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DYNAMICS OF ^{137}Cs IN THE FORESTS OF THE 30-KM ZONE AROUND THE CHERNOBYL NUCLEAR POWER PLANT

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ABSTRACT

Dynamics of the ^{137}Cs content in the components of the forests in the 30-km zone around the Chernobyl nuclear power plant(NPP) in 1986-1994 are associated mainly with such factors as the size of radioactive particles in the fallout, ecosystem humidification and soil type, tree age. The influence of particle size was especially noticable between 1986-1987 and was displayed by low biological availability of radionuclides in the near part of the zone (within the 10-km radius circle around the NPP) in comparison with more distant regions (within the 30-km radius circle). Later, the expression of this influence decreased, and transfer factor (the ratio of ^{137}Cs content in overground phytomass to the soil contamination density) became approximately the same for all plots with similar ecological and fallout characteristics. Humidity of landscape and soil type determined the velocity of radionuclide vertical migration in the soil and ^{137}Cs biological availability. These parameters were maximum for the hydromorphic soils of wet landscapes enriched in organic substance and poor clayey minerals. Differences of ^{137}Cs accumulation in overground phytomass of trees caused by tree age are displayed in the higher ^{137}Cs concentration in structural parts of young trees as compared with old ones.

***Keywords*: Radionuclides; Forest; Dynamics**

Introduction

In the radiobiological context, radioactive isotopes of caesium are some of the most hazardous radionuclides which were released into biosphere due to the Chernobyl Nuclear Power Plant accident as they are chemical analogues of potassium. They are included in the biological cycle and cause long-term irradiation to the forest biota and man. Their capability to enter the internal plant tissues by roots and other ways limits the possibility of the decontamination of the forest products.

Plant contamination dynamics has a complex character, because of the many processes which control it, such as natural decontamination of overground part of trees and radionuclide uptake by plant roots. Complexity of ^{137}Cs content dynamics makes prognosis of the nuclide redistribution in ecosystems difficult.

In July 1986 we began to study radionuclide behavior in the Ukraine and continue studies today. These researches have provided data on ^{137}Cs content dynamics in the components of the forest ecosystems in the 30-km zone around the Chernobyl nuclear power station between 1986-1994 and to discover the factors determining intensity and direction of ^{137}Cs migration.

Objects of investigations

Various plots were chosen in the 30-km zone to characterize the wide scale of contamination density, hydrological regime, type of the soil and plant species structure (Table 1). Near the border of the zone (at the so called distant part, 25-27 km from ChNPP) four experimental plots were selected (D1, D2, D3, D4). They compose geochemical landscape, as “paragenetic association of elementary

landscapes joined by element migration" (Perelman, 1975, Fortescue, 1980). The plots present the most typical elementary landscapes (eluvial, trans-eluvial, accumulative). Size of the radioactive particles in fallout did not exceed $10*10^{-6}$ m here. In the near part of the zone (5-7 km from ChNPP) probe plots were also chosen (Sh, Ch1, Ch2). Size of the radioactive particles reached $200*10^{-6}$ m in this part of the 30-km zone.

Methods

We have taken samples of soil, woody and grass plants at the chosen plots. Soil was taken at 1 cm layers to 15 cm depth, then it was sampled at 5 cm layers to the maximum depth of the radionuclide penetration.

The model trees of dominated species were selected, which had average characteristics for wood vegetation at the plot. Then, they were sawed down and divided into their structural components, such as young needles of the current year, old needles, foliage, large and small branches, generative organs (cones, acorns). External bark (dead cover tissues, epidermis, cuticle) and internal bark (bast), wood (total thickness sample and divided to the alburnum and the kernel wood) were taken at different trunk height - the top, the middle and the bottom. Grass plant samples were picked out using a 1 m^2 area frame. Dominated species were also collected.

We reduced samples to fragments, dried them untill absolutely dry condition and then milled them to a homogeneous mass. All samples were analyzed for ^{144}Ce, ^{134}Cs, ^{137}Cs, ^{95}Nb, ^{95}Zr, ^{106}Ru and some ^{90}Sr content.

