

# Radioecological modeling of the $^{131}\text{I}$ activity dynamics in different types of grass vegetation in the Chernobyl accident year\*

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## Abstract

The dynamics of  $^{137}\text{Cs}$  and  $^{131}\text{I}$  radioactivity in the crude biomass of the grass fodder and food vegetation in Mazovia, Poland, in 1986, the year of the Chernobyl accident, has been estimated. Density of  $^{137}\text{Cs}$  and  $^{131}\text{I}$  in the soil and vegetation have been measured as a function of rainfall and biomass density as of the time most of the fallout took place. A method is described to convert the instrumental data for the radionuclide activity dynamics in vegetation of one type to vegetation of other types. The results of such data conversion from lawn grass to other types of food and fodder grass vegetation are presented. A method is described for adjusting the dynamics of the radionuclide transport through the food chain components (pasture grass, green meat – milk – human body) by normalizing successively the estimated data in each next component for the average value of the instrumental data ratio to the estimated data in the preceding component. The proposed methods are intended to generate a mutually consistent base of estimated and reconstructed instrumental data:  $^{137}\text{Cs}$  and  $^{131}\text{I}$  activity in the atmosphere – rainfall –  $^{137}\text{Cs}$  fallout density on terrain – specific activity of  $^{131}\text{I}$  in vegetation. Such radioecological database will provide for a longer reliability of the estimated  $^{131}\text{I}$  specific activity dynamics in milk and in human body and, in the long run, when estimating the thyroid internal exposure doses.

## Keywords

Agro-radioecological model, Chernobyl accident, IAEA's EMRAS project, Warsaw scenario, instrumental data, estimated data, mutually consistent database, atmosphere, rainfall,  $^{137}\text{Cs}$  fallout,  $^{131}\text{I}$  in vegetation

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## Introduction

The paper deals with studying the dynamics of  $^{137}\text{Cs}$  and  $^{131}\text{I}$  radionuclides transport in the trophic chain: *atmosphere* –

*soil – vegetation – dairy cow organism – milk – human body*, following the accident at the Chernobyl NPP. In (Vlasov et al. 2019), the authors described the technology and generation of a mutually consistent in-

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put database for the computational model for the regions of Mazovia, Poland, and Bohemia, Czech Republic. The set of data in the base for the regions of interest included the major fallout period average or time dependencies of the  $^{137}\text{Cs}$  specific volumetric activities in the atmosphere, the rainfall in the fallout period, and the  $^{137}\text{Cs}$  fallout density. Homogeneous and heterogeneous cloud models were used for the mutual agreement of this dataset.

The materials of the Prague and Warsaw scenarios under the IAEA's EMRAS project (Krajewski et al. 2008; Bartuskova et al. 2009; Zvonova et al. 2010; IAEA-TECDOC-1678 2012) were used in (Vlasov et al. 2019) to generate such databases. The key conclusion made in (Vlasov et al. 2019) was that the use of mutually consistent data on the rainfall in the major fallout period, the specific volumetric activities of  $^{137}\text{Cs}$  in the atmosphere, and its fallout densities was expected to lead to a major decrease in the uncertainties involved in the  $^{137}\text{Cs}$  and  $^{131}\text{I}$  transport in the food chain and, therefore, to more accurately reconstructed internal exposure doses to the population residing in the contaminated areas. This statement was checked in (Vlasov et al. 2019b) dealing with the verification of a radioecological model using the instrumental data for the assessment of the dynamics of the  $^{131}\text{I}$  activities in grass in Bohemia and Mazovia. With regard to the specific nature of the grass radiometric sampling point, extra studies were carried out in the territory of the Warszawa Obserw Astr weather station in Mazovia for the grass type identification (annual or perennial lawn grass). On the basis of the results analysis it was found that the dynamics of the estimated data for perennial lawn grass agrees better with the measurement data than for annual lawn grass.

The final objective in building radioecological simulation models is to study and assess and the regularities of internal radiation dose formation to the public after radiological accidents with the release of radioactive products into the environment. When simulation models are used, the best way to improve the reliability of the estimates is successive normalization of the data for the radionuclides activity in the given food chain component with allowance for the value of the average instrumental data ratio to the estimated data in the preceding element.

