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Consequences of the Chernobyl Accident

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CONSEQUENCES OF THE CHERNOBYL ACCIDENT

Report on research in Austria

Soil contamination and uptake by crops and animal fodder

Reduction of cesium levels in the diet through management of food

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Report on research in Austria Ex.
concerning the consequences of the Ch. accident.

ABSTRACT

In Austria, the Cs-137 activity deposition per km^2 due to the Chernobyl fallout varies between 0.08 Ci and 2.05 Ci, the Sr-90 deposition being app. 20 to 40 times lower. The most severe problems were due to the direct contamination of early vegetables, winter cereals and pastures with iodine and cesium. A significant dose reduction was obtained by a sales ban for vegetables and a prohibition of grazing of cows in the year 1986. The feeding of cows and bulls with less contaminated fodder and the use of ammoniumhexacyanoferrate as feed additive caused a further reduction of the cesium concentration in foodstuff (30 to 70%).

The Cesium migration in the Austrian soils was greatest in the first hours and days after the fallout. At special sites cesium from Chernobyl fallout was detected down to 30 cm depth. Now the Cs-migration rate is significantly below 1 $cm.a^{-1}$.

Investigations of the radionuclide soil to plant transfer in the field resulted in quite low transfer factors into cereal grains (e.g.: Cs: maize: 0.0018, wheat: 0.0055; Sr: maize: 0.010, wheat: 0.10) and leaf vegetables as compared to the literature.

The high mobility of cesium in special natural and seminatural environments (alpine pastures, forest) gives rise to recent problems due to contaminated wild game and fungi.

Soil contamination and uptake by crops and animal fodder

ABSTRACT

The plant availability of radionuclides from contaminated soils is influenced by a couple of factors (e.g.: concentration in the soil solution, depth of tilled soil, ion competition, plant specific discrimination). The soil to plant transfer factor ($Ci.kg^{-1}$ plant fresh weight/$Ci.kg^{-1}$ soil dry weight) ranges from 0.002 to 0.03 and from 0.01 to 1.0 for cesium and strontium, respectively.

Plowing: The plowing of a contaminated soil leads to a decrease of the soil to plant transfer of at least 50%. This fact is of special importance for high contaminated pastures.

Fertilizer application: Potassium and cesium are taken up by plants by the same type of mechanism. Potassium treatments decrease the Cs soil to plant transfer, especially on soils with poor K contents. The same is true for strontium and calcium.

Plant specific uptake: The soil to plant transfer of radionuclides varies greatly between different plant species. Some leaf vegetables and potatoes show significantly lower transfer factors than other agricultural crops. A substitution of cereal production may be considered for higher contaminated sites.

Seminatural environments: Areas with extremely shallow soil profiles or exceedingly wet conditions cannot be plowed. Therefore, the radionuclide concentration in the top layer will decrease only due to the natural migration processes.

Reduction of cesium levels in the diet through management of food

ABSTRACT

Several processes influence the radionuclide concentration of food products during processing: dilution, losses, concentration.

Boiling of leaf vegetables yields a decontamination effect of up to 80% in the case of radioiodine. Peeling of potato tubers results in a reduction of the cesium concentration of 30%. The cesium and strontium concentration of flour is a factor of two lower as compared to the corresponding cereal grain due to the milling process.

Significant discrimination occurs during the milk processing. The skimmed milk is significantly richer in cesium, iodine and especially in strontium than the cream. It follows that butter is depleted in its radionuclide contents as compared to other milk produce. Strontium is concentrated in the casein.

Pressurized cooking in combination with salting or a treatment with acetic acid results in an Cs-activity loss of beef, veal and lamb meat of 50 to 90%.

REPORT ON RESEARCH IN AUSTRIA

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1. Introduction

Austria was one of those European countries, which received remarkable amounts of radionuclides due to the Chernobyl accident. This fact made the investigation of processes influencing the mobility of radionuclides in the biosphere worthwhile.

Up to now Chernobyl derived radionuclides are measurable in the Austrian environment. In certain cases radionuclide concentrations in food are above our legistic limits at present. Special problem regions are seminatural environments like alpine pastures and forests, where the cesium isotopes stay highly available in the biosphere.

The following discours shall bring a brief review of the results obtained in various research projects conducted after the Chernobyl accident.

2. Deposition levels in Austria

At 29th of April 1986 the first deposition maximum was observed in Austria. Table 1 shows the concentration of radionuclides in the air during the first maximum (IRLWECK and STEGER 1986). Typical nuclide ratios were: $^{131}I/^{137}Cs$: 10, $^{137}Cs/^{134}Cs$: 1.97, $^{137}Cs/^{90}Sr$: 24 . The ^{137}Cs-deposition (Table 2) in Austria varied greatly due to following factors:

- precipitation intensity (increasing wet deposition)

- sea level: the highest deposition was observed between 1500 and 2000m.
- plant interception: in forests the deposition was two to three times higher than on pastures.

^{90}Sr-deposition was 20 to 40 times lower as compared to the cesium isotopes.

3. Direct contamination of plants

The most severe problems after the Chernobyl accident were due to the direct contamination of early vegetables, winter cereals, fruit trees and pastures with iodine and cesium. From Table 3 it becomes evident that the winter cereals were well developed at the fallout date and had therefore the highest radionuclide concentrations (HAUNOLD et al. 1987). ^{103}Ru showed a lower translocation into the grains as compared to the Cs-isotopes, which are highly mobile due to their physiological similarity to the plant nutrient potassium. Crops seeded a short time before or immediately after the fallout like maize and sugar beet were drastically lower in their radionuclide contents than winter crops and fruits (Table 4).

The dose reduction obtained by a sales ban for early vegetables like spinach and salad yielded app. 50% of the overall dose reduction due to countermeasures.

4. Soil contamination

The vertical distribution of radionuclides varied greatly due to to the amount of wet and dry deposition and the soil types. Table 5 gives data of a chernozem in the eastern part of Austria, which received mainly dry deposition. However, measurable amounts of radionuclides could be detected below 5 cm depth one month after the fallout (GERZABEK 1986).

The influence of plowing on the vertical distribution of radionuclides in the soil is of special interest for the calculation of radioecological food chain models. Most terrestrial food chain models assume a homogeneous radionuclide distribution within the tillage depth. Results of LÖNSJÖ (1989), however, indicate that radioactive fallout is nonuniformly distributed after one plowing. An average depth distribution of radionuclides in cultivated soils cannot be determined by using an auger technique. Roughness of the soil surface, an inhomogenous horizontal radionuclide distribution due to cultivation and the possible contamination of deeper soil horizons makes a special sampling procedure necessary (MEISEL et al. 1989). Two parallel ditches with 50 cm distance are digged app. 10 cm below the desired sampling depth (40 to 100 cm) across the terrain slope leaving a 200 times 50 cm soil monolith undisturbed. A series of four pedons (40 times 40 cm) can be sampled with the help of four guiding steel sheets in one to five centimeter steps according to the necessary precision. The geometrical accuracy of this method is 1 mm with regards to thickness of the soil layer and 3 mm with regards to width and length.

Figure 1 showes a Stagno-Dystric Gleysol from Styria (MEISEL et al. 1990). In the year 1986 all radionuclide concentrations of the undisturbed soil layers showed a sharp decrease at a depth of 0 to 5 cm (except natural ^{40}K). ^{106}Ru and ^{125}Sb quickly dropped below the detection limit. In 1986 almost 90% of the total ^{137}Cs-content of the soil profile was bound to the first 5 cm from the top. The depth distribution of ^{134}Cs proves that the Chernobyl derived Cs partly migrated to a depth of 12 cm from May to August 1986. It may be assumed that this effect is mainly due to high migration rates during and shortly after the wet deposition (SCHIMMACK et al. 1989). The ^{90}Sr-concentration reached a plateau at a depth of 4 cm. This constant background level is presumably caused by weapons testing, which in the past 25 years has been already homogeneously distributed by plowing and migration. ^{134}Cs showed a significantly higher fixation to the soil surface as compared to the Chernobyl derived ^{90}Sr. The ^{134}Cs/^{90}Sr ratio decreased from 32.7 in the first two centimeters to 7.3 in a depth of 3 to 4 cm. After plowing in April 1987 the vertical distribution of the radionuclides changed drastically. All Chernobyl derived radionuclides showed a new maximum at a depth of 15 to 18 cm due to an extreme "turnover" effect instead of mixing. The peak concentrations decreased only by a factor of 4 to 5. Taking into account that most agricultural plants have a nonuniform root depth distribution with a maximum in the top soil, the calculation of the radionuclide uptake into plants by using a transfer factor, which is based on a homogeneous radionuclide distribution over the tillage depth, may, therefore lead to an overestimation of the radionuclide uptake by plants. The second plowing after the Chernobyl fallout led to a more uniform radionuclide distribution over the tillage depth.

Figure 2 gives the vertical distribution of radionuclides in a Dystric Cambisol in Styria. Measurable amounts of Chernobyl derived radionuclides could be detected at least down to 30 cm depth, twice that of site A. Obviously this resulted from a higher migration velocity at this site. After plowing in June 1987 an only slight change in the vertical distribution of the radionuclides could be detected. The Cs-, Ru- and Sb-isotopes had a new maximum at a depth of 3 to 4 cm. In this particular case the standard transfer concept may lead to an underestimation of the soil to plant transfer in the year 1987, especially for plants with shallow root systems (ANDERSEN 1967).

The great differences between the cultivation effects at the two sites can be explained by the different plowing methods used. At the first site the furrow slice was nearly turned upside down. The second site is characterized by an only 60° turnover against the slope gradient. It has to be concluded that in both cases plowing does not lead to a thorough mixing. At least two or three plowing steps may be needed.

5. Soil to plant transfer

More than 100 Cs- and 60 Sr-soil to plant transfer data were obtained in field studies in the years 1987 and 1988 (GERZABEK et al. 1990). The transfer factors were calculated as follows:

$$TF = \frac{\text{Ci/ kg plant fresh weight}}{\text{Ci/ kg soil dry weight}}$$

Table 6 gives the means of the measured transfer factors for cesium and their standard deviations. The results show a significant influence of plant species and great differences between vegetative and generative parts. The highest ^{137}Cs transfer values were obtained for straw of cereals. The transfer into grains was 1.6, 1.8, 4.2 and 10.5 times lower for rye, barley, wheat and corn, respectively. This effect is partly due to the comparability of potassium and cesium in plant physiology. From literature it is well known that most cereal grains are two to four times lower in their potassium content than the straw. Moreover, cereal grains have a slightly higher selectivity for potassium over cesium (GERZABEK et al. 1989).

Cesium transfer into vegetables and potatoes appeared to be lower than reported up to now.

The measured transfer factors vary greatly within the plant species. Therefore, physical and chemical soil properties were correlated to the actual transfer. The correlation analyses show minor influences of the exchangeable basic cations (Figure 3) and the clay content of the soil (Figure 4). However, the Cs-137 concentration in soil was best correlated with the Cs-transfer (Figure 5). These results correspond with findings of AHAMER et al. (1989). The Cs-transfer factor appears to be not a constant for different fallout levels, as it is usually assumed in most models for estimating the Cs-intake. This effect is probably due to an influence of resuspended Cs-containing particles. The Cs-resuspension increases distinctly with decreasing deposition (Figure 6, GARLAND and PATTENDEN 1989).

