INTRODUCTION

Hong Kong is a metropolitan city located on the southern coast of China with a population of some six million. About 90% of the population lives in heavily built-up areas, which accounts for less than 50% of the total area in the territory (Figure 1). In order to understand the spatial variations in the environmental radiation levels in Hong Kong, the Hong Kong Observatory (HK) had in early 1999 conducted a study of the environmental gamma absorbed dose rate in air both in the open fields and built-up areas. This paper describes the results of the study and compares the environmental gamma absorbed dose rate in air measured in Hong Kong with those reported in other places.

GAMMA DOSE-RATE MEASUREMENTS FROM FIXED STATIONS

A radiation monitoring network (RMN) has been in operation in Hong Kong since 1987 to continuously monitor the environmental gamma radiation levels over the territory as part of the emergency monitoring programme for response to nuclear accidents at a nearby nuclear power station. The network consists of ten fixed field stations each equipped with high pressure ionization chambers (Reuter-Stokes Model RSS-1013) and a central station (Figure 2). Data are transmitted to the central station by both radio and dedicated phone lines at one minute intervals and archived. A summary of gamma absorbed dose rate in air measured by this fixed station network is published monthly (for example, 1). These data formed an integral part of the Hong Kong Observatory 1999 Study.

Five of the ten RMN stations stand in the open field protected from human activities. These are at Kat O, Ping Chau, Sha Tau Kok, Tap Mun and Tsim Bei Tsui. The long history of the data from these five stations allows detailed analysis to be made to derive the seasonal variations in the environmental gamma radiation levels over the territory. On average the environmental gamma absorbed dose rate in air in January and February is 1.03 times of the annual figure. This seasonal correction is applied to the results of the year 1999 survey which was conducted in January and February.

MEASUREMENT OF COSMIC COMPONENTS

To estimate the terrestrial component of the environmental radiation field, the outdoor cosmic contribution was determined by the environmental gamma absorbed dose rates in air measured over two large fresh water reservoirs, where the terrestrial component is negligible. Contribution from other factors, such as those due to K-40 in human bodies and the internal noise from the ionization chamber was subtracted from the measured values (2). The cosmic contribution in Hong Kong was determined to be about 39 nGy/h.
THE HONG KONG OBSERVATORY 1999 STUDY

In the study, the territory of Hong Kong was divided into 42 grid boxes of 5 km x 5 km for open field and 61 grid boxes of 2.5 km x 2.5 km for built-up areas according to the population and land use. In local areas not covered by existing fixed-station data, the Observatory conducted a supplementary territory-wide radiological survey. A portable high pressure ionization chamber Reuter-Stokes Model RSS-112, was employed in the survey.

A map of Hong Kong with the grid boxes and the population distribution is shown in Figure 1. In each grid box, measurements were taken at locations near the centre of the grid box as far as possible. Measurement locations in adjacent grid boxes were separated by at least half of the grid length. Measurement locations were carefully chosen so that the environmental radiation levels were not affected by industrial activities, e.g. electricity power stations, refuse sites, etc.

Sampling locations must be representative of the environment to be measured. In Hong Kong, the total built-up area is less than 50% of the open field. In the survey, similar to usual practice in other places of the world, the environmental gamma absorbed dose rate in air (D_{out}) was measured in open field with underlying surface not affected by human activities, e.g. presence of concrete. The measurement locations were at distances of at least 50 m from nearest buildings.

As apparent in Figure 1, most of the population in Hong Kong is concentrated in heavily built-up areas with concrete high-rises closely packed on both sides by busy streets. The environmental radiation field is altered by contribution from the buildings. Therefore, gamma absorbed dose rates in air were also measured at street levels in built-up areas. Considering the fast moving traffic and that few people stay in the middle of the street for long, street measurements were made at the curbside of pavements at a distance of at least 1 m from buildings instead of in the middle of the street. This is a slight variation from the practice adopted elsewhere where measurements were made in the middle of the street (3). For comparison purpose, a number of test surveys were conducted where the measurements were made both in the middle of the street and at the curbside. An analysis of the test survey data together with the computation results based on a simple model (Appendix I) shows that the average difference between the two values is less than 10%, which is about the same as the measurement variations. It is considered that the measurements made at curbside are representative of the "street" environment. Hereafter environmental gamma absorbed dose rate in air in built-up areas is referred to as D_{street}.

SURVEY RESULTS

In total, 98 additional measurements (37 in open field, 61 on street) on environmental gamma absorbed dose rates in air were made in the year 1999 survey. The open field survey results were compiled together with available data from the five RMN stations which stand in the open field (a total of 42 sites) to give a representative picture of the outdoor gamma absorbed dose rate in air in the territory.