For instance, the residual errors of the estimated and instrumental data on the contamination of fodder and food vegetation with  $^{131}\text{I}$  and  $^{137}\text{Cs}$  can be used initially to adjust the calculation results for the dynamics of their specific activities in milk through the intake of radionuclides into the dairy cow body with green fodder. At the next stage, similar residual errors for food vegetation and milk can be also used to adjust estimated data of the radionuclide activities in the body of local residents through the dietary intake pathway. Such successive adjustment through the food chain is expected to lead to a major decrease in the uncertainties involved in the internal radiation dose assessments to the population residing in radioactively contaminated areas.

The most acceptable option for such successive adjustments is the amount of residual errors in the region of the maximum instrumental data values. The rationale for such selection is the direct proportion between the maximum values of the radionuclide activities in all series components in the *atmosphere – vegetation – milk – human body* food chain.

The Warsaw scenario includes instrumental data of the  $^{131}\text{I}$  activities in lawn grass and milk. There is no instrumental data for the dairy cow fodder vegetation in the scenario, which makes it impossible to use the same normalization for milk.

The paper deals with the development of a method to convert actual instrumental data of specific radionuclide activities in vegetation of one type obtained at one measurement point to reconstructed instrumental data for vegetation of another type from other points, specifically, the grass radiometry data for the territory of a weather station in Warsaw to the pasture grass data from the milk radiometry points in the milk producing areas in Mazovia.

The purpose of the study is to develop and implement the method of converting instrumental data of the radionuclides activity dynamics in grass vegetation of one type obtained at one point to the activity of radionuclides in vegetation of other types at points with different  $^{137}\text{Cs}$  fallout density and rainfall in the fallout period, as well as to develop the method for the consistent mutual agreement of estimated and instrumental data on the dynamics of the radionuclide transport in the *atmosphere – fallout – fodder and food vegetation – milk – human body* food chain.

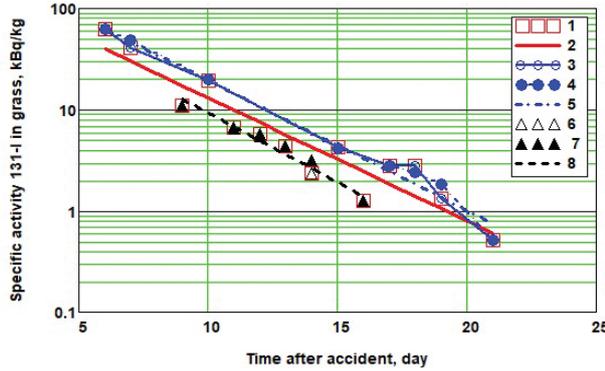
## Materials and methods

For analysis of the instrumental data on the parameters of the radiation situation in the central part of Mazovia in the year of the Chernobyl accident and radioecological modeling of the  $^{131}\text{I}$  activity dynamics in different types of grass vegetation of the agroecological block of a radioecological simulation model was used (Vlasov 2013). This block is a system of linear differential equations describing in real time the dynamics of the atmospheric  $^{131}\text{I}$  and  $^{137}\text{Cs}$  radionuclide fallout onto the ground and vegetation, and the dynamics of specific activities for grass, wild and cultured vegetation, and fodder and food crops with regard for the growth of their biomasses. The biomass dynamics is calculated with account of the weather data for the accident year. The model's input data consists of the following set of dynamic parameters: specific volumetric activities and occurrence forms of radionuclides in the atmosphere, daily average air temperatures from the beginning of the vegetation period, rainfall in the period of and after the fallout deposition, and crop yields in the accident year. This dataset, along with the data on the  $^{137}\text{Cs}$  fallout densities in residential areas (RA), is presented, to a greater or smaller extent, in the EMRAS project scenarios (Krajewski et al. 2008; Bartuskova et al. 2009; IAEA-TECDOC-1678 2012).

## Results and discussion

The Warsaw scenario includes instrumental data of the  $^{131}\text{I}$  specific activities only in lawn grass in the territory of the Warszawa Obserw Astr weather station in Warsaw.

The instrumental data of the  $^{131}\text{I}$  specific activity in this grass has an abnormal outlier on the ninth day and the second activity peak on the 16<sup>th</sup> day after the accident. A more detailed analysis shows the presence of two instrumental data series with practically identical rates of their exponential decrease (Fig. 1).