In order to compare the data received from the plots with different levels of contamination density, transfer factors (TF) were calculated :

$$TF = \frac{\text{plant radioactivity (Bq/kg abs. dry mass)}}{\text{contamination density of the soil (Bq/m}^2\text{)}}$$

To process data the expert and information system "ECORAD" was used, which was created in the Radioecology Laboratory of the MSU Soil Science Faculty for estimation and prognosis of consequences of terrestrial ecosystem radioactive contamination (Shaw, Mamikhin et al., 1996). On the base of the data mathematical model of Cs-137 vertical migration in a forest soil was developed (Mamikhin, 1995).

Results and discussion

After the 1986 fallout event radionuclide migration in the forest ecosystems took place generally as a result of the following dynamic processes:

I) natural decontamination, which is plant self-decontamination as a result of the fall of leaves, needle, branches, generative organs, external bark and wash off by atmospheric precipitation,

II) the downward radionuclide transport in wood plants from assimilative organs and bark to roots,

III) entry of radionuclides with the products of root vital functions,

IV) radionuclide absorption by roots from the soil and their upward transport into the aboveground phytomass,

V) abiotic vertical radionuclide migration, in soil by diffusion, lessivage (transfer with soil particles) and with water flow,

VI) biotic soil migration including radionuclide transfer as a result of vital functions of root, fungi and soil mesofauna.

The ^{137}Cs transfer between the main forest components are described by the flow diagram illustrated in Fig.1. The mathematical model of ^{137}Cs dynamics in the forest components was developed on the base of this scheme (Shaw, Mamikhin et al., 1996, Shaw G., Kliashtorin A. et al., 1996). The redistribution of radionuclides between wood forest floor and soil is the most dynamic process in contaminated forests.

Redistribution of ^{95}Nb, ^{95}Zr, ^{144}Ce and ^{106}Ru between these main subsystems of the forest ecosystems is a mechanical transfer from plant cover to the soil by natural decontamination. In addition, these radionuclides together with ^{134}Cs are radionuclides with intermediate radioactive half-lives, that make them less considerable objects of investigations.

In the contrast, long-lived ^{137}Cs as a chemical analogue of potassium enters into plant metabolism and then into food chains. For this reason ^{137}Cs is considered to be one of the most hazardous radioactive pollutants of the biosphere.

Radiocaesium isotopes dominate in radionuclide composition of the plant cover contamination. In the grass plants and in the components, protected from direct external contamination (wood, bast) or completely renewed after the accident (assimilative and generative organs), the contribution of radiocaesium isotopes in the total gamma-activity reaches ~100%.

^{137}Cs dynamics has been affected by the following factors: size of radioactive particles, landscape humidity and type of soil, age of trees. Initially, 3-5 years after the accident the main factor, which determines the dynamics of ^{137}Cs distribution in ecosystem components, was size of fallout particles, as illustrated by our data for 1986-1993 in Fig.2.

Initially, the woody floor of forest held 60-90% of the fallout. The latest decontamination of crowns in the distant part of the zone caused a decrease of this value to 17-18% in August 1986 and to 9-10% in July 1987. There was more fast wood floor cleaning at the near part, where more large fuel particles precipitated. Untill August 1987 the ^{137}Cs content in the aboveground mass of trees was only equal to 0.3% of the total contamination. Later, we were observed a sharp increase of ^{137}Cs content in wood vegetation which reached 1.7% by 1990.

This differences in ^{137}Cs dynamics at the distant part and at the near part of the 30-km zone (Fig.2) are explained by the following way:

- At the distant part of the 30-km zone size of radioactive particles did not exceed $10*10^{6}$ m. Small particles were held by the plant surface, which caused low intensity of vegetation decontamination. In the soil, radionuclides of small particles undergo a relatively fast leaching, which caused high biological radionuclide availability to roots, when fallout penetrated into the soil. This is the reason for higher plant contribution to the total forest contamination at the distant zone part.

