Mapping the terrestrial air-absorbed gamma dose rate based on the data of airborne gamma-ray spectrometry in southern cities of China

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Abstract

An environmental radioactivity survey by Airborne Gamma-ray Spectrometry (AGS) on a large scale was undertaken in Zhuhai Zone (ZZ) and Shenzhen Zone (SZ), which include major cities in southern China, covering areas of 3800 km^2 and 4660 km^2, respectively. Comparisons of AGS with different ground measurements are presented and show very good agreement. Maps of the terrestrial dose rate at 1m above ground level have been calculated based on the data of AGS. The mean dose rates are 84.37 ± 51.69 and 82.10 ± 32.98 nGy/h in ZZ and SZ, and the maximum rates are 343.11 and 368.36 nGy/h, respectively. Dose rates in some places are above 180 nGy/h; the areas covered where 149 km^2 in ZZ and 43 km^2 in SZ. The dominant geological conditions that evidently contribute to the radioactive anomalies are outcrops of middle and late Jurassic and Cretaceous biotitic-granite. The growth of industrialization and urbanization has dramatically altered radiation background. Stone mining results in the increase of radiation levels with maximum dose rates approaching 368.36 nGy/h in an open pit. The investigation results provide valuable background data and give a good example for mapping nationwide natural radiation terrestrial dose rates in China by AGS.

Keywords*：** ***Airborne gamma-ray spectrometry, full spectrum, dose rate, ionization radiation

Ⅰ. Introduction

Airborne Gamma-ray Spectrometry (AGS) is a fast, economical and reliable nuclear geophysical method. An airborne gamma-ray spectrometer normally consists of a NaI(Tl) detector and spectroscope with 256 or 512 channels. This method has been successfully used for geological mapping, uranium exploration and mineral resources exploration since it was first used for oil and gas prospecting in the 1960s. [1-4] The applications of the method have been

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expanded to environmental estimation of ionization radiation and the determination of Cesium-137 radioactive concentration in soil after the chernobyl nuclear reactor accident throughout Sweden, Russia, France, and so on. [5-7)]

Terrestrial gamma dose rate is a key parameter for the estimation of radiation exposure to the public. Due to the pioneering work of Lower *et al.* [8)] and Beck *et al*.[9-10)], a widely accepted procedure has been developed for the determination of nuclear specific soil activities per unit by *in-situ* gamma-ray spectrometry. The dose rate at a height of 1 m above the ground can be evaluated based on the data by *in-situ* or airborne gamma-ray spectrometry. The International Commission on Radiation Units and Measurements (ICRU) referenced this method and the dose rate conversion factor. [11)] The Sweden Geological Survey (SGS) has generated terrestrial dose rate contour map after the Chernobyl nuclear reactor accident by AGS[12)], and so the dose rate map around nuclear facilities in Sweden. [13)]

However, the estimation of natural radiation levels by AGS has not been widely used in China. In 1994, the Airborne Survey and Remote Sensing Center of Nuclear Industry carried out the first terrestrial dose rate survey in the areas around the Qinshan Nuclear Power Plant in Zhejiang Province by AGS.[14)] The estimated average dose rate at 1 meter above ground level was 52.7 nGy/h and it coincided with the figures measured by ionization chamber. The terrestrial dose rates in some areas in Gansu Province were evaluated based on the results of AGS in 2002. [15)]

An environmental radioactivity survey by AGS on a large scale was undertaken for environmental monitoring from 2002 to 2003 in Zhuhai Zone (ZZ) and Shenzhen Zone (SZ), an area including the major cities in southern China, by China Aero Geophysical Survey & Remote Sensing Center for Land and Resources and China University of Geosciences (Beijing) under the support of China Geological Survey (No. 200214100025) and Natural Science and Foundation of China (No.40274023). The main objectives of the projects were as follows:

- To determine the radioactive characteristics in ZZ and in SZ and define the distribution pattern of natural radio-elements in the geological formations encountered in the areas.
- To estimate the terrestrial dose rate based on the data of AGS in and near metropolitan areas.
- To acquire the background radiation data near nuclear power plants (NPP).

The survey regions covered by this airborne survey consist of the following areas:

(i) Zhuhai Zone (ZZ), mainly including Zhuhai City and Zhongshan City (at 1 km flight line spacing).

(ii) Shenzhen Zone (SZ), including Shenzhen City and Dongguan City and Huizhou City (at 1 km spacing, with some of them at 0.5 km spacing).

