DEPTH PROFILING OF RADIOACTIVE NUCLIDES IN SOIL

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ABSTRACT

Analyses of 114 soil samples in Ningbo City show that, in general, there are statistical differences of ^{137}Cs and ^{40}K contents between every layers; the other kinds of natural radionuclides present an increasing tendency with depth. When the γ radiation dose rate is estimated by Beck Formula, owing to the effect of those nonuniform distributions is less than 1% and can be ignored.

Keywords Natural radioactive nuclides, ^{137}Cs, Nonuniform distribution, Depth of soil, China

1 INTRODUCTION

Generally, the contents of natural radioactive nuclides in soil are different in distribution along horizontal in a larger range owing to the effects of geography, geology, meteorology and so on. Perhaps the vertical distribution, i.e., the depth profile would be nonuniform due to the effects of the water, vegetation, human activity, etc., but it is lack of investigation in depth and is always treated as an uniform distribution of the nuclide contents in soil. In order to understand the real distribution of nuclides including ^{238}U, ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs and its effects on estimating the γ radiation dose rate, 114 soil samples collected from different depths on 38 positions in Ningbo City were analysed in 1988.

2 MEASUREMENT

The soil samples were collected based on the principles which made a position net with 4.5 km wide and 3.5 km long, avoided the places where the effects of human activity are considerable, and selected 4 main kinds of soil in Ningbo city, i.e. Wet land: it is usually the waste land or dryland in the seaside plain cropped long before; paddy soil: it lies on the seaside plain or the river basin; red soil: it is a woodland, fruit garden or dryland in the hillyland; saline land: it is the seaside soil cropped not long. The sampled positions are shown in Fig.1.

Every position of the soil collection is divided into three layers named A, B and C. The collected depths of three layers are generally: layer A is 4~12 cm, B 40~56 cm and C 87~100 cm. After collected, the samples are dried below 100°C till the unchangeable weights, then powdered and sealed in the sample boxes more than 20 d.

The samples are measured by a HPGe γ spectroscope system (ORTEC Co.) with 1.95 keV resolution and 40% relative efficiency (for the 1332 keV peak of ^{60}Co). Its

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integral background was 3.7 cps from 50 keV to 2 MeV. The analytical deviations (2σ) were below 40% for ^{238}U and ^{137}Cs, 15% for ^{226}Ra, ^{232}Th and ^{40}K. The analytical results of ^{117}Cs were revised owing to its decay to the date when the samples were collected.

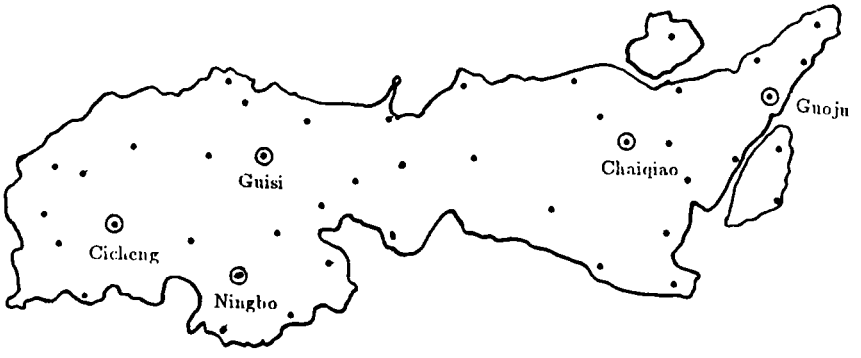

Fig.1 Positions of collected soils in Ningbo City

3 RESULT AND DISCUSSION

The measured averages and standard deviations of four kinds of soil are listed in Table 1. According to the statistics to compare the pairing data, it is necessary that the

