NATURAL BACKGROUND RADIOACTIVITY LEVELS IN THE TERRESTRIAL ENVIRONMENT OF HONG KONG

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ABSTRACT

This paper analyses and summarizes the natural radionuclide contents of soil and building materials, radon concentrations and the penetrating radiation levels in Hong Kong. From these, a thorough and objective assessment for the terrestrial background irradiation level of Hong Kong was made. Finally, the annual effective dose equivalent received by Hong Kong people due to the natural background irradiation was calculated to be 3.2 mSv.

Keywords: Natural radioactivity Absorbed gamma dose rate Indoor radon Soil and building materials Background levels Effective dose equivalent

1 INTRODUCTION

The research on the irradiation dose due to natural background irradiation received by population is very important. For Hong Kong, little work has been done before 1980[1]. After China decided to build a nuclear power plant in Daya Bay which is only 30 km away from Hong Kong, investigations on this topic have grown in number, which may be partly because the background radiation level in Hong Kong will change after the operation of the nuclear power plant.

In this paper, we summarize data since 1984 for the terrestrial natural background radiation (aquatic data still not available), including absorbed dose rate in air due to cosmic radiation and terrestrial radiation, indoor radon concentration and both indoor and outdoor potential α energy of radon daughters, and natural radionuclide contents of soil and building materials. Some of these data agree well each other, while others may show large discrepancies, which we will discuss. The natural radionuclide contents in soil and building materials are the main contributors to the terrestrial radiation and environmental radon level, and from the former we can estimate the latter. We use the UNSCEAR model to assess the summarized data, and

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compare the results with those from the nearby Guangdong Province and Shenzhen. We therefore obtain values for the absorbed terrestrial radiation dose rate in air and the indoor radon concentration which are representatives of Hong Kong. Finally, we make use of these results to calculate the annual effective dose equivalent due to the terrestrial natural radiation background received by Hong Kong people.

2 LEVELS OF NATURAL PENETRATING RADIATION

Table 1 lists the indoor and outdoor absorbed dose rates in air due to natural penetrating radiation, which includes the terrestrial and cosmic radiation, the latter being 2.9×10^{-8}— 3.1×10^{-8} Gy/h[10]. The 1984 measurement in Table 1 does not

Table 1

Measurements of gamma dose rates in Hong Kong

No.	Time	Method	Outdoor $/10^{-8}$Gy·h^{-1}			Indoor $/10^{-8}$Gy·h^{-1}			Remarks	Ref
			Sites	Range	Mean	Rooms	Range	Mean		
1	1984	NaI	25	1.71—15.1	8.06*	—	—	—	Method of total spectrum energy	2
2	1988	HPIC[1]	4	9.00—16.00	13.0	—	—	—	Annual mean	3
3	1988	TLDs[2]	48	8.00—18.0	12.2* *	—	—	—	Integrated annual dose	3
4	1990	G-M[3]	16	11.7—27.8	19.3	40	15.6—37.0	24.1	Original unit μR/h	4
5	1990	G-M[3]	25	15.6—29.2	23.8	—	—	—	Measured in streets	4
6	1990	G-M[4]	18	13.9—19.2	16.2	18	15.8—22.6	18.6	—	5
7	1991	TLDs	—	—	—	69	12.2—27.4	20.4	LiF(Mg, Ti)	6
8	1991	TLDs	—	—	—	69	9.22—28.5	21.3	LiF(Mg, Cu, P)	6
Guangdong		NaI	1712	1.50—29.1	10.3	1712	2.30—46.6	15.5	Model FD-71 γ dosimeter	7
		HPIC[1]	—	—	18.3	—	—	36.4	HBRA	8
Shenzhen		—	—	—	12.9	—	—	16.7	High rise buildings	9

HBRA: High background radiation area [1] High pressure ionization chamber, Model RS-111 (U.S.) [2] Thermoluminescent dosimeters [3] Model 491 γ dosimeter, calibrated with an RS-111 HPIC [4] Model MC-7 γ dosimeter, calibrated with an RS—1012 HPIC * Lower limit of energy range: 100 keV: Original data: 70.7 mrad/a * * No mean value given in the original report