**Figure 1.** Instrumental data of the  $^{131}\text{I}$  specific activity in lawn grass at the Warszawa Obserw Astr weather station: 1 – all data; 2 – exponential interpolation; 3 – series 1; 4 – interpolation 1; 5 – exponential regression 1; 6 – series 2; 7 – interpolation 2; 8 – exponential interpolation 2.

We shall note that the time dependencies for each series and the entire set of instrumental data have an exponential form. We took this peculiarity into account when comparing these with the estimated data.

There is no measurement data for the dynamics of the  $^{131}\text{I}$  activities in food and fodder vegetation in the Warsaw scenario. Using a simulation model (Vlasov et al. 2019), however, it is possible to convert actual instrumental data for the lawn grass at the Warszawa Obserw Astr weather station to the reconstructed instrumental data for vegetation of other types in other RAs where milk radiometry was undertaken. In our case, the conversion was done for cultivated grasslands, the primary source of the radionuclides a intake with the dairy cow ration in Mazovia during and after the cow placement on summer feed. Such conversion can be done using the following ratios: direct conversion – conversion from instrumental data of the lawn grass measurements,  $Q_{gr}^{M_1}$  to “measurement” data for vegetation of other types,  $Q_{gr}^M$ :

$$Q_{gr}^{M_1}(R_k^{met}, q_k^{atm}, M_{gr}, t_m) = Q_{gr}^M(t_m) \cdot \frac{Q_{gr}^C(R_k^{met}, q_k^{atm}, M_{gr}, t_m)}{Q_{gr}^C(R_0^{met}, q_0^{atm}, M_{grass}, t_m)}, \quad (1)$$

where  $Q^C$ ,  $Q^M$ ,  $Q^{M_1}$  are respectively calculated, direct and reconstructed data of specific vegetation activities, kBq/

kg;  $R_0^{met}(t)$ ,  $q_0^{atm}(t)$ ,  $M_{grass}(t)$  are respectively the intensity of rainfall in the fallout period (mm/day), the specific activity of radionuclides in the atmosphere (kBq/m<sup>3</sup>), and the density of the grass crude biomass (kg/m<sup>2</sup>), all for the measurement point RA<sub>0</sub>;  $R_k^{met}$ ,  $q_k^{atm}$ ,  $M_{gr}$  are same as above for the conversion point RA<sub>k</sub> and vegetation; and  $t_m$  is the measurement time, days.

The conversion using a heterogeneous cloud model:

$$Q_{gr}^{M_2}(R_k^{met}, q_k^{atm}, M_{gr}, t_m) = Q_{gr}^{M_1}(R_k^{met}, q_k^{atm}, M_{gr}, t_m) \cdot \frac{[(\sigma_{Cs}^{rec}(R_k)/\sigma_{Cs,k}^{dep})]/[(\sigma_{Cs}^{rec}(R_0)/\sigma_{Cs,0}^{dep})]}{[\sigma_{Cs}^{rec}(R_k)/\sigma_{Cs,k}^{dep}]}, \quad (2)$$

where  $q_k^{atm}$  are the parameters of the atmosphere in RA<sub>k</sub>; and  $q_0^{atm}$  are the parameters of the atmosphere in RA<sub>0</sub>. The relation  $q_k^{atm}$  may have the form

$$q_k^{atm} = [(\sigma_{Cs}^{rec}(R_k)/\sigma_{Cs,k}^{dep})]/[(\sigma_{Cs}^{rec}(R_0)/\sigma_{Cs,0}^{dep})] \cdot q_0^{atm}. \quad (3)$$

where  $\sigma_{Cs,0}^{dep}$  and  $\sigma_{Cs,k}^{dep}$  are the actual  $^{137}\text{Cs}$  fallout deposition densities in the residential areas RA<sub>0</sub> and RA<sub>k</sub>; and  $\sigma_{Cs,0}^{rec}(R_0)$  and  $\sigma_{Cs}^{rec}(R_k)$  are the densities of the  $^{137}\text{Cs}$  fallout in RA<sub>0</sub> and RA<sub>k</sub> reconstructed using the direct calculation model, kBq/m<sup>2</sup>.

