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Radioactivity measurement and dose rate calculation due to γ-ray of soil from Chashnikovo – Russia

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ABSTARCT

Using γ-ray spectrometer, radioactivity from NORM samples of soils were collected and measured from Chashnikovo – Russia. The content of the three main NORM radionuclides (Ra-226, Th-232 and K-40) were measured and radiocaesium -137. The radioactivity was measured in two selected sections. The depth of each one was about 50 cm depth and the radioactivity of the three main NORM radionuclides and radiocaesium were measured. In first section, the results shows that the average value of the radioactivity of Ra-226, Th-232, K-40 and Cs-137 is 26.89 ± 2.62, 33.03 ± 4.21, 557.40 ± 84.20 and 12.87 ± 10.11 Bq/kg, respectively. On the other hand, in the second section, the obtained results of the radioactivity of the same radionuclides is 20.68 ± 3.93, 17.44 ± 6.10, 448.64 ± 54.91Bq/kg, respectively. The research shows that the mean value of the obtained results of the NORM radionuclides within the worldwide range for soil. The absorbed dose rates, annual effective dose in air outdoor and indoor were calculated.

Key words: Radioactivity/ γ-ray spectrometer/ sod-podzolic soil/absorbed dose rate/annual effect dose in air outdoor and indoor/ Chashnikovo-Russia.

INTRODUCTION

Many radionuclides occur naturally in terrestrial soils and rocks and in building materials derived from them. Upon decay, these radionuclides produce an external radiation field to which all human beings are exposed. In terms of dose, the principal primordial (half-lives comparable to the age of the earth) radionuclides are ^{40}K, ^{232}Th, and ^{238}U. Both ^{232}Th and ^{238}U head series of radionuclides that produce significant human exposures. Naturally occurring radionuclides are present in the atmosphere owing to their production by cosmic ray interactions, the emanation of gases from soil or building materials and the resuspension of soil particles from the ground surface (UNSCEAR, 2000).

Soil radionuclide activity concentration is one of the main determinants of the natural background radiation. When rocks are disintegrated through natural process, radionuclides are carried to soil by rain and flows (Taskin et al., 2009). In addition to the natural sources; soil radioactivity is also affected by man-made activities.

External exposures to gamma radiation outdoors arise from terrestrial radionuclides occurring at trace levels in all ground formations. Therefore, the natural environmental radiation mainly depends on geological and geographical conditions (Florou and Kritidis,1992).

In this paper, radioactivity due to gamma ray was measured using gamma ray spectrometer Na(Tl). Samples were collected from the educational soil – environmental center – faculty of soil science – Moscow State University.

EXPERIEMNTAL METHOD

Area under investigation

Chashnikovo is an educational soil environmental center belongs to the faculty of soil science – Moscow State University. It is 150 km from Moscow in the direction of the east. There were two selected sections; the first section consists mainly from clay soil and the second one from sandy soil. The soils in these two sections are not destroyed.

The type of soil of the two sections is sod-podzlic soil but one of them on the basis of clay sediments and the other one on the basis of sandy ones. From each section of the soil; it was collected

samples from each layer downward to depth almost equal to 50 cm. The full description of the two sections is written down below as following:

Description of the first Section

Sod-podzolic deeply turf, deeply podzolic loamy on loams.

- O (0-3) cm - layer of leaves 0.5 cm, fermentative layer 1 cm, 1.5 cm humus transition marked the boundary is flat.
- A (3-20) cm - fresh, brownish-gray, light loam, medium-fine-structure is lumpy, loose structural addition, fine-pored, a transition marked the boundary is smooth, a lot of roots.
- AE (20-35) cm - Wet, brownish-yellow, light-silty loam, lumpy with horizontal divisibility, fine-pored, the roots exist, the transition is gradual, smooth boundary.
- E (35-50) cm - wet silty clay loam, light, whitish-yellow, with reddish-brown spots, finely porous platy structure, fine-pored, the roots of isolated, moving clear.
- B (50-…) cm - Fresh, reddish-brown, light loam, thick, prismatic structure with inclusions of gravel and fine gravel.