include the cosmic radiation because the method of total spectrum energy uses an energy region which has little effect from the cosmic radiation, and should become 11.2×10^{-8} Gy/h after adding this component. The outdoor absorbed dose rate measured in 1990 to be 23.8×10^{-8} Gy/h was obtained in urban streets, which makes it difficult to be compared with other outdoor values. Therefore the rural absorbed dose rate in air of the natural penetrating radiation should be within 11.2×10^{-8}—19.3×10^{-8} Gy/h. The large range is due to the different measurement and calibration methods, and also due to the different sampling sites. For example, most sampling sites of 19.3×10^{-8} Gy/h are in new towns consisting of high rise buildings and concrete roads, so the result is expected to be higher. In contrast, measurements made near rural areas, *e.g.* near a reservoir, are lower. It is therefore seen that population weightings should be used in estimating the dose. The indoor measurements are very similar to each other and the range is 18.6×10^{-8}—24.1×10^{-8} Gy/h. The difference arises mainly from the different building materials, structure and internal settings. As a whole, the natural penetrating radiation level in Hong Kong is high, which can be attributed to the geological material mostly being granite, and the relatively high radioactivity contents of the building materials employed in recent years.

3 ENVIRONMENTAL RADON LEVELS

In Table 2 those measured using open faced charcoal canisters (OFCCs) are close to each other, but are significantly lower than the two measurements using alpha track monitors. The discrepancy has to be investigated in the future. If we adopt the

Table 2

Measurements of concentrations of radon and its daughters in Hong Kong

Year	Method	Radon /Bqm^{-3}			Radon daughters / mWL			Remarks	Ref
		Sites	Range	Mean	Sites	Range	Mean		
1985	Filter	—	—	—	10	1.76—9.12	3.72	Indoor	11
		—	—	—	3	1.70—3.28	2.48	Outdoor	11
1988	ATMs[1]	98	31.0—938	212*	—	—	—	Indoor	12
		15	30.0—152	85.2*	—	—	—	Outdoor	12
1989	Filter	—	—	—	38	0.988—6.48	3.93	Indoor	13
		—	—	—	8	—	0.975	Country Parks	13
1990	OFCC[2]	60	7.50—276	45.4	—	—	—	Indoor	14
1991	OFCC	160	7.50—320	40.4	—	—	—	Indoor	6
1990	OFCC	140	9.00—140	41.4	—	—	—	Indoor	15
1991	ATMs	71	8.60—423	112	—	—	—	Model CR-39	6
Guangdong (HBRA)			—	31.8	—	—	4.62	Indoor	16
		—	—	16.4	—	—	4.35	Outdoor	16
Shenzhen		—	—	13.7	—	—	—	Outdoor	9

[1] Alpha track monitors [2] Open face charcoal canisters * No mean values given in the original report

OFCC results, the indoor radon concentration in Hong Kong is about 40.4—45.4 Bqm^{-3}. There are only two separate measurements for the potential α energies of indoor radon daughters, and these agree well each other, which when converted to the indoor equilibrium radon concentration give values within 13.8—14.5 Bqm^{-3}. From this apparently lower value, we can estimate the equilibrium factor F for indoor radon and its daughters to be less than 0.4. We have employed the RDA-200 Radon/Radon daughters detector for some in-situ measurements and have found that F does not exceed 0.3, which is smaller than the global typical value 0.5 given in the UNSCEAR 82 report. We adopt F to be 0.4 indoors and 0.5 outdoors. From the potential α energy of radon daughters measured outdoors in 1985 shown in Table 2, we can derive the outdoor radon concentration for Hong Kong to be about 18 Bqm^{-3}. It is certain that the indoor radon concentration in Hong Kong is relatively high, which is due to the high radioactivity contents of the building materials utilized.

4 NATURAL RADIOACTIVITY CONTENTS IN SOIL AND BUILDING MATERIALS

The discrepancies in Table 3 arise mainly from the different methods of sample processing and calibration. The investigation in 1990 was based on the Chinese

Table 3

Natural radionuclide contents of soil in Hong Kong Bq/kg

Year	Samples	^{238}U		^{226}Ra		^{232}Th		^{40}K		Ref.
		Range	Mean	Range	Mean	Range	Mean	Range	Mean	
1983-5	37	—	—	24.5—109	49.7*	32.9—173	40.0*	58.6—851	192	17
1990	15	50.0—140	92.5	33.1—112	77.1	61.5—231	146	383—1230	817	18
Shenzhen	—	—	76.4	—	84.7	—	161	—	556	9
HBRA of Guangdong		—	119	—	137	—	223	—	413	8

* Only contents of ^{228}Ac, ^{212}Pb, ^{212}Bi, ^{208}Tl, ^{214}Pb and ^{214}Bi were given in original report