In-situ gamma spectrometry, called Ground Gamma Spectrometry (GGS), used to determine radioactive concentrations of ^{238}U, ^{232}Th, ^{40}K, and a portable plastic scintillation dosemeter for determination of the terrestrial dose rate were employed during the airborne survey.[16-18]

Despite that efforts have been made in improving the accuracy of dose rates derived from the estimation by AGS over the last couple decades, the adoption of this approach for surveys in metropolitan areas has been limited. This survey provided a chance to assess the accuracy and precision of AGS against the *in-situ* dose rate measurement technique across a range of soil types in high background radiation areas.

Ⅱ. Instruments and methods

1. Airborne gamma-ray spectrometry (AGS)

AGS consists of a 32 liter NaI(Tl) gamma-ray spectrometer (Model GR-820, Exploranium Ltd., Canada), a GPS positioning system (positioning precision less than 5 m) and a radar-altimetry device. The single NaI(Tl) crystal is up to 4 liters in volume, which is a rectangular parallelepiped with dimensions of 10×10×40 cm.[19] Detector packages for AGS are made up of clusters of NaI(Tl) crystal, in our surveys the total crystal volumes are up to 32 liters. Full spectral data of 256 channels covering 0-3 MeV are recorded once per second for each measurement, along with relevant timing, GPS positioning and radar-altimetry data. The gain, resolution and sensitivity of the detector system are checked at the start of each day and are trimmed when necessary. The NaI(Tl) detector gain is monitored by the ^{40}K peak at 1462 keV during flights.

The flight line direction was North-South in ZZ and East-West in SZ. The flight line spacing was 1 km, but 0.5 km in Shenzhen Urban Area (SUA). The target flight height was 120 m but it may be higher than 200 meters above mountains, such as in ZMT (Zhang Mu Tou Town), HM (Hu Meng Town) and HG (Heng Gang Town). Spectral interferences were stripped out using stripping factors determined from calibration measurements using a series of calibration pads. The calibration measurement was conducted in May, 2002 at the Radiometric Exploration Methodology Station of Nuclear Industry in Shijiazhuang, Hebei Province, China. After the correction of dead time, background due to cosmic that radiation increases exponentially with height above mean sea level in all spectral windows, stripping and attenuation, the concentrations of K, eU and eTh can be easily estimated from the full spectrum data following the data processing procedure.[12]

2. *In- situ* dose rate measurement

Terrestrial gamma dose rate was also measured by a portable dosemeter (Model CKL-3120 made in China). The detector was an air equivalent plastic scintillator with a diameter of 3 inch and a height of 3 inch. The density of the air equivalent plastic scintillation detector was 1.05 g cm^{-3} and its range of energy response was from 0.08 MeV to 3 MeV.[20] The dosemeter was calibrated at the National Institute of Metrology, P.R. China, before field measurements were performed.

3. Conversion to the terrestrial dose rate

The terrestrial dose rate at 1m above ground is calculated based on the activity concentration of ^{238}U, ^{232}Th and ^{40}K using linear calibration functions (Equation 1), whose dose rate conversion factors are 0.0417, 0.462 and 0.604 (μGy·h^{-1}) / (Bq·g^{-1}) respectively, as recommended by ICRU (1994). [11)]

$$\dot{D}_{\gamma} = k_k A_k + k_u A_u + k_{Th} A_{Th} \qquad (1)$$

Where $\dot{D}_{\gamma}$: Dose rate, n Gy/h

k_k , k_u and k_{Th} : Dose rate conversion factors of ^{40}K, ^{238}U and ^{232}Th series, respectively, μGyh^{-1}/Bqg^{-1}

A_K, A_U *and* A_{Th}: Radioactivity concentrations of ^{40}K, ^{238}U and ^{232}Th, Bqkg^{-1}, respectively.

Ⅲ. Geological background of surveyed areas

The surveyed area covered by AGS in ZZ was about 3800 km^2, between 112^{0}59' - 113^{0}35'E and 22^{0}03' -22^{0}40' N, and 4660 km^2 in SZ, between 113^{0}40' - 114^{0}28'E, 22^{0}32' -23^{0}08'N. *In-situ* gamma ray spectrometry and dose rate survey were carried out in ZZ and covered an area of about 100 km^2. Geological strike was relatively simple in ZZ, but more complicated in SZ. A simplified geological map was extracted from a 1/500000 digital geological map database of China Geological Survey (CGS), and the areas covered by airborne survey and *in-situ* survey are shown in **Fig. 1**.

