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^{137}Cs AND ^{40}K CONCENTRATIONS IN FOREST SOILS AND WASTELANDS IN THE VICINITY OF SIEDLCE (EASTERN POLAND)

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Abstract: The activity of ^{137}Cs and ^{40}K in forest soils and wastelands in the vicinity of Siedlce (eastern Poland) were measured. The soil samples were collected on depths of 0–4 cm, 4–8 cm and 8–12 cm. The average specific radioactivity of ^{137}Cs in forest soils and wastelands were 57 Bq/kg and 15 Bq/kg, respectively. The highest specific radioactivity of ^{137}Cs was observed in superficial layers of forest soils with an arithmetic mean of 126 Bq/kq. The average specific radioactivity of ^{40}K in the soil samples was 200 Bq/kg independently of sampling depths. Positive correlations were found between ^{137}Cs and C_{org} concentrations. Both ^{137}Cs and ^{40}K were negatively correlated with the sand fraction and positively with silt and clay fractions.

INTRODUCTION

After the breakdown of the power reactor in Chernobyl in 1986, the highest concentration of radionuclides in the area of Poland was noted, for example, in eastern provinces [14]. A few places were registered as the ones where radioactive contamination was much higher than the national average. The neighborhood of Siedlce was one of those places [4, 16].

Out of all radionuclides released as a result of the breakdown of the power reactor in Chernobyl, ^{137}Cs isotope ($T_{1/2}$ = 30.1 years) is the one which is still present in the environment. Cesium has only one stable isotope (^{133}Cs) and about 20 artificial radioactive isotopes; one of them is ^{137}Cs isotope [1]. ^{137}Cs isotope undergoes β- and γ-transformation. The content of ^{137}Cs depends on the level of contamination after the power reactor breakdown, and on the type of soil. In 2004, the mean radioactivity of cesium in the area of Poland was about 19 Bq/kg [3]. The literature data (e.g. Dołhańczuk-Śródka *et al.* [5]; Kubica [8]; Litorowicz *et al.* [9]; Pachocki *et al.* [12]; Zhiyanski *et al.* [17]) indicate that the surface layers of soil accumulate large amounts of ^{137}Cs.

Potassium has three natural isotopes (^{39}K, ^{40}K, ^{41}K). ^{40}K nuclide is radioactive and it comprises 0.0119% of natural potassium. ^{40}K nuclei ($T_{1/2}$ = $1.3 \cdot 10^9$ years) undergo βand γ-transformation during which they change into stable ^{40}Ca [13]. Soil accumulates a considerable part of ^{40}K isotope. The ^{40}K radioisotope content depends on the content of stable isotopes of potassium (^{39}K, ^{41}K) and the type of soil. It is greater in places where potassium fertilizers are used.

Describing the radioactivity of ^{137}Cs forest and wasteland soils in the neighbourhood of Siedlce 20 years after the breakdown of the power reactor in Chernobyl was the main aim of studies. The radioactivity of ^{40}K isotope was also measured during the studies, mainly because of similar chemical properties of cesium and potassium.

The researches aimed to:

- determine the specific radioactivity of ^{137}Cs and ^{40}K isotopes in forest and wasteland soils,
- assess the degree of migration of the studied isotopes into the soil profile,
- determine correlations between the specific radioactivity of ^{137}Cs and ^{40}K in soils and chosen soil properties (reaction, the content of C_{org}, granulometric composition).

THE AREA OF STUDIES

The town of Siedlce (52°10' N, 22°17' E) is situated at Siedlce Plateau, which is the part of a bigger geographical unit – the South Podlasie Lowland [7]. The Plateau lies in the area of frontal moraines of the Middle-Polish Glaciations (Warta stage). The terrain is flat; the uplifts reach 190–200 m a.s.l. Brown and podsolic soils predominate in the region.

Study sites were chosen at random. The soil was collected from the sites located northwest and southeast of the town of Siedlce. 9 sampling sites in forests (Mokobody, Kisielany, Opole, Siedlce, Mościbrody, Skórzec, Wiśniew settlement, Wiśniew, Gostchorz) and 4 sampling sites in the area of wastelands (green strips along the roads running through the following places: Kiesielany, Opole, Mokobody, Wiśniew settlement) were appointed (Fig. 1).