The highest ^{90}Sr transfer values were obtained for vegetative plant parts (Table 7). The transfer into cereal straw showed only slight differences between the varieties. A significant difference exists between maize grain and grain of other cereals. The maize grain showed a lower ^{90}Sr uptake, which corresponds to the smaller Cs-transfer value. Quite low Sr-transfer factors were obtained for potato and celery tubers. This effect is probably due to the physiological similarity of Sr and Ca. Both cations are predominantly transported by the transpiration flow. Therefore especially the leaves show high Sr-uptake rates, but not the tubers. Extreemly high transfer factors were determined for hay and clover, but it has to be taken into account that the calculation of a soil to plant transfer ratio is based in this case nearly on a dry matter bases and that it includes the mobilisation of Sr in the roots and the root to shoot transfer in the case of perennial plants.

6. Fertilizer experiments

Series of pot experiments with different plants and fertilizers were conducted using contaminated soils of Upper Austria (GERZABEK et al. 1989,1990). In most cases the cesium transfer factors were hardly influenced by potassium- and magnesium-applications. These results were due to the high clay contents of the studied soils and the adequate autochthonous supply with potassium and magnesium. However, a large scale field study proved the potassium availability to be of significant influence on the cesium uptake of grass and hay (Figure 7, HORAK et al. 1987). Increasing potassium levels in the plants were correlated with decreasing cesium concentrations.

Recent literature gives evidence to the fact that ammonium influences the Cs-availability and uptake (GERZABEK and MÜCK 1989). In Austria two pot experiments were conducted to evaluate the effect of different nitrogen fertilizers on the Cs-transfer (GERZABEK et al. 1990). Figure 8 gives the results for rape straw.

The highest ^{137}Cs-transfer was observed into control plants. The $Ca(NO_3)_2$ and NH_4NO_3 applications decreased the transfer factor significantly. This effect was mainly due to the higher yields and therefore to a dilution effect. The Cs transfer decreased in the following order:

$$\text{control} \geq (NH_4)SO_4 \geq NH_4NO_3 \geq Ca(NO_3)_2$$

This result indicates that ammonium-N leads to the highest Cs soil to plant transfer. From the literature it is evident that ammonium is a strong exchange cation for cesium, but not a competitor like potassium for the cesium uptake.

7. Transfer plant - animal

The Cs-concentration of milk and beef meat had a first maximum short after the fallout due to feeding of fresh grass or grazing on contaminated pastures. Concentrations decreased app. 50 days after the fallout, because of lower cesium contamination of grass from the second and third cut. In winter a second maximum was observed due to feeding of high contaminated hay from the first cut.

A series of eight feeding experiments were conducted in Austria in order to get more information about transfer coefficients and possible countermeasures (RATHEISER 1986). Table 8 gives a summary of the most important results. Especially the low transfer coefficient into milk is noteworthy. NG et al. (1979) reported a mean transfer value of 0.0071. The highest transfer value was obtained for lamb meat (0.70), which seems to be due to differences in physiology. Table 9 shows the effect of different feed additives as a countermeasure for cesium transfer into various products. In most cases specific complexing resins like ammonium- or potassiumhexacyanoferrate give the highest reduction effect (up to 94%). In a large scale experiment in the region of a milk processing plant ammoniumhexacyanoferrate yielded a reduction of the cesium concentration in milk of 70% (MÜCK 1988).

8. Seminatural environments

The high mobility of cesium in special natural and seminatural environments gives rise to several problems.

SCHÖNHOFER and TATARUCH (1989) investigated the contamination of wild game in Austria. The concentration of radionuclides in game has decreased in most areas in Austria after the maximum due to the Chernobyl fallout. Nevertheless, up to now special sites show high cesium concentrations in roe deer. This was observed mainly in regions which are widely covered by forests. Thus the animals cannot feed from cultivated areas, where radiocesium is diluted due to plowing and the transfer to plants is low because of an optimum potassium supply. Cesium transfer into plants is significantly higher in forests than in agricultural areas due to completely different soil characteristics.

Another problem, which is closely related to the contamination of game is the high cesium uptake into fungi. Many authors provided sufficient information on the variability between certain species of fungi (GERZABEK et al. 1988, HEINRICH et al. 1989, HENRICH et al. 1988). Table 10 gives the results of 465 measurements. The highest cesium concentration was observed in *Xerocomus badius* and *Rozites caperata*. The most important edible fungi like *Boletus edulis* and *Cantharellus cibarius* had significant lower values. The high Cs availability in the organic matter and the influence of vegetation on the extent of Cs-interception and deposition seems to have been responsible for the following order of habitats leading to decreasing Cs-contents in fungi: coniferous forest - decidous forests - meadows.

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TABLE 1

concentrations of radionuclides in the air, 1986 04 29, 19^{50} - 20^{50}
Seibersdorf, Austria, first maximum

nuclide	10^{-9} Ci/m^3 air	half-life
I - 131	2,02	8.04 d
Te - 132	1,95	78.0 h
I - 132	1,60	2.3 h
Ru - 103	0,30	39.4 d
Cs - 137	0,19	30.1 y
Cs - 134	0,10	2.06 y
Sr - 89	0,04	50.5 d
Sr - 90	0,008	28.5 y

IRLWECK and STEGER (1986)

TABLE 2

Cs - 137 deposition in Austria after the Chernobyl accident

region	Bq $^{137}Cs\ m^{-2}$	Ci/km^2
Lower Austria	2850 - 56370	0,08 - 1,52
Burgenland	1953 - 28740	0,05 - 0,78
Upper Austria	46200 - 99300	1,25 - 2,68
Styria	32310 - 134400	0,87 - 3,63
Carinthia	75930	2,05

n = 93

TABLE 3

Concentrations of various radionuclides in cereals (10^{-9} Ci / kg FW)

plant		sampling date	^{131}I	^{103}Ru	^{134}Cs	^{137}Cs
winter barley /	whole plant	1986 06 04	6,1	13,5	3,7	8,1
spring barley /	whole plant	1986 06 04	0,5	0,5	0,6	1,0
winter barley /	grains	1986 07 16	-	0,2	1,9	3,6
	straw		-	19,0	14,5	28,6
winter rye /	grains	1986 07 16	-	<0,1	0,8	1,6
	straw		-	11,2	6,9	13,5
winter wheat /	grains	1986 08 04	-	<0,06	1,7	3,3
	straw		-	1,2	4,1	8,1
spring barley /	grains	1986 07 31	-	<0,07	<0,15	<0,07
	straw		-	<0,4	1,0	1,9

TABLE 4

Concentrations of various radionuclides in agricultural plants in Austria (10^{-9} Ci/kg FW)

plant	sampling date		^{103}Ru	^{134}Cs	^{137}Cs
winter wheat	1986 08 04	grains	0,06	1,70	3,30
		straw	1,19	4,11	8,11
rape	1986 08 06	grains	0,06	1,41	2,81
		straw	0,70	6,00	11,81
maize	1986 08 15	whole plant	-	-	<2,97
sugar beet	1986 08 15	leaves and beet	-	-	<2,07
black currant	1986 06 20		6,51	9,30	20,41

TABLE 5

Depth distribution of various radionuclides in a Chernozem in Austria (10^{-9} Ci / kg)

sampling: I : 1986 06 02 II : 1986 07 16

depth mm	^{131}J		^{134}Cs		^{137}Cs		^{103}Ru	
	I	II	I	II	I	II	I	II
0 - 3	5,0	0,3	4,6	1,7	9,5	4,4	10,1	1,7
3 - 50	0,63	<0,1	0,43	0,7	0,98	1,0	0,95	0,4
50 - 200	0,22	<0,1	0,16	<0,3	0,57	<0,3	0,46	<0,1

TABLE 6

CS-137 AVERAGE TF; FIELD CROPS AND OUTDOOR CONTAINER EXPERIMENTS

plant, part	TF (x. ± s)	number of samples	activity ratio (grain/straw)
maize, straw	0.019 ± 0.018	10	
maize, grain	0.0018 ± 0.0017	9	0.095
wheat, straw	0.023 ± 0.026	10	
wheat, grain	0.0055 ± 0.0056	9	0.239
barley, straw	0.024 ± 0.019	8	
barley, grain	0.013 ± 0.015	8	0.542
rye, straw	0.059 ± 0.079	3	
rye, grain	0.036 ± 0.049	3	0.61
potato, shoot	0.0136 ± 0.0083	4	
potato, tuber	0.0027 ± 0.0020	6	
leaf vegetables (lettuce,endive,spinach)	0.0017 ± 0.0017	8	
root and shoot vegetables (carrots,celery, cauliflower...)	0.0034 ± 0.0033	10	
fruit vegetables (cucumber,tomato, red pepper...)	0.012 ± 0.021	7	
fodder plants (grass,leguminous plants, rape)	0.016 ± 0.018	9	

TABLE 7

^{90}Sr Soil to plant Transfer Factors Derived from Field Studies in Austria During the Years 1987 - 1989.

plant species		n	$\bar{x}$	s	min	max
<u>1. cereals</u>						
wheat	grain	3	0,103	0,102	0,039	0,221
	straw	3	0,482	0,250	0,246	0,744
rye	grain	2	0,097	0,086	0,036	0,158
	straw	2	0,370	0,082	0,311	0,428
barley	grain	5	0,106	0,033	0,069	0,149
	straw	5	0,897	0,411	0,479	1,315
maize	grain	1	0,010			
	straw	1	0,494			
<u>2. vegetables</u>						
potato	tuber	3	0,026	0,006	0,018	0,030
	shoot	3	0,624	0,304	0,409	0,839
spinach		1	0,170			
salad		3	0,100	0,041	0,055	0,136
celery	tuber	2	0,047	0,060	0,005	0,090
	shoot	1	0,459			
cauliflower		1	0,072			
cabbage		1	0,064			
<u>3. fodder plants</u>						
hay		10	2,117	1,203	1,110	4,380
clover		2	1,595	0,276	1,400	1,790
rape		1	0,317			

TABLE 8

Results of Austrian research on the plant - animal transfer of Cs (RATHEISER ET AL. 1986)

	transfer factor	fodder
pork	0.25	whey
cattle		
bull	0.01	green forage
heifer	0.06	pasture
	0.017	hay
calf	0.15	milk replacer
milk	0.0023	green forage
lamb	0.70	hay

TABLE 9

Reduction of the Cs-transfer into milk and meat due to feed additives (RATHEISER et al. 1986)

	additive	reduction in %
calf	potassium hexacyanoferrate	94
	Berlin blue	59
	bentonite	20
	bolus alba	50
beef	Berlin blue	40
	ammoniumhexacyanoferrate*	30
	bentonite	20
	bolus alba	10
milk	Berlin blue	47
	ammoniumhexacyanoferrate*	70
	bentonite	24
	bolus alba	8
pork	bentonite	42
	bolus alba	26