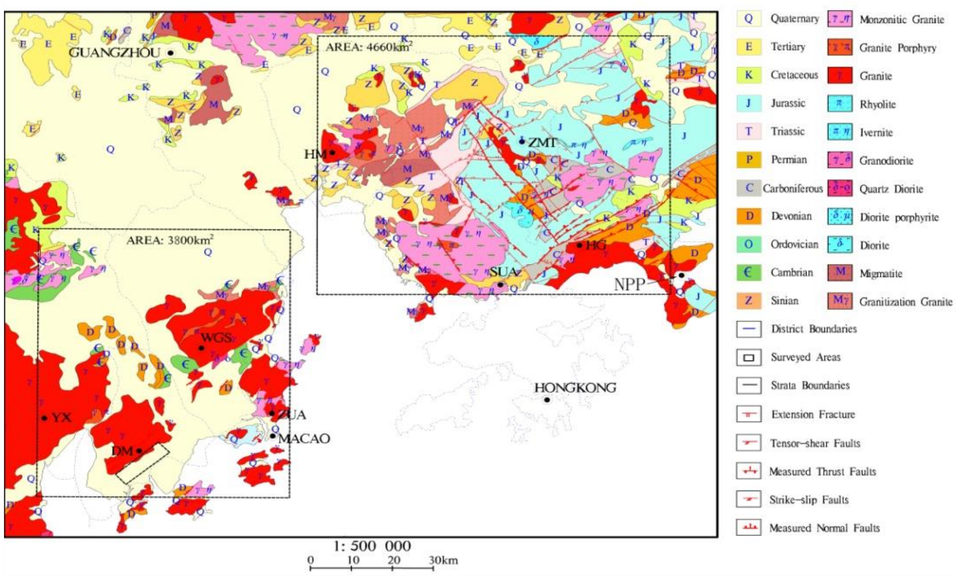

Fig. 1 Simplified geological map of surveyed areas

The strata developed in SZ include the Sinian Yunkai Group, the Upper Devonian Shuangtou Group, the Loer Caroniferous Ceshui Formation, the Mid-Jurassic Tangxia Group, the Upper Jurassic Gaojingping Group, the Upper Cretaceous Nanxiong Group, and the Quaternary. Quaternary is composed of gravel, sand, clay, silt and peat. Magmatic activity was very intense during the Yanshannian period in this area. The outcrop areas of Yanshanian granitiods and volcanic rocks cover up to about 56% of the entire area of Shenzhen City. Volcanic rocks are mainly composed of Mid-Jurassic and Late Jurassic rocks. The intrusive rocks are composited of the Middle and Late Jurassic and Cretaceous biotitic-granite and granodiorite. The sinian area has undergone three geologic tectonic development stages Devonian, Mid-Triassic and Late Triassic. The fractures can be grouped into the NE, the EW and the NW sets, in which the NE fractures are the leading structure in this area.

In the ZZ area, the surface deposits that formed since the Late Quaternary mainly consist of arene, medium sized arentilla and arentilla or silty sand and silty clay-clay. The intrusive rocks appear as the Middle and Late Jurassic and Cretaceous biotitic-granite and granodiorite. Zhuhai City is situated on products of granite rock and weathered granite congeries. There are just a few fractures.[21)]

Surveyed areas can be divided into three geomorphologic regions: coastal mountain region, hill and valley region, and littoral terrace plain region, where there is an oceanic monsoonal climate. The annual average temperature is 22.4℃ and the average relative humidity is 79 %. Dose rate characteristics related to typical geomorphologic and geological features are discussed in Section Ⅳ, 2.2.

Ⅳ. Investigation results

1. The apparent concentrations of K, eU and eTh based on AGS

An AGS survey was carried out in ZZ and SZ in 2002 and 2003, covering about 3800 km^2 and 4660 km^2, respectively. The calculated apparent concentrations of K(%), eU and eTh are listed in **Table 1** and corresponding frequency distribution histograms are shown in **Fig. 2**, not including the data of flight heights above 200 m. In the regions where data were omitted, there are some mountains above 400m. One of the main reasons for omitting the data for flight height above 200 m is because the uncertainties of the calculated apparent concentrations of K(%), eU and eTh increase due to gamma rays from the ground that are attenuated when passing through the air to the detector in the aircraft. So for the natural radioelement mapping in this survey using fixed wing aircraft, flying heights above the ground have been standardized at 120 m. Height attenuation can be closely approximated by an exponential form:

$$N_h = N_o e^{-\mu h} \qquad (2)$$

Where N_h: Background corrected and stripped count rate

N_0: The count rate at ground level

μ: Attenuation coefficient

h: The height above ground level, corrected to equivalent height at standard temperature and pressure.