- At the near part of the 30-km zone, where size of the radioactive particles reached $200*10^{-6}$ m, most of the large particles had been transfered quickly to the forest litter, and crown decontamination was more complete than at the distant one. Radionuclide leaching from these particles was relatively slow and continues up to now, being under the influence of precipitation and soil organic acids.

Thus, in the first stage, large particles played the role of a ^{137}Cs reservoir retaining radionuclide involved the biological cycle. Later, this process became faster and is displayed by an increase of ^{137}Cs concentration in structural components of woody vegetation. At present, the root rout of ^{137}Cs uptake by plants dominates in the near part, as radiocaesium is constantly leached from the fuel particles and is intercepted by roots rather then fixed by the soil.

The second important factor, which determinates direction and velocity of ^{137}Cs redistribution, is the humidity of an ecotope. Fig. 3 illustrates the dynamics of plant contribution to the total ecosystem contamination on the plots with contrasted hydrological regimes. Contamination density of the plots D1 and D3 is equal, the size of radioactive particles is the same, but ^{137}Cs content in plants on the hydromorphic plot D3 (accumulative landscape) was much higher then on the automorphic plot D1(eluvial landscape). Hydrological regime and soil hydromorphism influence ^{137}Cs content in the grass vegetation also (Table 2). In the system of the elementary landscapes ^{137}Cs concentrations increase by moving from the top to the bottom of geochemical landscape (D1-D2-D3-D4) and by increase of ecotope humidity (from automorphic to hydromorphic regime). ^{137}Cs content in grass plants being in order higher in accumulative landscapes (D3,D4) in comparison with eluvial ones (D1,D2). So, radiocaesium content in structural components of vegetation of highly humidified landscapes (hydromorphic) is higher then in the dry ones (automorphic), under the same other conditions. Superfluous ecotope humidification and soil hydromorphism in ecosystems cause more deep penetration of radiocaesium into the soil (Tikhomirov, Shcheglov et al., 1990) and increase of radionuclide biological availability. These parameters were maximum for the hydromorphic soils of wet landscapes enriched in organic substance and poor clayey minerals. It is obvious comparing field data obtained for geochemical landscape.

Tree age is an important factor causing the degree of ^{137}Cs wood contamination and radiocaesium redistribution in the structure components of woody plants. Comparative analysis of ^{137}Cs content data in structural parts of the different age pines (Table 3) suggests higher level of contamination of young tree phytomass. This regularity had been showed from 1989, but external contamination smoothed age influence. In 1990 differences in ^{137}Cs contamination of young (15-20 years) and mature (50-55 years) trees increased essentially in all structural parts. Uptake by roots was so intensive, that external contamination was not able to mask differences in radiocaesium entry into the young and mature trees. Needles, wood, internal bark and branches of young trees were contaminated by ^{137}Cs 2.5-3.5 times more then mature ones. For external bark the difference was not so great because of external contamination which masked root uptake.

Observed differences in ^{137}Cs contamination of young and mature trees are explained by a higher contribution of meristematic tissues, enriched with radiocaesium, in phytomass of the young trees in comparison with the older ones. Radiocaesium mainly entered from the soil via roots into these tissues.

Dynamics of the ^{137}Cs content in the different parts of the wood floor is presented on the Fig. 4, 5, 6. These data illustrate our reasoning about combined influence of 2 main pathways of ^{137}Cs plant uptake. At plot D1, the contribution of bark to the total contamination was maximum compared with other tree components. In addition to root entering the bark keep external contamination up to now. At plots D3 and Sh1 the influence of external contamination was masked by the root uptake, and the

more significant contribution to the total ecosystem contamination was made by another tree fractions.

5. Conclusions

The main factors, which influence the ^{137}Cs dynamics in forest ecosystems in 1986-1994, were the size of radioactive particles in the fallout, humidity of ecotope and soil type, tree age. Quality differences in ^{137}Cs content dynamics in the plants, caused by influence of the size of fallen particles, were very great in 1986-1987, but were sufficiently decreased by 1991.

