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INTERCEPTION AND RETENTION OF CHERNOBYL FALLOUT BY FORAGE GRASSES

Samples of perennial forage crops from experimental plots set up for field performance were utilized to assess fallout retention in the six weeks following the Chernobyl reactor accident. In the study, plant density and the concentration of Cs-137, Ru-106, and Sb-125 were determined in the four cultivars from 8th May to 17th June, 1986. The obtained results indicate that in the event of a nuclear reactor failure and for a short deposition time of fallout particles on pasture during normal plant growth the activity of Cs, Ru, and Sb would decrease by 50% about 10 days following the end of radionuclide deposition.

1. INTRODUCTION

Radionuclides emitted to the atmosphere are brought down to the earth's surface by wet and dry deposition processes. A portion of the total material deposited is intercepted by vegetation. However, once radionuclides are deposited on vegetation, removal processes involving environmental factors and plant growth will combine with radioactive decay to reduce the amount of initial contamination.

Samples of perennial forage crops from experimental plots set up for field performance trials were utilized to assess fallout retention in the six weeks following the Chernobyl reactor accident. Previous studies on plant retention of fallout particles have been made under field conditions with simulated fallout [1]–[5].

The knowledge of fallout particle retention by pasture forage for livestock is needed to determine realistic estimates of radionuclide transfer through the food chain.

Plant uptake of radionuclides from the soil is negligible in comparison to direct foliar contamination, which is the dominant mode in periods of relatively high fallout [6].

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2. MATERIALS AND METHODS

Four perennial grass cultivars (cultivars Dora and Prairial of *Dactylis glomerata* L.; Toro and Alpage of *Phleum pratense* L.) were tested for forage dry matter (DM) yield at Coviolo in the province of Reggio Emilia, part of the Parmesan cheese producing area. The experimental design was a split-plot with four replications, randomizing the cultivars as the main plots and the harvesting dates as the sub-plots. The cultivars were sown in September 1985 and were harvested on the following dates: May 8th (10 days after Chernobyl), 16th, 22nd, 29th; June 5th and 17th. Fresh weight was determined on each date; the samples were oven-dried at 80°C to constant weight for dry matter determination.

The dried samples were pulverized, homogenized, and analyzed by gamma-ray spectrometry with a 140 cm^3 PGT coaxial intrinsic germanium detector (efficiency relative to 1.33 MeV Co-60 gamma-ray efficiency obtained with a $3'' \times 3''$ NaI (Tl) at a distance of 25 cm: 30.7%; energy resolution (full width) at half maximum: 2.02 keV at 1.33 MeV; shielding: 10 cm lead, 0.1 cm cadmium, 0.1 cm copper, 0.8 cm methacrylic resin). The detector was coupled to an 8K Cicero-Silena analyzer. The peak analysis was performed using a Silena-quantitative isotopic analysis option mod. 8500-Quan.

The samples were counted in 250 cm^3 Marinelli beakers for 40,000 seconds. The counting efficiency for different photon energies was determined from measurements made in a sample of forage harvested in 1985 containing the known amounts of mixed radionuclide (gamma-ray standard solution, cod. Q.C.Y.44).

The data (expressed in Bq/kg of DM) are affected by an approximate 8% statistical counting error at a 95% confidence level. Standard deviation calculated on the four replications within each treatment ranged from 5 to 25%.

The nuclide activity was not measured immediately after the harvest of samples; therefore in this study the retention only of the long-lived radionuclides Cs-137, Ru-106, Sb-125, having radioactive half-life of 11,000, 366 and 730 days, respectively, is taken into account.

3. RESULTS

The end of ground deposition due to fallout following the Chernobyl reactor accident on 26th April, 1986 can be approximately dated in Italy to the period of 8th–10th May, 1986. In this study, plant density (kg DM/m^2) and the concentrations of Cs-137, Ru-106, Sb-125 (Bq/kg DM) were determined in the four cultivars harvested from 8th May to 17th June, 1986.

The density data were subject to the variance analysis, and then density regression over time was calculated. For all cultivars, the quadrature component was found to be highly significant, and the interaction between cultivars and the quadrature component of harvesting was also significant. Figure 1 shows the density curves of the four cultivars and the amount of rainfall during the period studied.