Table 4

Natural radionuclide contents of building materials in Hong Kong Bq/kg

Category	Measurement*		^{226}Ra		^{232}Th		^{40}K		Remarks
		n	Range	Mean	Range	Mean	Range	Mean	
Cement	1	29	11.0—33.0	25.9	7.00—22.0	12.2	48.0—158	99.0	
	2	10	15.2—21.4	19.2	14.4—22.0	18.9	127—181	159	
Stone	1	31	38.0—159	101	47.0—123	95.6	414—986	814	Ballasts of all kinds
	2	6	174—230	202	130—149	140	905—1150	1030	
Brick	1	63	38.0—123	76.8	44.0—143	79.0	92.0—986	581	Bricks of all kinds
	2	6	80.6—205	143	125—191	158	677—1020	850	
Sand	1	13	10.0—16.0	13.0	10.0—20.0	16.0	403—463	445	River and sea sand
	2	6	20.8—27.7	24.3	22.4—29.8	27.1	473—1210	840	
Plaster	2	—	—	5.04	—	MDL	—	MDL	
Road based materials	2	4	83.0—136	110	82.5—144	121	747—1000	915	Mixture of concrete ballasts and bitumen
Coal ash	1	6	110—130	120	103—126	114	206—283	264	
Coal slag	1	6	106—125	112	93—113	98	147—287	182	China coal

* Measurements 1 made in 1988[19]; Measurements 2 made in 1990[18]; MDL: Minimum detectable level

national standard "gamma spectroscopy of radionuclides in soil" (GB-11743-89). For this investigation, comparisons have also been made with a comparison sample (code GHS-1) which has previously been employed during the measurement of soil samples of the high radiation background area (HBRA) of China, and the greatest deviation is less than 12 %. The discrepancies in Table 4 are similar to those observed for soil samples. However, since the cement samples do not require processing (in both cases), the measured values are very close.

5 ASSESSMENT OF TERRESTRIAL NATURAL BACKGROUND RADIATION

5.1 Terrestrial absorbed radiation dose rate in air calculated from natural radionuclide contents in soil and building materials

We adopt for our calculations the method shown in the appendix B of the UNSCEAR 1977 report. The data for soil and building materials are taken from the 1990 measurements. Indoor models will be used for urban streets, with correction factors for the "doors" and "windows". Parameters and formulae for the calculations and results are listed in Table 5. The absorbed dose rates for rural outdoors $\dot{D}_{o1} = 15.4$, that for urban outdoors $\dot{D}_{o2} = 18.1$ and that for indoors $\dot{D}_i = 21.3 \times 10^{-8}$ Gy/h. The outdoor value can be obtained using population-weighted rural and urban values, *i.e.*, $D_o = 0.33\ \dot{D}_{o1} + 0.67\ D_{o2} = 17.2 \times 10^{-8}$ Gy/h, and thus $\hat{D}_i : \hat{D}_o = 1.24$. We see that the calculated results agree with the in-situ measurements and therefore can represent the terrestrial radiation level of Hong Kong, which are respectively higher than the indoor and outdoor levels of the nearby Shenzhen by 25 % and 33 %.

5.2 Indoor radon concentration calculated from radon exhalation rates from building surfaces

The in-situ measurements of radon exhalation rates from building surfaces in

Table 5

Absorbed dose rates calculated from natural radioactivity contents of soil and building materials

	Contents /Bq · kg⁻¹					Absorbed dose
	^{238}U	^{226}Ra	^{232}Th	^{40}K	Formulae for calculations	rate /10^{-8} Gyh^{-1}
Soil(1)	83.3	69.4	131	735	$0.0427C_U + 0.0662C_{Th} + 0.00430C_K$	15.4 (Urban)
	[50.0]	[49.7]	[40.0]	[192]	$0.0427C_U + 0.0662C_{Th} + 0.00430C_K$	[5.61]
Mixed building materials	—	115	108	750	$0.0598C_{Ra} + 0.0924C_{Th} + 0.00602C_K$	21.3(Indoor)
of concrete buildings(2)	—	[68.0]	[67.1]	[576]	$0.0598C_{Ra} + 0.0924C_{Th} + 0.00602C_K$	[13.7]
Equivalent building materials(3)		97.2	116	757	$0.0512C_{Ra} + 0.0792C_{Th} + 0.00516C_K$	18.1(Rural)

(1) Water contents in soil: 10 %; data from Table 3 (2) Composition of material: Concrete: Brick = 1:1 Composition of concrete: Stone: Sand: Cement = 3: 2: 1, Reinforcing bars and plaster: 10 %; data from Table 4

(3) Composition of material: mixed building materials:soil:basal road construction materials = 3:2:1, Water and other materials: 10 %; data from Table 4

Hong Kong are in agreement with the Ra concentration in the building materials. From Table 6, it is also seen that the calculated indoor radon concentration is 45.0 Bqm^{-3} using the methodology outlined in the appendix B of the UNSCEAR 1977 report, which is also within the range of in-situ measurements. These results show that the indoor radon concentrations are comparatively quite high. The above results will be much lower if we adopt the measurements for soil made in 1985 and values for building materials made in 1988, which are shown in brackets in Tables 5 and 6. The $\dot{D}$ and C_{Rn} values thus obtained are below the lower limits of the in-situ measurements.

