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Measurement of Absorbed Dose Rate from Terrestrial Background Radiation in Hong Kong*

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ABSTRACT

Measurements of the absorbed dose rate from soil samples and above the ground at the site, from which the soil samples were taken, were carried out in Hong Kong by means of spectrometric method using a plastic scintillator. Under the present experimental setup used, a correlation factor of 14.9 between the absorbed dose rate at one meter above the ground in site measurement and that of the corresponding soil sample was obtained. The overall average values of 70.5 mrad/y and 15.9 mrad/y were obtained for the absorbed dose rate due to natural radioactivity and fall-out radioactivity, respectively. The absorbed dose rates due to the fall-out differed by a factor of approximately three, between the two geographically separated areas; Stanley-Sau Ki Wan and Kowloon-N. T.

INTRODUCTION

Frequent nuclear detonation now-a-days draws our close attention to the problem of radioactive contamination of the ground we inhabit. To safeguard the public health, quantitative information on the absorbed dose rate from terrestrial background radiation is essential.

Conventionally, for the measurement of radiation dose rate, Geiger-Müller counters calibrated against the standard radium source, ionization chambers1), and plastic scintillation detectors with multichannel pulse height analyzers2) have been used. To avoid the difficulty and inconvenience of carrying around the pulse

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height analyzer in field measurements, Watanabe[3] has proposed, on the assumption that all the radionuclides were distributed uniformly in the soil, a new method for obtaining the absorbed dose rate at a site by means of the measurement of soil samples taken from the site of concern. This will require, however, a correlation factor between the absorbed dose rate at the site and the absorbed dose rate from the soil sample. In the measurements made by Watanabe, a single channel pulse height analyzer was used although the energy absorption range of electrons was divided into ten channels, and only one site measurement was taken. While, following Watanabe's sample size and experimental geometry, we have used a 100-channel pulse height analyzer, and have taken 17 site measurements; a more reliable correlation factor is thought to have been obtained.

It is hoped that the data and information obtained in this work can be used as the reference for the future consideration on the terrestrial radiation due to fall-out and other radioactive contaminations.

The principal aims of the present work are: (1) to provide definite information on the absorbed dose rate from terrestrial background radiation, and also (2) to test the new method for the measurement of absorbed dose rate by means of spectrometric method using a plastic scintillator proposed by Watanabe.

EXPERIMENTAL METHOD

I) *Soil sampling* A soil sampler with a hollow-cylindrical container ($4''\Phi \times 4''$) of stainless steel was struck into the ground so that a soil sample entered into the cylinder. With the natural condition kept unchanged, the soil sample was then transferred into a PVC (polyvinyl chloride) container of the size slightly larger than the stainless steel container, and was covered with two lucite lids. The soil sample is now ready for the absorbed dose rate measurement.

Soil samples were taken from various places in Hong Kong; including the Hong Kong island, Kowloon, the New Territories (to be abbreviated as N. T.) and the outlying islands (Table 1). Soil samples were taken from several points in a site of concern, and at various depths down to one meter on the campus of Chung Chi College. Several sand samples were also taken from the coastal area.

II) *Apparatus and energy calibration of the pulse height analyzer* The apparatus for absorbed dose rate measurement was a TMC (abbreviation of Technical Measurement Corporation) 100-channel pulse height analyzer provided with a plastic scintillator as the detector.

In using a plastic scintillator for absorbed dose rate estimation, the energy-distribution of electrons inside the scintillator must be precisely known. Calibration of the energy spectrum was made by means of the Compton edge E_e of Cs-137 gamma-ray E_γ (=0.667 Mev) according to the equation[4]:

$$E_e = E_\gamma \frac{1}{(1+0.511/2E_\gamma)}$$

The linear amplifier and pulse height analyzer were adjusted so that the pulse

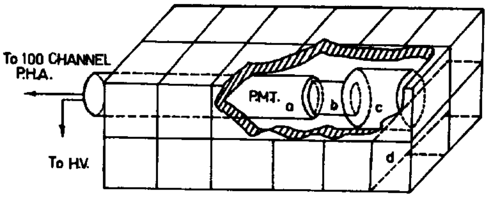

Fig. 1. Setup for the measurement of absorbed dose rate due to soil sample. a, photomultiplier tube, b, plastic scientillator (1.5×1.5 in), c, PVC soil sample container (4×4 in) d, lead block (2.5×4×8 in)