At May 8th, the cultivars Dora, Toro and Alpage had a similar density (about

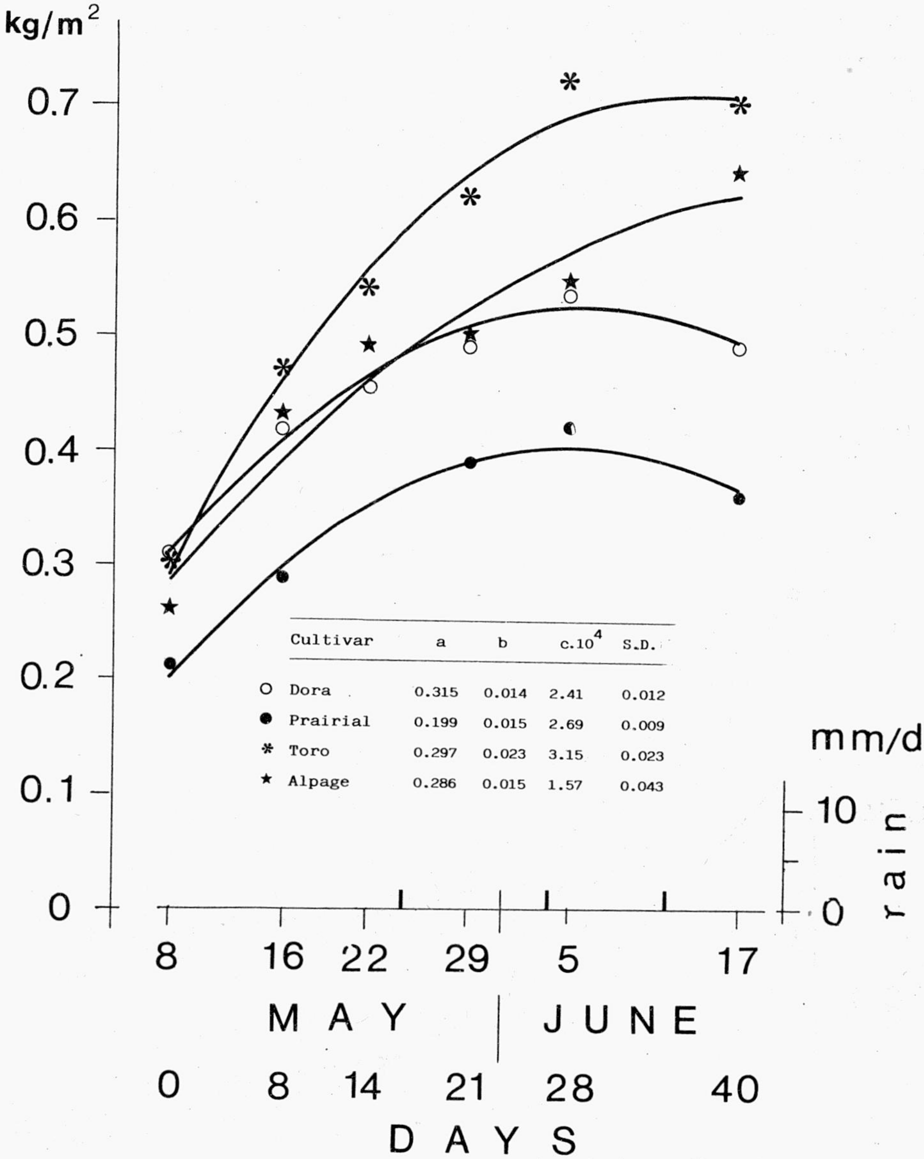
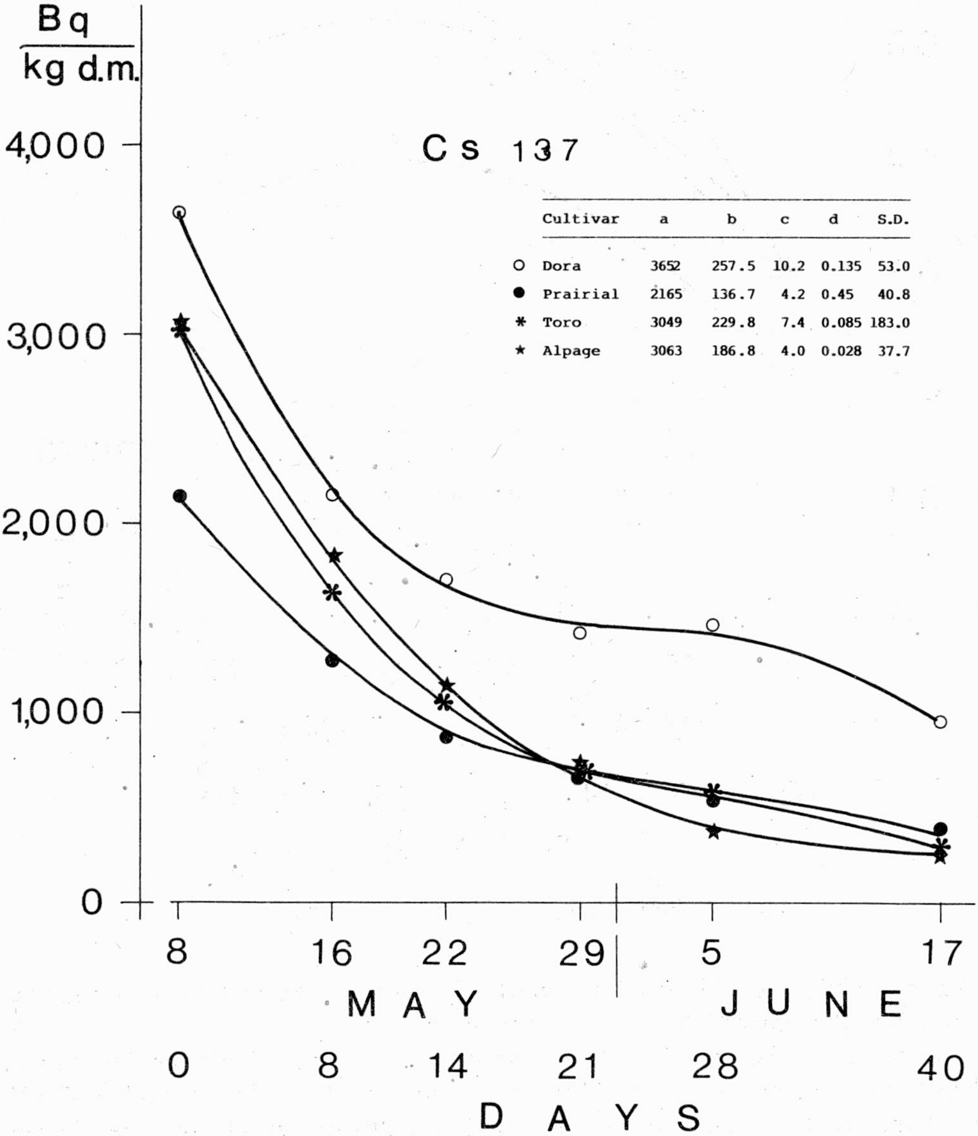