Fig. 1. The location of sampling sites: 1 – Mokobody, 2 – Kisielany, 3 – Opole, 4 – Siedlce, 5 – Mościbrody, 6 – Skórzec, 7 – Wiśniew settlement, 8 – Wiśniew, 9 – Gostchorz

MATERIAL AND METHODS

The soil samples were collected in October and November 2005. The places from which the samples were collected were marked at the map (Fig. 1). The samples were taken from the surface layer of soil, from the depth up to about 12 cm. Soil samples were taken in the form of 12 cm high cores. Then the soil cores were cut into slices; each 4 cm high. Three layers of soil were obtained in this way: level A (0–4 cm), level B (4–8 cm), level C (8–12 cm). In forests, also litter was collected. Each of the soil and litter samples weighed 1 kg. The soil was dried aerially and then washed in a sieve of 2 mm mesh size which allowed to eliminate plant remains and small stones from the samples.

Altogether, 27 samples of forest soils, 9 samples of litter and 12 samples of wasteland soils were prepared for analysis. The following physical and chemical properties of soil were determined: reaction in 1 M KCl, the percentage concentration of organic carbon determined with the use of Tiurin method, granulometric composition determined with use of Bouyoucos method, modified by Casagrande and Prószyński [11].

The activity of ^{137}Cs and ^{40}K isotopes in the soil and litter samples was measured with use of γ-spectrometry method and semi-conductor spectrometer with coaxial germanium detector made by the Canberra Company. The spectrum analysis was carried out with use of Genie 2000 Applications Software (model S501C). Each sample was measured for 80000 seconds.

The results of the analysis of the radioactivity of ^{137}Cs and ^{40}K in soils, and of chosen physical and chemical parameters of soils (granulometric composition, the percentage concentration of organic carbon and the reaction of soils) were put to the statistical analysis (Statistica 5.0). Pearson correlation factors were calculated.

RESULTS

Soils chosen for studies were sandy, mainly represented by sand, weakly loamy sand and loamy sand. All the collected soils had similar granulometric composition, which results from the fact that the area of studies was relatively small.

The reaction of the studied soils was very acid and acid; it varied from 2.77 (forest in Gostchorz – A) to 4.75 (wastelands in Niwiski – level A). In forest soils, the reaction increased with every deeper level; it varied from 3.19 (level A) to 3.63 (level C). In wasteland soils, the highest reaction (pH – 4.15) was noted in level A, and the lowest – in level C (pH – 3.85).

The percentage concentration of organic carbon in the collected material varied between 0.4 and 8.83%. In forest soils, the content of C_{org} decreased with depth; the mean content of C_{org} in each level of forest soils was: level A – 3.63%, level B – 2.12% and level C – 0.93%. The mean content of C_{org} in each level of wasteland soils was about 1%.

The mean radioactivity of ^{137}Cs in forest soils, at the depth of 12 cm, was 57.5 Bq/kg. The greatest radioactivity of all sampling sites was measured in forest soils taken from Opole – 188.5 Bq/kg and Kisielany – 101.2 Bq/kg. The surface layer of soil (level A) was the richest in ^{137}Cs isotope. The radioactivity of cesium in that level was 126.2 Bq/kg. The highest radioactivity was noted in litter with an arithmetic mean of 205.9 Bq/kg (Fig. 2a).

The mean radioactivity of ^{137}Cs in wasteland soils was 15.6 Bq/kg. The greatest radioactivity (18.2 Bq/kg) was noted in samples taken from Mokobody. No significant differences in the radioactivity of ^{137}Cs in each level of wasteland soils were noted (Fig. 2b).