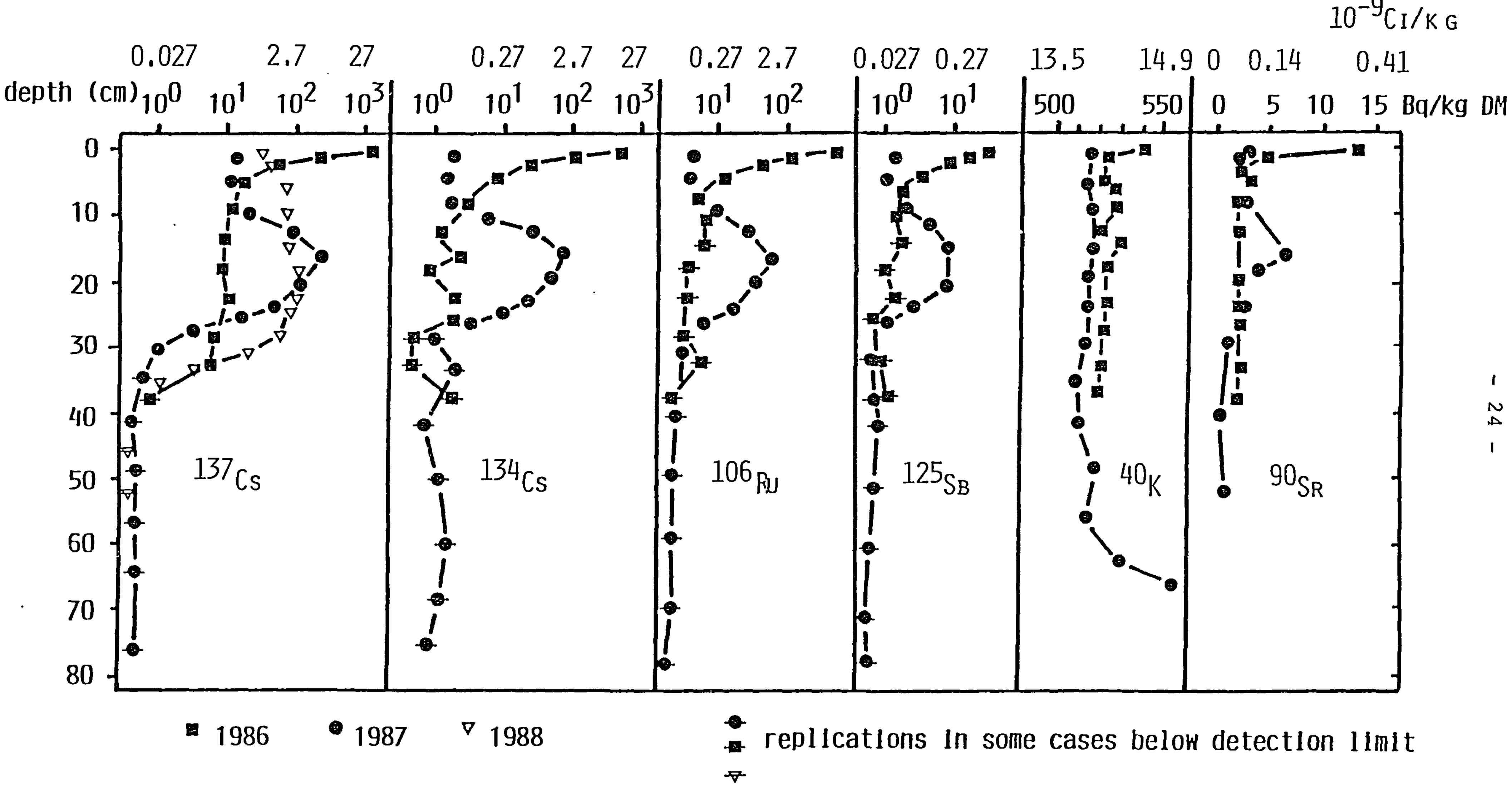
* "GIESE salt"

TABLE 10

Cs-137 concentrations in fruitbodies of various fungi after the Chernobyl accident in Austria (10^{-9} Ci / kg DW)

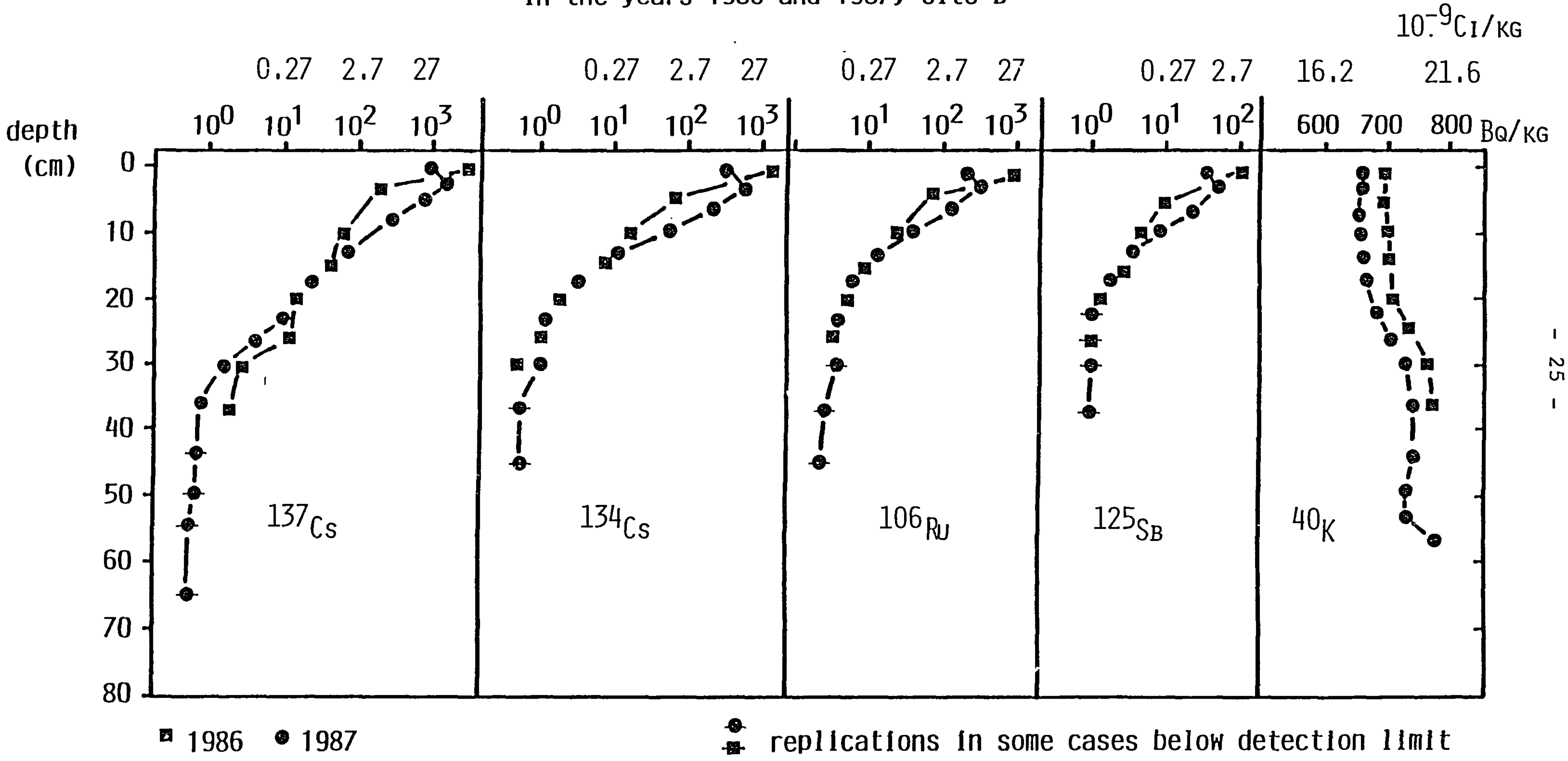
	number of observations	$x \pm s_x$	maximum
Agaricus	20	6,0 ± 5,1	21
Amanita rubescens	3	30,0 ± 46,1	84
Armillariella mellea	4	42,0 ± 32,2	81
Boletus edulis	104	11,5 ± 11,2	73
Calocybe gambosa	3	8,7 ± 3,5	12
Cantharellus cibarius	217	35,3 ± 31,2	230
Chroogomphus rutilus	1	12,0	12
Coprinus comatus	1	2,0	2
Craterellus cornucopioides	8	12,3 ± 5,8	23,8
Kuehneromyces mutabilis	1	2,0	2,0
Lactarius	5	191,0 ± 211,2	421
Langermania gigantea	1	7,0	7,0
Leccinum	10	19,7 ± 40,9	135
Lepista nebularis	1	11,0	11
Macrolepiota procera	18	21,6 ± 29,6	130
Marasmius oreades	1	14,0	14
Morchella	5	62,4 ± 115,4	268,5
Pleurotus ostreatus	5	55,5 ± 69,8	153
Rozites caperata	6	458,2 ± 416,7	1251
Russula	4	5,1 ± 4,9	12
Stropharia rugosoannulata	16	79,0 ± 75,5	232
Suillus	5	146,6 ± 184,2	468
Xerocomus badius	26	1339,1 ± 1044,3	3980

FIGURE1: Depth distribution of various radionuclides in a cultivated Stagno-Dystric Gleysol in the years 1986, 1987 and (1988), site A



MEISEL et al. (1990)

FIGURE 2: Depth distribution of various radionuclides in a cultivated Dystric Cambisol in the years 1986 and 1987, site B



MEISEL et al. (1990)

FIGURE 3: ^{137}Cs - transfer into maize in response to the exchangeable basic cations (K^+, Na^+, Ca^{++}, Mg^{++})
(ARTNER, GERZABEK, HORAK, MÜCK 1990)

