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A Review of Radon Pollution in Buildings in Hong Kong

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Indoor radon concentrations, radon emanation rates from building surfaces, radioactivity contents of building materials and the indoor gamma dose rates for Hong Kong are all in general higher than values obtained elsewhere. An interesting phenomenon has been noted that the values of indoor radon concentrations and radon emanation rates from building surfaces in Hong Kong tend to decrease with the age of the buildings, while the absorbed gamma dose rate remains about the same. The total average annual effective dose equivalent, and contribution from radon, thoron and their daughters, and that related to building materials will be shown. The number of radon-induced lung cancer deaths will also be discussed.

1. INTRODUCTION

RADON is a natural radioactive gas which is ubiquitous in nature and there are no ways to avoid it. However, since humans construct buildings to live and work in of materials that have high radon emanation rates and then provide inadequate air exchange, we refer to these radon level enhancements as radon pollution. The main isotope of radon is ^{222}Rn, which is a direct decay product of radium (^{226}Ra) which in turn is naturally and continuously produced in the environment as the Earth's crust contains ^{238}U which decays to ^{226}Ra. While most of the radon gas inhaled at any time will be exhaled, its progeny (or called its daughters) produced by the radon that decays, being solid (e.g. Bi, Pb), may deposit on the epithelial cells of the alveolar tissues of the lungs. These particles are also radioactive and decay by emitting alpha particles. This causes a radiation dose to the lungs so increasing the probability of contracting lung cancers. The increase in the probability of uranium miners who had been exposed to a high level of radon was one of the early indications of the health hazards imposed by radon and its daughters.

In an indoor environment, radon concentrations may build up considerably. There are four main sources for this: radon gas that seeps through the cracks in the foundation of the house and through openings and loose drainage pipes; building materials containing uranium; natural gas; and tap water containing dissolved radon. The first two sources are usually the most important ones.

Inhalation of short-lived Rn daughters in houses is one of the most important sources of radiation exposure for the general population. According to the UNSCEAR (United Nation Scientific Committee on the Effects of Atomic Radiation) 1982 report, radon and its daughters contribute about 50% to the effective dose equivalent from all the natural radiation source to the public [1]. The UNSCEAR 1988 report increases the original estimated effective dose equivalent by about 40% of the initial value [2]. The general public spends about (or more than) 80% of their time indoors, so it is essential to investigate the problems of indoor radon and its daughters.

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2. RADON RELATED INFORMATION IN HONG KONG

Indoor radon concentrations

Surveys on indoor radon concentrations in Hong Kong have been carried out [3, 4], which give a mean value of about 45 Bqm^{-3}. This is higher than the global value [1] of 30 Bqm^{-3} by about 50% (1 Bq means 1 disintegration per second on average), which is consistent with the findings that the uranium and radium contents of building materials [5] and the indoor gamma dose rates [4] for Hong Kong are higher than other places (see below).

Although most people think that the radon concentrations in granitic areas are higher (because granite has relatively higher natural radioactivity contents), there is no significant difference found in different regions in Hong Kong with different rock types [3]. This is because most of the buildings in Hong Kong are high rise and the main contribution to indoor radon concentrations comes from building materials. The radon source is therefore basically determined by the radium content of the building materials used.

Window type air conditioners are growing more common for dwellings in Hong Kong. In summer, most of the domestic air conditioners are switched on only after office hours or at night, and switched off in the rest of the day with the windows closed all the time. This results in a poor exchange rate of the indoor air with the outside air, and in turn cause a high indoor radon concentration. These sites have significantly higher radon concentrations than those with natural ventilation (at $\alpha = 0.05$ in the t-test) [3]. This may be one of the causes of the relatively high indoor radon concentrations in Hong Kong.

Radon emanation rates from building surfaces

Most scientists agree that indoor radon generally comes from soil beneath buildings and from building materials, i.e. the radon emanates from different building surfaces such as floors, walls and ceilings. In Hong Kong, most of the buildings are high rise, which would suggest that the contribution from building materials may be more significant.

Apart from the radium content of the building materials, the radon emanation rate also depends on the physical characteristics of the materials, the structure of the buildings, environmental factors (such as temperature, air pressure, relative humidity, etc.), and the covering decorative materials utilized. The radon emanation rates can thus vary significantly even for the same type of building materials.

A survey on the radon emanation rates from building surfaces in Hong Kong has been performed [6]. It has been found that the radon emanation rates from floor surfaces on ground floors are significantly greater than those on other levels, while the rates at other levels are more or less the same. These results are expected and are similar to those obtained by other workers. The cause for the difference is the significant additional contribution to the emanation rate from the soil underneath and around the building on the ground floor.

The radon emanation rate is lowered by varying amounts when a concrete surface is covered by different decorative cladding materials. Some are very efficient at inhibiting the radon emanation, such as plastic lined wall paper, glazed ceramic and terrazo, and are thus economical and practical materials for reducing indoor radon concentration. In addition, it has been noted that at places where the covering material is removed or where cracks exist, or at junctions between covering materials the radon emanation rates are comparatively higher. The weighted mean radon emanation rate from bare concrete wall surfaces is 16 $mBq \cdot m^{-2} \cdot s^{-1}$. This value is higher than the average value (3.3 $mBq \cdot m^{-2} \cdot s^{-1}$) for buildings in Beijing, China, by a factor of 5, higher than the average value (4.6 $mBq \cdot m^{-2} \cdot s^{-1}$) for buildings in Norway by a factor of 3, and higher than the typical value (2 $mBq \cdot m^{-2} \cdot s^{-1}$) quoted in the UNSCEAR-82 report by a factor of 8. This is one of the main reasons for high indoor radon concentrations in Hong Kong.