Table 1 The apparent concentrations of K, eU and eTh in ZZ and SZ by AGS

Location	Parameters (unit)	Case Number	Average /median	Standard deviation	Range
ZZ	K(%)	112104	1.35/1.30	0.69	0.01-5.76
SZ		116429	1.42/1.38	0.65	0.01-6.82
ZZ	eU(ppm)	112104	4.10/3.57	2.67	0.01-19.05
SZ		116429	4.65/4.40	2.16	0.01-26.10
ZZ	eTh(ppm)	112104	17.69/13.18	12.94	0.01-76.94
SZ		116429	15.08/13.73	7.37	0.01-69.87

Note: ZZ- Zhuhai Zone; SZ- Shenzheng Zone

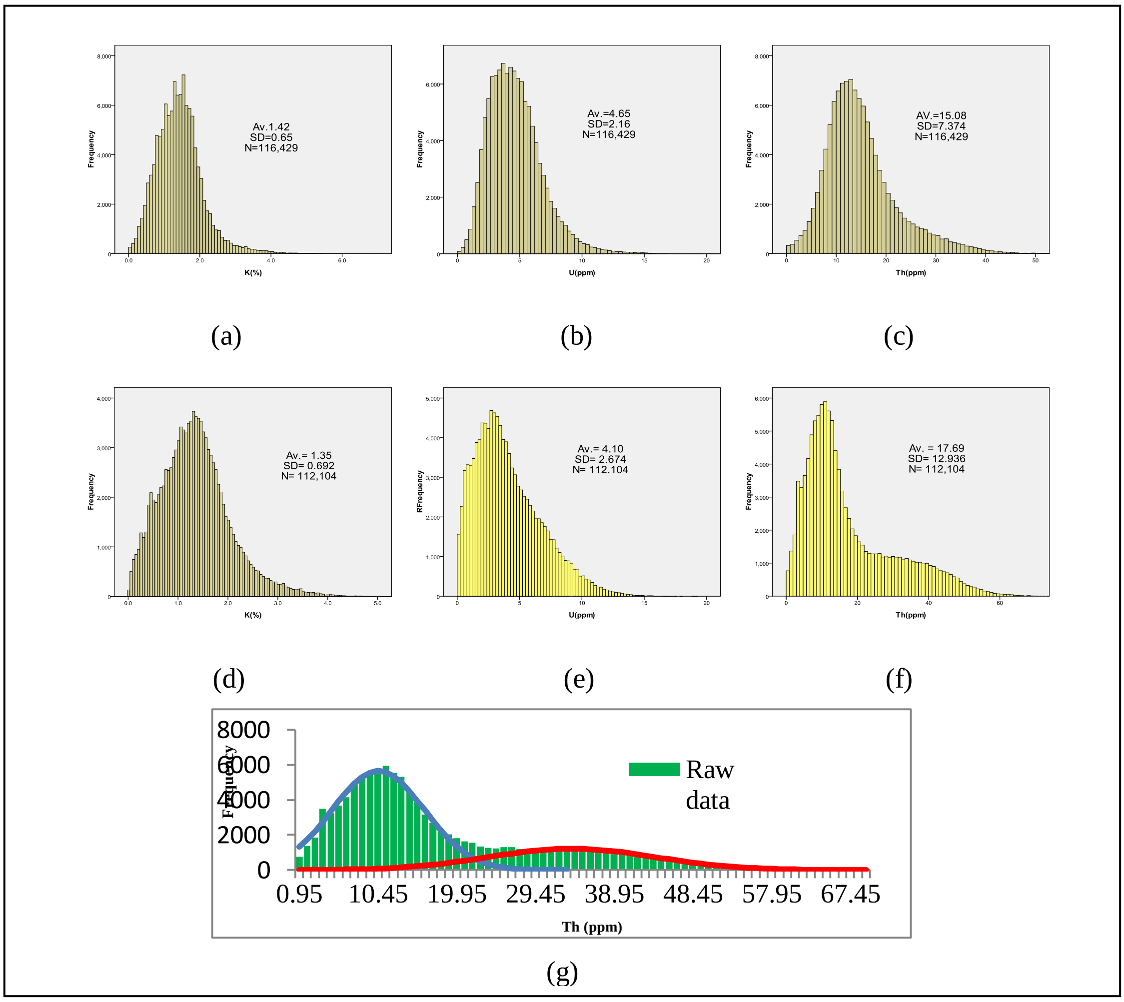

Fig. 2 The frequency distribution of radioactivity concentration of K, U and Th in ZZ and SZ