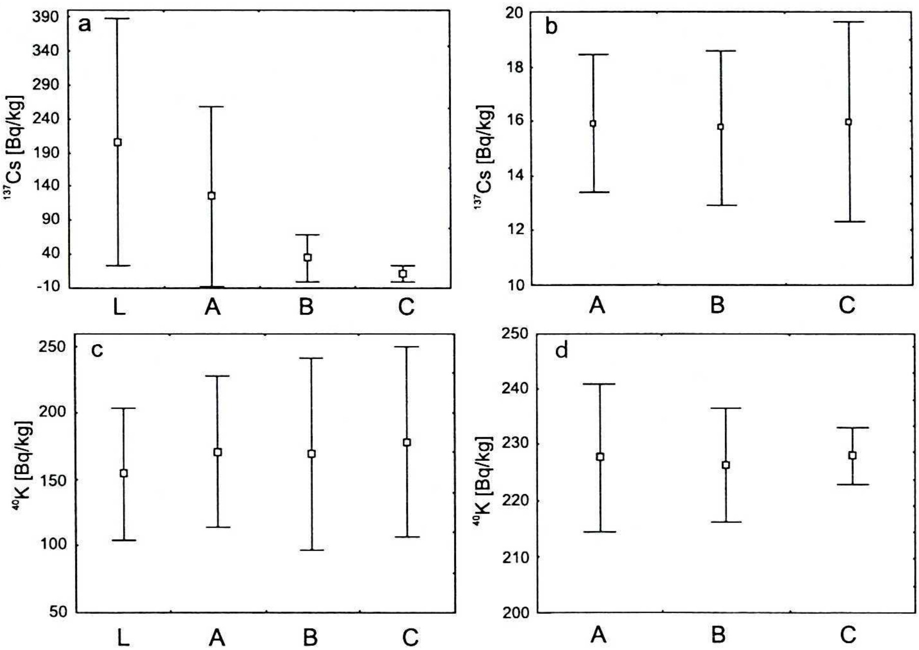

Fig. 2. Average ^{137}Cs and ^{40}K radioactivity versus sampling depth in (a, c) forest soils, (b, d) wastelands; uncertainties are quoted as one standard deviation (± SD), sampling depths: L – litter, A – 0–4 cm, B – 4–8 cm, C – 8–12 cm

The radioactivity measured for ^{40}K isotope was within the range: 103.6 Bq/kg (level B of Mościbrody forest soil) – 349.0 Bq/kg (level C of Opole forest soil). The mean content of ^{40}K was: 172.7 Bq/kg in forest soils, and 211.9 Bq/kg in wasteland soils. The values of ^{40}K radioactivity in each level of the studied soils were almost the same (Fig. 2c, d).

Calculated values of Pearson's (linear) correlation factors indicate that there are statistically significant correlations between the radioactivity of ^{137}Cs in soils and the reaction of soil ($r = -0.5575$, $p < 0.001$) (Fig. 3a), as well as the percentage concentration of organic carbon ($r = 0.8639$, $p < 0.001$) (Fig. 3b). Similar correlations were not noted for ^{40}K. The contents of the two radioactive nuclides were correlated with soil fractions: positively with silt and clay fraction, and negatively with the content of sand fraction (Tab. 1).

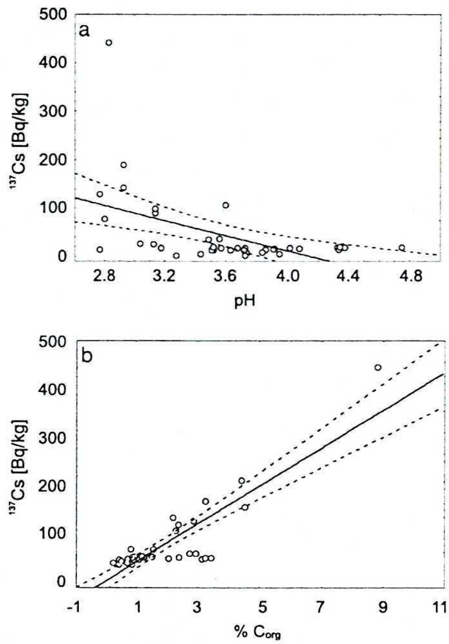

Fig. 3. Correlations between ^{137}Cs radioactivity in soil (a) soil reaction and (b) percentage concentration of C_{org}

Table 1. Pearson correlation factors for ^{137}Cs and ^{40}K radioactivity and percentage soil fractions, (p – level of significance)

	Soil fractions (mm)		
	2.0–0.05	0.05–0.002	< 0.002
^{137}Cs	-0.3573 p = 0.026	0.3599 p = 0.024	0.4161 p = 0.008
^{40}K	-0.6383 p < 0.001	0.5986 p < 0.001	0.4304 p = 0.006

DISCUSSION

The analyses of soil conducted in a few places located in the vicinity of Siedlce showed that soils in the region are still contaminated with radioactive cesium.

The radioactivities of ^{137}Cs noted in the studied forest soils are three times higher than the mean contents of this isotope in soils of Poland (about 19 Bq/kg) calculated by Biernacka and Isajenko [3]. Also Chibowski *et al.* [4] and Szewczyk [16] confirm the existence of anomalous zones in the vicinity of Siedlce where, after the breakdown of the power reactor in Chernobyl, significantly higher radiation back-ground was noted as a result of ^{137}Cs nuclei disintegration. Our studies show that the anomalies could take place, for example, in the areas located northwest of Siedlce.

The distribution of cesium in forest soils is not the same in all the soil levels. The highest radioactivity of cesium was noted in the surface layers of the forest soil. The data are confirmed by Dołhańczuk-Śródka *et al.* [5], Kubica [8], Litorowicz *et al.* [9], Pachocki *et al.* [12] and Zhiyanski *et al.* [17]. No similar observations were made in wastelands.