Table 1

Radioactive nuclide contents in three layers of soil Bq/kg

Soil	layers	n	^{238}U	(1σ)	^{226}Ra	(1σ)	^{232}Th	(1σ)	^{40}K	(1σ)	^{137}Cs	(1σ)
Wet land	A	6	21.2	2.34	30.7	1.92	55.1	1.46	638	25.0	7.88	0.76
	B	6	22.7	2.71	28.6	1.55	58.6	1.50	675	30.0	1.39	0.96
	C	6	20.0	2.62	29.5	0.56	58.7	2.80	676	37.6	0.14	0.15
Paddy soil	A	16	24.9	1.70	37.5	0.99	60.6	1.90	636	10.5	14.6	0.92
	B	16	25.0	1.84	36.3	1.41	63.1	1.29	725	12.5	0.14	0.07
	C	16	24.6	2.01	36.9	1.65	65.2	1.38	764	17.1	0.26	0.18
Red soil	A	11	29.2	3.22	37.0	1.44	69.6	4.54	723	67.8	14.5	3.73
	B	11	30.0	4.15	40.6	2.54	76.9	5.61	739	58.0	2.42	1.19
	C	11	31.6	3.83	39.8	2.48	76.3	6.41	796	65.0	0.10	0.07
Saline land	A	5	20.4	3.19	28.0	1.15	52.4	1.00	638	21.0	5.48	1.26
	B	5	20.0	2.48	29.5	0.42	57.4	1.48	688	25.9	4.25	1.70
	C	5	23.6	3.10	29.0	0.58	55.5	1.76	682	20.8	0.79	0.69
In gen.	A	38	25.0	1.32	35.0	0.87	61.3	1.77	662	20.3	12.3	1.24
	B	38	25.4	1.53	35.4	1.18	65.6	2.05	716	17.6	1.54	0.46
	C	38	25.8	1.56	35.5	1.18	66.1	2.23	749	21.1	0.26	0.12

difference of the pairing data should be tested (see Table 2). The results of statistic test are listed in Table 3. The averages of the pairing datum ratios are listed in Table 4, in order to understand the vertical distributions of the natural radioactive nuclides more clearly. The points distributions of (B-A)/A, (C-A)/A and (C-B)/B are shown in Fig.2 and Fig.3.

From Tables 1~4, it can be seen among A, B, C layers of general 38 positions that ^{137}Cs distributes mainly in layer A and in general its content of each layer decreases an

order gradually from up to down and there is very evident difference between any layers. but the content of layer B is similar to layer C in the paddy soil and layer A approaches to layer B in the saline land.

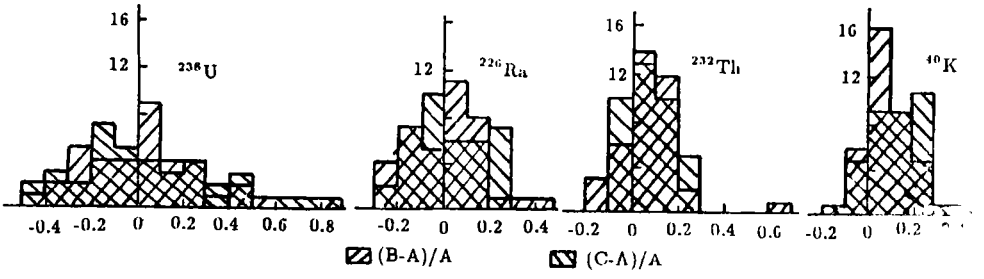

Fig.2 Position number distribution of (B-A)/A and (C-A)/A

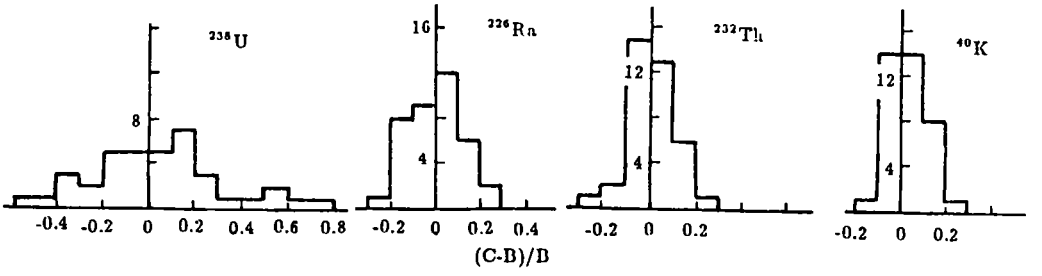

Fig.3 Position number distribution of (C-B)/B

In general, ^{232}Th content in layer A is 8% lower than layers B or C and presents very evident difference; layer B approaches to C, but there exists a very evident difference in the paddy soil.

The statistic difference of ^{238}U or ^{226}Ra content between layers is not found in every kinds nor in general of soil in this work.

