The effect of sorption properties of soil minerals on the vertical migration rate of cesium in soil

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The vertical distribution of $^{137}$Cs is shown for two types of soil: silty loamy "supposed" soil and silty lessive one, slightly eroded, occurring in the vicinity of Lublin (Eastern Poland). Based on the distribution data the vertical migration rates of $^{137}$Cs are calculated for both soils. These rates are found to be 0.045 and 0.3 cm/year respectively. The percent contribution of $^{137}$Cs originating from the damaged reactor in Chernobyl is also calculated. The kinetics of cesium adsorption and its adsorption isotherms on minerals separated from the tested soils are also studied. The sorption of Cs on soil minerals markedly affects the migration rate of $^{137}$Cs in soil. The experimental results indicate that, among the extracted mineral fractions, the largest adsorption takes place on marls from the silty loamy soil. This work is supplemented by results of a physicochemical analysis of the studied soils.

Introduction

The presence of radionuclides in different types of soil and their migration, both vertical and horizontal, are very important issues in research on the after-effects of radioactive contamination of the natural environment. The determination of the retention mechanism of radionuclides in soil systems as well as the determination of the migration rate constitute the basis for learning the rules that govern the behavior of isotopes in different types of soil. Such research despite its purely scientific aspect has also a very practical objective, namely, it allows to predict possible sites of cumulation of radionuclides. This should also help to determine the accessibility of isotopes to plants and, more generally, to food chains.

This work presents results of studies carried out on two different soil profiles. Concentrations of radioactive isotopes were measured in particular layers of the two profiles. After physicochemical analysis the samples were split into fractions and laboratory tests of adsorption kinetics of $^{137}$Cs were conducted. The adsorption isotherms were also determined. A special attention was paid to effects of mineral composition of the two soils on the migration rate of $^{137}$Cs.

Experimental

Sampling procedure

The soil profiles were taken in October 1996. The sampling points were localized in the Pagory Chelmskie area (the Lubelska Upland, Eastern Poland). The sampling spots were situated far from inhabited areas and any active agricultural or industrial objects. The selected soils had not been farmed for last thirty years or so and were scarcely overgrown with short plants. Profiles of two types of soil were taken: (1) silty lessive soil, slightly eroded, sampled from an elevation with a slope of 3%, and (2) silty loamy "supposed" soil, sampled from a flat terrain.

The sampling procedure included removal of consecutive soil layers, each of 20×30 cm² area. Initially, the topmost and the second layers were 2 and 3 cm thick, respectively. All subsequent layers had a thickness of 5 cm. Before sampling, the soil surface was cleaned of the overground plant parts and larger organic pieces. The samples taken from each profile level were stored in polyethylene bags.

A grass sample was also taken from the same location as the profile of the silty lessive soil. Since in case of the silty loamy soil there were very few plants growing on it, no sample of the plant material was taken. In order to avoid any contamination with soil the grass was cut away 5 cm above the ground and then stored in plastic bags.

Sample preparation

After transferring to the lab, the samples were dried in a drier at 80 °C and then screened on a 1 mm sieve to remove stones and larger organic fragments. The grass was pulverized using a Fritsch pulverizer. Homogenized samples of the soils and grass were then placed in 0.5 dm³ Marinelli beakers.

Loams for laboratory testing were separated from the silty lessive soil. In order to do that, the 10–15 cm soil layer was washed on a 0.25 mm sieve into a 1 dm³ glass beaker. Then the beaker was filled up with water and the contents mixed. The separation of loams into size fractions was carried out following KÖHN's sedimentation method in a vessel 15 cm high at 20 °C. Under these conditions, using data from KÖHN's table, three size fractions were separated: 0.2–0.1, 0.1–0.05
and 0.05–0.02 mm. The sedimentation times of these fractions, from a height of 10 cm, were 4.4, 15.5 and 57.1 seconds, respectively. The extracted fractions of loams were rinsed with distilled water and then dried at 100 °C.

Marl and sand were extracted from the silty loamy soil, from the layer taken at a depth of 10–20 cm. This sample was screened on a 0.5 mm sieve. Because of a large density difference between sand and marl, these two were separated by sedimentation. The sand was cleaned additionally in an ultrasonic bath.

**Physicochemical analysis**

The physicochemical properties of the soil profiles were examined as follows: the pH was measured in a 1M KCl solution using an ERH-110 combined electrode and a N-510 Mera-Elwro pH-meter, the organic material content was determined with the use of the roasting method. Exchangeable cations were assayed in a buffered 1N ammonium acetate solution using the SCHOLLENBERG’s method. The exchangeable hydrogen concentration was determined by means of the KAPPEN’s method. Analysis of the granulometric composition was carried out with the use of the BouYoucos’s method modified by CASAGRAND and PROSZYNSKI. Results for the tested soils are presented in Table 1.

**Spectrometric measurements**

The samples of the soil layers from the two tested profiles were placed in 0.5 dm³ Marinelli beakers. Cesium activity measurements were carried out with the use of a Silena spectrometer with a 4096-channel amplitude analyzer coupled with a germanium detector (Princeton GammaTech). The detector was cooled with liquid nitrogen. Resolution of the detector was 1.7 keV for 1.33 MeV peak and its efficiency was 15%. Quantitative analysis was performed using a SIMCAS II, ver. 4.11 computer program. Each spectrometric measurement took 20 hours.

**Adsorption experiments**

Laboratory measurements of cesium sorption were carried out on 0.2–0.1, 0.1–0.05 and 0.05–0.02 mm size fractions of loams as well as on marls and sand. The tests were conducted in 50 cm³ flasks at 20 °C. Volume of each tested solution was 20 cm³ and the amount of sorbent added was 0.5 g. Concentration of CsCl solutions, traced with 137CsCl, ranged from 8·10⁻⁴ to 8·10⁻⁴ mol/dm³. Before the addition of the sorbent 0.1 cm³ aliquots of the solutions were taken and their activities measured. When the sorbent was added the suspensions were stirred continuously and after 60 minutes the activities of the remaining solutions were measured.

<table>
<thead>
<tr>
<th>Profile</th>
<th>Yields of size fractions, %</th>
<th>pH (KCl)</th>
<th>Corg (g/kg)</th>
<th>Ca²⁺ (meq/kg)</th>
<th>Mg²⁺ (meq/kg)</th>
<th>K⁺ (meq/kg)</th>
<th>Na⁺ (meq/kg)</th>
<th>H⁺ (meq/kg)</th>
<th>Sum of basic cations</th>
<th>Sorption capacity, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silty-loamy soil, slightly eroded</td>
<td>0-2</td>
<td>59 65 30 10</td>
<td>4.7</td>
<td>1.02 4.15</td>
<td>0.88 0.79 0.05 3.30</td>
<td>5.58 9.15</td>
<td>64.15</td>
<td>2-5</td>
<td>11 58 31 12</td>
<td>4.3 4.3</td>
</tr>
</tbody>
</table>