(a), (b), and (c) is K, eU and eTh distribution in SZ, respectively;

(d), (e), and (f) is K, eU and eTh distribution in ZZ, respectively;

(g) is the eTh frequency distribution of Statistical samples A and samples B in ZZ

The average values of K and eU in ZZ are lower than those in SZ, but eTh is slightly higher. The frequency distribution pattern of eTh in ZZ appears as a double Gaussian function as shown in **Fig. 2** (f). In fact, there are two main lithology, granite (biotitic-granite or granodiorite) and Quaternary sediments according to field investigation and the geological map of ZZ (**Fig. 1**). The statistical Sample A and Sample B are divided depending on their lithology. Sample A represents Quaternary sediments and Sample B is the group of granite and weathered products of granite. The statistical eTh means of Sample A and Sample B are 10.50 and 33.84 ppm with standard deviations of 5.59 and 10.07 ppm, respectively, shown in **Fig. 2** (g). Th/U ratios of Quaternary sediments (sample number: 60809) and granite (sample number: 21653) from AGS are 4.54±3.01 and 5.45±2.43, respectively. Th/U ratios of sediments and granite samples are 4.73 and 5.49, respectively, based on the average concentrations of Th and U derived from soil samples analysis in the laboratory by a high purity germanium spectrometer (HPGe, ORTEC Ltd.) in the Domen District of ZZ.[16] The Th/U ratio from AGS shows very good agreement with the values obtained by HPGe spectrometry.

2. Comparison of calculated dose rate and measured dose rate

2.1 Comparison of profiles of AGS and GGS

In order to assess the accuracy and precision of AGS against the *in-situ* dose rate measurement technique, a profile was established in ZZ. The P-P' profile had a length of 3 km and was approximately oriented NE-SW as shown in **Fig. 4**. The profile was flat and located in Guiqing Industrial Developing District where there are no tall buildings or mountains. In the middle of the profile, weathered granite sands laid on top of the Quaternary sediments. Observed dose rates and estimated values based on eU, eTh and K (%) by AGS and GGS along this profile are shown in **Fig. 3**.

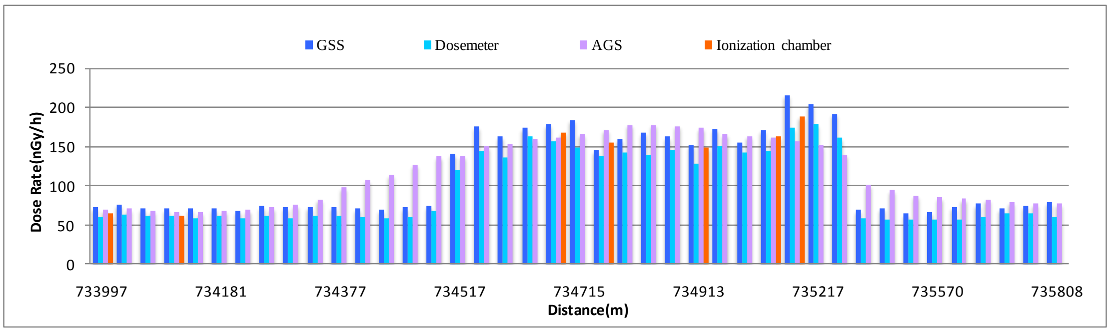

Fig. 3 Comparison of dose rate by AGS, GGS and a dosemeter

The dose rate is relatively low at the beginning and the end of this profile, but high in the middle. The maximum measured dose rate reaches 178.2 nGy/h and the higher dose rate values are related to the outcrops of weathered granite, extending to about 1 km in width. The average values of observed dose rates using a dosemeter, calculated dose rates using GGS and AGS are 94.81, 111.35 and 117.87 nGy/h, respectively. It is noted that the dose rate by AGS is nearly double that of GGS between distances from 734407 m to 734575 m. The reason is that there is a definite boundary of weathered granite and Quaternary sediment around 734407 m. For a typical fixed wing survey at a height of 120 m, speed of 140 km/h (40 m/s) and accumulation time of 1s, the area represented by each sample is about 240 m × 280 m by AGS. Normally with GGS, the typical measurement area is a circle with a diameter of 10m. Because the aircraft moves forward during the accumulation time, the ground area sampled becomes elongated.[12)] As can be seen, calculated dose rates by GGS are normally higher than observed dose rates and the GGS method has higher spatial resolution than the AGS method. Dose rates of some sites along this profile were measured by ionization chamber (IC).[22, 23)] Results of various methods for assessment of dose rate are compared with the data by IC listed in **Table 2** and **Fig. 3**. It is obvious that values by IC are higher than that by a dosemeter but lower than that by GGS. We think this is caused by the different detector energy responses. IC results appear higher than the plastic scintillator (PS), perhaps due to their response to the cosmic ray component. A NaI(Tl) scintillator has a higher response to low energy gamma rays than either IC or PS. From **Table 2**, the relative error between measured dose rates by IC and by a dosemeter is within ±15%, as well as estimated dose rate by GGS. The site locations covered by IC are shown in **Fig. 4**.