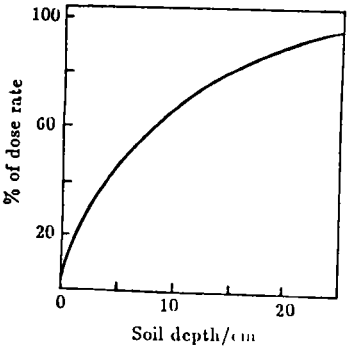

Fig.4 Contribution of the soil depth to dose rate

Fig.2 and Fig.3 indicate that the distribution curves of the relative differences of ^{232}Th and ^{40}K contents in every layers are very narrow. They almost concentrate in ±0.20 range and trend toward the right obviously. The distribution curves of ^{226}Ra are a little wider but concentrate mainly in ±0.20 range and they also present some trend toward the right. The distribution curves of ^{238}U are low and wide due to its bigger analytical error, but the trend toward right can be yet observed.

Table 4 shows that in general, all contents of the natural radioactive nuclides present an increasing tendency from up to down, and are higher in layer B than those in layer A but not much higher in layer C than B.

Table 2
Difference ranges and averages of the pairing content data in three layers of soil Bq/kg

		Wet land	Paddy soil	Red soil	Saline land	In gen.
		(B-A)				
^{238}U	Range	-3.57~7.68	-15.9~15.8	-11.8~12.4	-11.4~4.47	-15.9~15.8
	Aver(1σ)	1.47 1.71	-0.08 2.19	0.76 2.44	0.41 3.19	0.99 1.18
^{226}Ra	Range	-7.41~4.88	-7.65~12.6	-4.78~16.7	-1.09~4.07	-7.65~16.7
	Aver(1σ)	-2.05 2.62	-1.15 1.46	3.58 1.72	1.53 0.94	0.43 0.92
^{232}Th	Range	-1.38~7.71	-12.2~11.0	-4.06~30.8	0.12~7.57	-12.2~30.8
	Aver(1σ)	3.45 1.42	1.81 1.74	7.35 3.22	5.00 1.48	4.09 1.21
^{40}K	Range	-18.8~92.4	17.5~168	-84.8~159	31.0~77.1	-84.8~168
	Aver(1σ)	36.6 10.6	88.5 12.9	15.8 25.4	50.4 10.4	54.3 10.4
^{137}Cs	Range	-9.41~-1.62	-18.7~-8.58	-37.6~2.58	-3.05~0.62	-37.6~2.58
	Aver(1σ)	-6.50 1.43	-14.5 0.92	-12.0 4.24	-1.22 0.74	-10.8 1.44
		(C-A)				
^{238}U	Range	-11.7~6.21	-10.8~11.2	-4.30~14.0	-12.4~10.7	-12.4~14.0
	Aver(1σ)	-1.40 3.02	-0.34 1.80	2.39 1.95	3.12 4.89	0.74 1.15
^{226}Ra	Range	-6.37~4.93	-10.6~8.09	-3.93~10.8	-3.01~5.46	-10.6~10.8
	Aver(1σ)	-0.04 1.91	-0.56 1.73	2.80 1.61	0.97 1.60	0.70 0.91
^{232}Th	Range	-3.01~12.5	-6.94~12.6	-3.17~27.0	-0.72~5.56	-6.94~27.0
	Aver(1σ)	2.28 2.44	4.60 1.44	6.74 3.11	3.12 1.24	4.66 1.11
^{40}K	Range	-7.56~123	49.3~269	-109~202	-39.8~145	-109~269
	Aver(1σ)	41.1 21.5	128 15.1	73.1 35.1	44.5 33.3	87.4 13.6
^{137}Cs	Range	-9.41~-5.36	-18.7~-7.00	-37.0~-2.18	-6.56~-3.05	-37.0~-2.18
	Aver(1σ)	-7.74 0.76	-14.4 1.01	-14.4 3.68	-4.68 0.74	-12.0 1.25
		(C-B)				
^{238}U	Range	-14.2~9.78	-9.91~9.12	-10.0~13.2	-3.85~10.2	-14.2~13.2
	Aver(1σ)	-2.87 3.92	-0.40 1.68	1.63 1.92	3.53 3.10	0.31 1.11
^{226}Ra	Range	-2.62~11.9	-5.60~7.90	-8.68~6.58	-1.92~1.39	-8.68~11.9
	Aver(1σ)	2.01 2.50	0.59 1.04	-0.78 1.82	0.56 0.68	0.27 0.75
^{232}Th	Range	-10.7~7.70	-3.79~6.95	-16.5~11.8	-3.80~0.71	-16.5~11.8
	Aver(1σ)	-1.17 2.64	2.79 0.88	-0.61 2.61	-1.88 0.94	0.56 0.93
^{40}K	Range	-48.5~54.9	-66.6~142	-48.1~242	-72.3~101	-72.3~242
	Aver(1σ)	4.45 18.6	39.4 13.8	57.3 27.9	-5.95 32.5	33.1 11.0
^{137}Cs	Range	-4.09~0.80	-0.71~2.65	-12.0~0.60	-5.40~0.00	-12.0~2.65
	Aver(1σ)	-1.24 1.02	0.12 0.21	-2.33 1.20	-3.46 1.17	-1.27 0.45

