Radiation Protection Dosimetry
Vol. 67, No. 2, pp. 139–141 (1996)
Nuclear Technology Publishing

TECHNICAL NOTE

# THE REDUCTION OF INDOOR RADON CONCENTRATION BY USING LIGHTWEIGHT CONCRETE IN HIGH-RISE BUILDINGS

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*Received October 23 1995, In final revised form March 11 1996, Accepted April 30 1996*

**Abstract** — The radon exhalation rates from surfaces of different types of lightweight concrete used in the building industry in Hong Kong have been studied using standardised activated charcoal canisters and $\gamma$ spectroscopy. It is found that all the lightweight concretes investigated have considerably smaller radon exhalation rates than those from ordinary concrete. Considering a concrete room of a typical size for Hong Kong, the possible reduction in the indoor radon concentrations has been calculated to be greater than 15 Bq.m$^{-3}$ when lightweight concrete is used instead of ordinary concrete for the non-construction walls. The average indoor radon concentration in Hong Kong is about 45 Bq.m$^{-3}$. Therefore, a simple and economical way to reduce the indoor radon concentrations and the corresponding radiation dose from radon has been demonstrated. This technique applies to future buildings.

## INTRODUCTION

Surveys of radon and radon progeny in Hong Kong(1,2) have shown that the levels here are significant, giving an average value of 45 Bq.m$^{-3}$ when compared to the global average value of about 33 Bq.m$^{-3}$(3). Because of the universal aim of reducing exposures to ionising radiations as much as reasonably achievable, it is necessary to identify efficient mitigation methods to remedy the situation (e.g. Refs. 4–6). Most of the buildings in Hong Kong are high rise, and people seldom work or live on the ground floor, so the main contribution to indoor radon concentration in Hong Kong should come from the concrete used as the building material.

Recently, lightweight drywall construction has been introduced in Hong Kong. As lightweight concrete (LWC) does not contain the crushed granite of normal concrete (NC), which has been found to be the main source of radon(7), their radon exhalation properties should be very different from those of the NC. This work focuses on the difference in the radon exhalation rates between the two, and on the possibility of the application of LWC to mitigate the indoor radon concentrations and the corresponding radiation dose from radon.

## LIGHTWEIGHT CONCRETE

LWC has an air-dry density below 1850 kg.m$^{-3}$(8) as compared to 2350 kg.m$^{-3}$ of NC. It can be classified broadly into three major groups by the method of production; they are aerated concrete, no-fine concrete and lightweight aggregate concrete. Aerated concrete is obtained by introducing foam bubbles inside the cement matrix or the sand–cement grout. In Europe, it is also called 'gas concrete'. By varying the foam–cement–sand ratio, concrete densities ranging from 300 to 1600 kg.m$^{-3}$ can be obtained. No-fine concrete, as its name implies, is concrete without any fine aggregate. By eliminating the fine particles of size less than 5 mm, voids are created within the cement matrix which reduce the concrete density and provide insulating properties but still retain considerable compressive strength. Lightweight aggregates employed in LWC have a wide range of sources which can be natural materials, processed natural materials or synthetic substance from processed by-products or environmental wastes. Five types of LWC materials available in Hong Kong will be investigated in the present study. Their properties are summarised in Table 1.

## METHODOLOGY

The method for the measurement of the radon exhalation rates from the LWC surfaces has been described by Yu *et al*(9). Standardised charcoal canisters(10) are used to collect the radon exhaled for two to three days. These are sealed against the concrete surfaces with silicone sealer to stop air leakage. After collection, the charcoal canisters are removed from the surface, sealed, and stored for the radon decay to reach equilibrium. The radon activities inside the canisters are then determined by counting the gamma ray photons emitted by the radon decay products inside at energies 295 keV, 352 keV and 609 keV using a NaI gamma spectrometer for 10 min.

## REDUCTION IN RADON EXHALATION RATES

The five types of LWC blocks have either been donated to the laboratory, purchased from the market or cast in the laboratory. For each of the LWC blocks, two to three positions or surfaces have been chosen for the measurements of the radon exhalation rates. All the experiments have been carried out at nearly the same time to avoid significant effects due to changes in the ambient environment or due to other unknown factors.