Table 2 Comparison of measured dose rate and calculated dose rate by GGS (nGy/h)

Site No.	Soil type	Measured dose rate by a ionization chamber	Measured dose rate by a dosemeter	calculated dose rate by GGS
A10	Sediments	64.89	60.69	72.60
A13	Sediments	62.13	60.91	70.37
A29	Weathered granite	168.06	155.93	178.02
A31	Weathered granite	154.96	137.53	144.75
A35	Weathered granite	149.14	132.44	151.79
A38	Weathered granite	162.82	141.72	170.85
A39	Weathered granite	188.28	173.65	215.65

2.2 Comparison of estimated dose rate and measured dose rate in Doumen District

The validity of the method that estimates terrestrial dose rate by AGS has been proven and verified in the field through detailed dose rate survey by a portable dosemeter, covering an area of 60 km^2 in the Doumen District of ZZ. The dose rate contour maps are shown in **Fig. 4**.

(1) **Figure 4** illustrates that the increase of dose rate is principally related to the outcrops of the Cretaceous biotitic-granite or the Late Jurassic biotitic-granite, and to the places covered by weathered products of granite, either by AGS or by a dosemeter.

(2) The median of observed dose rate by a dosemeter is close to the estimated rates by AGS, listed in **Table 3,** but the observed average value shows an 18.47% increase over that by AGS. The difference is mainly caused by resolution of AGS and *in-situ* measurement. There are three inconsistent regions marked A, B and C in **Fig. 4** (a) and **Fig. 4** (b)**.**

Table 3 Comparison of calculated and measured dose rate (nGy/h)

Method	Number of samples	Average /Median	Standard deviation	Range
Dose rate calculated by AGS	1347	84.71/71.40	43.99	11.08 - 251.56
Dose rate Measured by a dosemeter	347	103.91/81.59	46.32	44.54 - 248.72

The dose rates in region A are normally below 120 nGy/h in **Fig. 4** (a) but are higher than 120 nGy/h in **Fig. 4** (b). It is because the flight direction of AGS is toward the northeast so that the abnormalities caused by smaller outcrops of the Lower Cretaceous biotitic-granite disappear.

The area below 60 nGy/h marked B in **Fig. 4**(b) is bigger than that in **Fig. 4**(a). Investigations in the field indicate that creeks and vegetation (sugar cane) result in the decrease of observed dose rate because gamma rays are attenuated by the vegetation.

Conversely, the area less than 60 nGy/h (marked C) in the southeast in **Fig. 4** (a) is a lot bigger than that in **Fig. 4** (b). It is because there are a lot of pools in this area.

The dose rate differences in the three regions lead to the lower average dose rate by AGS.

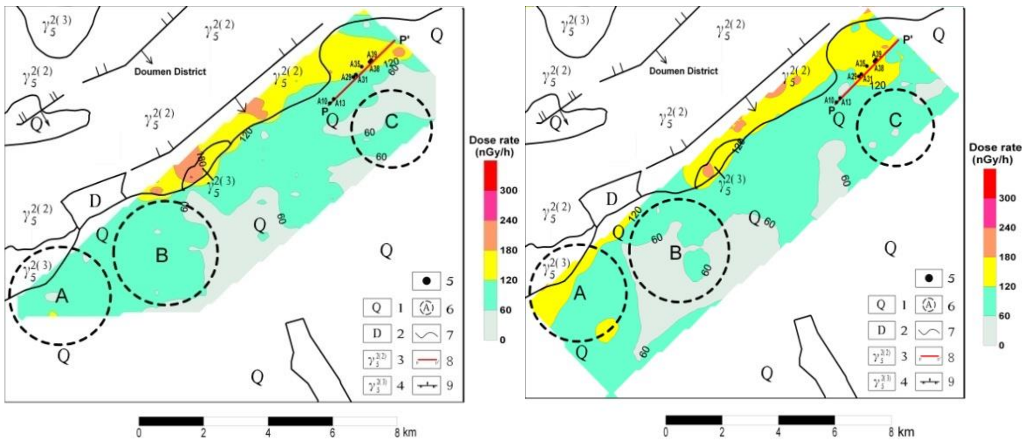

Fig. 4 Contour map of dose rate by AGS (a) and by a dosemeter (b)