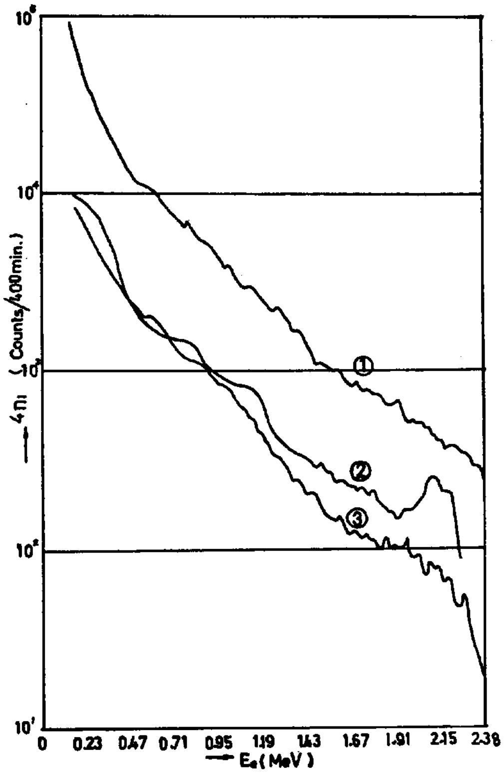

Fig. 2. Typical electron energy spectra
1, Site measurement (Kowloon Ton Park)
2, Soil sample (0 m depth, on Chung Chi campus)
3, Background measurement (dummy sample)

heights corresponding to the 4th and 100th channel of the analyzer were 0.089- and 2.38-Mev, respectively. The channel width was therefore kept 0.024-Mev. The counts in the 2nd and 3rd channels (identified through background measurements) were due to the consistent noise of the electronic circuit of the counting system and were therefore not taken into consideration in the absorbed dose rate calculations (the 1st channel is designed for "live time" storage). A slight drift of the energy spectrum during the period of measurement was corrected, from time to time, against the known Compton edge.

III) *Soil sample measurement* The detector and the soil sample were shielded by lead blocks from surrounding radiation (Fig. 1). The background radiation was measured by placing a dummy sample, sugar having the density of about the same as that of the soil, in the PVC container. The energy-spectrum of the background radiation thus obtained was subtracted from the corresponding energy spectrum of soil samples. Typical spectra of soil samples due to radiations of natural or natural plus artificial radioactive fall-out are shown in Fig. 2.

IV) *Site measurement* Site measurements were carried out at the same places where the soil samples were taken. During the measurement, the scintillator was covered with "light tight" black paper and cloth, and placed at one meter above the ground in horizontal position. To reduce the noise due to over-heating of the photomultiplier tube by sunshine, the detector was placed in the shade if possible, and the period of each measurement was limited to 100 min. Under this condition, the reproducibility of the measured absorbed dose rate at a given spot was always within the statistical fluctuation.

Site measurement was limited to the places where transportation and electric power supplies were available (Table 1). It is worth noting here that without the use of a 100-channel pulse height analyzer it would not have been practical to carry out as many measurements with the attained accuracy as were actually made.

V) *Calculation of absorbed dose rate* Following the definition of absorbed dose rate, the absorbed dose rate D_e can be calculated from the electron energy spectrum obtained from site measurement. That is, the absorbed dose rate D_e is expressed by

$$D_e = \frac{\sum_{i=1}^{97} n_i \tilde{E}_i \times 8.41 \times 10^{-5}}{m} \text{ (rad/y)}$$

$$= \sum_{i=1}^{97} n_i \tilde{E}_i \times 81.2 \times 10^{-8} \text{ (rad/y)} \quad (\text{for } m = 103.6 \text{ g})$$

Where n_i is the number of counts per one hundred min. stored in the ith channel of the pulse height analyzer (the mean electron energy of the ith channel is $\tilde{E}_i$-Mev), and m is the mass of the plastic scintillator used.