After cosmic and seasonal corrections, D_{out} ranges from 51 to 123 nGy/h with an average of 87 nGy/h. The values of D_{out} are in general higher on the southwestern part of the territory, especially over Lantau Island. After cosmic and seasonal corrections, D_{street} ranges from 135 to 229 nGy/h with an average of 179 nGy/h. A map showing the spatial distribution of D_{out} and D_{street} is given in Figure 3.
COMPARISON WITH NEIGHBOURING CITIES

The level of $D_{out}$ is largely dependent on the geology of the territory. As most part of Hong Kong is largely made up of igneous rocks which contains higher concentrations of primordial radionuclides than sedimentary rock, it has an important bearing on the relatively high level of $D_{out}$. The average value of 87 nGy/h is 47% higher than the world average value of 59 nGy/h (4). Though $D_{out}$ in Hong Kong is relatively high, it compares very well with the values of 89 nGy/h in Shantou and 88 nGy/h in Shenzhen (5). The value of Guangzhou also stands high at 114 nGy/h (5). This is to be expected as the geology of south China is predominantly igneous. The average value of the Guangdong Province is 86 nGy/h (5).

As illustrated in the Appendix, the difference between $D_{street}$ measured in the middle of the street and that at the curbside is less than 10% so in the following $D_{street}$ in Hong Kong is compared against the values in south China without further differentiation. $D_{street}$ over south China apparently varies with the degree of urbanization with the highest value of 179 nGy/h found at Hong Kong. The value of Guangzhou is 123 nGy/h (5).

The comparison of $D_{out}$ and $D_{street}$ in Hong Kong with neighbouring cities in Guangdong (5) is summarized below:

<table>
<thead>
<tr>
<th>Province</th>
<th>$D_{out}$ nGy/h (range)</th>
<th>$D_{street}$ nGy/h (range)</th>
<th>$D_{out}/D_{street}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guangdong Province</td>
<td>86 (18 - 193)</td>
<td>91 (27 - 179)</td>
<td>1.06</td>
</tr>
<tr>
<td>Guangzhou</td>
<td>114 (52 - 165)</td>
<td>123 (53 - 166)</td>
<td>1.08</td>
</tr>
<tr>
<td>Shenzhen</td>
<td>88 (77 - 88)</td>
<td>105 (102 - 128)</td>
<td>1.19</td>
</tr>
<tr>
<td>Shantou</td>
<td>89 (36 - 165)</td>
<td>95 (38 - 152)</td>
<td>1.07</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>87 (51 - 123)</td>
<td>179 (135 - 229)</td>
<td>2.06</td>
</tr>
</tbody>
</table>

Hitherto, there is little published data systematically comparing $D_{street}$ in cities. In some literature $D_{street}$ are compared to $D_{out}$ in the same table without differentiation. For example, in the UNSCEAR 1993 report, Annex A, Table 4: "Estimates of Outdoor Absorbed Dose Rates in Air from Terrestrial Radiation Sources 1 m Above Ground Level Obtained in Large Scale Surveys" compares the environmental gamma absorbed dose rates in air reported by various places in the world (4). A value of 160 nGy/h, which was obtained from a survey covering the built-up areas and hence essentially $D_{street}$ (6), was reported for Hong Kong. This is the highest value in the Table but apparently this value cannot be meaningfully compared against other data in the Table which are in the open field context.

CONCLUSION

After cosmic and seasonal corrections, $D_{out}$ ranges from 51 to 123 nGy/h with an average of 87 nGy/h. This is typical of the igneous geology in south China and compares well with those of neighbouring cities in Guangdong.

Environmental gamma absorbed dose rate in air in the built-up areas in Hong Kong is greatly enhanced due to the source geometry of the high rise buildings closely packed along the streets, and also the change in source intensity due to paving of the natural environment. After cosmic and seasonal corrections, $D_{street}$ ranges from 135 to 229 nGy/h with an average of 179 nGy/h.
As the degree of urbanization increases the environmental radiation field is greatly enhanced. The significant difference between $D_{street}$ and $D_{out}$ suggested that it would be useful if the outdoor gamma absorbed dose rates in air would be reported separately as $D_{out}$ and $D_{street}$ so as to enable meaningful comparison of environmental gamma absorbed dose rate in air at various places on a "like-with-like" basis.

APPENDIX I: Variations of $D_{street}$ due to Source Geometry

The following examples and calculations based on a simple source-detector geometry illustrate the variations of $D_{street}$ arising from the changes in source geometry. The variability of $D_{street}$ due to changes in source intensity will be investigated in the next survey scheduled for the year 2000, in which radionuclides in soil and rock samples collected at the measurement point will be assayed.