Fig. 1 shows the first section:

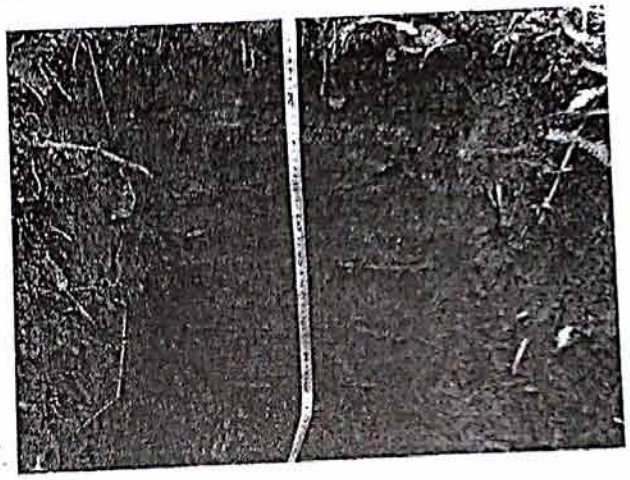

Fig.1 shows the first section of the loamy soil

Description of the second Section

Sod-podzolic weakly differentiated, weakly loamy turf on fluvioglacial sands.

- A (2-10) cm wet, light gray, light, there is an abundance of roots, fine-grained, few large pores, without cracks, soft.
- EB (10-28) cm light brown, sandy, the abundance of roots is also noted, there is little, poorly structured cloddy structure.
- B (28-50) cm wet, rusty-brown, sandy, cloddy structure, soft. Down the profile become more inclusions of pebbles and sand on the organic material (Humus) changes, with a depth of the sand grains become larger.
- BC (50-….) cm coarse-grained, structureless, a lot of round stones

Fig.2 shows the second section.

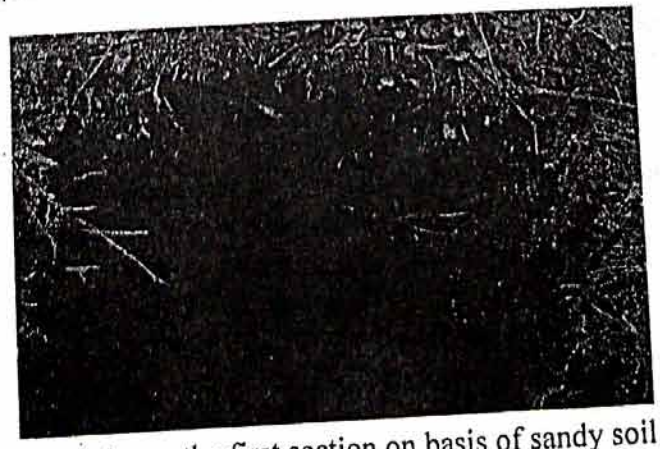

Fig.2 shows the first section on basis of sandy soil

Radiation detection device (gamma ray spectrometer)

In order to carry out our measurements at the laboratory we used gamma ray spectrometer with a scintillation detector made from NaI(Tl). The spectrometer MULTIRAD - gamma with detection block BDKS-63-01A was used in the measurements.

The main features of the used spectrometer

1. The energy range of the registration radiations from 40 to 3000 kev.
2. The range of the measured activity for Cs-137 from 3 to 50^4 Bq, for Ra-226 and Th-232 from 8 to 50^4 Bq and for K-40 from 40 to 50^4 Bq.
3. Dimensions of the detector are diameter 88 mm and length 370 mm.
4. The limit of the permissible relative error in the measured activity is not greater than ±10 % for the activity due to gamma ray emitters.
5. BDKS - 63-01A is calibrated for measuring the activity from NORM radionuclides (^{40}K, ^{226}Ra, ^{232}Th) and man-made radionuclide radiocaesium-137.