Landscape humidity and soil type, which determine the rate of such parameters of ^{137}Cs dynamics in forest ecosystems as the velocity of radionuclide vertical migration in the soil and biological availability of radiocaesium, are dominate today. These parameters gave rise to the higher value in the hydromorphic landscape soils enriched in organic substance and poor clayey minerals. Hence, radiocaesium is very mobile in these soils.

For the last 2 years of observations (1993-1994), the plant contribution to the total ecosystem contamination by radiocaesium has not changed significantly in the automorphic landscapes (Fig.3, D1). Amount of ^{137}Cs, which is available to plants, is stabilised by fixation in the absorbing complex of automorphic soils. Entry of radionuclides is approximately equal to natural decontamination. Thus, quasi steady state for ^{137}Cs distribution in the forest ecosystems is reached for automorphic landscapes today. In the accumulative landscapes the equilibrium will be reached later, since it will need additional time for final fixation of ^{137}Cs in the hydromorphic soils because of high ^{137}Cs mobility in these soils. Possible ^{137}Cs external entrance from the eluvial and trans-eluvial elementary landscapes must be also taken into account for accumulative landscapes.

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Table 1

Characteristics of the plots (1993)

Site code	Site name	km from ChNPP, direction	Ecosystem type	Tree age (years)	Landscape	Soil type	^{137}Cs (MBq/m^2)
distant part of the 30-km zone							
D1	Dityatky	28.5 South	mixed forest, (5Oak, 3Pine)	55	eluvial	surface podzolic	0.18
D2	Dityatky	27 South	mixed forest, (7Birch, 2Oak, 1Aspen)	55	trans-eluvial	soddy podzolic sandy	0.18
D3	Dityatky	26 South	black alder forest, (5Alder, 4Birch, 1Pine)	45	accumulative	peaty-humus-podzolic-gley	0.18
D4	Dityatky	25.5 South	wet meadow		accumulative	peaty	0.18
near part of the 30-km zone							
Ch1	Chistogalovka	5.2 South-West	pine forest, (10Pine)	55	trans-eluvial	soddy podzolic sandy	5.9
Ch2	Chistogalovka	5.9 South-West	pine forest, (10Pine)	55	trans-eluvial	soddy podzolic sandy	5.2
Sh	Shepelitchy	7 West	mixed forest, (8Pine, 2Birch)	45	eluvial	soddy podzolic sandy	23.4

Table 2

^{137}Cs content in the grass plants in 1987-1993 (kBq/kg.abs.dry mass).

	Plots			
Year	**D1**	**D2**	**D3**	**D4**
Cereals (mixed probe of different species)				
1989	0.89	1.33	14.1	33.7
1990	1	-	18.5	34
1991	1.07	-	17.4	40.7
1992	0.56	-	14.8	19.6
1993	0.34	-	11.5	-
Ferns (mixed probe of different species)				
1987	1.67	1.81	-	-
1988	0.51	0.78	21.3	-
1989	1.44	1.41	36.3	-
1990	0.89	-	59.2	-
1991	0.32	-	59.2	-
1992	0.48	-	40.7	-
1993	0.77	-	33.4	-

Table 3

Influence of tree age on the ^{137}Cs contents in the structural parts of the pine on the plots at the near part of the 30-km zone (kBq/kg of absolutely dry mass).

Year	Age (years)	Needles		Wood	Bark		Branches	
		Current annual increment	Old		External	Internal	Large	Small
Plot Ch1								
1989	50-55	21.8	5.9	0.5	20.8	6.8	3.7	4.1
1989	15-20	15.9	4.4	1.3	22.8	12.2	23.3	7.4
Plot Ch2								
1990	50-55	31.5	10.4	2.4	27.0	22.6	4.1	9.3
1990	15-20	96.2	30.7	6.3	39.2	61.8	15.2	22.9

Fig.1 Flow diagram of ^{137}Cs transfer between the main forest components.

