MODELLING VERTICAL MIGRATION OF $^{137}$Cs IN LITHUANIAN SOILS

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Abstract. $^{137}$Cs vertical migration in soil was evaluated using two methods: evaluating migration parameters using the quasi-diffusion model, and modelling vertical migration using VS2DI software package, which is intended for simulating transport of pollution in different types of soil. $^{137}$Cs distribution in soil was compared in elevated contamination “spots” in 1992 and 1999–2000. It was determined that $^{137}$Cs vertical distribution in soil has two maxima caused by the $^{137}$Cs global fallout due to nuclear weapon tests and by the fallout due to the ChNPP accident. $^{137}$Cs concentration simulated by VS2DI software package is close to the measured $^{137}$Cs concentration, especially to values measured in 1992. This shows that the software is able to simulate $^{137}$Cs vertical migration due to a single fallout. The quasi-diffusion model is adequate for description of long-term $^{137}$Cs vertical migration, and the results of measurements and calculations agreed within error limits. Parameters of long-term vertical migration of $^{137}$Cs in soil, the transfer rate $w$ and the diffusion coefficient $D$ were found for each region: in the western region of Lithuania (mainly sandy loam) $D = 0.12 \text{ cm}^2/\text{year}^{-1}$, $w = 0.26 \text{ cm}/\text{year}^{-1}$, in the southern region of Lithuania (mainly loam) $D = 0.13 \text{ cm}^2/\text{year}^{-1}$, $w = 0.29 \text{ cm}/\text{year}^{-1}$, and on the Curonian Spit (mainly fine sand) $D = 0.1 \text{ cm}^2/\text{year}^{-1}$, $w = 0.22 \text{ cm}/\text{year}^{-1}$.

Keywords: $^{137}$Cs, modelling, vertical migration, ChNPP accident, soil, transfer rate, quasi-diffusion coefficient.

1. Introduction

After the Chernobyl nuclear power plant (ChNPP) accident in 1986, $^{137}$Cs is considered as one of key artificial radionuclides in the environment. There were two most important periods of $^{137}$Cs contamination of the Lithuanian territory: the first one was during the period of nuclear weapon tests in the atmosphere during 1945–1980, and the second one was after the ChNPP accident in 1986. This radionuclide contaminates environment, forms extra human exposure, and it is a tracer of geochemical and geophysical processes.

After the ChNPP accident Lithuania was directly in the path of contaminated air masses coming from Chernobyl. In 1987, it was determined that $^{137}$Cs pollution density ranged from 7.4 $\times$ 10$^2$ to 3.0 $\times$ 10$^4$ Bq m$^{-2}$. The regions of elevated level of $^{137}$Cs contamination, called “spots”, ranging from square meters to square kilometres were observed (Butkus et al. 1994). The largest amount of $^{137}$Cs after the ChNPP accident is accumulated in the same areas, where fallout anomalies were registered after nuclear weapon tests (Butkus et al. 2001). At present, contamination with $^{137}$Cs is evaluated all over the whole territory of Lithuania, but the measurements were performed during different time periods.

Studies of distribution of $^{137}$Cs in soils are relevant to the estimation of the density of contamination of soil layers, exposure forecast, determining the penetration depth as well as calculating the rate of natural self-decontamination (Baturin 1997; Израэль et al. 1998). The content of $^{137}$Cs in soil is mainly influenced by vertical migration, less influenced – by transfer in the groundwater and in the geosphere, even much or far less – migration in plants, and the least – by resuspension with wind (Шестопалов et al. 2001). In soil with high moisture content radionuclide migration is significant (Фесенко et al. 1997). The major processes of vertical migration are diffusion, convection transfer with the soil liquid, and migration via the roots of plants (Акаёв et al. 1999). One of the most important factors is the presence of certain kinds of vegetation, in particular, coniferous trees, the litter of which retains radionuclides for a long time and carries out the role of a specific filter; or some representatives of berries and mosses. So, after the initial fallout radionuclides can hardly get into a soil with moss cover because they are engulfed by mosses and are kept fixed in them for a long time (Hrabovský et al. 2004).