Samples collection

1. Collection of samples from each layer from each section.
2. Storage: directly after collection, the samples must be stored to avoid contamination.
3. Initial drying and cleaning: samples should be dried with a slow-air flow for several days and cleaning by removing the vegetation stones.
4. Drying and ashing: weight and volume reduction of the samples is obtained as a result of drying and this many also extend storage. The fresh weight should be determined and the sample may then be dried in low temperature oven at 90 ^{o}C to avoid loss of radionuclides and acquire a constant dry weight.
5. Grinding and sieving: the soil samples are crushed to reduce the particle size to get some form of homogeneity; then sieved after that to remove any undesirable particle size, samples should pass a mesh of size 2 mm mesh.
6. Packing and sealing: the meshed soil samples of known weight must be sealed in a suitable standard container similar to the source to be used with the gamma ray detector (i.e. Marinelli beaker). Each container should be carefully sealed and stored for four weeks to achieve the secular equilibrium between ^{226}Ra and its daughter ^{222}Rn (IAEA, 1989).

Calculation of the activity concentration

The activity concentrations of the natural radionuclides in the measured samples were calculated using the relation by (Noorddin, I. 1999).

$$A_s\left(Bq\ /\ kg\right) = C_a\ /\ \varepsilon \times P_r \times M_s \quad (1)$$

Where C_a is the net gamma counting rate (counts per second), ε the detector efficiency of the specific gamma-ray, P_r the absolute probability of gamma decay and M_s the mass of the sample (kg).

Figure 3 and 4 show the spectrums of one layer from each type of the studied soils.