The occurrence of ^{137}Cs is correlated with the soil reaction, the percentage concentration of organic carbon in soil, as well as with the content of silt and clay fractions in soils. The negative coefficient of the correlation between the radioactivity of ^{137}Cs and the soil reaction shows that the more acidified the environment the greater the content of cesium. The correlation between the radioactivity of cesium and the percentage concentration of organic matter in soil shows that the content of this element increases with the rise of carbon bound to organic compounds. It is confirmed by the literature data (e.g. Bergeijk *et al.* [2], Dołhańczuk-Śródka *et al.* [6], Zhiyanski *et al.* [17]) which indicate that the organic matter is a filter absorbing, for example, cesium.

The amount of finest fractions of soil has also an influence on the radioactivity of ^{137}Cs in the studied soils. Cesium is usually arrested in soils which are abundant in colloidal parts, while soils abundant in sand have little retention of that element [4, 10].

Isotope ^{40}K belongs to the group of natural radioactive isotopes which occur in the environment. The mean radioactivity of ^{40}K isotope in the soils of Poland is 400 Bq/kg [3]. The results of measurements of the content of ^{40}K in soils in the vicinity of Siedlce show that in relation to mean values calculated in the area of Poland, the soils in the neighborhood of Siedlce are poor in potassium. The type of parent rock has a great influence on that. In the studied area, the basement complex consists mainly of gravels, sands and boulder clay [15].

The level of soil has no significant influence on the radioactivity of ^{40}K in soils in the vicinity of Siedlce. Such observations are different from the data noted by Kubica [8] who indicates that the maximum radioactivity of ^{40}K is measured in the third level of the soil profile, at the depth of 7–10 cm.

It is worth-noting that the radioactivity of ^{40}K isotope is correlated with all soil fractions; positively with silt and clay fractions, and negatively with the sand fraction. The content of ^{40}K in the upper level of soil depends on the content of colloidal parts [4]. That isotope occurs in smaller amounts in sandy soils. Unlike in the case of ^{137}Cs, no significant correlations between the content of ^{40}K and the soil reaction, as well as the percentage concentration of organic carbon were noted.

The analysis of the obtained results allowed to follow the way in which two radioactive isotopes, which represent elements of similar chemical properties, accumulate in soil. The difference in the "behavior" of artificial ^{137}Cs and naturally occurring ^{40}K is distinct.

CONCLUSIONS

1. 20 years after the breakdown of a power reactor in Chernobyl, the contamination of soils by ^{137}Cs in the vicinity of Siedlce still holds. The highest accumulation of ^{137}Cs is noted in forest soils, the smallest – in wasteland soils.
2. The highest concentration of radioactive cesium is noted in the surface levels of forest soil; deep into the soil profile, the concentration of that nuclide decreases.
3. The occurrence of ^{137}Cs is strictly correlated with chosen properties of soil, such as: soil reaction, the percentage concentration of organic carbon and the content of silt and clay fractions.
4. In soils in the vicinity of Siedlce, the radioactivity of ^{137}Cs is considerably smaller in comparison with the radioactivity of ^{40}K.
5. The content of ^{40}K in soils in the vicinity of Siedlce is about two times smaller in comparison with the mean content of that isotope in the soils of Poland.

6. The ^{40}K content is correlated with all soil fractions: negatively with the sand fraction and positively with the silt and clay fractions.

REFERENCES

[1] Avery S.V.: *Fate of caesium in the environment: distribution between the abiotic and biotic components of aquatic and terrestrial ecosystem*, J. Environ. Radioactivity, **30**(2), 139–171 (1996).

[2] Bergelijk van K.E., H. Noordijk, J. Lembrechts, M.J. Firssel: *Influence of pH, soil type and soil organic matter content on soil-to-plant transfer of radiocesium and strontium as analyzed by a nonparametric method*, J. Environ. Radioactivity, **15**(3), 265–276 (1992).

[3] Biernacka M., K. Isajenko: *Radiologiczna mapa Polski w latach 1988–2005*, [in:] Czarnobyl 20 lat później: skażenie środowiska i żywności, skutki zdrowotne. Energetyka jądrowa w Polsce: za i przeciw, XXI Szkoła Jesienna, Polskie Towarzystwo Badań Radiacyjnych im. M. Skłodowskiej-Curie, Materiały konferencyjne, Zakopane 2006, 95–111.

[4] Chibowski S., J. Solecki, R. Szczypa, R. Suprynowicz: *Study of radioactive contamination of Eastern Poland*, Sci. Total Environ., **158**, 71–77 (1994).