Fig. 1. Cultivar density (kg DM/m^2) curves and rainfall

0.3 kg/m^2), while that of Prairial was markedly lower (0.2 kg/m^2) due to a poor seed germination that caused low plant population.

The curves of the two *Dactylis glomerata* cultivars were fairly similar showing a density increase up to the late May and a substantial stability thereafter. On the other hand, each of the two *Phleum pratense* cultivars, which are late ripeners, evidenced a differentiated density increase beyond that date, i.e., Toro registered a maximum value around 10–15 June, while Alpage's increase continued right up to the last harvesting date.

The average (four replications) concentration values of Cs-137, Ru-106, Sb-125 were corrected for radioactive decay and analysed statistically like the foregoing density data. For all cultivars the cubic component was found to be highly significant; interaction between cultivars and harvest date was also significant (figs. 2, 3, 4).



Cultivar	a	b	c	d	S.D.
○ Dora	3652	257.5	10.2	0.135	53.0
● Prairial	2165	136.7	4.2	0.45	40.8
✱ Toro	3049	229.8	7.4	0.085	183.0
★ Alpage	3063	186.8	4.0	0.028	37.7

Fig. 2. Activity curves of Cs-137 for cultivars Toro, Alpage, Dora, and Prairial

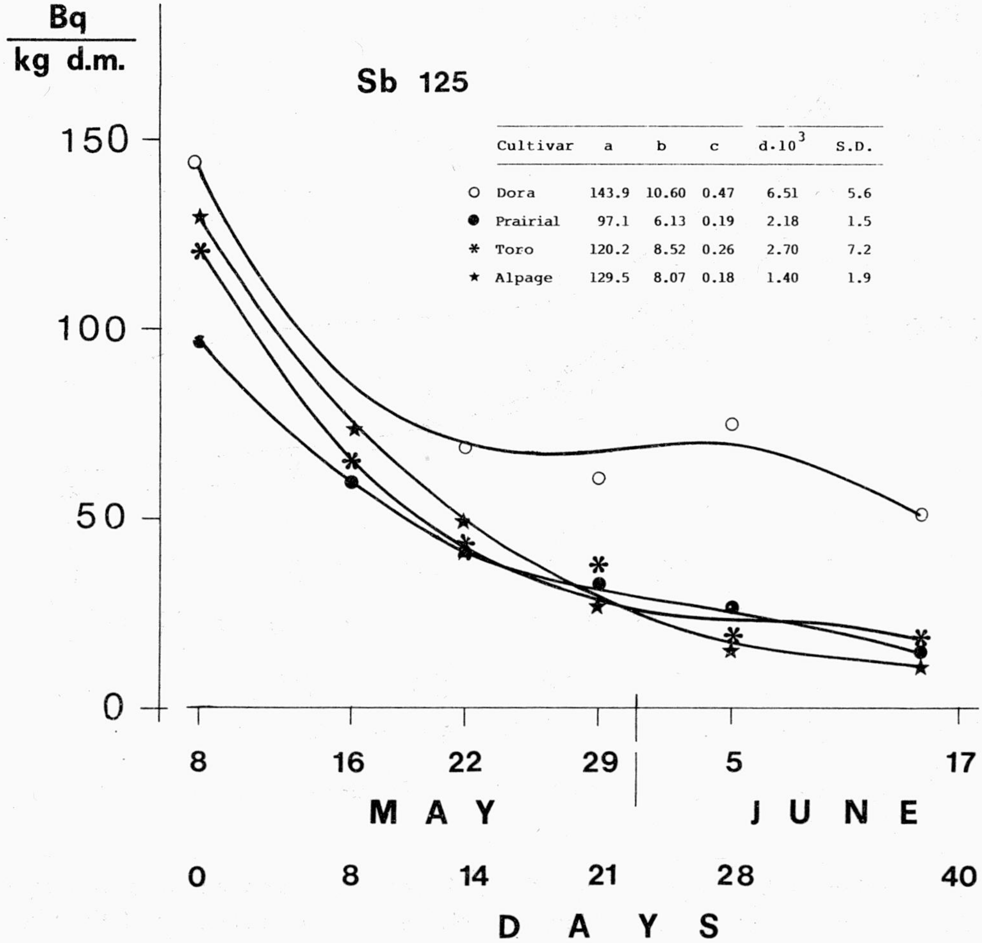


Fig. 3. Activity curves of Ru-106 for cultivars Toro, Alpage, Dora, and Prairial

It should be noted that grass samples were collected from the end of fallout deposition onward. Radionuclide activity values at $t = 0$ are not those of the initial maximum interception because of the field losses due to intervening meteorological factors between 29th April and 8th May.

At $t = 0$ fallout particle interception for all cultivars was similar except Prairial, for which it was markedly less. This shows that the radiocontamination of apparently similar plants can be strikingly different.

The reduced extent of contamination varied in all four cultivars. Both *Phleum pratense* cultivars showed an approximately 10% retention on the last harvest date, the retention rates for Prairial and Dora being 18% and 26%, respectively.