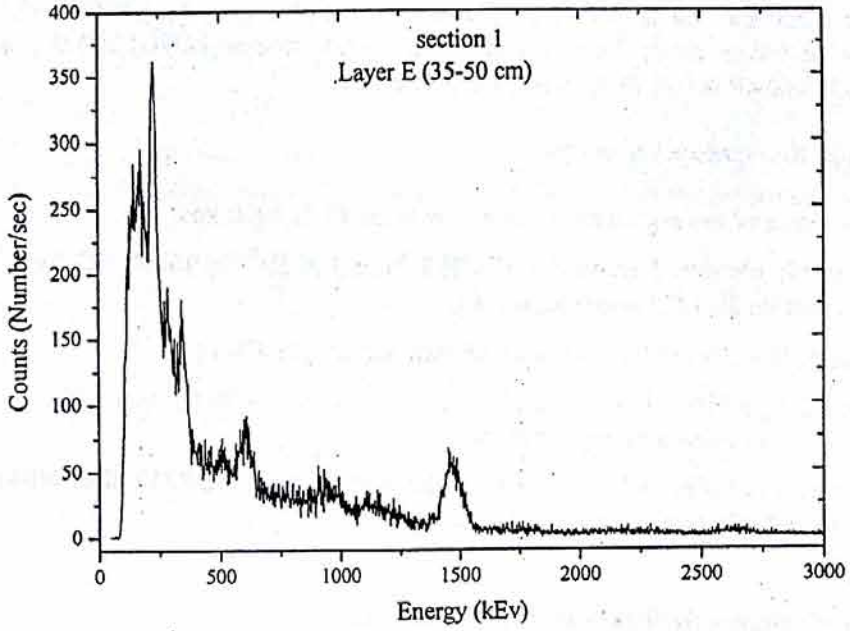

Fig.3 spectrum of the layer E (35-50 cm) in the first section – clay soil

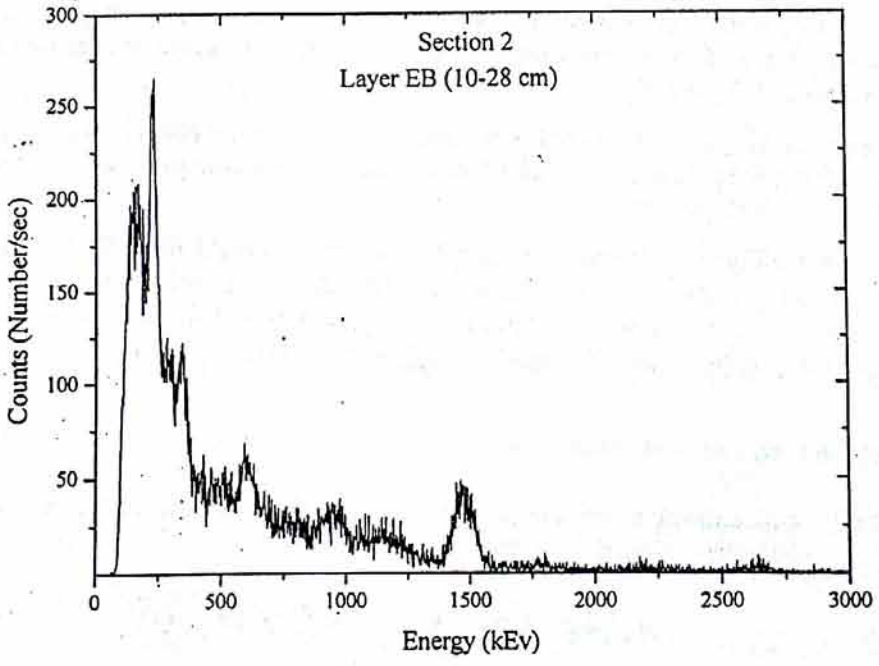

Fig.4 spectrum of the layer EB (10-28 cm) in the second section – sandy soil

Calculation of the dose rate

Calculation of absorbed dose rate from the surface of the soil at 1 m height, and the annual effective dose in air outdoor and indoor, the equations from (UNSCEAR, 2000; Tzortzis. M et al, 2003; Clouvas. A et al,, 2000; Beck. H.L., et al, 1972) were used as follows:

Calculations of absorbed dose rate can be done by equation 2 as following:

$$D = C \times F \quad (2)$$

Where D – the absorbed dose rate at 1 m height from the surface of the earth in units of (nGy/h), C is the concentration of each radionuclide (Bq/kg) and F – the conversion coefficient (nGy h^{-1} / Bq kg^{-1}).

Calculations of annual effective dose rate in air outdoor in μSv:

$$\mathrm{Deff}_{\mathrm{outdoor}} = \mathrm{D} \times h \times K_1 \times K_2 \times 10^{-3} \quad (3)$$

Where $\mathrm{Deff}_{\mathrm{outdoor}}$ is the annual effective dose rate in air outdoor in μSv, h- number of hours in one year, $K_1 = 0.7$ – the conversion factor from absorbed dose into effective dose in units of Sv/Gy, $K_2 = 0.2$ – the occupancy factor in air outdoor.

Calculations of annual effective dose rate in air indoor in μSv:

$$\mathrm{Deff}_{\mathrm{indoor}} = \mathrm{D} \times h \times K_1 \times K_2 \times 10^{-3} \quad (4)$$

Where $\mathrm{Deff}_{\mathrm{indoor}}$ is the annual effective dose rate in air indoor in μSv, h- number of hours in one year, $K_1 = 0.7$ – the conversion factor from absorbed dose into effective dose in units of Sv/Gy, $K_2 = 0.8$ – the occupancy factor in air outdoor.