Radioactivity contents of building materials

The radioactivity levels of natural radionuclides such as uranium, radium and thorium in building materials used in Hong Kong are listed in Table 1. The radionuclide contents in small stones used as aggregate for concrete are the highest, which have much higher radioactivity contents than those of other countries. They are imported from China. The average uranium, radium and thorium contents of typical buildings in Hong Kong are 143, 128 and 120 $mBq \cdot kg^{-1}$ respectively [6]. From the average radium contents, estimations have been made of the indoor radon concentration and the radon emanation rates from building surfaces in Hong Kong, which are in good agreement with *in-situ* measurements [6].

Indoor gamma dose rates

Natural radionuclides in building materials such as uranium, radium and thorium are also gamma ray emitters. The indoor gamma dose rates [4] for Hong Kong are higher than other places. Nevertheless, for individual sites, it is not definite for sites that have high gamma dose levels to have high indoor radon concentrations [4], which may be due to other factors that affect the radon concentrations, e.g., the air exchange rate and the relative humidity, etc.

Variation with age of buildings

A surprising phenomenon is that the values of indoor radon concentrations and the radon emanation rates from building surfaces in Hong Kong tend to decrease with the age of the buildings, while the absorbed gamma dose rate remains about the same [3, 4, 6]. There seems to be a discrepancy, because the radon concentration and the radon emanation rate should in some way correlate with the radium content of the building materials, which in turn should correlate with the absorbed gamma dose rate. Therefore, we may have to say that the variation of indoor radon concentration with the ages of buildings is

Table 1. Comparison of radionuclide contents in building materials

Material	Country/Region	Contents ($Bq \cdot kg^{-1}$) U-238	Ra-226	Th-232	Ref.
Cement	California, U.S.	50.4	—	8.22	[10]
	U.S.S.R.	—	44.4	44.4	[11]
	Global average	—	52.0	41.0	[1]
	Hong Kong	19.3	19.2	18.9	[6]
Sand	California, U.S.	34.5	—	9.77	[10]
	U.S.S.R.	—	13.3	18.5	[11]
	Global average	—	15.0	15.0	[1]
	Hong Kong	29.4	24.3	27.1	[6]
Granite ballast	F.R.G.	—	96.2	81.4	[11]
	U.K.	—	88.8	85.1	[10]
	U.S.S.R.	—	111	167	[11]
	Global average	—	96.0	93.0	[1]
	Hong Kong	231	202	140	[6]
Brick	California, U.S.	44.4	—	42.3	[10]
	F.R.G.	—	96.2	96.2	[11]
	Global average	—	67.0	67.0	[1]
	Hong Kong	157	143	158	[6]

not due to ventilation conditions or other constructional differences, but may be due to that the ability of either the building materials to inhibit radon diffusion or the cladding decorative materials to inhibit radon emanation should have changed over the years. Further investigations in this area seem necessary.

3. HEALTH EFFECTS

The annual effective dose equivalent H_{Rn} of the Hong Kong population, due to inhaled radon and radon daughters, has been calculated to be 1.34 mSv, within which 1.11 mSv comes from indoors and 0.23 mSv from outdoors [5]. This value is a little higher than the global average value 1.06 mSv given in the UNSCEAR 1988 report.

The total average annual effective dose equivalent H_{eff} from external natural background radiations is contributed from four parts, namely, H_c from cosmic rays, H_γ from the gamma dose, H_{Rn} from radon and their daughters, and H_{Th} from thoron and their daughters (thoron is another isotope of radon, namely ^{220}Rn), which is then $H_\gamma + H_{Rn} + H_{Th} + H_c = 3.26$ mSv, within which 50% comes from radon, thoron and their daughters, and 80% is related to building materials [6]. Therefore, building material is the primary source of natural background radiation in Hong Kong. More extensive studies and perhaps limitation of the radionuclide concentration of building materials in the near future seems necessary.

From a relative risk model [7], about 13% (about 300 cases) of all the lung cancer deaths are expected to be attributable to ^{222}Rn [8]. For a comparison, using the constant risk from the International Commission of Radiological Protection [9] and taking the Hong Kong population of 6 million, the estimated number of Rn-induced lung cancer deaths per year is also about 300.

4. CONCLUSIONS

The average indoor radon concentration in Hong Kong is about 45 Bqm^{-3}, which is higher than global value by about 50%. This is expected because the radioactivity contents of building materials, the indoor gamma dose rates for Hong Kong, and the radon emanation rates from building surfaces are relatively higher. Window type air conditioners and central air conditioning systems which provide poor ventilation may be the other cause.

An interesting phenomenon has been noted that the values of indoor radon concentrations and radon emanation rates from building surfaces in Hong Kong tend to decrease with the age of the buildings, while the absorbed gamma dose rate remains about the same. One conclusion may be that the ability of either the building materials to inhibit radon diffusion or the cladding decorative materials to inhibit radon emanation should have changed over the years. Further investigations in this area seem necessary.

The total average annual effective dose equivalent H_{eff} from external natural background radiations is 3.26 mSv, within which 50% comes from radon, thoron and their daughters, and 80% is related to building materials. The number of radon-induced lung cancer deaths has been estimated to be about 300. Unless remedial actions can be taken to reduce the Rn exposure, the number of Rn-induced lung cancer deaths is expected to grow with the population. An obvious measure to lower the risk due to radon and also the total radiation risk due to building materials is to limit the radioactivity contents of building materials used in Hong Kong.

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