The absorbed dose rate due to soil sample D_s is slightly different, and is expressed by

$$D_s = \sum_{i=1}^{97} (N_i - \tilde{N}_i) \cdot \tilde{E}_i \times 81.2 \times 10^{-8} \text{ (rad/y)}$$

Where N_i is the number of counts per one hundred min. stored in the ith channel of the pulse height analyzer due to the soil sample, and $\tilde{N}_i$ is that of background radiation with the dummy sample in place.

Calculation of the absorbed dose rate, together with the accuracy in standard deviation for the results, were performed by the IBM-1130 computer installed in the Chinese University of Hong Kong. In every case, the absorbed dose rate D_e, is correlated by a factor f, to the corresponding absorbed dose rate D_s due to soil sample; $D_e = D_s \cdot f$.

RESULTS AND DISCUSSION

The results of the calculated absorbed dose rates and the correlation factors are tabulated in Table 1.

The value of 70.5 mrad/y for the overall average of the absorbed dose rate due to natural background radiation in Hong Kong is about the same as the value of the world-wide average of 70 mrad/y shown in the UNSCEAR Report of 1958[5]. The observation of a small fall-out contamination on the ground in Hong Kong is consistent with the predicted possible contamination, based on the places of nuclear detonations and the direction of wind in the stratosphere. The remarkable differ-

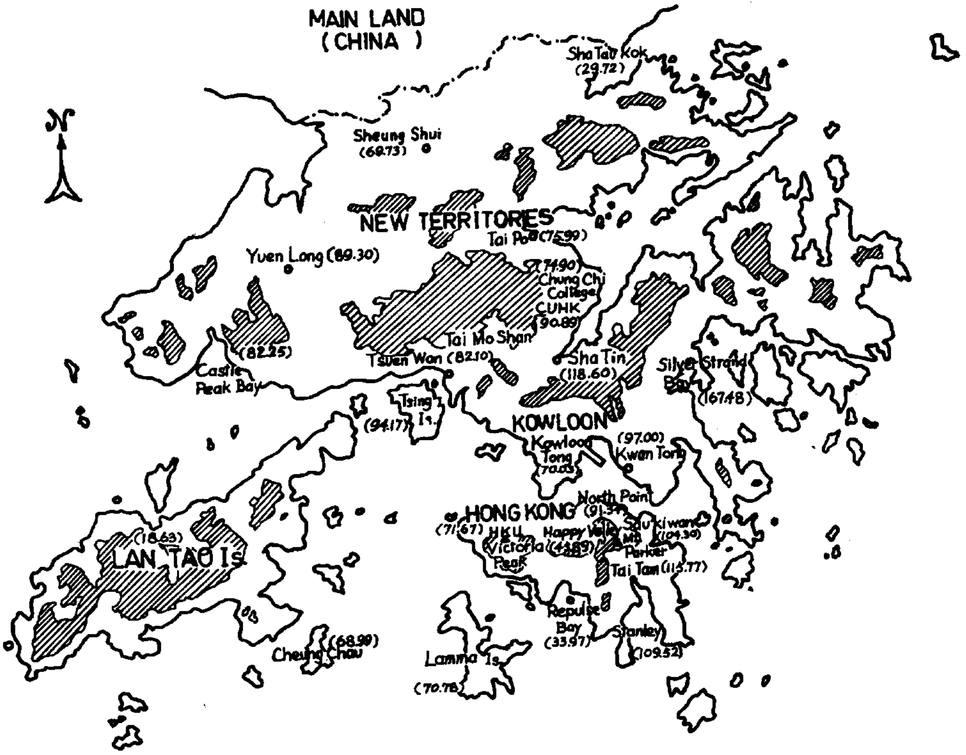

Fig. 3. Distribution of absorbed dose rate (Figures in the blackets are the absorbed dose rate expressed in unit of mrad/y. The shaded areas in the map are mountaneous areas of elevation above 250 m)