The relation between the effective dose rate in air outdoor and indoor (UNSCEAR, 2000, El Arabi A.M et al, 2008) can be expressed as following:

$$\mathrm{Deff}_{\mathrm{indoor}} = 1.4 \times \mathrm{Deff}_{\mathrm{outdoor}} \quad (5)$$

RESULTS AND DISCUSSION

The activity concentration from each layer in the soil for the two sections is shown in table 1. It is obvious from the results that the activity concentration in the first section ranges from 22.49 ± 6.25 Bq/kg (ground litter 0-3 cm) to 28.77 ± 6.46 Bq/kg (E (35-50 cm) with a mean value 26.89 ± 2.62 Bq/kg for Ra-226, for Th-232 the activity concentration ranges from 25.63 ± 6.91 Bq/kg for (ground litter 0-3 cm) to 35.98 ± 7.02 Bq/kg for layer B (50-...) with an average of 33.03 ± 4.21 Bq/kg, but in case of K-40, the activity concentration ranges from 420 ± 63.7 Bq/kg for (ground litter 0-3 cm) to 670 ± 137 Bq/kg for layer E (35-50 cm) with an average value of 557.40 ± 84.20 Bq/kg. It was detected a mount of radiocaesium – 137 in the soil samples from each layer except one layer B (50-...), the content of radiocaesium -137 in soil samples varied from 3.10 ± 2.39 Bq/kg for layer E (35-50 cm) to 22.63 ± 4.06 Bq/kg for layer (ground litter 0-3 cm) with an average value of 12.87 ± 10.11 Bq/kg. Similarly, we can discuss the second section from the table.

The activity concentration of naturally occurring radionuclides is higher than that found in Egypt by (W.B.Badawy et al., 2004, Higgy et al, 1998, and Ibraheim et al, 1993). The high activity concentration of the soils of the investigated area Chashnikovo – Russia from naturally occurring radionuclides due to the use of fertilizers in this soil more than 50 years ago. But the presence of this amount of radiocaesium, it comes as a result of the nuclear activities of the country and the accident of Chernobyl 1986.

Absorbed dose rate in nGy/h also was calculated from the soil samples for each radionuclide and the obtained results are shown in Table 2.

Tab. 1 Activity concentration of the soil from each layer in Bq/kg of the area under investigation

Section 1						Section 2					
Layer cm	^{226}Ra	^{232}Th	^{40}K	^{137}Cs	Total±SD	Layer cm	^{226}Ra	^{232}Th	^{40}K	^{137}Cs	Total±SD
Ground litter (0-3)	22.49 ± 6.25	25.63 ± 6.91	420 ± 63.7	22.63 ± 4.06	490 ± 64.51	Ground litter (0-2)	22.26 ± 8.62	12.99 ± 8.38	449 ± 135	24.39 ± 6.52	508.64 ± 135.69
A (3-20)	28.35 ± 7.04	33.84 ± 7.76	551 ± 125	20.48 ± 4.72	633.67 ± 125.53	A (2-10)	24.91 ± 6.32	21.22 ± 6.11	496 ± 114	14.12 ± 3.76	556.24 ± 114.40
AE (20-35)	28.38 ± 6.15	34.78 ± 7.11	614 ± 128	5.27 ± 2.49	682.43 ± 128.37	EB (10-28)	21.25 ± 5.65	26.32 ± 6.36	500 ± 111	5.30 ± 2.53	552.87 ± 111.35
E (35-50)	28.77 ± 6.46	34.93 ± 7.12	670 ± 137	3.10 ± 2.39	736.80 ± 137.36	B (28-50)	14.27 ± 4.24	12.27 ± 4.16	365.4 ± 83.8	2.05 ± 1.66	393.99 ± 84.03
B (50-…)	26.47 ± 6.01	35.98 ± 7.02	532 ± 113	**ND***	594.45 ± 113.38	BC (50-…)	20.74 ± 4.89	14.39 ± 4.29	432.8 ± 93.7	2.41 ± 1.78	470.34 ± 93.94
Mean value±SD	26.89 ± 2.62	33.03 ± 4.21	557.40 ± 84.20	12.87 ± 10.11	627.62 ± 93.27	Mean value±SD	20.68 ± 3.93	17.44 ± 6.10	448.64 ± 54.91	9.65 ± 9.57	496.42 ± 67.24