Models often used for description of $^{137}$Cs vertical migration are those with Gaussian or exponential distribution of the radionuclide profile in an undisturbed soil (Фесенко et al. 1997; Hrabovský et al. 2004; Schuller et al. 2002; Isaksson, Erlandsson 1998; Барисич et al. 1999; Ivanov et al. 1997; Rosen et al. 1999; Holge, Malý 2000; Bossew, Kirchner 2004). Some authors use the exponential function of depth and experimentally determined parameters (Schuller et al. 2002; Isaksson, Erlandsson 1998). The authors of (Барисич et al. 1999) describe $^{137}$Cs vertical migration by a logarithmic-polynomial equation, using coeff-
cients which can be found by the least-squares method using the measured cesium activities in the sampled soil compartment. Compartment models are also used, where migration is described by rate equations, and the rate parameters are transfer coefficients which characterize the rate of migration of a radionuclide between the layers (Kanapickas et al. 2005). The authors of (Holgye, Maly 2000) use both the compartment model and diffusion model and find the transfer rate ranging from 0.18 cm/year to 0.99 cm/year\(^{-1}\). In this work we use the quasi-diffusion model where the main parameters are transfer rate and diffusion coefficient (Baturin 1997; Фесенко et al. 1997; Hrabovsky et al. 2004; Ivanov et al. 1997; Rosen et al. 1999; Bossew, Kirchner 2004). In the Ukrainian soils the diffusion coefficient \((D)\) ranged from 0.06 to 0.69 cm/year\(^{-1}\), and the transfer rate \((w)\) ranged from 0.07 to 0.89 cm/year\(^{-1}\) (Ivanov et al. 1997) as well as the main values were: \(D = 0.20\) cm\(^2\)/year\(^{-1}\), and \(w = 0.55\) cm\(^{-1}\) year\(^{-1}\) (Hrabovsky et al. 2004). At the same time in Sweden the transfer rate value ranged from 0.2 cm/year\(^{-1}\) to 0.6 cm/year\(^{-1}\) (Isaksson, Erlandsson 1998; Rosen et al. 1999).

The aim of the present work is to evaluate the long-term vertical radionuclide migration using two methods: quasi-diffusion model for vertical \(^{137}\)Cs migration, and simulation with VS2DI software package. VS2DI is intended for modelling of pollution transport in varied porous media; thus, it can be used for simulation in different soil types.

2. Materials and methods

2.1. Sampling and measurement of \(^{137}\)Cs concentration

In 1999–2000, the soil sampling was repeated in the regions of elevated contamination, ("spots"), where \(^{137}\)Cs concentration was measured after the ChNPP accident: in the southern and western regions and the Curonian Spit (Fig. 1). Each region has a different soil type: the soil in the southern region is mostly clay loam, in the western region it is clay and sandy loam, and in the Curonian Spit it is mostly fine sand.

Soil was sampled in the 0–50 cm depth soil layer, in flat open places with an undisturbed structure of soil, at meadow or glade, not closer than 50 m from trees or shrubbery, and not closer than 100 m from roads. A metal ring with the 14 cm diameter and 5 cm height was driven into the soil, and soil samples were cut with a shovel. Each sample was divided into layers of 2 cm thickness from 0 to 20 cm depth and layers of 5 cm from 20 to 50 cm depth. 3 profiles were sampled in the southern "spot", 4 profiles – in the western "spot", and 8 ones were sampled in the Curonian Spit.

The soil samples were transported to the laboratory in plastic bags, dried and weighed, and their density was determined. The \(^{137}\)Cs activity was determined using a gamma semiconductor Ge(Li) spectrometer with the registration efficiency of 0.26 % in the standard cells: 1 L volume Marinelli vessels. The radionuclide was identified by its radiation energy at 662 keV as well as \(^{137}\)Cs concen-

tration (Bq kg\(^{-1}\)) and deposition density (Bq m\(^{-2}\)) were evaluated.

2.2. Evaluation of \(^{137}\)Cs vertical migration in soil using a quasi-diffusion model

It was accepted that \(^{137}\)Cs vertical migration was diffusion and directional transfer, and the second-order differential equation was solved (Butkus et al. 2001; Фесенко et al. 1997; Ivanov et al. 1997; Holgye, Maly 2000; Bossew, Kirchner 2004):

\[
\frac{\partial q(x,t)}{\partial t} = D \frac{\partial^2 q(x,t)}{\partial x^2} - w \frac{\partial q(x,t)}{\partial t} - \lambda q(x,t),
\]

where \(q(x,t)\) is concentration of \(^{137}\)Cs in soil, Bq m\(^{-3}\); \(D(x,t)\) is the quasi-diffusion coefficient, m\(^2\)/year\(^{-1}\); \(\lambda\) is a constant of radioactive decay, year\(^{-1}\); \(w\) is the transfer rate, m\(^{-1}\); \(x\) is the depth of penetration, m; \(t\) is time of migration, year.