As discussed in the text, $D_{street}$ was measured at the curbside of pavements at a distance of at least 1 m from buildings instead of at the middle of the street. To study the effect of the exposure of the measurement point to surrounding buildings, $D_{street}$ was also measured in the middle of the street at three locations, with results as shown below:

<table>
<thead>
<tr>
<th>Location</th>
<th>$D_{street}$ at middle of street (M), nGy/h</th>
<th>$D_{street}$ at curbside of pavements (C), nGy/h</th>
<th>M/C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shun King Street</td>
<td>219</td>
<td>207</td>
<td>1.06</td>
</tr>
<tr>
<td>King‘ee44ee4e4e4s Road</td>
<td>185</td>
<td>170</td>
<td>1.08</td>
</tr>
<tr>
<td>Holly Road</td>
<td>214</td>
<td>199</td>
<td>1.08</td>
</tr>
</tbody>
</table>

$D_{street}$ at the curbside of pavement are about 6% to 9% smaller than those in the middle of the street, reason being the reduced field of view to buildings on the same side of the street. Figures A1 to A3 clearly depict the variation of the exposure of the measurement points to surrounding buildings at the three locations.

The ratio of $D_{street}$ in the middle of the street to that at the curbside of pavement, $M/C$, can be estimated quantitatively based on a simple source-detector geometry as shown in Figure A4. Assuming that:

(a) buildings on both sides of the street with width $W$ can be regarded as vertical rectangular planes with length $L$ and height $H$,

(b) source activity concentration on the vertical planes and the ground surface is uniform,

(c) photons in the energy range 0.5 MeV to 2 MeV with unit activity concentrations per unit area are emitted, and

(d) the detector has an isotropic response.

The photon flux $F$ intercepted by the detector at the middle of the street or curbside of the pavement can then be evaluated by summation of the integrals:

$$ F = \Sigma_{\text{photons from 0.5 MeV to 2 MeV at 100 keV interval}} \Sigma_{\text{two vertical planes, ground surface}} \int_A B \exp(-\mu l) \, dA / l^2 $$

where:

$A = \text{surface area under consideration, } dA = dx dy$

$B = \text{exposure build up factor for the medium of air}$

$\mu = \text{linear attenuation coefficient of air to photon under consideration}$
\[ l = \text{distance from } dA \text{ to detector}, = \sqrt{h^2 + x^2 + y^2}, \text{ where } h \text{ is the vertical distance from the detector to the surface under consideration.} \]

In evaluating \( F \) for the measurement point at the middle of the street, \( h \) is 1 m for the ground surface and \( W/2 \) m for the two vertical planes. In evaluating \( F \) for the measurement point at the curbside of pavement, \( h \) is 1 m for the ground surface, \( W - 1 \) m for the far side vertical plane and 1 m for the near side vertical plane. The linear attenuation coefficient \( u \) for air and exposure build up factor for the medium of air \( B \) are taken from the Handbook of Health Physics and Radiological Health (7).

For \( L = 2 \) km, \( H = 60 \) m and \( W = 40 \) m, which are values typical of the busier streets in Hong Kong, \( M/C \) is 1.05. Sensitivity analysis shows that for \( H = 60 \) m, \( M/C \) increases from 1.01 to 1.13 when \( W \) is varied from 20 m to 100 m. While for \( W = 40 \) m, \( M/C \) decreases slightly from 1.05 to 1.04 when \( H \) is varied from 10 m to 200 m. Variation of \( L \) has little effect on \( M/C \). These results agree very well with the measurements. Of the three streets in Figures A1 to A3, King's Road is the widest, hence the highest value of \( M/C \) of 1.09. Shun King Street is narrower and the corresponding \( M/C \) is 1.06. Holly Road is the narrowest but the effect on \( M/C \) is partially offset by that of the low rise three storey buildings on both sides, hence the comparable \( M/C \) of 1.08 with that of King's Road.

REFERENCES

Figure 1: Grid boxes of the year 1999 survey and the population distribution (to the nearest thousand) in Hong Kong. The 5 km x 5 km grid boxes are open field areas and the 2.5 km x 2.5 km grid boxes are built-up areas.

Figure 2: Locations of the Radiation Monitoring Network stations and the Guangdong Nuclear Power Station.

Figure 3: Spatial distribution of outdoor and street level gamma absorbed dose rates (nGy/h) in air in Hong Kong.
Figure A1: Shung King Street, Whampo Garden, 6 indicates measurement points in middle of the street and at curbside.

Figure A2: King's Road, Causeway Bay, 6 indicates measurement points in middle of the street and at curbside.

Figure A3: Holly Road, Happy Valley, 6 indicates measurement points in middle of the street and at curbside.

Figure 4A: Source-detector geometry for measurement points (♀) in middle of the street and at curbside.