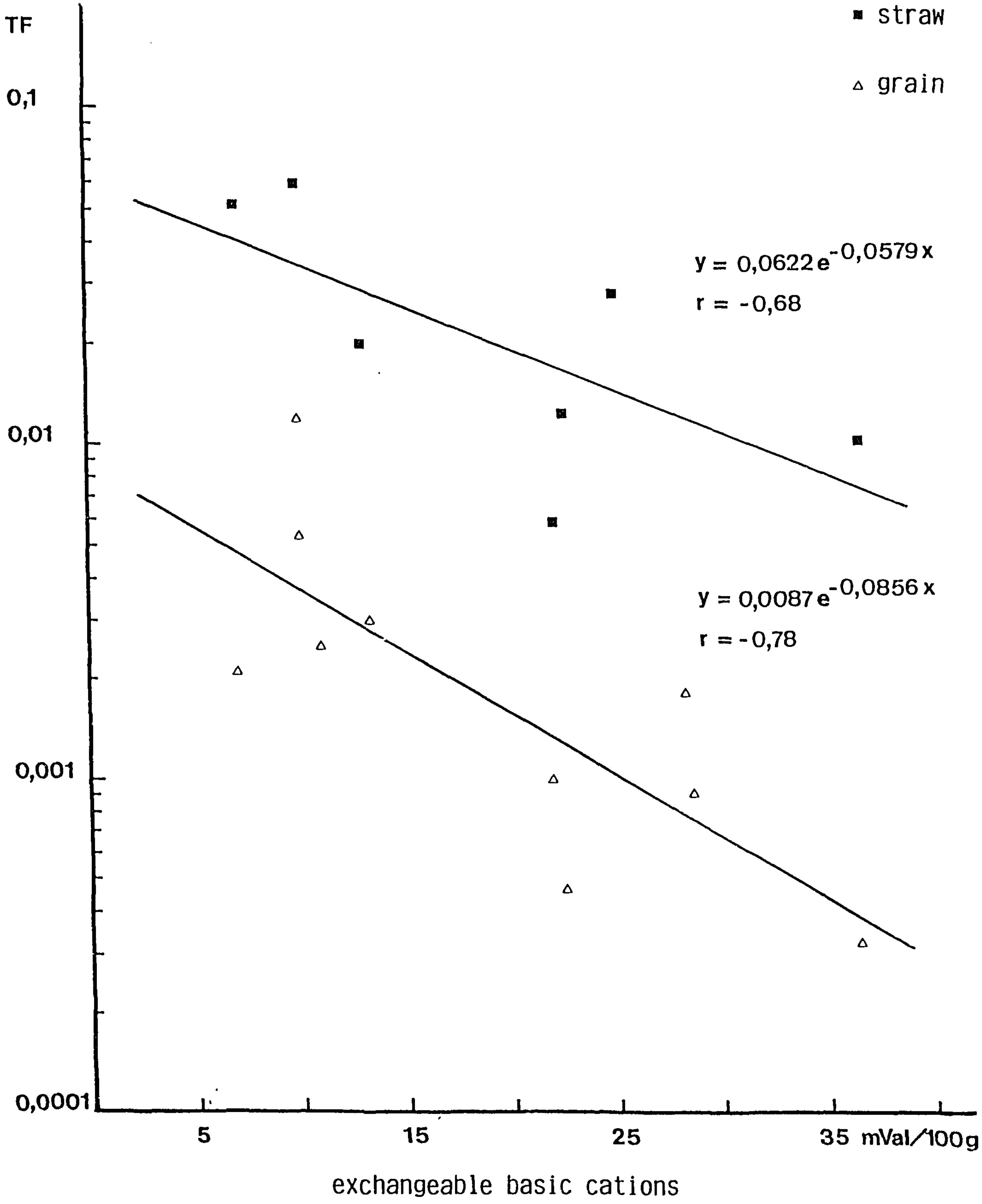


FIGURE 4: ^{137}Cs - transfer into wheat depending on the clay content of the soil

(ARTNER, GERZABEK, HORAK, MÜCK 1990)

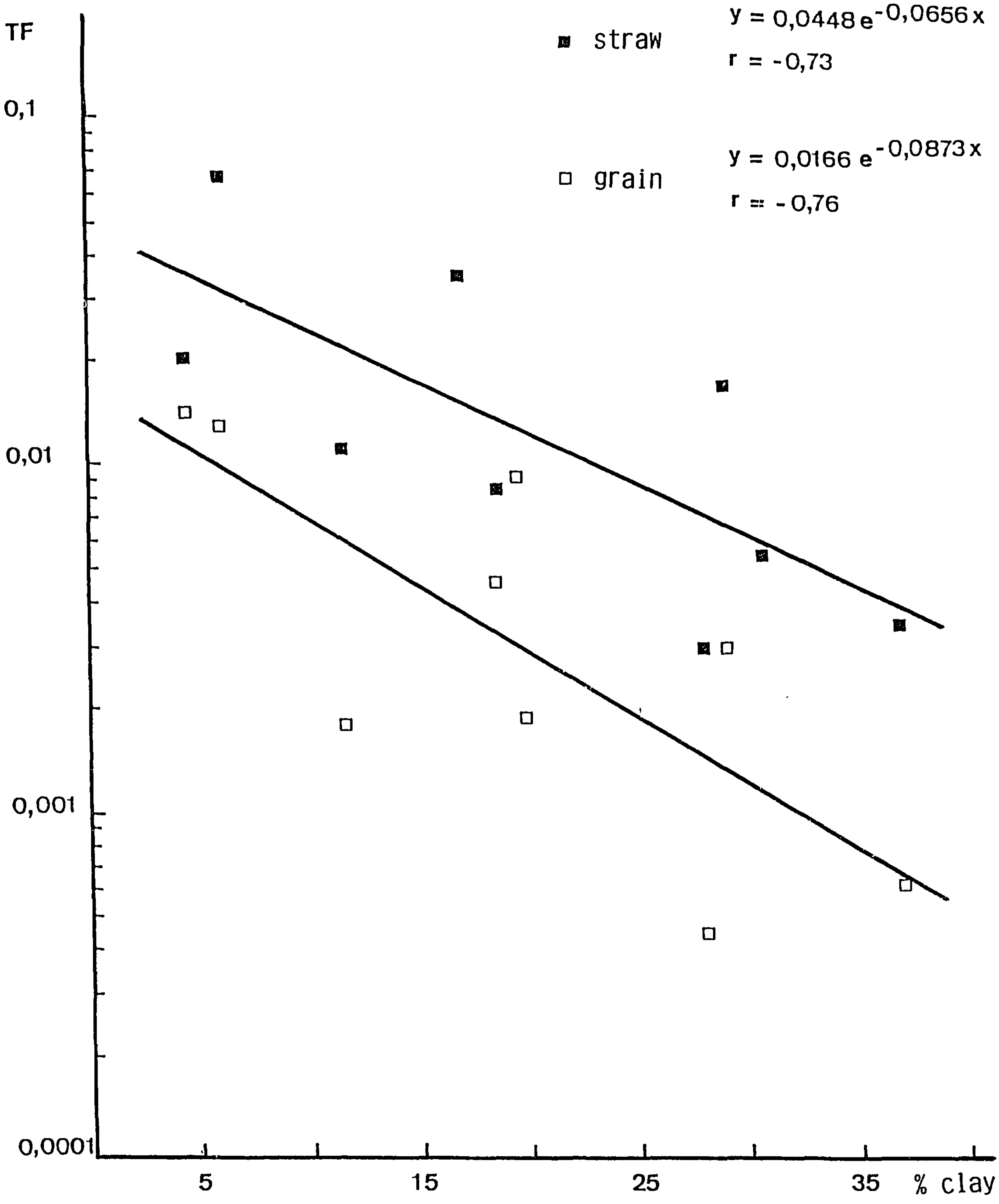


FIGURE 5

Relationship between the ^{137}Cs - concentration in the soil and the ^{137}Cs - transfer into three different types of cereal grains (ARTNER, GERZABEK, HORAK, MÜCK 1990)

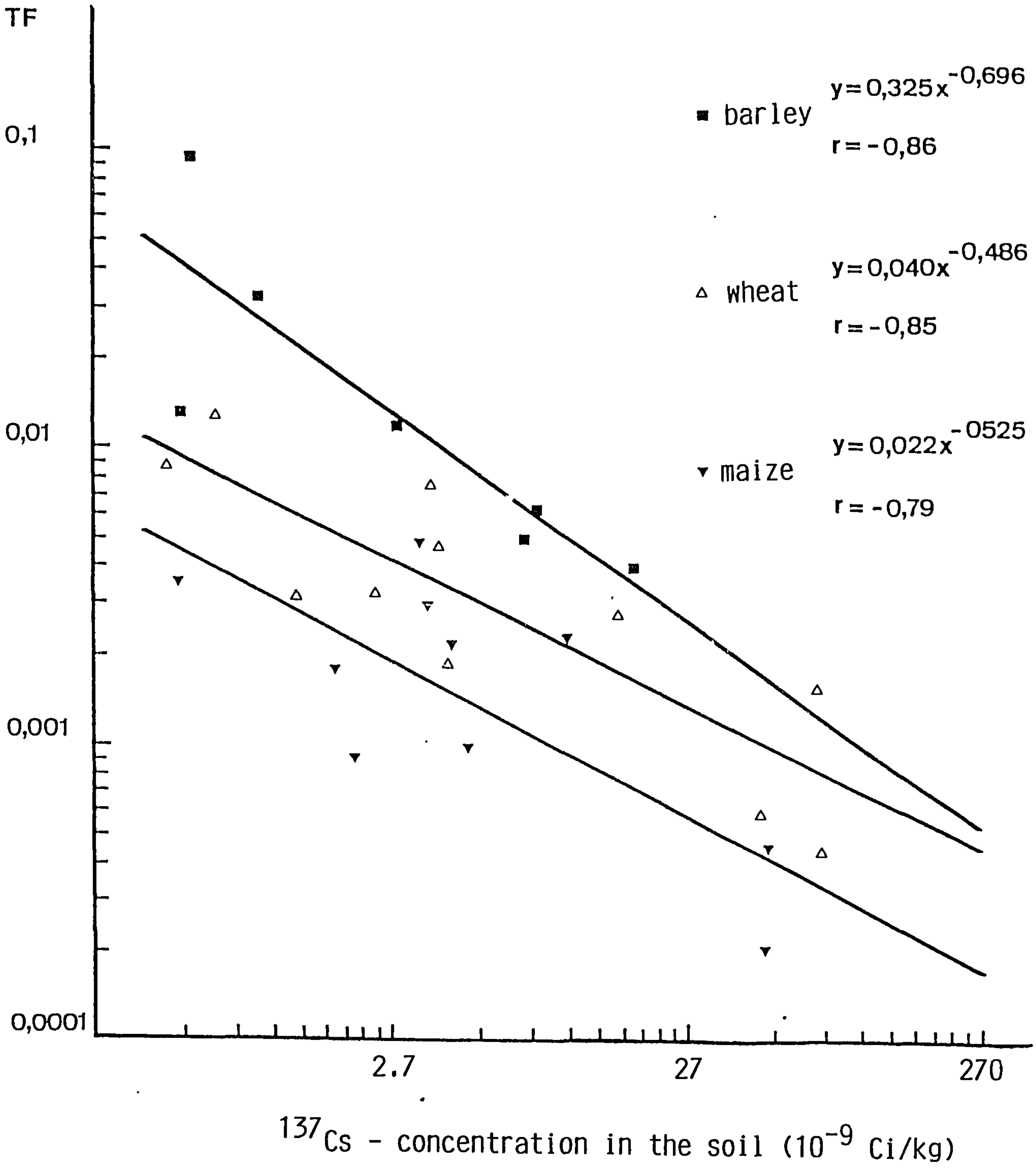
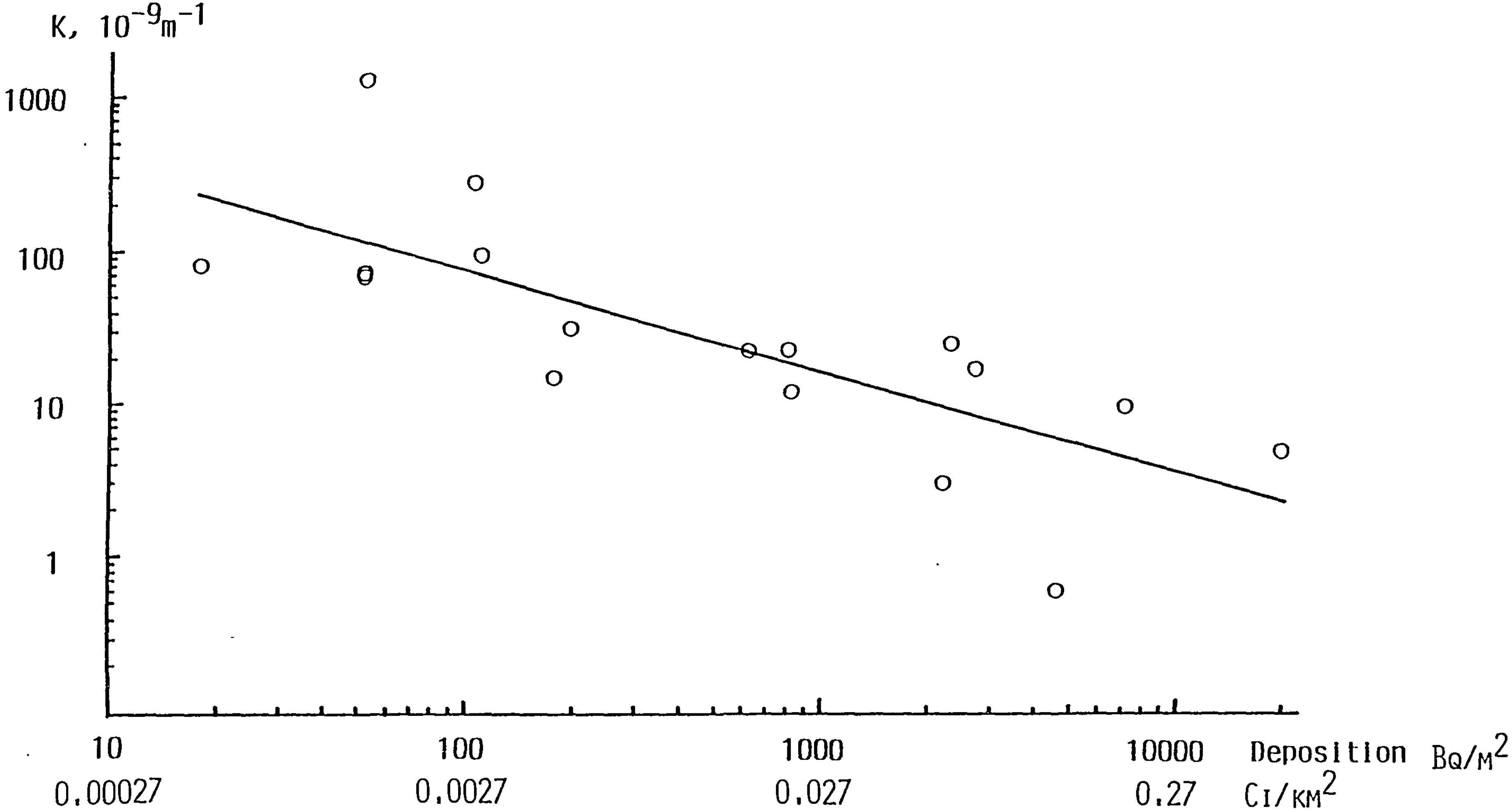