This model is applicable if the following simplifications may be applied: the vertical component is probably the dominant one, i.e. the model is purely one-dimensional; the soil is homogeneous; \(D\) and \(w\) parameters are considered constant over the soil column as well as constant over time; sorption of \(^{137}\)Cs is constant; only mobile form of \(^{137}\)Cs takes part in the process; the parameter \(D\) combines two different physical processes, molecular diffusion and hydrodynamic dispersion of the solute, into a single constant (Bossew, Kirchner 2004). The mostly used solution of this equation, describing a single fallout with initial and boundary conditions, is:

\[
q(x,t) = 0, \text{ when } t = 0;
\]

\[
q(x,t) = 0, \frac{\partial q(x,t)}{\partial x} = 0, \text{ when } x \to 0, t > 0;\]

\[
D \frac{\partial^2 q(x,t)}{\partial x^2} - w q(x,t) = Q \delta(t), \text{ when } x = 0, t \geq 0,
\]

where \(\delta(t)\) is the delta function; \(Q\) is the deposition density, Bq m\(^{-2}\).
The solution of the equation is as follows (Butkus et al. 2001; Fëtesë et al. 1997; Isaksson, Erlandsson 1998; Bossew, Kirchner 2004):

\[ q(x,t) = Q \cdot \exp(-\lambda \cdot t) \left[ \frac{1}{\sqrt{\pi} \cdot D \cdot t} \exp \left( \frac{(x-w-y)^2}{4 \cdot D \cdot t} \right) - \frac{w}{2 \cdot D} \exp \left( \frac{w \cdot x}{D} \right) \left[ 1 - \operatorname{erf} \left( \frac{x+w-y}{2 \cdot \sqrt{D \cdot t}} \right) \right] \right] , \tag{3} \]

where \( \operatorname{erf}(x) \) is the error distribution function.

However, the present \(^{137}\text{Cs}\) contamination of Lithuanian soils is determined not only by deposition after the ChNPP accident. It was accepted that distribution of \(^{137}\text{Cs}\) in the studied regions was formed in two stages. The fallout took place during 1945–1963 (global) and in 1986 (“Chernobyl”). Thus, the equation was modified, and the migration of \(^{137}\text{Cs}\) was estimated by solving the equation (Butkus, Konstantinova 2003):

\[ q(x,t) = Q_1 \cdot \exp(-\lambda_1 \cdot t_1) \left[ \frac{1}{\sqrt{\pi} \cdot D_1 \cdot t_1} \exp \left( \frac{(x-w-y)^2}{4 \cdot D_1 \cdot t_1} \right) - \frac{w}{2 \cdot D_1} \exp \left( \frac{w \cdot x}{D_1} \right) \left[ 1 - \operatorname{erf} \left( \frac{x+w-y}{2 \cdot \sqrt{D_1 \cdot t_1}} \right) \right] \right] + \]
\[ Q_2 \cdot \exp(-\lambda_2 \cdot t_2) \left[ \frac{1}{\sqrt{\pi} \cdot D_2 \cdot t_2} \exp \left( \frac{(x-w-y)^2}{4 \cdot D_2 \cdot t_2} \right) - \frac{w}{2 \cdot D_2} \exp \left( \frac{w \cdot x}{D_2} \right) \left[ 1 - \operatorname{erf} \left( \frac{x+w-y}{2 \cdot \sqrt{D_2 \cdot t_2}} \right) \right] \right] , \tag{4} \]

where \( Q_1 \) and \( t_1 \) are \(^{137}\text{Cs}\) deposition density and time after the global fallout, \( Q_2 \) and \( t_2 \) are \(^{137}\text{Cs}\) deposition density and time after the Chernobyl fallout.

2.3. Evaluation of \(^{137}\text{Cs}\) vertical migration in soil using VS2DI software package

For the forecast of \(^{137}\text{Cs}\) vertical migration the VS2DI software was used. VS2DI is a graphical software package for simulating different pollution transport in saturated porous media. It combines a graphical user interface with a numerical model to create an integrated, window-based modelling environment. Users can specify and change initial information: hydraulic and transport properties, initial and boundary conditions, grid spacing and other model parameters (Table) (Hsieh et al. 2000).

