of 1 mSv y⁻¹ from artificial sources of radiation recommended by the ICRP (23,24).

**Radiation Dose Equivalents – Radon**

The annual mean effective radiation dose equivalents were calculated from the indoor radon progeny concentrations (Bq m⁻³ EEC) in rammed earth and non-rammed earth dwellings in Margaret River. The effective radiation dose equivalents were derived by utilizing a conversion factor of 0.061 mSv Bq⁻¹ m⁻³ for radon progeny recommended by UNSCEAR (19). The mean
annual effective radiation dose equivalents for indoor radon progeny concentrations (Bq m$^{-3}$ EEC) in rammed earth and non-rammed earth dwellings were $1.4 \pm 1.3$ mSv y$^{-1}$ and $0.6 \pm 0.5$ mSv y$^{-1}$ respectively. The rammed earth dose rate is higher than the average estimated dose rate for the US [0.84 mSv y$^{-1}$] (4), Italy [1.1 mSv y$^{-1}$] (25), Switzerland [0.92 mSv y$^{-1}$] (26), Great Britain [1.3 mSv y$^{-1}$] (5), Perth [1.06 mSv y$^{-1}$] (7) and Western Australia [0.23 mSv y$^{-1}$] (15).

Table 2 shows the mean concentration of indoor thoron progeny measured in rammed earth and non-rammed earth dwellings in Margaret River. The mean concentrations in these dwellings were $3.9 \pm 3.8$ Bq m$^{-3}$ EEC (11.8 Bq m$^{-3}$) and $0.8 \pm 0.4$ Bq m$^{-3}$ EEC (2.4 Bq m$^{-3}$) respectively. The mean thoron progeny concentration in rammed earth dwellings was higher than the mean concentration found in the 104 Perth homes (including some homes in the Perth Hills area) in 1991–1992, which was $2.3$ Bq m$^{-3}$ EEC (7). In comparison the mean thoron progeny concentration found in homes in the Perth Hills area was $14$ Bq m$^{-3}$ (8) equivalent to $4.7$ Bq m$^{-3}$ EEC. The mean thoron progeny concentrations in the non-rammed earth dwellings were lower than levels detected in both the Perth studies. There have only been limited studies that have looked at indoor thoron progeny largely due to its short half-life (55.6 s), which presents measurement difficulties and problems with defining representative values of thoron gas and hence progeny concentrations (3). Consequently it is believed that indoor thoron is more likely to originate from building materials rather than from outdoor soil (24).

Radiation Dose Equivalents – Thoron

The annual mean effective radiation dose equivalents were calculated from the indoor thoron progeny concentrations (Bq m$^{-3}$ EEC) in rammed earth and non-rammed earth dwellings in Margaret River. The effective radiation dose equivalents were derived by utilizing a conversion factor of 0.29 mSv Bq$^{-1}$ m$^{-3}$ for thoron progeny recommended by UNSCEAR (19). The mean annual effective radiation dose equivalents for indoor thoron progeny concentrations (Bq m$^{-3}$ EEC) in rammed earth and non-rammed earth dwellings were $1.1$ mSv y$^{-1}$ and $0.2$ mSv y$^{-1}$ respectively. The rammed earth dose rate is higher than the average estimated dose rate for dwellings located within the Perth metropolitan area (0.7 mSv y$^{-1}$) (7) and is approximately 6 times higher than the average value given by UNSCEAR (27) and the ICRP (23). It is likely that this is due to an enhanced emanation rate of thoron derived from thorium and its progeny present in the laterite within the rammed earth walls.

Table 3 shows the background gamma radiation levels measured in rammed earth and non-rammed earth dwellings in Margaret River.

Table 4 shows the annual effective radiation dose equivalents (mSv y$^{-1}$) from combined indoor radon and thoron progeny concentrations and background gamma radiation measured in rammed earth and non-rammed earth dwellings. The mean annual effective radiation dose equivalents from combined indoor radon and thoron progeny concentrations (Bq m$^{-3}$ EEC) and background gamma radiation measured in rammed earth and non-rammed earth dwellings were $4.1 \pm 2.1$ mSv y$^{-1}$ and $2.2 \pm 0.6$ mSv y$^{-1}$ respectively. It is likely that the higher equivalent radiation dose rate in the rammed earth dwellings is due to an enhanced emanation rate of radon and/or thoron derived from uranium and/or thorium progeny present in the laterite within the rammed earth walls.

<table>
<thead>
<tr>
<th>Type of Dwelling</th>
<th>Arithmetic Mean (Bq m$^{-3}$)</th>
<th>Minimum Value (Bq m$^{-3}$)</th>
<th>Maximum Value (Bq m$^{-3}$)</th>
<th>Standard Deviation (l)</th>
<th>No. of Dwellings &gt; 16 Bq m$^{-3}$ EEC *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rammed Earth</td>
<td>24.1</td>
<td>1.5</td>
<td>65.6</td>
<td>21.0</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SE = (±) 7</td>
<td></td>
</tr>
<tr>
<td>Non-Rammed Earth</td>
<td>9.3</td>
<td>0.9</td>
<td>26.7</td>
<td>8.1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SE = (±) 3</td>
<td></td>
</tr>
</tbody>
</table>