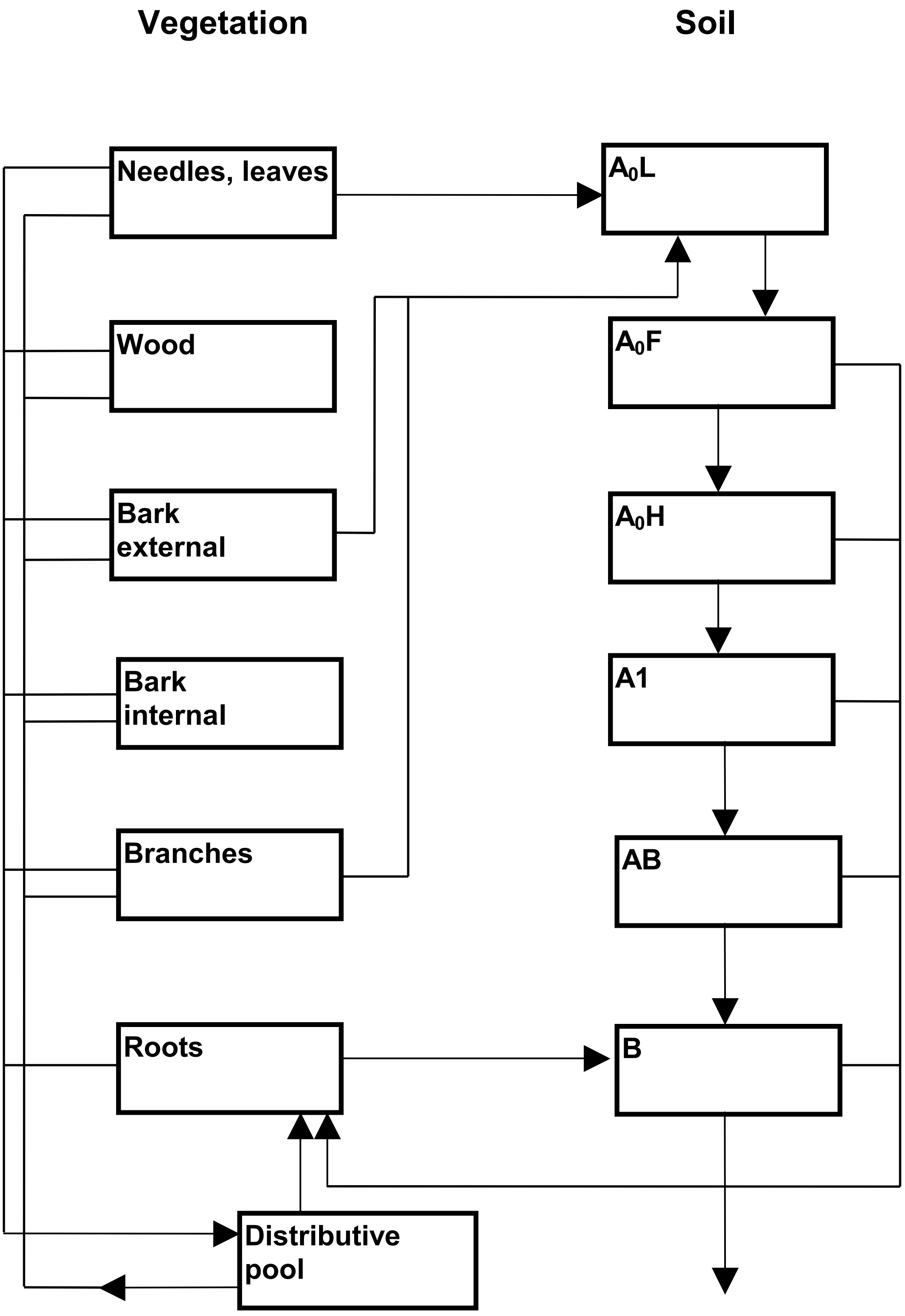


Fig.2 Dynamics of plant contribution to the total contamination of the forests (fallout particles had different size)