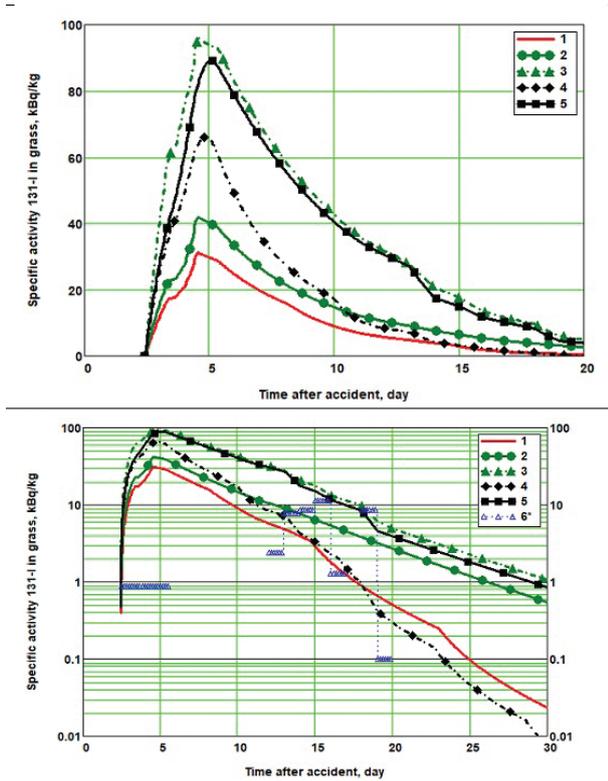
The conversion, using a homogeneous cloud model, from the effective rainfall  $R_0^{eff}$  with the atmospheric parameters  $q_0^{atm}$  for RA<sub>0</sub> to the effective rainfall  $R_k^{eff}$  with the atmospheric parameters  $q_k^{atm}$  for RA<sub>k</sub> is done using the relation

$$Q_{gr}^{M_3}(R_k^{eff}, q_k^{atm}, M_{gr}, t_m) = Q_{grass}^M(t_m) \cdot \frac{Q_{gr}^C(R_k^{eff}, q_k^{atm}, M_{gr}, t_m)}{Q_{grass}^C(R_0^{eff}, q_0^{atm}, M_{grass}, t_m)}. \quad (4)$$

The dynamics of the biomass density for vegetation of different types, specifically dairy cow fodder (pasture grass, sown annual grass for green fodder) and the human ration’s vegetation component (annual and perennial green) was calculated based on the model in (Vlasov et al. 2019) using the Warsaw scenario data on the annual cycle of the daily average air temperatures, rainfall data, and the respective crop yields in the Chernobyl accident year. An example of the calculations is presented in Fig. 2.

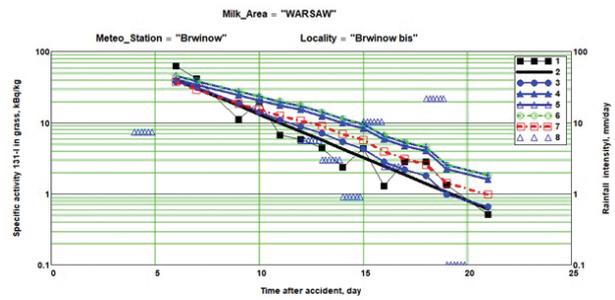
Table 1 presents data on the cumulative effective biological temperatures of the vegetation development phases and their respective occurrence times. It was assumed in the calculations that sown perennial grass was mown for being used as green fodder simultaneously after its ripening, lawn grass was mown when its biomass was 1 kg/m<sup>2</sup>, and annual and perennial green was consumed as human food after its biomass gain phase was over. The biomass of the grass not mown was assumed to be equal to 0.2 kg/m<sup>2</sup>.

The results of such instrumental data reconstruction for different types of grass vegetation in the Brinow bis community (the maximum values have been recorded in the Warsaw milk producing area: the  $^{137}\text{Cs}$  fallout density