***Not Detected**

Tab. 2 Absorbed dose rate of the soil from each layer in nGy/h of the area under investigation

Section 1						Section 2					
Layer cm	^{226}Ra	^{232}Th	^{40}K	^{137}Cs	Total±SD	Layer cm	^{226}Ra	^{232}Th	^{40}K	^{137}Cs	Total±SD
Ground litter (0-3)	9.67 ± 2.69	17.07 ± 4.60	17.64 ± 2.68	2.81 ± 0.50	47.19 ± 5.98	Ground litter (0-2)	9.57 ± 3.71	8.65 ± 5.58	18.86 ± 5.67	3.02 ± 0.81	40.11 ± 8.81
A (3-20)	12.19 ± 3.03	22.54 ± 5.17	23.14 ± 5.25	2.54 ± 0.59	60.41 ± 7.99	A (2-10)	10.71 ± 2.72	14.13 ± 4.07	20.83 ± 4.79	1.75 ± 0.47	47.42 ± 6.86
AE (20-35)	12.20 ± 2.64	23,16 ± 4,74	25,79 ± 5,38	0,65 ± 0,31	61,81 ± 7,64	EB (10-28)	9,14 ± 2,43	17,53 ± 4,24	21,00 ± 4,66	0,66 ± 0,31	48,32 ± 6,76
E (35-50)	12,37 ± 2,78	23,26 ± 4,74	28,14 ± 5,75	0,38 ± 0,30	64,16 ± 7,96	B (28-50)	6,14 ± 1,82	8,17 ± 2,77	15,35 ± 3,52	0,25 ± 0,21	29,91 ± 4,84
B (50-…)	11,38 ± 2,58	23,96 ± 4,68	22,34 ± 4,75	**ND***	57,69 ± 7,15	BC (50-…)	8.92 ± 2.10	9.58 ± 2.86	18.18 ± 3.94	0.30 ± 0.22	36.98 ± 5.30
Mean value±SD	11.56 ± 1.13	22.00 ± 2.80	23.41 ± 3.95	1.60 ± 1.25	58.25 ± 6.61	Mean value±SD	8.89 ± 1.69	11.61 ± 4.07	18.84 ± 2.31	1.20 ± 1.19	40.55 ± 7.65

*** Not Detected**

Tab. 3 Annual effective dose in air outdoor μSv

Section 1						Section 2					
Layer cm	^{226}Ra	^{232}Th	^{40}K	^{137}Cs	Total±SD	Layer cm	^{226}Ra	^{232}Th	^{40}K	^{137}Cs	Total±SD
Ground litter (0-3)	11.86 ± 3.30	20.93 ± 5.64	21.63 ± 3.28	3.44 ± 0.62	57.87 ± 7.34	Ground litter (0-2)	11.74 ± 4.55	10.61 ± 6.84	23.13 ± 6.95	3.71 ± 0.99	49.19± 10.81
A (3-20)	14.95 ± 3.71	27.64 ± 6.34	28.38 ± 6.44	3.11 ± 0.72	74.09 ± 9.79	A (2-10)	13.13 ± 3.33	17.33 ± 4.99	25.55 ± 5.87	2.15 ± 0.57	58.16 ± 8.42
AE (20-35)	14.97 ± 3.24	28.41 ± 5.81	31.63 ± 6.59	0.80 ± 0.38	75.80 ± 9.37	EB (10-28)	11.21 ± 2.98	21.50 ± 5.19	25.75 ± 5.72	0.81 ± 0.38	59.26 ± 8.29
E (35-50)	15.17 ± 3.41	28.53 ± 5.82	34.51 ± 7.06	0.47 ± 0.36	78.68 ± 9.76	B (28-50)	7.53 ± 2.24	10.02 ± 3.40	18.82 ± 4.32	0.31 ± 0.25	36.68 ± 5.94
B (50-…)	13.96 ± 3.17	29.39 ± 5.73	27.40 ± 5.82	ND*	70.75 ± 8.76	BC (50-…)	10.94 ± 2.58	11.75 ± 3.50	22.29 ± 4.83	0.37 ± 0.27	45.35 ± 6.50
Mean value±SD	14.18 ± 1.38	26.98 ± 3.44	28.71 ± 4.85	1.96 ± 1.54	71.44 ± 8.11	Mean value±SD	10.91 ± 2.07	14.24 ± 4.98	23.11 ± 2.83	1.47 ± 1.46	49.73 ± 9.38