* 16 Bq m$^{-3}$ EEC of Rn-222 Progeny Concentration equates to 1 mSv y$^{-1}$ using the conversion factor of 0.061 mSv Bq$^{-1}$ m$^{-3}$ for Rn-222 Progeny Concentration (19).
Table 2
Indoor Thoron (Rn-220) Progeny Concentration (Bq m⁻³ EEC) Measured in Rammed Earth and Non-Rammed Earth Dwellings in Margaret River

<table>
<thead>
<tr>
<th>Type of Dwelling</th>
<th>Arithmetic Mean (Bq m⁻³)</th>
<th>Minimum Value (Bq m⁻³)</th>
<th>Maximum Value (Bq m⁻³)</th>
<th>Standard Deviation (SE)</th>
<th>No. of Dwellings &gt; 3 Bq m⁻³ EEC *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rammed Earth</td>
<td>3.9</td>
<td>0.6</td>
<td>11.1</td>
<td>3.8 SE = (1) 1</td>
<td>4</td>
</tr>
<tr>
<td>Non-Rammed Earth</td>
<td>0.8</td>
<td>0.2</td>
<td>1.2</td>
<td>0.4 SE = (1) 0.1</td>
<td>Nil</td>
</tr>
</tbody>
</table>

* 3 Bq m⁻³ EEC of Rn-220 Progeny Concentration equates to 1 mSv y⁻¹ using the conversion factor of 0.29 mSv Bq⁻¹ m⁻³ for Rn-220 Progeny Concentration (19).

Table 3
Background Gamma Radiation Measured in Rammed Earth and Non-Rammed Earth Dwellings in Margaret River (mSv y⁻¹)

<table>
<thead>
<tr>
<th>Type of Dwelling</th>
<th>Arithmetic Mean (mSv y⁻¹)</th>
<th>Minimum Value (mSv y⁻¹)</th>
<th>Maximum Value (mSv y⁻¹)</th>
<th>Standard Deviation (SE)</th>
<th>No. of Dwellings &gt; 1 mSv y⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rammed Earth</td>
<td>1.5</td>
<td>1.2</td>
<td>2.2</td>
<td>0.4 SE = (1) 0.1</td>
<td>100%</td>
</tr>
<tr>
<td>Non-Rammed Earth</td>
<td>1.4</td>
<td>1.2</td>
<td>1.8</td>
<td>0.2 SE = (1) 0.1</td>
<td>90%</td>
</tr>
</tbody>
</table>

Table 4
Annual Effective Radiation Dose Equivalents (mSv y⁻¹) from Combined Indoor Radon and Thoron Progeny Concentrations (Bq m⁻³ EEC) and Background Gamma Radiation Measured in Rammed Earth and Non-Rammed Earth Dwellings in Margaret River

<table>
<thead>
<tr>
<th>Type of Dwelling</th>
<th>Arithmetic Mean (mSv y⁻¹)</th>
<th>Minimum Value (mSv y⁻¹)</th>
<th>Maximum Value (mSv y⁻¹)</th>
<th>Standard Deviation (SE)</th>
<th>No. of Dwellings &gt; 1 mSv y⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rammed Earth</td>
<td>4.1</td>
<td>1.6</td>
<td>8.5</td>
<td>2.1 SE = (1) 0.7</td>
<td>100%</td>
</tr>
<tr>
<td>Non-Rammed Earth</td>
<td>2.2</td>
<td>1.6</td>
<td>3.3</td>
<td>0.6 SE = (1) 0.2</td>
<td>100%</td>
</tr>
</tbody>
</table>
In 1990 the ICRP set a public exposure limit of an annual effective dose equivalent of 1 mSv y⁻¹ from artificial sources of radiation (28). This limit applies to enhanced levels of radiation and not to background radiation. The question is, if a dwelling has an internal effective radiation dose equivalent in excess of 1 mSv y⁻¹, is the excessive level of radiation an enhanced/arteral level of radiation or background radiation? In this study it is evident that the higher annual effective radiation dose equivalents from combined indoor radon and thoron progeny concentrations measured in rammed earth dwellings, is due to elevated levels of radiation contributed by the enhanced emanation rate of radon and/or thoron derived from uranium and/or thorium progeny present in the laterite within the rammed earth walls.

CONCLUSIONS

This study has found that indoor radon and thoron progeny concentrations in some dwellings constructed of rammed earth can be significantly higher than levels found in other conventional styles of constructed dwellings. The mean indoor radon and thoron progeny concentration in rammed earth dwellings was approximately 3 times higher than levels measured in non-rammed earth dwellings. The reason for this variation is probably due to elevated levels of uranium and/or thoron that can be present in laterite (gravel), which is used as a building material to construct the walls of rammed earth and mud brick dwellings.

There is sufficient evidence to indicate that precautions should be taken when building dwellings and commercial buildings out of laterite materials. Since the building materials themselves appear to be the main source of elevated indoor radon and thoron levels, regulations should be put in place to require the radiological testing of the specific activity of the laterite that is intended to be used for the construction of rammed earth dwellings and commercial buildings. The cost of implementing such precautions would be insignificant (< 1%) in respect to the overall cost of constructing an average sized rammed earth dwelling.

ACKNOWLEDGEMENTS

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