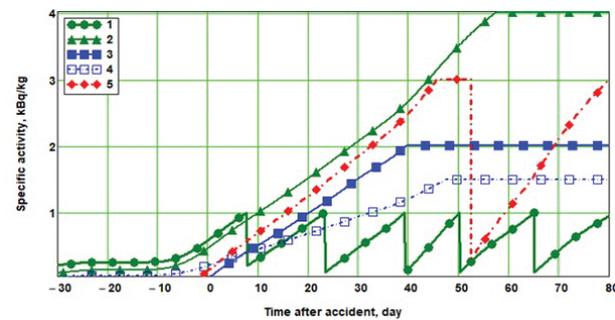


**Figure 2.** Dynamics of the <sup>131</sup>I specific activity in grass vegetation (a) and estimated data of the <sup>131</sup>I specific activity in the atmosphere (b): 1 – perennial lawn grass, Warsaw Obserw Astr\*; 2 – annual green, Warsaw Obserw Astr\*; 3 – perennial green, Przasynski\*\*; 4 – perennial lawn grass, County Ostrolecki\*\*; 5 – cultivated pasture grass, County Ostroleka\*\*; 6- rainfall, meteo station Warsaw Obserw Astr\* (\* – direct data; \*\* – data with conversion for the minimum <sup>137</sup>Cs fallout deposition densities in a milk producing area).

of 22.7 kBq/m<sup>2</sup>, and the rainfall of 7.3 mm in the major fallout period) from the perennial lawn grass at the Obserw Astr weather station with the rainfall of 0.8 mm and the <sup>137</sup>Cs fallout density of 3.3 kBq/m<sup>2</sup>, based on a direct calculation model, are presented in Fig. 3, and the crude



**Figure 3.** Dynamics of reconstructed instrumental data for the <sup>131</sup>I specific activity within the Brinow bis community in the Warsaw milk producing area: 1 – instrumental data; 2 – exponential interpolation; 3 – perennial lawn grass, direct calculation; 4 – cultivated pasture grass, reconstruction; 5 – annual greens, reconstruction; 6 – perennial greens, reconstruction; 7 – sown annual grass for green fodder, reconstruction; 8 – rainfall intensity.



**Figure 4.** Growth of crude biomass in Mazovia: 1 – perennial lawn grass; 2 – cultivated pasture grass; 3 – annual green; 4 – perennial green; 5 – sown grass for green fodder.

biomass dynamics for the above grass vegetation types is presented in Figs 3, 4 also presents

- direct instrumental data of the <sup>131</sup>I specific activity in grass specimens;
- an approximation of the instrumental data using an exponential dependence;

**Table 1.** Cumulative effective biological temperatures for the fodder and food grass vegetation development phases and their occurrence times.

Development phase, days	Cumulative effective temperatures, °C (Vlasov 2013)	Time prior to and after accident, days	Cumulative effective temperatures, °C (Vlasov 2013)	Time prior to and after accident, days
		Annual green		
Seeds	0	-46	0	-33
Seedling	70	0	80	0
Mass gain	570	0-46	330	0-25
Ripening*	670	46-52	480	25-40
First growth	670	52		
Mass gain	970	52-80		
Ripening*	1070	80-91		
Aftergrowth	1070	91		
End of growth	1730	318		
		Perennial lawn grass		
Seeds	0	-33		
Seedling, start of growth	80	0	0	-39
Mass gain	330	0-158	600	48
End of growth	1700	158	1690	155

\*-without biomass gain

- the calculated  $^{131}\text{I}$  activity in mown perennial lawn grass as of the measurement times.

According to the calculation data, the density of the cultivated pasture grass crude biomass as of 26 April 1986 was  $0.55 \text{ kg/m}^2$ , this practically coincided with the Warsaw scenario data which said that it was the warm spring with the temperature of about  $20 \text{ }^\circ\text{C}$  in Mazovia in 1986. The temperature conditions accelerated the growth of vegetation, especially the pasture grass, its crude biomass density was about  $0.4 \text{ kg/m}^2$  in late April, 1986.

Figs 5, 6 present estimated dependencies of the  $^{131}\text{I}$  specific activity in grass vegetation on its crude biomass and the rainfall for the fallout period, with regard to direct instrumental data of the  $^{131}\text{I}$  activity dynamics and atmospheric occurrence forms, according to the Warsaw scenario.

The estimated data in Figs 5, 6 show that the specific activity of  $^{131}\text{I}$  in grass decreases as its biomass grows (the growth is the faster, the larger the rainfall is), and increases as the rainfall grows (the growth is the faster, the lower the density of its grass biomass is). Of the same form is the data on the dependence of the maximum reconstructed instrumental data values for the  $^{131}\text{I}$  activities in grass vegetation of different types on their biomass as of the fallout start time obtained based on the data of the  $^{131}\text{I}$  specific activity dependencies (see Figs 1–4) and presented in Table 2.