We specified the following parameters: geometry and boundaries of the initial polluted region (in our case – the vertical section 10–20 cm); time, mass and depth dimension; initial hydraulic condition (in our case – open vertical section); soil type (in our case – clay loam, sandy loam and fine sand) (Fig. 2) (Lietuvos...1985); relative hydraulic conductivity, porosity, moisture content; decay constant and initial concentration of pollution (in our case – \(^{137}\text{Cs}\)), and time of migration (Hsieh et al. 2000).

3. Results and discussion

It has been obtained that vertical distribution of \(^{137}\text{Cs}\) in all three soil types has two peaks. The first one is in the topsoil layers (in clay loam and sandy loam in the 2–4 cm layer, and in fine sand at the 0–2 cm depth). The second peak was observed at the 6–20 cm depth, depending on the soil type and landscape. We propose that the first increase is the result of the ChNPP accident fallout, and the second one is caused by the global \(^{137}\text{Cs}\) fallout as a result of nuclear weapon tests, when \(^{137}\text{Cs}\) migrated below the 20 cm depth.

The maximum peak was observed in the western region (sandy loam soil). In western Lithuania, in 1983, the \(^{137}\text{Cs}\) surface activity density reached 1040 Bq m\(^{-2}\), and in the territory of Lithuania it was not higher than 780 Bq m\(^{-2}\) (Butkus, Konstantinova 2003). In the southern region and the Curonian Spit, before the ChNPP accident, the surface activity density of \(^{137}\text{Cs}\) was not very high relative to the western region. Non-identical vertical distribution of \(^{137}\text{Cs}\) in the regions could be explained by different physical and chemical parameters depending on the properties of soil. In particular, it may be the soil composition (loam prevails in the southern region, there is loam and sandy loam in the western region, and fine sand on the Curonian Spit), the soil moisture content, or landscape characteristics and vegetation (Hlčeronož et al. 2001; Hrabovskyy et al. 2004; Barišić et al. 1999; Holgye, Malý 2000).

As the forest litter retains caesium, the migration rate decreases significantly. On the Curonian Spit, most of the samples were taken in forests covering most of its territory. So, in this “spot” parameters of \(^{137}\text{Cs}\) vertical migration are lower than in other regions.

For modelling of the quasi-diffusion coefficient and the transfer rate, \( Q_1 \) and \( Q_2 \) values were selected for each “spot”. Modelled \( Q_1 \) and \( Q_2 \) values were based on real deposition density values determined in 1979–1984 and in 1992–2000, and they were extrapolated using the values taken in 1963 and in 1986, respectively (Butkus et al. 2001). Modelled \( t_1 \) and \( t_2 \) values represent time after the global fallout (37 y) and time after the Chernobyl fallout (14 y). Consequently, the modelled parameters of the quasi-diffusion coefficient \( D \) and the transfer rate \( w \) for each region and soil type are as follows: in the western “spot” (mainly sandy loam) \( D = 0.12 \text{cm}^2 \text{y}^{-1}, w = 0.26 \text{cm y}^{-1} \), in the southern “spot” (mainly loam) \( D = 0.13 \text{cm}^2 \text{y}^{-1}, w = 0.29 \text{cm y}^{-1} \), and in the Curonian Spit “spot” (fine sand) \( D = 0.10 \text{cm}^2 \text{y}^{-1}, w = 0.22 \text{cm y}^{-1} \) (Butkus, Konstantinova 2003).

These values are within the ranges given in the referred works, determined in the Ukraine and Sweden (Axašion et al. 1999; Isaksson, Erlandsson 1998; Ivanov et al. 1997; Rosen et al. 1999).

Fig. 3 shows comparison of the results of two modelling methods and the measurement results of \(^{137}\text{Cs}\) distribution in 1992. \(^{137}\text{Cs}\) concentration at different depths was measured only in the southern “spot” and the Curonian Spit.
Fragment of calculations of VS2DI software

<table>
<thead>
<tr>
<th>MASS BALANCE SUMMARY FOR TIME STEP 35</th>
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<tr>
<td>PUMPING PERIOD NUMBER = 1</td>
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<td>TOTAL ELAPSED SIMULATION TIME = 1.700E+01 YEAR</td>
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**VOLUMETRIC FLOW BALANCE**