FIGURE 6: Resuspension Factors after Chernobyl in Europe (July 1986 - June 1987)
(GARLAND and PATTENDEN 1989, Vienna)



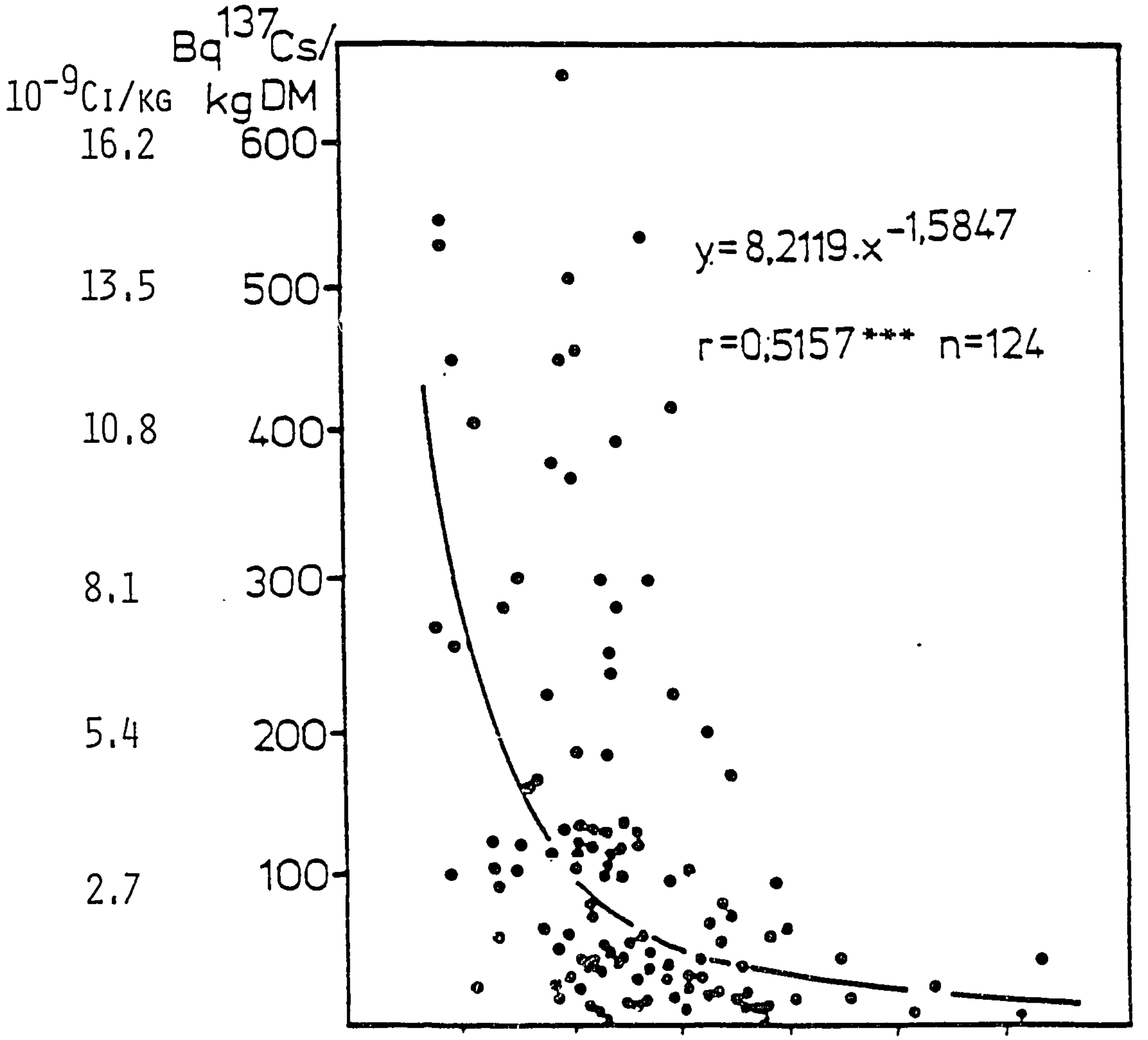
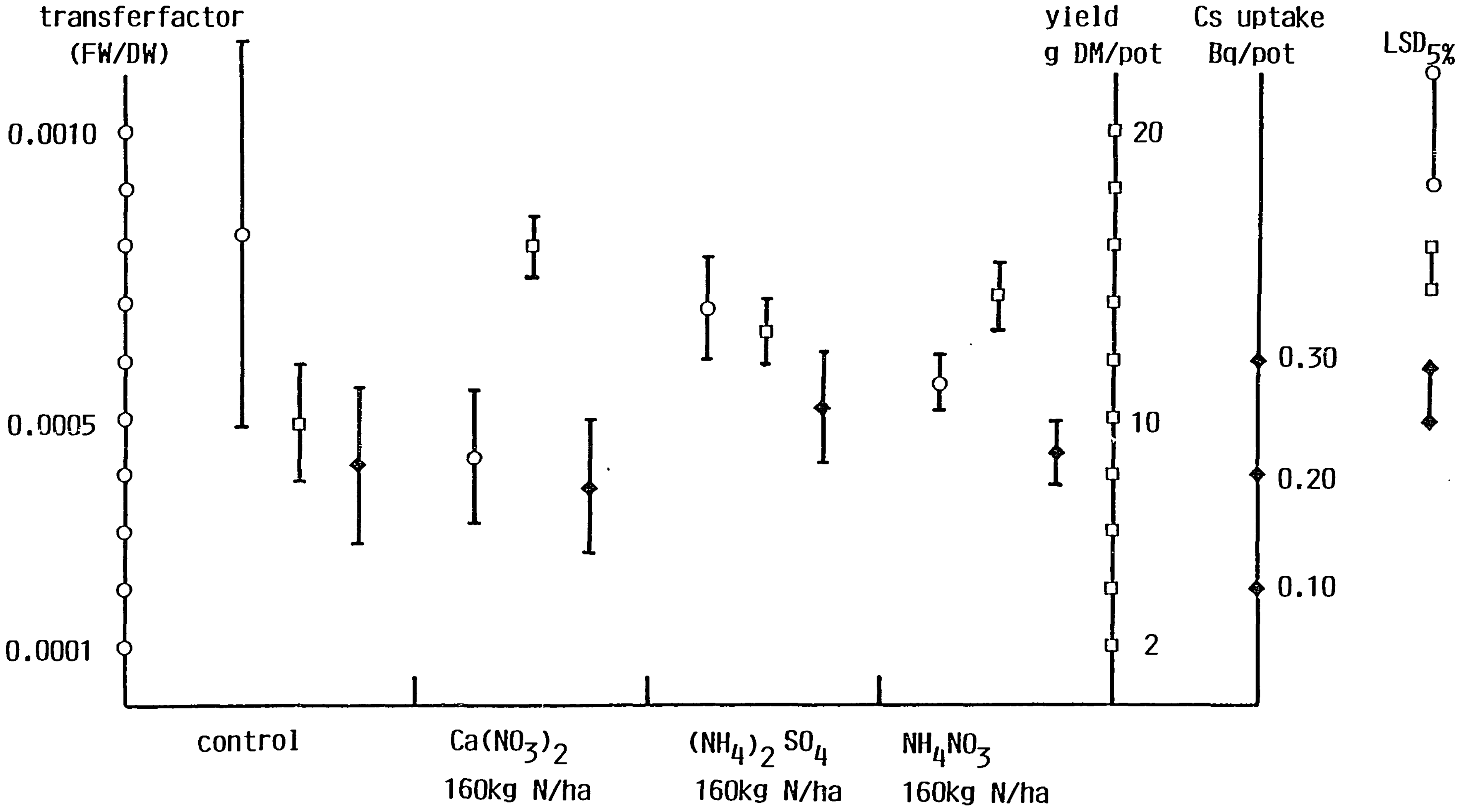


Figure 7. Relation between Cs-137 activity and potassium contents of grass and hay (harvest 1987).

(HORAK, GERZABEK, MÜCK, HAUNOLD 1987)

FIGURE 8: Influence of different N-treatments on straw yield and Cs uptake of winter rape.
(n = 7)



SOIL CONTAMINATION AND UPTAKE BY CROPS AND ANIMAL FODDER

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1. Introduction

As a concequence of a large scale radioactive fallout several pathways of radionuclides to man have to be taken into consideration (Figure 1). In the first year after the fallout the direct contamination of cereals, vegetables, fruits and forage plants leads to an increase of the radionuclide uptake by man both due to direct consumption of contaminated plants and animal produce. Later on the influence of direct contamination ceases in favour of the soil to plant transfer. Especially radionuclides with considerable high half times and low mobility in the soil stay plant available for a long time and give rise to problems in the agricultural production.