ence in the radioactive contamination due to fall-out of the two geographically separated areas (*i.e.* Kowloon-N. T. and Stanley-Sau Ki Wan), with the Victoria Peak-Mt. Parker as the separating barrier, is of interest in seeing the effect of wind direction on the conveyance of fall-out dust. It is thought that south-easterly winds from the South-Pacific, where frequent nuclear detonation tests have been made, have carried the fall-out dust to the Stanley-Sau Ki Wan area and washed down to the ground by the rain before carried over the hills of the Victoria Peak-Mt. Parker (Fig. 3). Despite the noticeable fall-out contamination in the Stanley-Sau Ki Wan area, we can say with relief that at this stage, the problem of fall-out contamination on the ground of Hong Kong is insignificant.

A correlation factor of value 14.9 between the absorbed dose rate at one meter above the ground in site measurement and that of the corresponding soil sample was obtained. While, with the same sample size and geometry of measurement as our's, Watanabe obtained the value of 6.7. Disagreement between the two correlation factors, may have induced from the following differences in the method of measurements: (a) In the measurement of Watanabe, no mentioning on the method of background measurement was given. If no dummy sample is used in the background measurement, a correlation factor, smaller than that obtainable in the case of measurement using dummy sample will be obtained; (b) Watanabe has taken only one site measurement in the determination of the correlation factor, and this single measurement may have been an abnormal one; the results of his calculation for the absorbed dose rate using the obtained correlation factor, have always proved to be smaller than that determined by means of Hultiqvist's method[3,6]; (c) The difference in the degree of radioactive contamination of the lead blocks used for the shielding of the detector and the sample.

The absorbed dose rate calculated from the sand samples averaged 41.8 mrad/y, about one half of the value of that calculated from the soil samples. It is obvious that continuous washing by the tide will lead to a decrease of radioactive contamination of the sand. An exceptional case of high absorbed dose rate, 167.48 mrad/y for sandy-sand, and 181. 33 mrad/y for stony-sand, from the Silver Strand Bay have been measured. Further study on the nature of the radioactive contents in the sand and the stone from Silver Strand Bay is yet to be made.

Abnormally high exposure dose rate of 105.8 mrad/y, averaged from four samples taken from different spots, was measured in Tsuen Wan, the center of Hong Kong industries. Possible contamination of the ground surface due to the exhausts of some radioactive chemicals used in the area may have caused this result. It is therefore advisable that thorough filtration of the exhausting smoke from the chimnies should be carefully considered.

Although it was not our primary interest to study the radioactive distribution in different layers of the ground soil, we have noticed, from measurements of the soil samples taken from different depths of the ground on Chung Chi College campus, an interesting result; as shown in Table 1, radioactive content of the soil increases gradually from 5.02 mrad/y on the ground layer to the maximum content of 8.44 mrad/y at depth of 70 cm, and then decreased to 7.90 mrad/y at 100 cm depth. Taking into account the quality of the soil (sandy loam) in the area where these soil samples were taken, the mode of radioactive distribution just described, may have been resulted from the continuous sinking of the radioactive elements with diffusing rain water as the carrier. The ways of distribution of radioactivities in different soil layers at various depths is likely to be a function of the soil quality, type of rain, and age of the radioactive elements at the place of interest.

Table 1. Radioactivity in different soil layers

Place	D_e (mrad/y)	D_s (mrad/y)	$f_i - D_e/D_s$	$(D_e)_w - D_s \cdot \bar{f}$ (mrad/y)
Kowloon	67.2^n	4.70	14.3	70.03^{k-n}
Royal Obs.	78.3^t			
Diocesan Boys School	77.3^t	6.40	12.1	95.36^{k-n}
Shatin	74.1^t	7.96	9.3	118.60^{k-n}

Table 1. (continued)