Table 6

Comparisons of the calculated radon exhalation rates and radon concentrations with the measured values

		Radon exhalation rate /mBqm $^{2}\cdot$ s ^{1} Range	Mean	Radon concentration /Bqm ^{3}	Remarks
Experiment	Wall	0.4—35	5.10	—	Considering covering
	Floor	0.4—34	6.90	—	materials of all
	Ceiling	0.4—34	7.0C	—	kinds; Ref [20]
	Room	$\varepsilon=5.72$		$C_{Rn,i}=40.4$—45.5	Wall:Floor:Ceiling = 4:1:1
Calculation	formulae:	$\varepsilon=C_{Ra}\varepsilon_o$ (1)		$C_{Rn,i}=(3.6\,\varepsilon S/V\lambda_V)f_s+C_{Rn,o}$ (2)	Ref. [4, 14]
	Results:	5.75 [2.96]		45.0 [28.7]	—

(1) C_{Ra}: Ra contents of mixed building materials (115 Bq/kg, see Table 5) ε_o: Radon exhalation rate per unit concentration in building material, taken to be 0.05 mBq · m ^{2}s ^{1}/Bq · kg ^{1} (2) S and V: Surface area and volume of a room of dimension given by $L\times W\times H=4\text{ m}\times 3\text{ m}\times 3\text{ m}$ f_s: Correction factor for windows and doors, taken as 0.7 λ_V: Typical air exchange rate, taken as 1h ^{1} $C_{Rn,o}$: Outdoor radon concentration, taken as ≈18.4 Bqm ^{3}

6 CONCLUSIONS AND DOSE ESTIMATION

a. The outdoor and indoor absorbed dose rates in air due to penetrating radiation

Table 7

Natural background radioactivity (NBR) levels in the terrestrial environment and the resulting dose received by Hong Kong people

Sources	NBR levels	Formulae for dose assessment	Average annual effective dose equivalent / μSv	Remarks
Terrestrial gamma radiation	$\dot{D}_o$ 17.2×10 ^{8} Gy/h* $\dot{D}_i$ 21.3×10 ^{8} Gy/h	$H_\gamma=61.3\,(q_o\dot{D}_o+q_i\dot{D}_i)$	1255	$q_o=0.2$ $q_i=0.8$
Cosmic radiation	$\dot{D}_o$ 3.00×10 ^{8} Gy/h $\dot{D}_i$ 2.72×10 ^{8} Gy/h**	$H_c=87.6\,(q_o\dot{D}_o+q_i\dot{D}_i)$	242	
Radon exposure	C_o 18.4 Bq/m ^{3} C_i 45.0 Bq/m ^{3}	$H_{Rn}=31\,F_oC_o+61F_iC_i$	1383	$F_o=0.5$ $F_i=0.4$
Thoron exposure		$H_{Th}=H_{Rn}/4.5$	307	Ref.[11]
Total average		$H_{eff}=H_\gamma+H_c+H_{Rn}+H_{Th}$	3187	

* $\dot{D}_o=0.33\times15.4+0.67\times18.1$, where 0.33 and 0.67 are weighting factors respectively due to the different population in rural and urban areas ** Evaluated value.

are 11.2×10^{-8}—19.3×10^{-8} Gy/h and 18.6×10^{-8}—24.1×10^{-8} Gy/h respectively. The indoor radon concentrations are 40.4—45.4 Bqm^{-3}. In consideration of the calculated results in Table 5 and 6, we have assessed the absorbed dose rate and the indoor radon concentration, and have thus obtained values for the terrestrial natural radioactivity levels as shown in Table 7.

b. From these levels, and following the methods given in the UNSCEAR 1977 report appendix B and 1982 report appendix D, we have calculated the annual effective dose equivalent received by Hong Kong people due to the natural background radiation to be 3.2 mSv, which is higher than the global typical value given in the UNSCEAR 1988 report by a factor of 1/3. Nevertheless, this value can still be regarded as normal.

c. The issues of outdoor radon concentration and radon daughter equilibrium factor F should be further investigated.

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