2. Migration of deposited radionuclides in soils

Figure 2 shows the vertical distribution of ^{137}Cs, ^{134}Cs, ^{106}Ru, ^{125}Sb and ^{90}Sr in a Stagno-Dystric Gleysol from Styria two years after the Chernobyl fallout (MEISEL et.al. 1990). The concentration of the Cs-, Ru- and Sb- isotopes decreased sharply in the first 15 cm of the profile. The decrease of ^{137}Cs was less pronounced as compared to ^{134}Cs, which is to be explained by the resonable amounts of ^{137}Cs from the weapons testing still predominantly present in the first 20 cm. The vertical distribution of ^{134}Cs was characterized by an only slightly smaller concentration decrease than in an adjacent field sampled in August 1986 prior to any plowing after the Chernobyl accident (MEISEL et al. 1990). From these results it seems to be evident that the main cesium migration took place in a short period after the Chernobyl fallout. SCHIMMACK et al. (1989) reported migration rates for Cs of 0.3 cm.h^{-1} during and shortly after the wet deposition. BECKER-HEIDMANN et al. (1989) found an initial penetration of Chernobyl derived Cs of 15 cm. ^{106}Ru and ^{125}Sb could be detected down to 20 cm depth (Figure 2). ^{90}Sr showed a completely different behaviour. The concentration ratio of the first to the tenth cm was 2.2. This should be compared to the field samples in 1986 which showed a value of 6.5. From this, but also from the fact that a significant concentration increase from the first to the second cm is observable a high mobility of ^{90}Sr may be deduced. However, a precise calculation of the ^{90}Sr concentration derived from the weapons testing for this undisturbed pasture is not possible, because the pre-Chernobyl vertical distribution is not known. Therefore the higher migration rate from these data cannot be concluded with certainty.

An even higher migration velocity was observed in the top layer of an undisturbed Dystric Cambisol in the year 1987 (Figure 3). This pasture is characterized by an increase of the radionuclide concentrations from the first to the second cm in a range of 47% (^{134}Cs) to 90% (^{125}Sb). As a matter of fact even the natural ^{40}K-content increased significantly. This result gives evidence to the presumtion that the first cm of the pasture profile has an only very low cation retardation capacity.

Literature data give a large range of migration velocities for cesium and strontium. However, average values for Cs and Sr are between 0.1 and 1.0 $cm.a^{-1}$ and 1.33 and 3.57 $cm.a^{-1}$. Exceedingly high values of app. 10 $cm.a^{-1}$ are reported for both radionuclides in forest soils (BACHHUBER et al. 1982, SCHREIBER and WOERNER 1979).

3. Factors influencing the mobility of radionuclides and their plant availability

On principle the mobility and plant availability of plant nutrients and radionuclides in the soil is due to the following factors:

- concentration in the soil solution
- rate of mobilisation
- depth of tilled soil
- soil moisture/transport rate
- ion competition and synergism
- toxic substances
- O_2 - concentration in the soil air
- soil temperature
- root development depth
- plant specific discrimination during uptake

The cation fixation capacity of different soils is mainly determined by their clay contents. The adsorption of cations on clay minerals increases with their valence and secondly with greater ion diameters. According to SCHEFFER and SCHACHTSCHABEL (1979) the adsorption increases in the following order:

$$Li^+ < Na^+ < K^+ < Rb^+ < Cs^+$$

$$Mg^{2+} < Ca^{2+} < Sr^{2+} < Ba^{2+}$$

BOVARD et al. (1968) reported results for adsorption of radionuclides on humic substances:

$^{131}I < {}^{137}Cs < {}^{90}Sr \leq {}^{60}Co < {}^{54}Mn < {}^{59}Fe < {}^{144}Ce$

However, the plant uptake of radionuclides seems to be influenced by a couple of other factors. Therefore, the soil to plant transfer increases as follows (NISHITA et al. 1965):

$^{144}Ce, {}^{91}Y, {}^{147}Pm, {}^{95}Zr\text{-}Nb < {}^{106}Ru = {}^{137}Cs < {}^{140}Ba < {}^{131}I \ll {}^{90}Sr$

3.1. Cesium

The Cs- availabilty increases with higher humus contents and decreases with the clay content of the soil (D'SOUZA et al. 1980). Figure 4 shows the ^{137}Cs distribution in the particle size fractions of two Austrian Cambisols, which had average ^{137}Cs-concentrations of 50.10^{-9} $Ci.kg^{-1}$ (GERZABEK and ULLAH 1988). Obviously app. 90% of the total activity is fixed to the clay minerals. Vermiculite adsorbs Cs stronger than other clay minerals. This is due to a specific adsorption mechanism (COLEMAN et al. 1963). Figure 5 gives the relationship between the clay content of the soil and the Cs-uptake by red clover and rye-grass (ANDERSEN 1967). The Cs-transfer decreased significantly from 3 to app. 12% clay. Recent results obtained by HORAK et al. (1989) on soils contaminated by the Chernobyl fallout are quite consistent with the older literature (Figure 6).

A second important factor influencing the plant availability of cesium is the concentration of competing ions in the soil solution. JACKSON et al. (1965) found two antagonistic mechanisms. On the one hand competing ions may exchange cesium from the clay minerals and thus enhance the plant availability, on the other hand they may decrease the plant uptake due to ion competition (Figure 7). Ammonium is a strong exchanging ion, but hardly inhibits the cesium uptake. Rubidium at low concentrations enhances the cesium transfer, at high concentrations it diminishes the cesium uptake. A significant decrease can only be expected after increasing the potassium concentration in the soil solution due to fertilzer treatments. However, significant effects will be obtained only on soils with a resonable potassium demand. MIDDLETON et al. (1960) and recently GERZABEK et al. (1989) reported no significant influences of potassium treatments on soils high in potassium. The behaviour of cesium and potassium in plant physiology is quite similar. Nevertheless, plants can discriminate between Cs and K during uptake and translocation. Most plants show a slightly higher potassium uptake as compared to cesium (NISHITA et al. 1965).

Cesium stays highly mobile in the plant tissue. Translocation from one plant part to another is remarkable. HAUNOLD et al. (1987) observed a translocation of more than 10% of the cesium activity in the vegetative parts of winter cereals contaminated by the Chernobyl fallout to the grains.

3.2. Strontium

Contrary to cesium strontium is easily plant available, not exchangeable fractions are in most cases below 20% (NISHITA et al. 1965). The binding due to sorption increases with pH and therefore with the frequency of strontium-humus complexes (JUO and BARBER 1970). The affinity of Sr to clay minerals decreases in the following order (HEALD 1960):

vermiculite > bentonite > illite > caolinite

Calcium treatments can lead to a competitive reduction of the strontium uptake. 12 to 15 meq Ca/100g soil yields a significant inhibition of the Sr uptake (Figure 8, ANDERSEN 1967).

The translocation of strontium within the plant after contamination of leafes is nearly neglectable (BUKOVAC et al. 1965, MIDDLETON 1959).

3.3. Ruthenium

Ruthenium, a noble metal, migrates in the soil mainly as an anion. The migration velocity is somewhat higher than for cesium (D'SOUZA and MISTRY 1980). Higher pH values and lower cation concentrations in the soil solution promote the Ru-binding.

Ruthenium soil to plant transfer ranges in the same order of magnitude like cesium. However, translocation after foliar contamination is significantly lower (HAUNOLD et al. 1987).

3.4. Plutonium

The most stable Pu-compound in soil is PuO_2 (RAI et al. 1980). Plutonium inclines to complex formation. The Pu migration in the soil increases therefore with the organic matter content (VYAS and MISTRY 1980). The overall mobility of Pu seems to be low due to the low solubility of PuO_2 (IRLWECK 1977).

The soil to plant uptake of plutonium is nearly neglectable. The foliar uptake may be an important pathway to man (McLEOD et al. 1980).

4. Modelling the soil to plant transfer

The uptake of radionuclides and other substances can be described by a soil to plant equilibrium concentration ratio, the transfer factor. This factor is a radionuclide specific value, which includes all influences determining the plant uptake. In the case of radionuclides the most common definition for the transfer value is the ratio of activity (Ci) per kg plant fresh weight divided by the activity (Ci) per kg soil dry weight. For pastures on undisturbed soils the use of transfer factors related to the deposition per square meter may be more praticable, especially if data on the vertical distribution of the radionuclides are lacking. These TF have to be adapted to the changes of the radionuclide plant uptake with time (ERIKSSON 1989). A second problem arises in modelling pastures. Perennial plants store radionuclides in roots. They are mobilized in spring and translocated into the upper plant parts. Thus the yield and therefore the dilution of the translocated radionuclides have an important influence on the nuclide concentration in the green fodder.

The transfer factors (TF) vary greatly due to soil characteristics, plant species, climatic conditions and the thickness of the contaminated soil layer. There are two further factors of uncertainty. Firstly the reliability of transfer calculations depends on the vertical distribution of the nuclide in the soil profile. The standard transfer concept calculates with a homogeneous radionuclide distribution. Recent studies demonstrate that plowing does not lead to an uniform distribution in any case. Two or more plowing steps may be necessary to reach this aim (MEISEL et al. 1990). Secondly there may be a significant contribution of resuspended particles to the radionuclide concentration of plants (GERZABEK et al. 1989). The influence of resuspension decreases with higher deposition levels.

More sophisticated efforts in modelling the soil to plant transfer result in multifactorial correlation equations (FRISSEL and KOSTER 1987). However, without precise input data this model cannot be used in practice.

Table 1 presents mean transfer values for different radionuclides and four important plant groups (HAUNOLD et al. 1987). Recent field studies led to Sr-transfer values, which are in good agreement with the older literature (ARTNER et al. 1990). In the case of cesium, vegetables had a three to ten times lower uptake than expected (HORAK et al. 1989).

On a long-term basis precise predictions can only be obtained by using values from field experiments conducted in that area, which has to be evaluated. Mean literature transfer factors are required for a first assessment.

5. Evaluation of effective countermeasures

The soil to plant transfer of radionuclides depends to a great extent on the vertical distribution in the soil. Contamination of the top layer (0-5 cm) lead to the highest ^{90}Sr uptake into barley, rye-grass and red clover during a five years experiment (ANDERSEN 1967a, Figure 9). A homogeneous distribution in the first 20 cm decreased the Sr-uptake by a factor of two. However, labelling a soil layer from 80 to 85 cm yielded one fourth of the strontium transfer from the top layer, or approximately half the uptake as compared to the 0 - 20 cm contamination. From this it has to be concluded that deep plowing results in an only slightly smaller transfer as compared to the standard tillage depth of 20 to 25 cm. These results are well true for all other radionuclides.

A second effective countermeasure is the fertilizer application. Especially potassium treatments can be used to diminish the cesium uptake and liming to decrease the strontium transfer. This countermeasure will only be effective if the soil lacks potassium or calcium.

Another possibility is to modify the crop rotation. The soil to plant transfer varies greatly between different plant species, as it was discussed earlier. Some leaf vegetables and the potatoes show significantly lower transfer factors than other agricultural crops. Thus a substitution of cereal production may be considered for areas with higher contamination.

6. Seminatural environments

Differences in the plant availability to intensively cultivated areas arise due to the following factors (GERZABEK and MÜCK 1989):

- no thorough mixing of the top layer (only bioturbation)
- higher organic matter contents
- low pH values
- poor in plant nutrients
- extreme water conditions

In a large scale study milk was chosen as a sensitive indicator of Cs-activity cocentrations in food and fodder as milk averages over a great number of animals and fodder area (MÜCK et al. 1989). Figure 10 shows the main results. All investigated sites were within a distance of 100 km. While the three valley tours show a significant decrease in activity concentration from first to second and to third year, the three sites of alpine pastures above an altitude of 1000 m show an only small reduction. It is obvious that the ^{137}Cs-concentration in milk two years after the fallout is not correlated with the deposition. The investigated alpine sites are characterized by extreemly shallow soil profiles. Therefore the rooting density in the first centimeters is higher than usual. KIRCHNER (1989) reported that 85% of the total cesium deposition is bound to the roots of the perennial plants. This may be the explanation for the observed phenomenon.