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<th>Total Time Step cm **3/year</th>
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</thead>
<tbody>
<tr>
<td>Flux Into Domain Across Specified Pressure Head Boundaries</td>
<td>0.00000E+00</td>
<td>0.00000E+00</td>
</tr>
<tr>
<td>Flux Out of Domain Across Specified Pressure Head Boundaries</td>
<td>-8.5996E-06</td>
<td>-2.9798E+03</td>
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<td>0.00000E+00</td>
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<tr>
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<tr>
<td>Transpiration</td>
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<td>0.00000E+00</td>
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<tr>
<td>Total Evapotranspiration</td>
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<td>0.00000E+00</td>
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<tr>
<td>Change in Fluid Stored in Domain</td>
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</tr>
<tr>
<td>Fluid Volume Balance</td>
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**SOLUTE MASS BALANCE**

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</tr>
</thead>
<tbody>
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<td>0.00000E+00</td>
</tr>
<tr>
<td>Flux Out of Domain Across Specified Pressure Head Boundaries</td>
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<td>-4.1901E+08</td>
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<tr>
<td>Flux Into Domain Across Specified Flux Boundaries</td>
<td>0.00000E+00</td>
<td>0.00000E+00</td>
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<tr>
<td>Flux Out of Domain Across Specified Flux Boundaries</td>
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<td>Diffusive/Dispersive Flux Into Domain</td>
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<td>Total Flux Into Domain</td>
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<td>4.2084E+08</td>
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<td>Total Flux Out of Domain</td>
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<td>Solute Mass Balance</td>
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</tr>
</tbody>
</table>

Fig. 2. Map of granulometric composition of Lithuanian soils (Lietuvos... 1985)
Comparison of $^{137}$Cs concentration measured and modelled using VS2DI software shows (Figs. 3, 4) that this software is good for evaluation of pollution after a short fixed time period. However, the vertical migration of the radionuclide in soil is a complex process which depends on a significant number of natural factors. Besides, multiplex deposition was not taken into account.

In 1992 it was observed that $^{137}$Cs vertical distribution was exponential (Lietuvos… 1985). At such a time “Chernobyl” $^{137}$Cs was mainly in the first (top) soil layer (0–2 cm), so, exponential approximation was used for description of $^{137}$Cs vertical migration.

Fig. 4 shows comparison of the results of two methods of modelling and measurement of $^{137}$Cs distribution in 1999–2000. $^{137}$Cs concentration in soil profile was measured in the southern, western “spots” and the Curonian Spit “spot”.

What can be the causes for some disparity observed between the measured $^{137}$Cs concentration in soil and that calculated using both models? Even though the soil used in the experiment was not cultivated, it might be disturbed, for example, by wild animals as well as by worms and insects. Irregularity in the distribution of the radionuclide could result from changes in the soil moisture, irregular drying out of soil and by roots of plants.
Fig. 4 shows that equation (4) is sufficiently adequate for the description of the long-term $^{137}$Cs vertical migration, and the results of measurements and calculations coincide within the limits of error.

As we can see, VS2DI software does not give the second peak which appears using measuring and equation (4). The results of modelling and measurement coincide approximately to 7 cm depth. $^{137}$Cs vertical migration modelled using VS2DI in the topsoil is close to $^{137}$Cs concentration values measured in 1992. However, this program is not adequate for the description of the long-term $^{137}$Cs vertical migration (in 1999–2000). Hence, we conclude that VS2DI software can be used for the description of the radionuclide vertical migration only in the case of a single fallout.

4. Conclusions

1. $^{137}$Cs vertical distribution in the soil of the studied regions (in three types of soil – clay loam, sandy loam and fine sand) has two peaks: the first one is in topsoil (in clay loam and sandy loam it is from 2 to 4 cm depth, in fine sand – from 0 to 2 cm depth), and the second one is at a depth from 6 to 20 cm, depending upon the soil type or landscape. We suppose that the first one is the result of the Chernobyl accident fallout, and the second one is caused by the global $^{137}$Cs fallout as a result of nuclear weapon tests, when $^{137}$Cs migrated deeper than to 20 cm depth.

2. Variations of $^{137}$Cs concentration in time modelled using VS2DI software are close to measured ones, particularly in 1992. This proves suitability of VS2DI software for simulation of $^{137}$Cs vertical migration in the case of a single fallout.

3. The quasi-diffusion model is adequate for description of long-term $^{137}$Cs vertical migration, and the results of measurements and calculations agreed within the limits of error. The parameters of long-term vertical migration of $^{137}$Cs in soil, the transfer rate $w$ and the diffusion coefficient $D$, were determined for each region: in the western region of Lithuania (mainly sandy loam) they are: $D = 0.12$ cm$^2$/year$^{-1}$, $w = 0.26$ cm/year$^{-1}$; in the southern region of Lithuania (mainly loam)– $D = 0.13$ cm$^2$/year$^{-1}$, $w = 0.29$ cm/year$^{-1}$; on the Curonian Spit (mainly fine sand) – $D = 0.1$ cm$^2$/year$^{-1}$, $w = 0.22$ cm/year$^{-1}$.