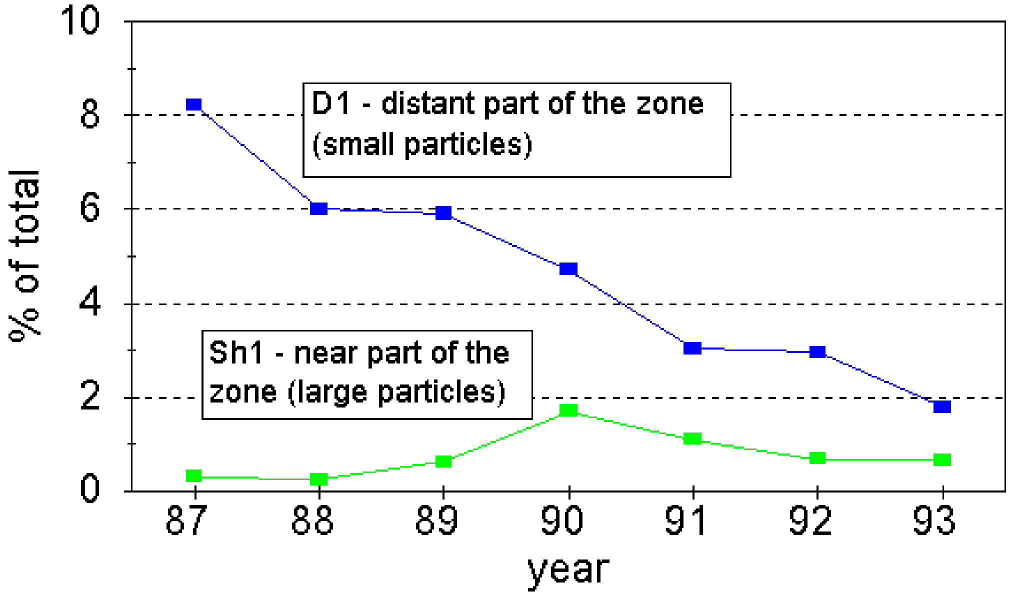


Fig.3 Dynamics of plant contribution to the total contamination of the forests with contrasted hydrological regimes