There are many other examples for the fact that radionuclides stay highly available in certain seminatural environs.

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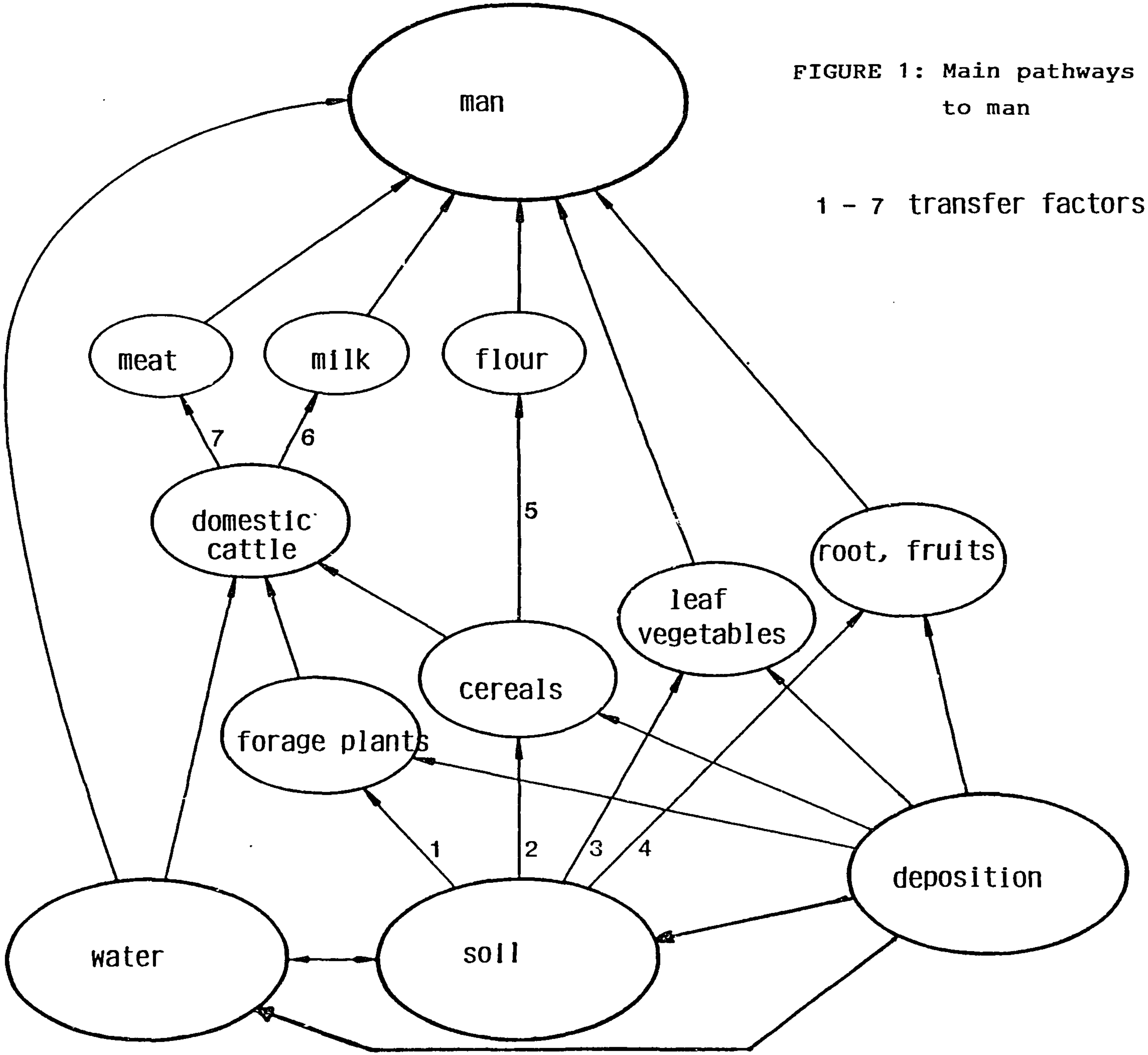


FIGURE 1: Main pathways of radionuclides to man

1 - 7 transfer factors

FIGURE 2

Depth distribution of various radionuclides in a Stagno-Dystric Gleysol in the year 1988, pasture, site A

(MEISEL et al. 1990)

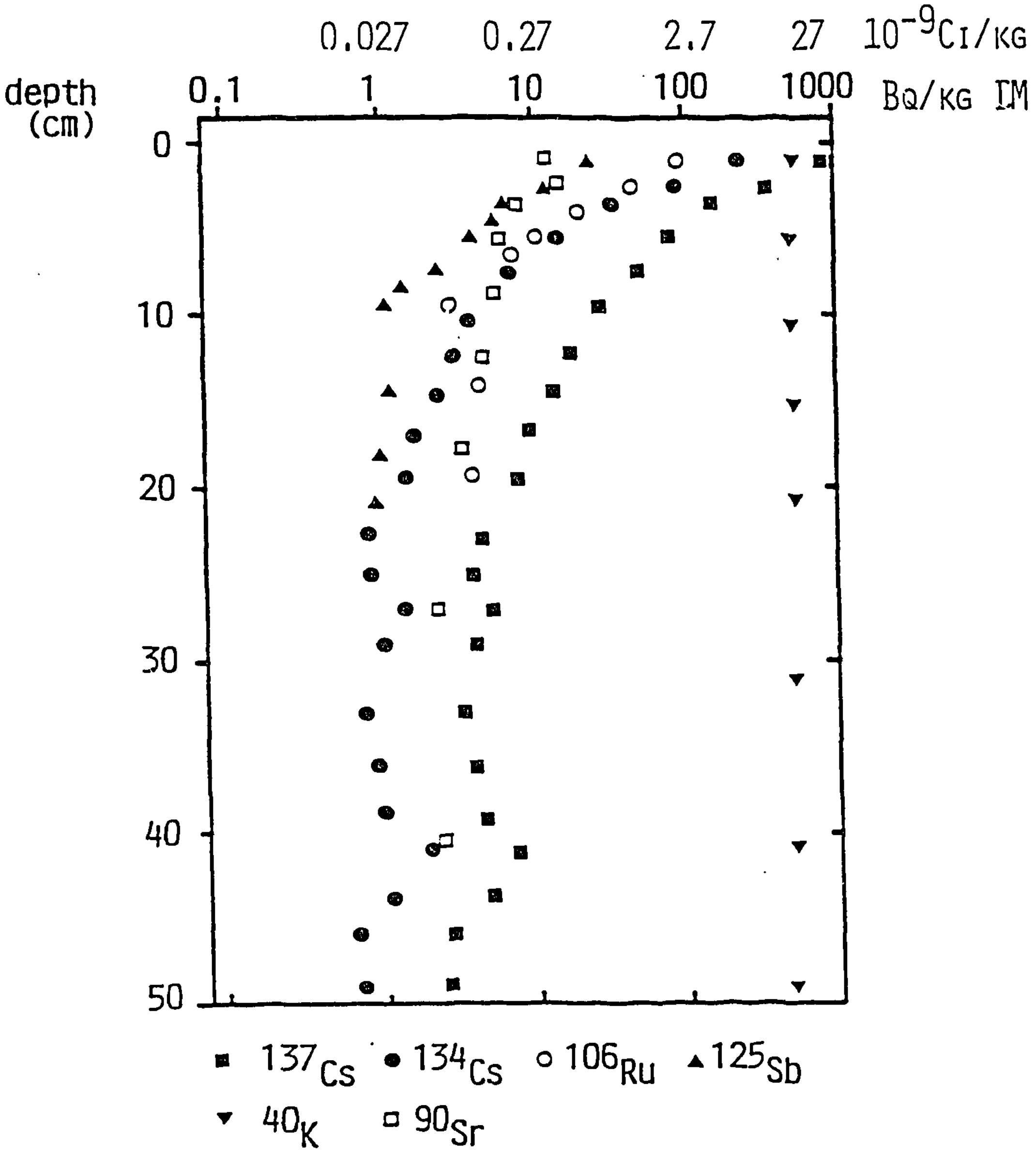


FIGURE 3

Depth distribution of various radionuclides in a Dystric Cambisol in the year 1987, pasture, site B

(MEISEL et al. 1990)

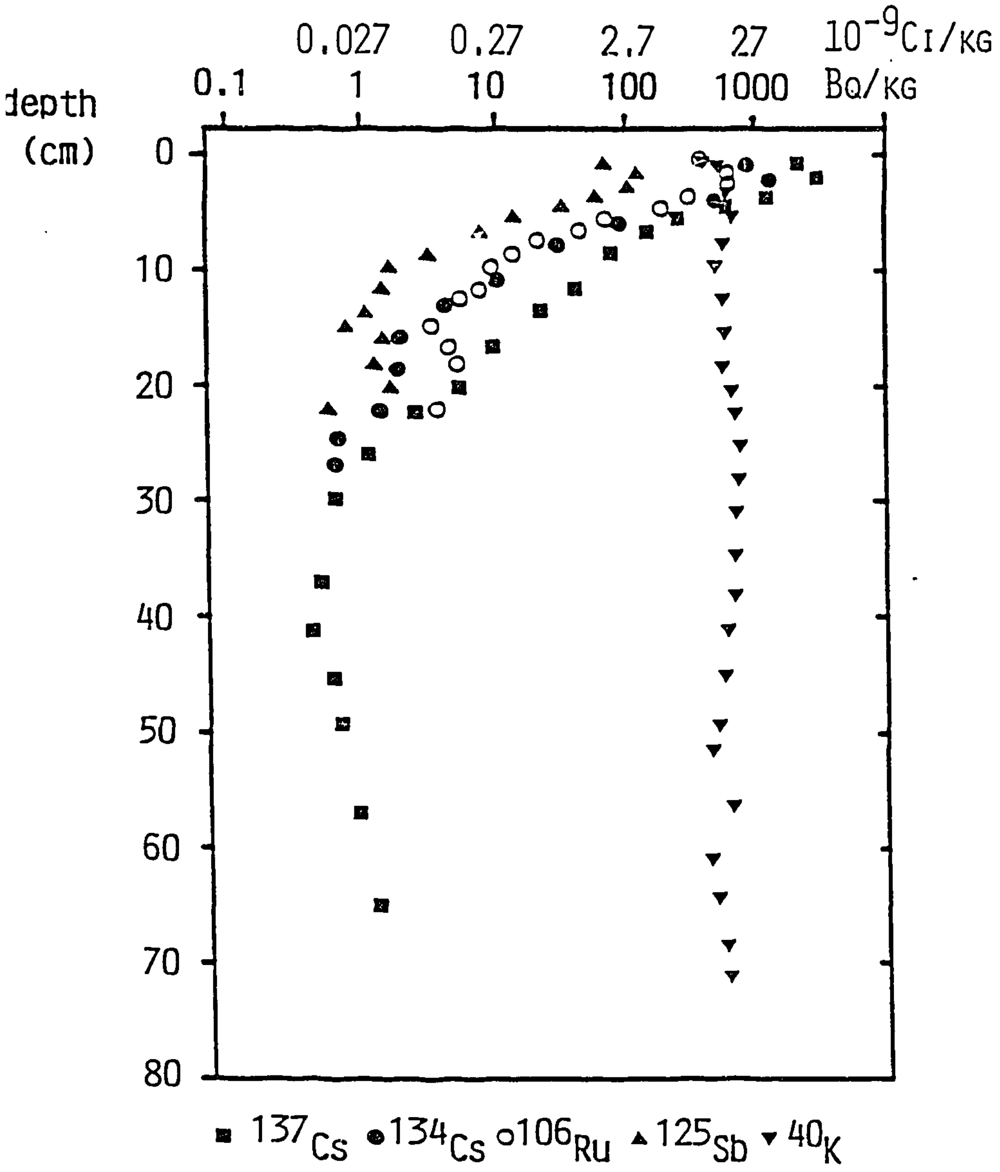


FIGURE 4: ^{137}Cs distribution in the particle size fractions of two Austrian Cambisols (GERZABEK and ULLAH 1989)