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137Cs VERTIKALIOSIOS MIGRACIJOS LIETUVOS DIRVOŽEMIUIOSE MODELIAVIMAS

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Santrauka

137Cs vertikalioji migracija dirvožemyje buvo ivertinta, matuoant jo savitąjį aktyvumą dirvožemyje ir taikant du metodus: radionuklidu vertikališkos migracijos įvertinimas pagal kvazidifuzinį modelį ir jos modeliavimas, naudojant VS2DI kompiuterinę programą, kuri skirta tautos skirtimui įvairių tipų dirvozo modeliui. 137Cs pasiskirstymas dirvožemyje buvo pašalintas su 137Cs dideles užtaršos plotuose („karštos dėmesė“) 1992 ir 1999–2000 m. Buvo nustatyta, kad 137Cs vertikalų pasiskirstymas turi dvi smailès, pirmoji atsirado dėl 137Cs globalios iškritos, sukeltošs branduolino ginklo bandymai, antroji – dėl Černobylio avarijos iškritos. 137Cs savitasis aktyvumas, sumodeliuotas naudojant VS2DI kompiuterinę programą, yra artimas šimatinui 137Cs savitajam aktyvumui, ypač šimatan 1992 m. Tai rodo, kad ši programa tinka vienkartinės taršos 137Cs vertikalai migracijai modeliuoti. Tačiau ilgalaikė 137Cs vertikalai migracija aprašyti laisvai tinka kvazidifuzinės modelis, ir jo rezultatai bei matavimo rezultatai sutampa neviršydami paklaidų ribų. Ilgalaikes 137Cs vertikališkos migracijos dirvožemyje parametrai, kryptingos pernašos greitis w ir kvazidifuzinės pernašos koeficientas D buvo nustatytos kiekvienam regione: Vakarų Lietuvos regione (vyrauja priesmėlis) D = 0,12 cm/m², w = 0,26 cm/m², Pietų Lietuvos regione (vyrauja priemolis) D = 0,13 cm/m², w = 0,29 cm/m², o Kurišų nerijoje, kur vyrauja smulkišs smėlis, D = 0,1 cm/m², w = 0,22 cm/m².

Reikšminiai žodžiai: 137Cs, modeliavimas, vertikalioji migracija, ČAE avarija, dirvožemis, kryptingos pernašos greitis, kvazidifuzinės pernašos koeficientas.

МОДЕЛИРОВАНИЕ ВЕРТИКАЛЬНОЙ МИГРАЦИИ 137Cs В ПОЧВАХ ЛИТВЫ

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Резюме

Вертикальная миграция 137Cs в почве была исследована при измерении его концентрации в почве, а также при помощи двух методов: оценки параметров миграции с помощью квазидиффузионного метода и с использованием компьютерной программы VS2DI, предназначенной для моделирования переноса загрязнения в различных типах почв. Сравнивается распределение 137Cs в областях повышенной загрязненности („горячих пятнах“) в 1992 г. и 1999–2000 гг. Установлено, что вертикальное распределение 137Cs имеет два максимума, обусловленных глобальным выпадением 137Cs в результате ядерных испытаний и вследствие Чернобыльской аварии. Концентрация 137Cs, смоделированная с помощью программы VS2DI, близка к измеренной, особенно к значениям, измеренным в 1992 г. Это свидетельствует о том, что программа может быть использована для моделирования вертикальной миграции одиночного выпадения 137Cs. Квазидиффузионная модель приемлема для описания долгосрочной вертикальной миграции, причем результаты измерений и вычислений совпадают в пределах погрешности. Были найдены параметры долгосрочной вертикальной миграции 137Cs, направленная скорость переноса w и коэффициент диффузии D для каждого из регионов: в Западной Литве (преобладает супесчаная почва) D = 0,12 cm/m², w = 0,26 cm/m², в Южной Литве (преобладает глуф) D = 0,13 cm/m², w = 0,29 cm/m², а на Куршской косе (преобладает мелкий песок) D = 0,1 cm/m², w = 0,22 cm/m².

Ключевые слова: 137Cs, моделирование, вертикальная миграция, авария на ЧАЭС, почва, направленная скорость переноса, коэффициент диффузии.


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