The results on the radon exhalation rates are shown in Table 1. It is seen that most of the measurements are below the minimum detectable limit (around 1.3 mBq.m$^{-2}$.s$^{-1}$). Positive detections have only been obtained from systems B and E, both having pulverised fuel ash (PFA) as a component of the raw materials. This is reasonable because PFA can have high radon exhalation rates(11). In comparison, the mean radon exhalation rate from internal concrete building surfaces for Hong Kong is 13 mBq.m$^{-2}$.s$^{-1}$(12). Morover, since it is customary to clad walls with material that might affect radon emission(13), the realistic radon exhalation from walls built using LWC should be even smaller in absolute units.

## POSSIBLE BENEFITS

For calculation purposes, a concrete room of a typical size and typical parameters for Hong Kong has been adopted(13). These are described as follows. The dimensions of the room are $V = L \times W \times H = 4 \times 3 \times 3$ m$^3$. Therefore the volume is 36 m$^3$ and the total wall area $S_w$ (excluding those of the ceiling $S_c$ and the floor $S_f$, both being 12 m$^2$) is 25.2 m$^2$ if we introduce a correction factor $f = 0.6$ for windows and doors(13). Suppose two adjacent walls are construction walls built with traditional NC and the other two adjacent walls are non-construction walls which can be built with LWC, the areas $S_{wc}$ and $S_{wnc}$ of the construction and non-construction walls respectively are both 12.6 m$^2$. The air exchange rate $\lambda_v$ is taken to be 1 h$^{-1}$. The outdoor radon concentration is denoted as $C_{Rn,o}$ (in Bq.m$^{-3}$).

**Table 1. Properties of, and radon exhalation rates from, lightweight concrete systems used in Hong Kong.**

| System | Raw materials | Radon exhalation rate (mBq.m$^{-2}$.s$^{-1}$) |
|---|---|---|
| A | Autoclave aerated concrete (plus lime) | <1.2<br><1.2<br><1.2 |
| B | Autoclave aerated concrete (plus PFA) | 3.0 ± 1.2<br>2.7 ± 1.2<br>2.6 ± 1.2 |
| C | Synthetic aggregate 'Leca' | <1.3<br><1.3<br><1.3 |
| D | Polystyrene bean as aggregate | <1.3<br><1.3 |
| E | Wood fibre as aggregate (plus PFA) | <1.3<br><1.3<br>2.6 ± 1.2 |

Measurements for individual samples have been made at three different locations of the same sample, and uncertainties are due to counting errors.

It can easily be shown that, at equilibrium, the indoor radon concentration $C_{Rn,i}$ (also in Bq.m$^{-3}$) of a concrete room, of which the internal surfaces are all uncovered, is given by(13)

$$C_{Rn,i} = C_{Rn,o} + \{\epsilon_{wc}[S_{wc} + S_f)] + \epsilon_{wnc}S_{wnc}\}\left(\frac{3.6}{\lambda_v V}\right) \tag{1}$$

where $\epsilon_{wc}$ is the radon exhalation rate (in mBq.m$^{-2}$.s$^{-1}$) from the surfaces of the construction walls built with NC and $\epsilon_{wnc}$ is the radon exhalation rate (in mBq.m$^{-2}$.s$^{-1}$) from the surfaces of the non-construction walls which can be built with LWC. We therefore obtain the reduction in the indoor radon concentration $\Delta C_{Rn,i}$ (Bq.m$^{-3}$) by using LWC to be

$$\Delta C_{Rn,i} = (\Delta\epsilon)(S_{wnc})\left(\frac{3.6}{\lambda_v V}\right) \tag{2a}$$

where $\Delta\epsilon$ is the difference between $\epsilon_{wc}$ and $\epsilon_{wnc}$. Substituting typical values, we have

$$\Delta C_{Rn,i} = 1.26\Delta\epsilon \tag{2b}$$

From Table 1, it can be seen that with a suitable choice of LWC, i.e. those without PFA as a component, the radon exhalation rate is always less than about 1.3 mBq.m$^{-2}$.s$^{-1}$. For a reference, take $\epsilon_{wc}$ to be the mean radon exhalation rate from internal concrete building surfaces of 13 mBq.m$^{-2}$.s$^{-1}$(12). Therefore $\Delta\epsilon$ is greater than 11.7 mBq.m$^{-2}$.s$^{-1}$ and $\Delta C_{Rn,i}$ becomes greater than about 15 Bq.m$^{-3}$. Recalling that the average indoor radon concentrations in Hong Kong is about 45 Bq.m$^{-3}$(1), it is seen that the reduction in the indoor radon concentration can be very significant. The anticipated reduction in the radiation dose from radon is about 0.2 mSv.y$^{-1}$(2,4,5).