Table 3
***P* test of the pairing data differences of the nuclide contents in soil**

Soil kinds	Sample No.	(B-A) ^{232}Th	(B-A) ^{40}K	(B-A) ^{137}Cs	(C-A) ^{232}Th	(C-A) ^{40}K	(C-A) ^{137}Cs	(C-B) ^{232}Th	(C-B) ^{40}K	(C-B) ^{137}Cs
w.l.	6	<0.05	-	< 0.01	–	–	< 0.01	–	–	-
p.s.	16	–	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	–
r.s.	11	<0.05	–	<0.05	<0.05	–	<0.01	–	–	–
s.l.	5	<0.05	<0.01	–	<0.05	–	<0.01	–	–	<0.05
gen.	38	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	–	<0.01	<0.01

The Fig.4 indicates[2,3] that about 75% γ radiation dose rate originates from 12 cm thick soil below the surface, its 90% from 20 cm thick soil layer and only 2.5% from the soil below 25 cm depth. When the dose rate is estimated by Beck Formula, it is supposed that layer A soil be collected for analysis and the nuclide contents between layers A,

B be the middle values. So, the results of the estimated dose rate compared with the estimated in the uniform distribution as layer A content, are found that ^{226}Ra is about within 0.97~1.05 and the average is 1.00, ^{232}Th within 0.98~1.08 and the average 1.01, ^{40}K within 0.98~1.05 and the average 1.01. Generally, as gamma radiation dose rate in soil is estimated by Beck formula of the uniform distribution model, effect of nonuniform distribution of radioactive nuclides is less than 1% and can be ignored.

Table 4

Pairing datum ratios of the nuclide contents in three layers of soil in general

	^{238}U			^{226}Ra			^{232}Th			^{40}K		
	Range	Ave.	1σ	Range	Ave.	1σ	Range	Ave.	1σ	Range	Ave.	1σ
B/A	0.54~1.87	1.04	0.04	0.78~1.43	1.02	0.03	0.84~1.60	1.08	0.02	0.87~1.43	1.09	0.02
C/A	0.53~1.82	1.06	0.05	0.75~1.28	1.02	0.02	0.91~1.28	1.08	0.02	0.83~1.51	1.14	0.02
C/B	0.48~1.78	1.05	0.05	0.79~1.21	1.01	0.02	0.80~1.22	1.01	0.01	0.90~1.32	1.04	0.02

4 CONCLUSION

From the analyses of 114 soil samples on 38 positions, it would be shown that:

4.1 In general, the nuclide ^{137}Cs in soil distributes mainly in layer A. Its content is very low in layer B and only a few in layer C. They decrease an order layer by layer from A to C, but the layer B content in the saline land approaches to layer A and that in the paddy soil approaches to layer C.

4.2 The ^{40}K distribution increases gradually from up to down, and there is a very evident difference between every layers in general. The ^{40}K content in layer B is 9% higher than in layer A averagely, that in layer C is 14% higher than A.

4.3 In general, ^{232}Th content in layer A all presents a very evident difference from layer B or layer C, and is 8% lower than B or C averagely. There is no statistical difference between layers B and C but still exists a increasing tendency from B to C.

4.4 ^{238}U and ^{226}Ra contents in every layers are not found statistic differences in every kinds of soil nor in general, but an increasing tendency can be observed from A to C.

4.5 Besides the human activities and the vegetations can cause the nonuniform vertical distribution of natural nuclides in soil, the immersion, permeation and flow of water also can.

4.6 As gamma radiation dose rate in soil is estimated by Beck formula of the uniform distribution model, effect of nonuniform distribution of radioactive nuclides is less than 1% in general and can be ignored.

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