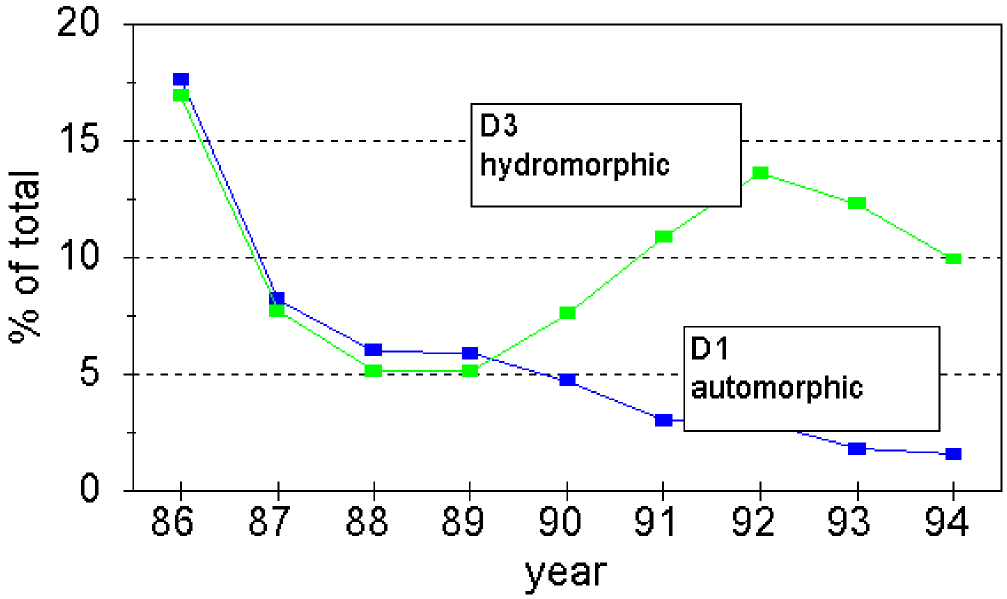
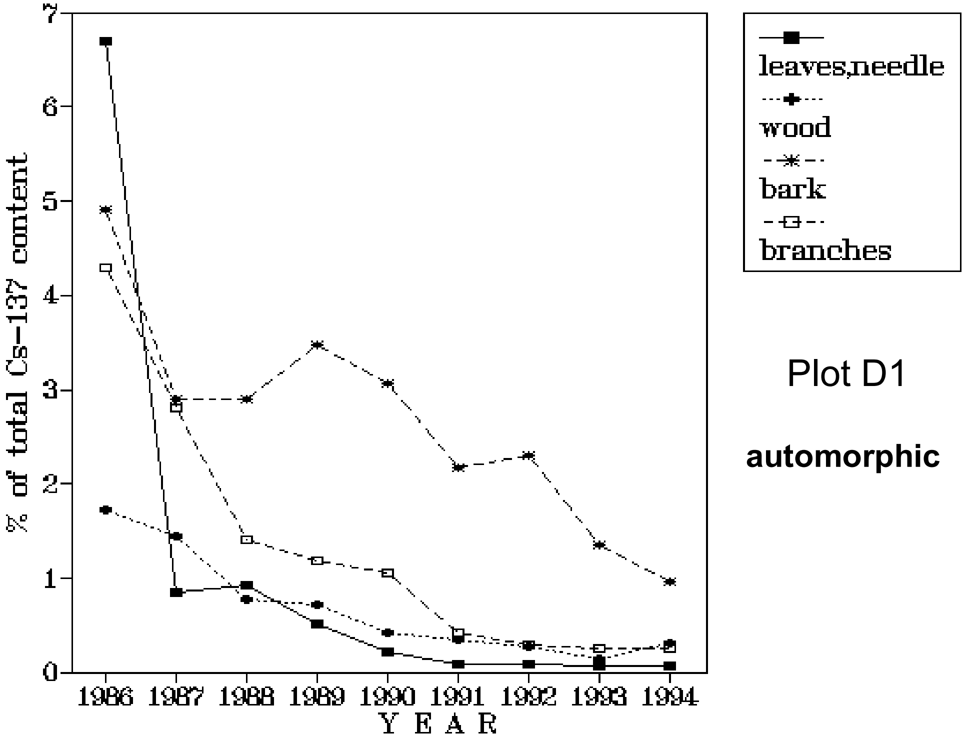