(1:Quaternary 2:Devonian 3:Upper Jurassic Black Mica Granite 4:Lower Cretaceous Black Mica Granite 5:The Site of Measured Points in Table 2 6:Abnormal Areas 7:Strata Boundaries 8:The Contrast Line of AGS, GGS and Dosemeter 9:Measured Thrust Faults)

2.3 Terrestrial dose rates in ZZ and SZ

Based on the data of eU, eTh and K (%) by AGS, we calculated the terrestrial dose rate at the height of 1m above ground with equation (1) and created dose rate contour maps of ZZ and SZ as shown in **Fig. 5**. The dose rate statistics are given in **Table 4**. We note the following points from **Fig. 5** and **Table 4**:

(1) Four zones respectively of higher radioactive level zones of K, eU and eTh were found in ZZ and SZ, which were marked by Wuguishang District (WGS), Zhuhai Urban Area

(ZUA), Domen District (DM) and Yaxi Town (YX) in ZZ and Humen Town (HM), Shenzhen Urban Area (SUA), Zhangmutou Town (ZMT) and Henggang Town (HG) in SZ, shown in **Fig. 1**, as well as in **Fig. 5**. These delineated high radiation zones of K, eU and eTh exhibit coincidence with that of dose rate. The higher concentrations of K, eU and eTh are related to outcrops of granite and weathered granite, as well as newly developed industrial districts.

The average of terrestrial dose rate in SUA is at least approximate to that in ZUA. The mean terrestrial dose rate is 84.4 nGy/h in ZZ and 82.1 nGy/h in SZ; the standard deviation (σ) is 51.69 and 32.98 nGy/h, respectively. This implies a lower degree of homogeneity in surveyed areas. The means are obviously higher than the world average of 60 nGy/h.[24)] The maximums dose rates are 343.11 nGy/h in ZZ and 368.36 nGy/h in SZ.

(2) The dominant geological conditions that evidently contribute to the radioactive anomalies occurring in ZZ and SZ are outcrops of middle and late Jurassic and Cretaceous biotitic-granite.

(3) The dose rates higher than 120 nGy/h are mainly distributed in ZUA, WGS, DM and YX in ZZ, and SUA, HM, ZMT and HG in SZ. These areas are covered with granite or volcanic rocks. The low dose rates (less than 60 nGy/h) are observed in regions of Quaternary sediments in ZZ and regions covered with the Jurassic fragmental rocks or Quaternary sediments in SZ.

(4) Radioactive anomaly zones have been found in HM, where the dose rates are higher than 240 nGy/h for a 5.6 km^2 area, and higher than 180 nGy/h for a 16.01 km^2 area. This anomaly is related to the Late Jurassic granite outcrops, where there is a stone mine with no surrounding vegetation. The maximum dose rate reaches 368.36 nGy/h.

Table 4 Comparison of terrestrial dose rate by AGS and by dosemeter in ZZ and SZ (n Gy/h)

Area	Number of site	Mean/median	SD	Range	Data source
ZZ	112104	84.4/71.9	51.69	0.44-343.11	By AGS
ZUA	524	145.2	26.33	88.19-266.54	Reference 22
	3	151.9	7.8	91.6-160.2	In the farm, reference 25
		153.2	17.2	99.1-167.7	On the road, reference 25
SZ	116429	82.1/78.6	32.98	1.90-368.36	By AGS
SUA	3	88.3	1.0	77.3-88.3	In the farm, reference 25
		104.5	1.1	101.5-127.8	On the road, reference 25
HZ	51	90.9	27.6	43.2-193.1	In the farm, reference 25
		99.6	28.5	50.0-176.8	On the road, reference 25