From the above, it is concluded that using LWC for partition walls can be a simple and economical way to reduce the indoor radon concentrations and the corresponding radiation dose from radon. However, there are a number of assumptions made in obtaining the final figures. Nevertheless, it is believed that our figures have been on the conservative side because the radon exhalation rates from LWC can be well below the minimum detectable limits, or approach zero in some cases, so the reduction in the annual effective dose equivalent due to indoor radon can even be greater. It is planned to survey the indoor radon properties in those flats which have their non-construction walls built with LWC. In this way, a clearer view of the benefits of using LWC can be obtained.

Besides the radiological point of view, LWC has also other advantages. For example, LWC can find a wide range of applications, from insulation to structural applications. However, in Hong Kong, it is limited to the non-structural use in non-load-bearing partition walls. Nevertheless, this usage can already: (1) reduce the self-load of a building and the size of foundation required, (2) reduce the overall cross sections of structural members and permit larger beam span and clear column space, (3) permit larger pre-cast units to be handled and save labour and transport costs, (4) provide better sound insulation for the machine room and, (5) better thermal insulation to roof/floor. Furthermore, LWC enjoys the advantage of being able to use recycled matter from environment waste such as artificial lightweight aggregate from coal ash and sewage sludge. In this way, the production of LWC with synthetic aggregate may be an effective alternative to handling the environmental waste of the territory.

## ACKNOWLEDGEMENT

This research is partially supported by a research grant no. 7000599 from the City University of Hong Kong.

## REFERENCES

1. Yu, K. N., Young, E. C. M., Stokes, M. J., Luo, D. L. and Zhang, C. X. *Indoor Radon and Environmental Gamma Radiation in Hong Kong*. Radiat. Prot. Dosim. **40**, 259–263 (1992).
2. Yu, K. N., Young, E. C. M. and Li, K. C. *A Survey of Radon Properties for Dwellings for Hong Kong*. Radiat. Prot. Dosim. **63**, 55–62 (1996).
3. UNSCEAR. *Ionizing Radiation: Sources and Biological Effects* (New York: United Nations) (1982).
4. Yu, K. N., Guan, Z. J., Liu, X. W., Young, E. C. M., Stokes, M. J. and Cheung, T. *The Effects of Positive and Negative Ions on the Lung Dose from Environmental Radon*. Radiat. Prot. Dosim. **58**, 65–67 (1995).
5. Yu, K. N., Guan, Z. J., Liu, X. W., Young, E. C. M., Stokes, M. J. and Cheung, T. *Mitigation of Indoor Radon Hazard by Air Conditioning*. J. Radiol. Prot. **15**, 67–71 (1995).
6. Yu, K. N., Young, E. C. M., Guan, Z. J. and Liu, X. W. *The Reduction of Radon Hazard in Smoke Free Working Environments*. Radiat. Prot. Dosim. **63**, 147–149 (1996).
7. Yu, K. N., Guan, Z. J., Stokes, M. J. and Young, E. C. M. *The Assessment of the Natural Radiation Dose to the Hong Kong Population*. J. Environ. Radiact. **17**, 31–48 (1992).
8. Federation Internationale de la Precontrainte. *FIP Manual of Light Weight Aggregate Concrete*. 2nd edn (London: Surrey University Press) (1983).
9. Yu, K. N., Chan, T. F. and Young, E. C. M. *The Variation of Radon Exhalation Rates from Building Surfaces of Different Ages*. Health Phys. **68**, 716–718 (1995).
10. Cohen, B. L. and Cohen, E. S. *Theory and Practice of Radon Monitoring with Charcoal Adsorption*. Health Phys. **45**, 501–508 (1983).
11. Yu, K. N. *The Radon Emanation from Concrete with Pulverized Fuel Ash (PFA)*. Build. Environ. **29**, 545–547 (1994).
12. Yu, K. N., Guan, Z. J., Young, E. C. M. and Stokes, M. J. *In-situ Measurements of Radon Exhalation Rate from Building Surface in Hong Kong*. Nucl. Sci. Tech. **4**, 176–180 (1993).
13. Yu, K. N. *The Effects of Typical Covering Materials on the Radon Exhalation Rate from Concrete Surfaces*. Radiat. Prot. Dosim. **48**, 367–370 (1993).