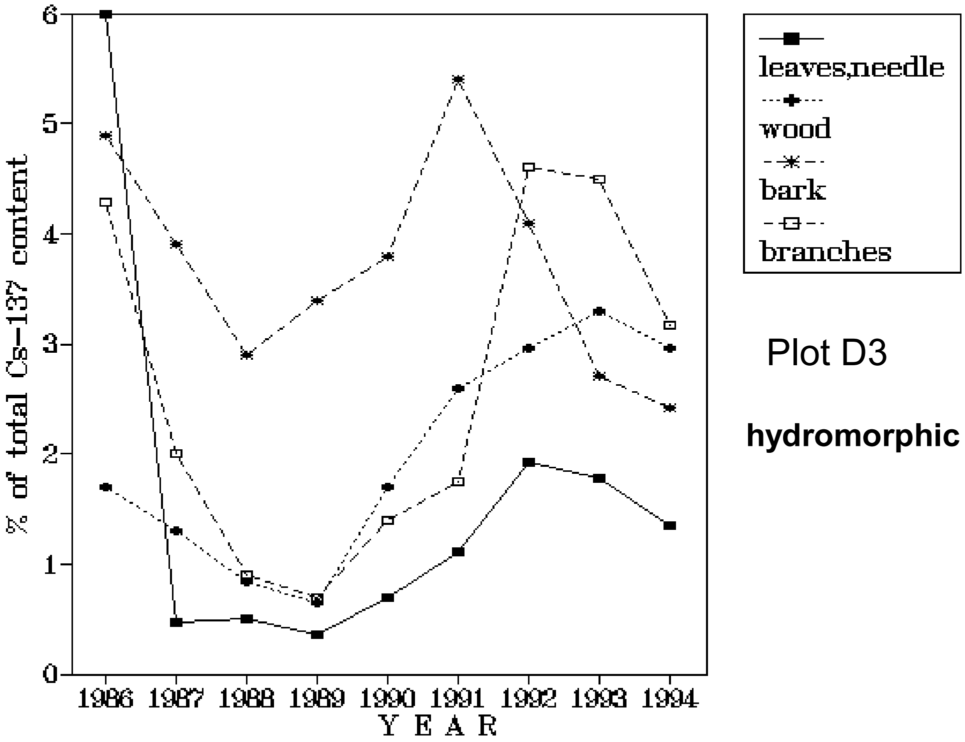
Fig.4 Contribution of tree components to the total contamination
(dry forest, small particle fallout)



Plot D1

automorphic

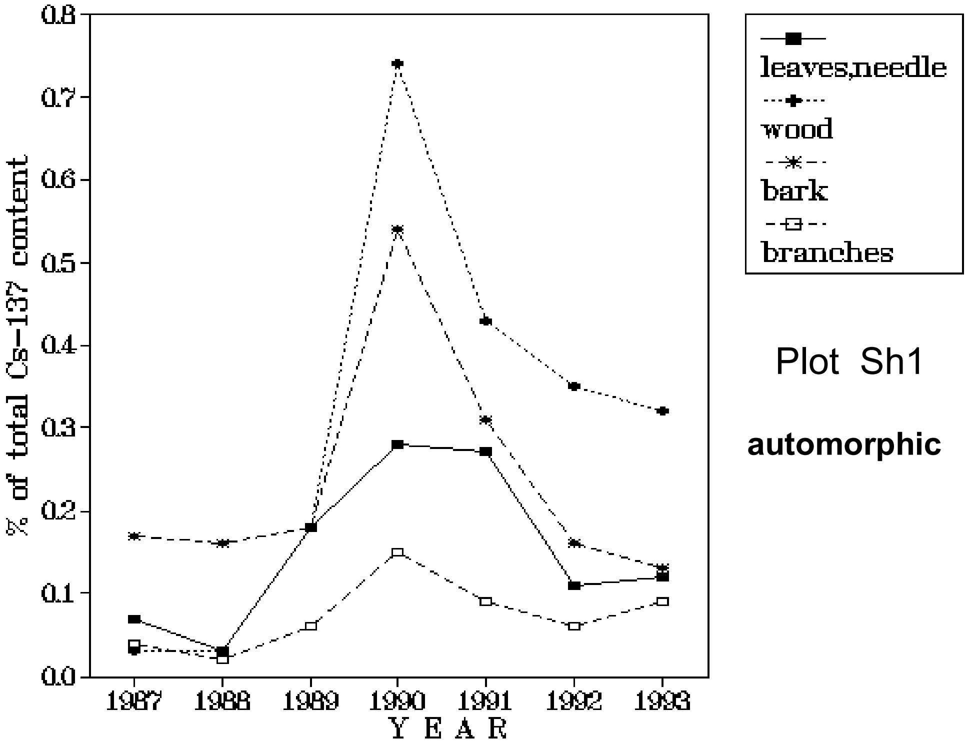
Fig.5 Contribution of tree components to the total contamination
(wet forest, small particle fallout)



Plot D3

hydromorphic

Fig.6 Contribution of tree components to the total contamination
(dry forest, large particle fallout)



Plot Sh1

automorphic