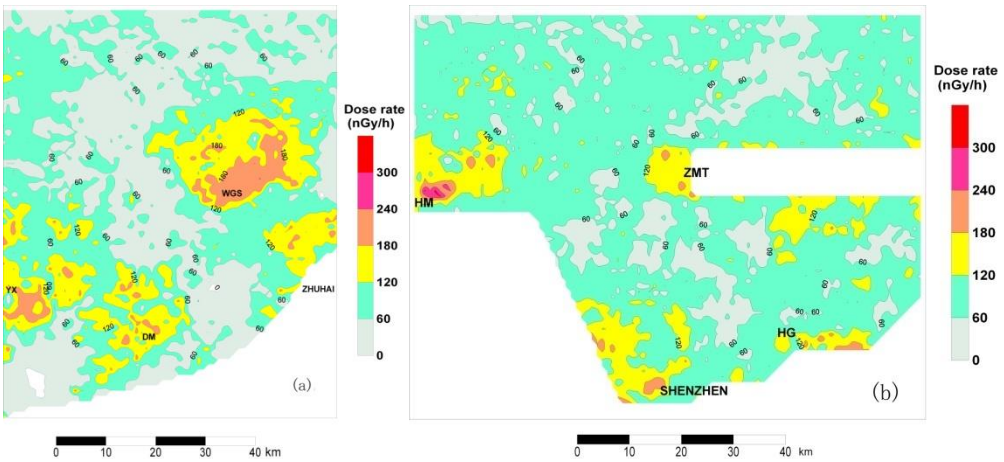

Fig. 5 Contour map of calculated dose rate based on data by AGS in ZZ (a) and in SZ (b)

Regarding topography, coastal mountain regions and hills are composed of granite rocks in ZZ so high dose rates appear in mountains and hills; littoral terrace plain regions are normally covered with Quaternary sediments, so they have a low dose rate. Geological conditions are not so simple in SZ. Mountains and hills are composed of intrusive rocks, volcanic rocks or metamorphic rocks, such as tuff, rhyolite, ivernite and diorite porphyrite. It is true that outcrop areas of granite produce high dose rates, whether mountains or hills, in SZ. It is worth noting that littoral terrace plain regions will have high dose rates where weathered granite products are present.

Table 5 Dose rate characteristics in ZZ and SZ

Location	Geomorphological features	Typical regions	Highest Elevation (m)	Main geological features	Range of dose rate (nGy/h)
ZZ	mountain, hill and valley region	WGS	80-531	Granite[a)]	120-240
		ZUA	2-232	Granite	120-180
		DM	1-301	Granite	120-180
		YX	80-544	Granite	120-240
	Pearl River Delta		2-25	Quaternary sediments	10-120
SZ	mountain, hill and valley region	HM	2-295	Granite	120-300
		SUA	2-200	Granite	120-240
		HG	70-180	Granite	120-240
		ZMT	30-100	Volcanic rocks Granite and Volcanic rocks	120-240
	littoral terrace plain region		2-25	Quaternary sediments	60-120

Note: a) Granite is a kind of intrusive rocks

Ⅴ. Conclusions and discussion

The terrestrial dose rates have been estimated from AGS data, covering an area of 3800 km^2 and 4660 km^2 in ZZ and SZ, respectively. The investigation results indicate that estimation values of terrestrial dose rate from AGS data is normally consistent with measured dose rate by a portable dosemeter. The natural background radiation has considerably been changed by industrialization and urbanization in ZZ and SZ. The investigation results provide valuable background data for radiation estimation near Nuclear Power Plants.

There are perhaps large differences between estimation dose rate by AGS and measured rates by a dosemeter when the flight profiles pass through an abruptly changed lithology boundary, such as from lower radioactivity concentration rocks or soil to higher ones. This is because each sampling area by AGS is much larger than that by the *in-situ* method.

The gamma-ray intensity decreases with increasing attenuation coefficients for some kinds of surface medium. In this study, observed dose rate decreased in large areas covered with sugar cane and pools in ZZ because gamma rays were attenuated by the vegetation and water. A correction could be made in cases where the attenuation coefficient of the vegetation was known, thereby increasing the accuracy and precision of calculated dose rate by AGS.

It is a problem that the flight height is too high over metropolitan areas due to many skyscrapers. The intensity of gamma-rays decreases with the increase of flight height, which leads to increased uncertainties of calculated dose rate. Simulations and corrections for skyscrapers and mountains are quite difficult.

Many worldwide examples of environmental radiation level and radioactive contamination estimation by AGS demonstrate that the AGS method is reliable, fast and relatively inexpensive, especially for monitoring radiation levels after a nuclear accident. The investigation by AGS in ZZ and SZ provides a good example to map nationwide natural radiation terrestrial dose rate in China based on the data of nearly 4,000,000 km^2 by AGS. However some of these data measured before the 1980s recorded only total counts and need to be processed again with some examination of radiation anomalies needed. One benefit of this work would be to prevent the development of new towns in areas with potentially high radiation levels.

Additional research is required for post-flight data in order to enhance techniques for environmental radiation level estimation from airborne data.

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