Place	D_e (mrad/y)	D_s (mrad/y)	$f_i = D_e/D_s$	$(D_e)_w = D_s \cdot \bar{f}$ (mrad/y)
Chung Chi College: Student Canteen				
(0 m depth)	72.5^{n}	5.02	14.4	74.80^{k-n}
(0.3 m depth)		7.33*		
(0.5 m depth)		7.93*		
(0.7 m depth)		8.44*		
(1.0 m depth)		7.90*		
Inside the Physics Department	105.8*			
Infront of the Machine Shop	85.7	6.64	12.9	98.94^{k-n}
CUHK	63.1^{n}	6.10	10.3	90.89^{k-n}
Tai Po		5.10		75.99^{k-n}
Sha Tau Kwok (the Border)		5.35		29.72^{k-n}
Sheung Shui	88.1^{t}	4.68	18.8	69.73^{k-n}
Castle Peak (coast)	76.5^{t}	5.52 (s)	13.9	82.25 (s)
Yuen Long		6.53		89.30^{k-n}
Tsuen Wan	133.1*	5.98	22.3	89.10^{k-n}
Kwan Tong		6.51		97.00^{k-n}
Silver Strand Bay:				
Sandy		11.24 (s)		167.48* (s)
Stony Sand		12.17 (st)		181.33* (st)
H. K. Univ.	95.8^{t}	4.81	19.9	71.67^{k-n}
Happy Valley	79.1^{n}	3.08	25.7*	45.89^{k-n}
North Point		6.13		91.34^{k-n}
Sau Ki Wan		7.00		104.30^{s-s}
Stanley (St. Stephens College)	114.7^{t}	7.35	15.6	109.52^{s-s}
Tai Tam		7.77		115.77^{s-s}
Repulse Bay (coast)	61.5*	2.28 (s)	27.0*	33.97 (s)
Lanto Island		1.25 (s)		18.63 (s)
Tsing I Island		6.32		94.17
Lamma Island		2.28 (s)		33.98 (s)
		4.75 (st)		70.78 (st)
Cheung Chau		4.63 (st)		68.99 (st)

$$\bar{f} = \frac{\sum f_i}{n} = \frac{163.8}{11} = 14.9$$

$$(\overline{D_e})_w = \frac{\sum (D_e)_w}{n} = \frac{1576.77}{18} = 87.6 \text{ (mrad/y)}$$

$$(\overline{D_e})_n = \frac{\sum D_e^n}{n} = \frac{281.9}{4} = 70.5 \text{ (mrad/y)}$$

$$(\overline{D_e})_w^{k-n} = \frac{\sum (D_e)_w^{k-n}}{n} = \frac{1248.34}{15} = 83.2 \text{ (mrad/y)}$$

$$(\overline{D_e}) = \frac{\sum D_e^t}{n} = \frac{604.8}{7} = 86.4 \text{ (mrad/y)}$$

$$(\overline{D_e})_w^{s-s} = \frac{\sum (D_e)_w^{s-s}}{n} = \frac{328.77}{3} = 109.6 \text{ (mrad/y)}$$

$$(\overline{D_e})_f = (\overline{D_e}) - (\overline{D_e})_n = 86.4 - 70.5 = 15.9 \text{ (mrad/y)}$$

$$(\overline{D_e})_w^{s} = \frac{\sum (D_e)_w^{(s)}}{n} = \frac{166.98}{4} = 41.8 \text{ (mrad/y)}$$

(The errors, of statistical nature only, for the absorbed dose rates were estimated to be 20–25% in fractional standard deviation)

Table 1. (continued)

Notation used:

D_e—Absorbed dose rate: attached with super-scripts "n" and "t" are the values of D_e, used for the computation of the average values of D_e due to natural background radiation, $(\overline{D}_e)_n$, and due to natural plus fall-out radiation, $(\overline{D}_e)$, respectively;

D_s—Absorbed dose rate, due to soil sample: attached with (s) and (st) are those samples of "sand" and "stony" qualities, respectively;

f_i—Correlation factor: $\bar{f}$ is the average value;

$(D_e)_w$—Absorbed dose rate, calculated by means of Watanabe's method $(D_e)_w=(D_s)\cdot\bar{f}$: attached super-scripts $k-n$, $s-s$, and s indicate those values for Kowloon-N. T. and Stanley-Sau Ki Wan areas, and that due to sand samples, respectively;

*—Values of exceptional cases, and are excluded in obtaining the average value of the quantity of interest.

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