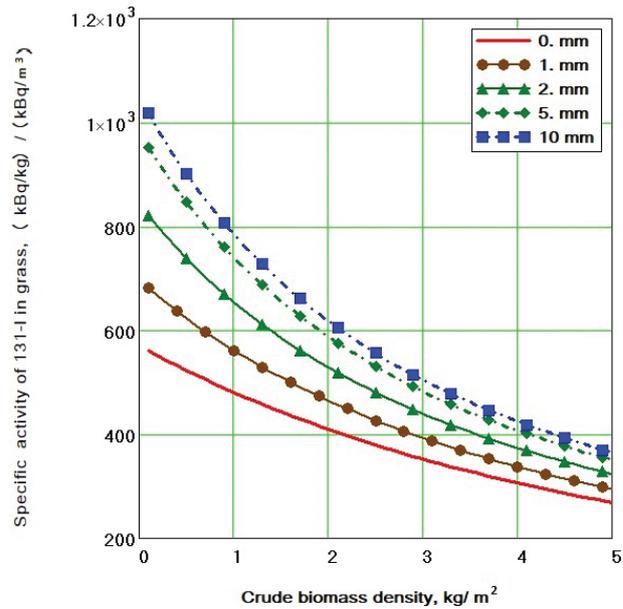
**Table 2.** Maximum values of the reconstructed instrumental data for the  $^{131}\text{I}$  activities in grass vegetation of different types on their biomass as of the fallout start time.

Grass type	Biomass as of the fallout start time, $\text{kg/m}^2$	Activity maximum, $\text{kBq/kg}$ / ( $\text{kBq/m}^3$ )	
		for the measurement time	absolute values
Perennial green	0.21	46.68	53.88
Annual green	0.26	46.57	53.73
Green fodder grass	0.39	42.99	52.70
Pasture grass	0.72	39.06	44.91
Perennial lawn grass	0.83	37.35	46.43

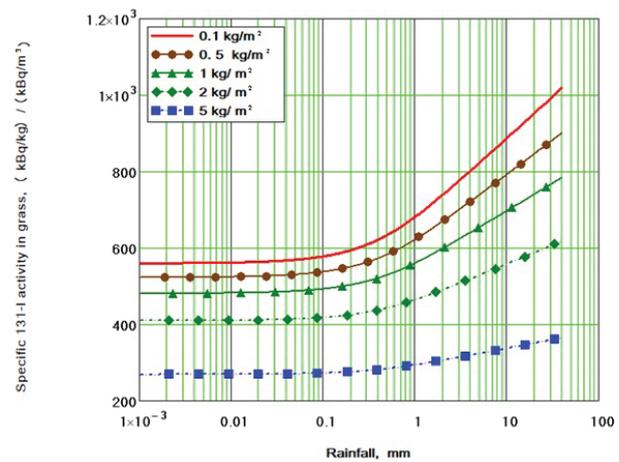
The calculation results show that the mowing of lawn grass led to an increase in the growth rate of its net biomass. Owing to this, its activity decrease rate was much higher than for pasture grass, increasing with the growth in the grass cutting frequency. The activity of vegetation with no cutting decreased with time only due to the radioactive decay of  $^{131}\text{I}$ , wind, the rainfall after the fallout was over, and the natural net biomass growth.

## Key results

A method has been proposed and implemented to convert actual instrumental data of the radionuclide specific activity in vegetation of one type to reconstructed instrumental data for vegetation of other types.



**Figure 5.** Specific activity of  $^{131}\text{I}$  in grass vegetation as a function of its crude biomass normalized to the unit specific volumetric activity of  $^{131}\text{I}$  in the atmosphere.



**Figure 6.** Specific activity of  $^{131}\text{I}$  in grass vegetation as a function of the rainfall in the major fallout period (2.4 to 4.6 days after the accident) normalized to the unit specific bulk activity of  $^{131}\text{I}$  in the atmosphere.

## Conclusion

The proposed and implemented method to convert instrumental data for the radionuclide activity in vegetation of one type to fodder and food vegetation of other types can be used to adjust the dynamics of the radionuclide human intake with the human ration's vegetation component, the activities of radionuclides in milk, and further in the chain of their intake with the dairy component.

The statistical parameters of the calculated data relations for the measurement time to the entire series of instrumental data can be used to estimate the uncertainties of the radioecological model as the whole.

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