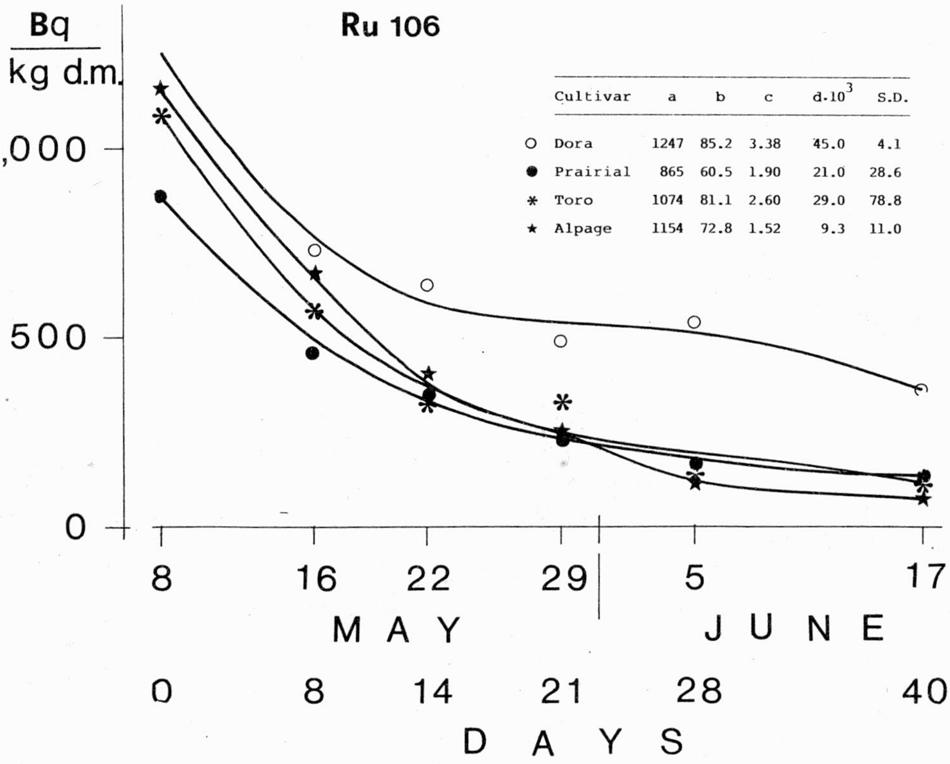


Fig. 4. Activity curves of Sb-125 for cultivar Toro, Alpage, Dora, and Prairial

The radionuclide curves in figs. 2, 3, 4 show an exponential character of time-dependent retention. The concentration of a radionuclide on fallout-contaminated grass, $C(t)$, as a function of time after fallout is usually approximated by:

$$C(t) = C \cdot e^{-\lambda_{\mathrm{eff}}} \tag{1}$$

where λ_{eff} is the effective decay constant for the radionuclide and is equal to $\ln 2/T_{\mathrm{eff}}$.

The effective half-life T_{eff} is given by

$$T_{\mathrm{eff}} = \frac{T_r \cdot T_w}{T_r + T_w} \tag{2}$$

where T_r is the radioactive half-life and T_w is the weathering half-life due to the action of meteorological parameters (wind, rain) and plant growth. For long-lived radionuclides, however, T_w will directly control the value of T_{eff}.

As far as the effect of growth inhibition is concerned, the development of herbaceous plant up to maturity can be represented as an exponential process. As a result, the mass concentration of any material associated with the vegetation will decrease at about the same rate as plant growth. This process of growth inhibition is implicitly included when the values of T_w are based on the measurements of radioactivity per unit mass of vegetation.

Apart from decay-corrected data, the values of T_w can be calculated from growth decay environmental processes as follows:

$$T_w = \frac{T_g \cdot T_e}{T_g + T_e}, \tag{3}$$

where T_g is the growth half-life and T_e is the environmental half-life exclusively due to meteorological factors.

Our aim was to determine independently the values of T_w and the extent of the growth inhibition T_g and weathering removal factors T_e (wind and rain), T_w be derived also as a function of specific removal mechanism.

T_w is determined via regression of the activity concentration in grasses over time. The paremeters T_g and T_e are determined via regression over time of the concentrations C_d and C_e calculated as follows:

$$C_d = \frac{d_0 \cdot C_0}{d_t}, \tag{4}$$

$$C_e = \frac{d_t \cdot C_t}{d_0} \tag{5}$$

where d_0 and d_t as well as C_0 and C_t (calculated on the best fit curves in figs. 1 and 2) are the plant densities (kg DM/m^2) and the radionuclide concentrations (Bq/kg DM), respectively, at $t = 0$ and on different dates.

The analysis of the curves in fig. 2 shows that the changes in radionuclide activity imply a compartmentalization into two time components, 0–14 and 14–40 days, for all radionuclides in all cultivars. The T_w values for the two time components were determined by linear regression of the concentration's logarithm over time.

The values of C_d and C_e calculated by equations (4) and (5) were analysed similarly.

The radionuclide values of T_w, T_g, and T_e for each cultivar and for the two time components are given in the table.