[5] Dołhańczuk-Śródka A., B. Kiczma, M. Wacławek: *Ocena skażenia gleb ^{137}Cs*, Chem. Dydakt. Ekol. Metrol., **7**(1-2), 69–71 (2002).

[6] Dołhańczuk-Śródka A., M. Ząbkowska-Wacławek, G. Kusza: *Radiocez w środowisku leśnym*, [in:] Obieg pierwiastków w przyrodzie, Monografia III, 27–30 (2005).

[7] Kondracki J.: *Geografia regionalna Polski*, PWN, Warszawa 2001.

[8] Kubica B.: *Pilotażowe badania zawartości ^{137}Cs, $^{239+240}Pu$, ^{40}K w próbkach gleby z Tatrzańskiego Parku Narodowego*, Kosmos, **51**(4), 408–413 (2002).

[9] Litorowicz M., T. Majcherczyk, A. Solecki, W. Wacławek: *Spatial Variation of Cesium ^{137}Cs and Natural Radionuclides Activities in Forest and Field Soil Localities of the Opole Anomaly Area By Means of Laboratory and Field Gamma – Spectrometric Measurements*, Chem. Inż. Ecol., **11**, 1333–1343 (2004).

[10] Niesiobędzka K.: *Transport naturalnych nuklidów promieniotwórczych w ekosystemie gleba – szata roślinna*, Chem. Inż. Ecol., **6**(1), 78–87 (1999).

[11] Ostrowska A., S. Gawliński, Z. Szczubiałka: *Metody analizy i oceny właściwości gleb i roślin, Katalog*, Instytut Ochrony Środowiska, Warszawa 1991.

[12] Pachocki K., M. Bekas, Z. Różycki: *Analiza skażeń cezem-137 powierzchniowych warstw gleby w Polsce po awarii w Czarnobylu*, [in:] Czarnobyl 20 lat później: skażenie środowiska i żywności, skutki zdrowotne, Energetyka jądrowa w Polsce: za i przeciw, XXI Szkoła Jesienna Polskie Towarzystwo Badań Radiacyjnych im. M. Skłodowskiej-Curie, Materiały konferencyjne, Zakopane 2006, 441.

[13] Polański A.: *Geochemia izotopów*, Wydawnictwa Geologiczne, 1961.

[14] *Raport w sprawie następstw katastrofy w Czarnobylu*, Wyd. Zespół Prezesa Państwowej Agencji Atomistyki do spraw Elektrowni Jądrowej „Żarnowiec", Warszawa 1991.

[15] Strzelecki R., J. Szewczyk, S. Wołkowicz, Z. Jędrzejczak: *Badanie promieniotwórczości gamma na obszarze Polski: efekt Czarnobyla, skażenia przemysłowe, promieniotwórczość naturalna*, Przeg. Geolog., **40**(6), 365–370 (1992).

[16] Szewczyk J.: *Skażenia ^{137}Cs w rejonie Warszawa – Terespol*, Przeg. Geolog., **41**(3), 149–151 (1993).

[17] Zhiyanski M., S. Sokolowska, E. Lucot, P.M. Badot: *Cs-137 contamination in forest ecosystems in southwest Rila Mountain, Bulgaria*, Environ. Chem. Letters, **3**, 49–52 (2005).

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ZAWARTOŚĆ ^{137}Cs I ^{40}K W GLEBACH LEŚNYCH I NIEUŻYTKACH ROLNYCH OKOLIC SIEDLEC (WSCHODNIA POLSKA)

W glebach leśnych i nieużytkach rolnych okolic Siedlec (wschodnia Polska) mierzono aktywność radioizotopów ^{137}Cs i ^{40}K. Próbki gleby pobierano z głębokości: 0–4 cm, 4–8 cm i 8–12 cm. Średnia aktywność izotopu ^{137}Cs w glebach leśnych i nieużytkach wynosiła odpowiednio: 57 Bq/kg i 15 Bq/kg. Największą zawartość ^{137}Cs (126 Bq/kg) odnotowano w powierzchniowych warstwach gleb leśnych. Średnia aktywność radioizotopu ^{40}K w badanych próbkach gleby wynosiła około 200 Bq/kg i nie zależała od głębokości poboru prób. Odnotowano dodatnią korelację pomiędzy aktywnością ^{137}Cs i procentową zawartością węgla organicznego. Zawartość obu radioizotopów była ujemnie skorelowana z zawartością w glebach frakcji piasku i dodatnio z zawartością frakcji pyłu i iłu.