***Not Detected**

Tab. 4 Annual effective dose in air indoor μSv

Section 1						Section 2					
Layer cm	^{226}Ra	^{232}Th	^{40}K	^{137}Cs	Total±SD	Layer cm	^{226}Ra	^{232}Th	^{40}K	^{137}Cs	Total±SD
Ground litter (0-3)	58.18 ± 16.17	102.69 ± 27.69	106.13 ± 16.10	16.88 ± 3.03	283.88 ± 36.00	Ground litter (0-2)	57.59 ± 22.30	52.05 ± 33.58	113.45 ± 34.11	18.20 ± 4.86	241.28 ± 53.03
A (3-20)	73.34 ± 18.21	135.59 ± 31,09	139,23 ± 31,59	15,28 ± 3,52	363,44 ± 48,05	A (2-10)	64,42 ± 16,35	85,02 ± 24,48	125,33 ± 28,81	10,53 ± 2,81	285,30 ± 41,28
AE (20-35)	73,42 ± 15,91	139,36 ± 28,49	155,15 ± 32,34	3,93 ± 1,86	371,85 ± 45,98	EB (10-28)	54,97 ± 14,62	105,46 ± 25,48	126,34 ± 28,05	3,95 ± 1,89	290,73 ± 40,66
E (35-50)	74.43 ± 16.71	139.96 ± 28.53	169.30 ± 34.62	2.31 ± 1.78	385.99 ± 47.90	B (28-50)	36.92 ± 10.97	49.16 ± 16.67	92.33 ± 21.17	1.53 ± 1.24	179.94 ± 29.12
B (50-…)	68.48 ± 15.55	144.16 ± 28.13	134.43 ± 28.55	**ND***	347.07 ± 42.99	BC (50-…)	53.65 ± 12.65	57.66 ± 17.19	109.36 ± 23.68	1.80 ± 1.33	222.47 ± 31.90
Mean value±SD	69.57 ± 6.77	132.35 ± 16.86	140.84 ± 23.79	9.60 ± 7.54	350.45 ± 39.79	Mean value±SD	53.51 ± 10.16	69.87 ± 24.45	113.36 ± 13.87	7.20 ± 7.14	243.94 ± 46.00

***Not Detected**

Tab. 5 Absorbed dose rate in nGy/h, effective dose rate in μSv/y in air outdoor and indoor.

Sod-podzolic soil of Chashnikovo - Russia					
Dose	Radionuclide				
	^{226}Ra	^{232}Th	^{40}K	^{137}Cs	Total
Absorbed dose rate nGy/h	10.23 ± 1.34	16.81 ± 5.19	21.13 ± 2.29	1.4 ± 0.2	49.56 ± 5.83
Annual effective dose in air outdoor μSv/y	12.54 ± 1.64	20.61 ± 6.37	25.91 ± 2.80	1.71 ± 0.24	60.78 ± 7.15
Annual effective dose in air indoor μSv/y	61.54 ± 8.03	101.11 ± 31.24	127.1 ± 13.74	8.40 ± 1.20	298.16 ± 35.08

From table 5, it is obvious that the absorbed dose rate from NORM radionuclides is 48 nGy/h and this value within the range of 51 nGy/h which published by report of UNSCEAR, 2000 and so close to the value calculated by us for the same type of soil (sod-podzloc soil) of 35 nGy/h by Aleksakhin, 1982.