When equation (3) is used, the independently determined values of T_g and T_e give T_w values that are obviously consistent with those found directly from the experimental data. The T_w values in the table are independent of the chemical nature of the radionuclide and for Prairial, Toro, and Alpage ranged over the 0–14 and 14–40 day time components from 9 to 11 days and from 11 to 21 days, respectively. The T_w values for Dora, being independent of the nature of the radionuclides in the 0–14 day time component, range from 33–36 days for Cs and Ru, respectively, and up to 69 days for Sb. Higher values of T_w for Dora can be attributed to a greater

Table

Weathering half-life (T_w), growth half-life (T_g), environmental half-life (T_e) of Cs-137, Ru-106, Sb-125 on grasses

Cultivar, time components (days)	Cs-137			Ru-106			Sb-125		
	T_w	T_g	T_e	T_w	T_g	T_e	T_w	T_g	T_e
Dora									
0–14	13	24	26	13	24	28	13	25	29
14–40	33	365	37	36	346	41	69	346	87
Prairial									
0–14	11	17	36	10	17	25	11	16	36
14–40	21	888	22	20	990	20	19	866	19
Toro									
0–14	10	15	22	9	15	22	10	16	27
14–40	15	77	19	15	77	19	16	79	20
Alpage									
0–14	10	20	20	9	20	25	10	20	19
14–40	12	63	15	11	63	14	11	60	14

absorption of radionuclides as well as to a greater difficulty in removing foliar contamination.

Insofar as the T_g and T_e values are concerned, it can be said that in the 0–14 day range the effects due to growth inhibition are greater than the effects of the environmental removal processes. By contrast, the removal processes prevail in the 14–40 day time component because the grasses have a lower growth rate. In fact, the T_g values for the two early cultivars of *Dactylis glomerata* are far greater than those of the other two cultivars.

4. CONCLUSIONS

The half-life values of field-loss weathering T_w, growth dilution T_g, and environmental processes T_e from wind and rain of Cs-137, Ru-106, Sb-125 for four cultivars contaminated by Chernobyl fallout were determined as two time components from 5th May to 15th June, 1986.

While radionuclide concentrations during the first week are very important for estimates of acute contamination, those remaining thereafter are more important for determinations involving the entry of radionuclides into the food chain.

The foregoing data indicate that in the event of a nuclear reactor failure and for a short deposition time of fallout particles on pasture during normal plant growth, the activity of Cs, Ru, Sb would decrease by 50% about 10 days following the end of radionuclide deposition. The contamination level 40 days thereafter should remain almost constant with a value lower than or at most equal to that of natural radioactivity from K-40. The average value of the latter in the grasses analysed was about 800 Bq/kg DM.

The detected T_g values clearly showed the decontaminating effects on the grasses of growth inhibition and, hence, the importance of the plant growth stage at the time of fallout. Another important finding was the marked variability of contamination in the cultivars, even in those belonging to the same species and apparently the same. The data found in the literature on the T_w of radionuclides deposited on grasses by simulated fallout indicate that there is some uncertainty associated with T_w values [7], [8]. The T_w values detected in the first time component (10 day mark) are, however, in good accordance with the literature data [3] for field trials during the growth season.

It should also be pointed out that mathematically more complex descriptions than those used here to calculate T_w are definitely needed [9].

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PRZECHWYTYWANIE I ZATRZYMYWANIE OPADU PROMIENIOTWÓRCZEGO PRZEZ PASZE ZIELONE PO KATASTROFIE W CZARNOBYLU

W próbkach pasz zebranych z pól doświadczalnych określono stopień zatrzymania opadu promieniotwórczego po sześciu tygodniach od katastrofy w Czarnobylu. W okresie od 8 maja do 17 czerwca 1986 r. określono gęstość roślin oraz stężenie Cs-137, Ru-106 i Sb-125 w czterech wybranych uprawach. Stwierdzono, że po krótkim czasie opadania cząsteczek promieniotwórczych, powstałych w wyniku awarii reaktora jądrowego, aktywność Cs, Ru i Sb zmniejszyła się o połowę po około 10 dniach, które upłynęły od całkowitego opadnięcia chmury promieniotwórczej na pastwisko.

ПЕРЕХВАТЫВАНИЕ И ЗАДЕРЖИВАНИЕ РАДИОАКТИВНЫХ ОСАДКОВ ЗЕЛЕНЫМ КОРМОМ ПОСЛЕ КАТАСТРОФЫ В ЧЕРНОБЫЛЕ

В пробах зеленого корма, собранных из опытных делянок, определили степень задерживания радиоактивньх осадков по истечении шести недель со времени катастрофы в Чернобыле. В период с 8 мая по 17 июня 1986 года определили плотность растений, а также концентрацию Cs-137, Ru-106 и Sb-125 в четырех избранных культурах. Было установлено, что после короткого времени оседания радиоактивных частиц, возникших в результате аварии атомного реактора, активность Cs, Ru и Sb понизилась наполовину после ок. 10 дней, которые истекли от полного осаждения радиоактивной тучи на пастбище.