We noticed no significant value of radiocaesium -137 in the formation of absorbed dose and it is equal to 1.4 nGy/h, this means about 2.8% from the total dose formed by the naturally occurred radionuclides.

On the basis of our obtained results for the two sections, we realize these results in form of figure as shown in figure 5 as follows:

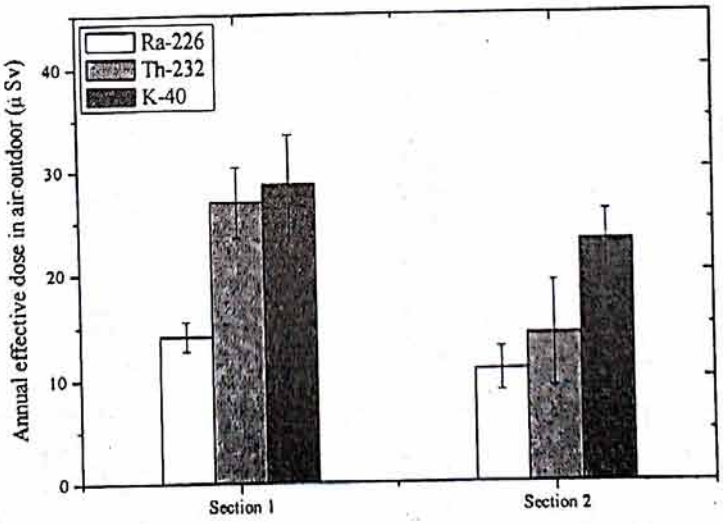

Fig. 5 annual effective dose (μ Sv) in air outdoor for the two sections

The following table 6 shows the absorbed dose rate in some countries from gamma ray emitted from soil for the NORM.

Tab. 6 Absorbed dose rate in nGy/h for some countries from gamma ray emitted from soil

Country	Absorbed dose rate nGy/h	Reference
Egypt*	12	W. M. Badawy, 2009
Russia**	48	Current work
Algeria	70	(Benkrid et al, 1992)
US	47	(Miller, 1992; Oakely, 1972)
China	62	(China, 1990)
India	56	(Nambi et al, 1986)
Finland	71	(Arvela et al, 1995)
Sweden	56	(Mjönes, 1986)
Australia	93	(Clarke et al, 1993)

* The sample were collected from two areas Heet (small village in El Minofia governorate) and Inshass (the site of the second Egyptian research reactor)
**The samples were collected from the training center for students of Moscow State University in Chashnikovo – Moscow.

CONCLUSION

From the results, it is clear that the use of γ-ray spectrometer is a powerful tool to measure the activity concentration of the γ-emitter radionuclides. Moreover, the current work confirms the fact that clay soil includes high activity concentration due to NORM radionuclides more than that included by sandy soil in normal situations. Consequently, the calculated absorbed dose rate, annual effective dose in air outdoor and indoor is higher in case of clay soil.

The area under investigation is a location for training for students of faculty of soil science _ Moscow State University as mentioned before in the text of the paper, and it was so important to get such information about the background radiation in this place to calculate the dose rate received by them during their work with these soils on their practice.

Under the intention of making a radiological atlas for this place, our present data in the current research is a helpful and valuable to be reflected on a radiological map for the location.

We compared our obtained results from Chashnikovo – Russia with our previously obtained results from some areas in Egypt (Heet and Inshass), the results show that the results of activity concentration gained from soils of Chashnikovo are higher in 4 times than obtained for the same soil types from some areas in Egypt and this is due to the use of fertilizers for these soils more than 50 years ago.

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للعلوم النووية و تطبيقاتها

ردمـــــــد ٠٤٥١ ــ ١١١٠

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