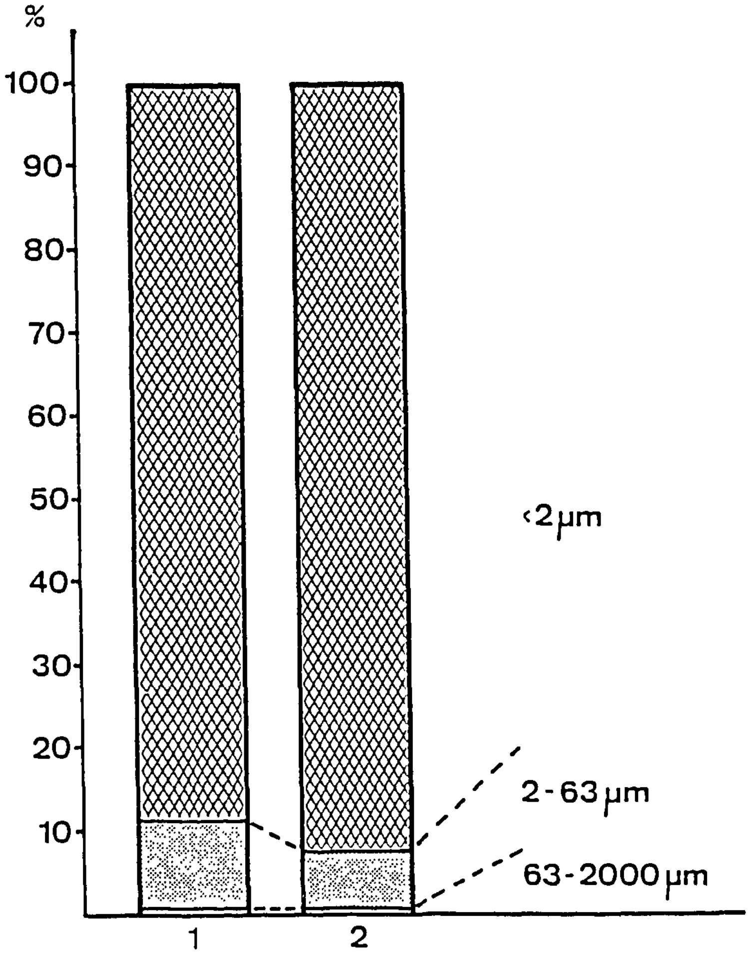


FIGURE 5: The influence of the clay content on the ^{137}Cs uptake into red clover and rye-grass

(ANDERSEN 1967)

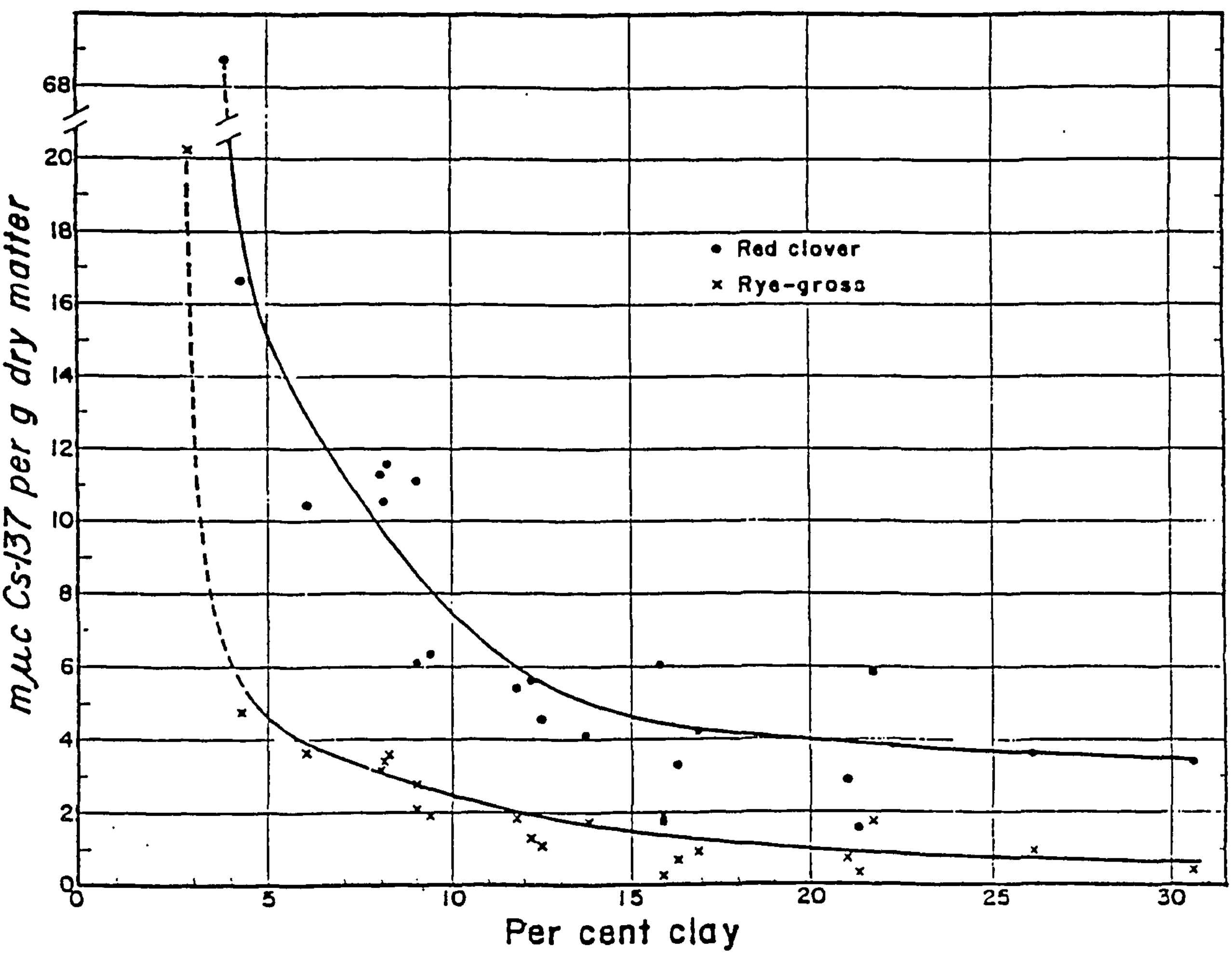


FIGURE 6: ^{137}Cs-soil to plant transfer factors for endive grown in container experiments on four soils with different contamination levels and clay contents

(HORAK et al. 1989)

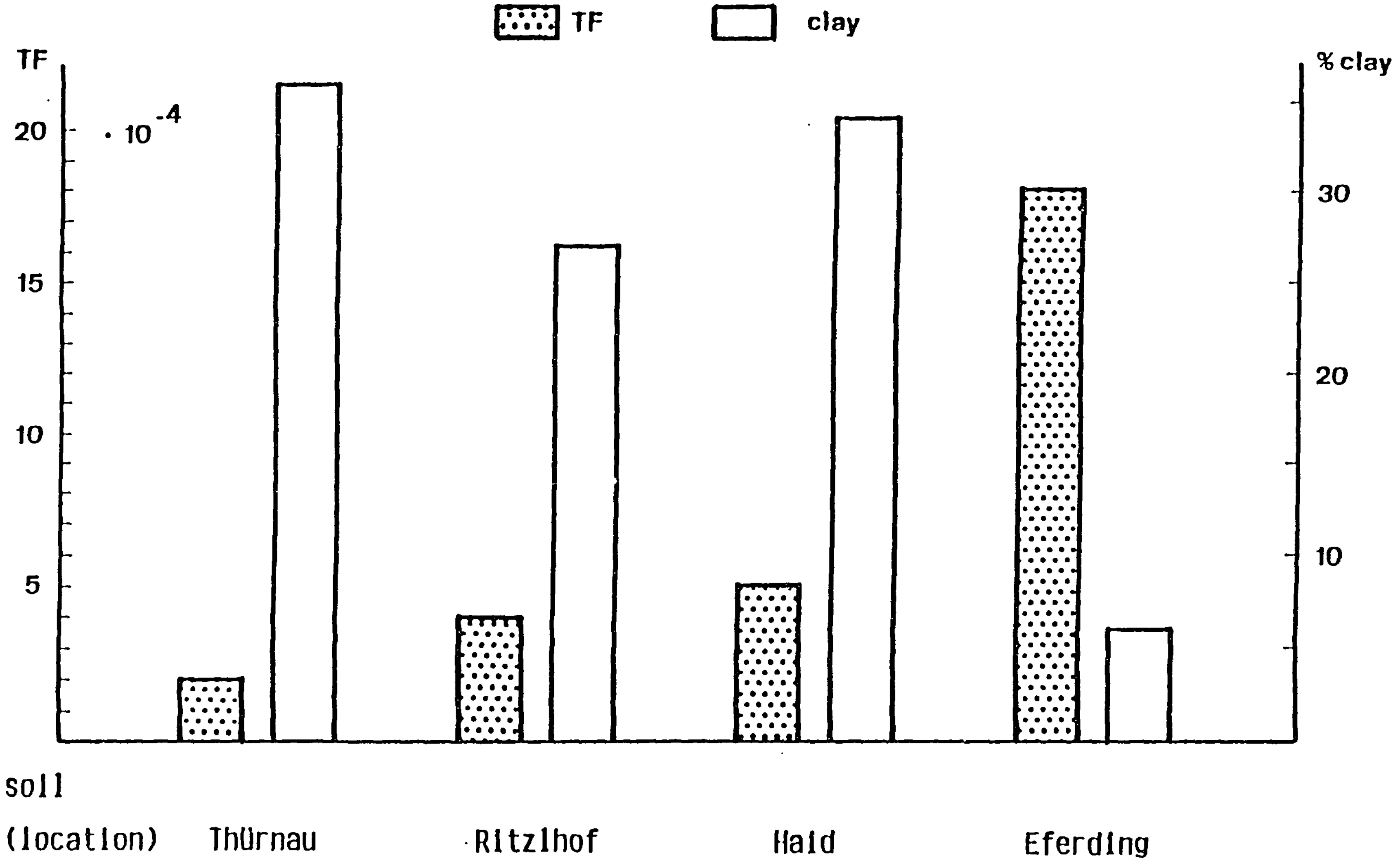


FIGURE 7

The influence of the soil concentration of K, NH_4 and Rb on the ^{137}Cs uptake (JACKSON et al 1965)

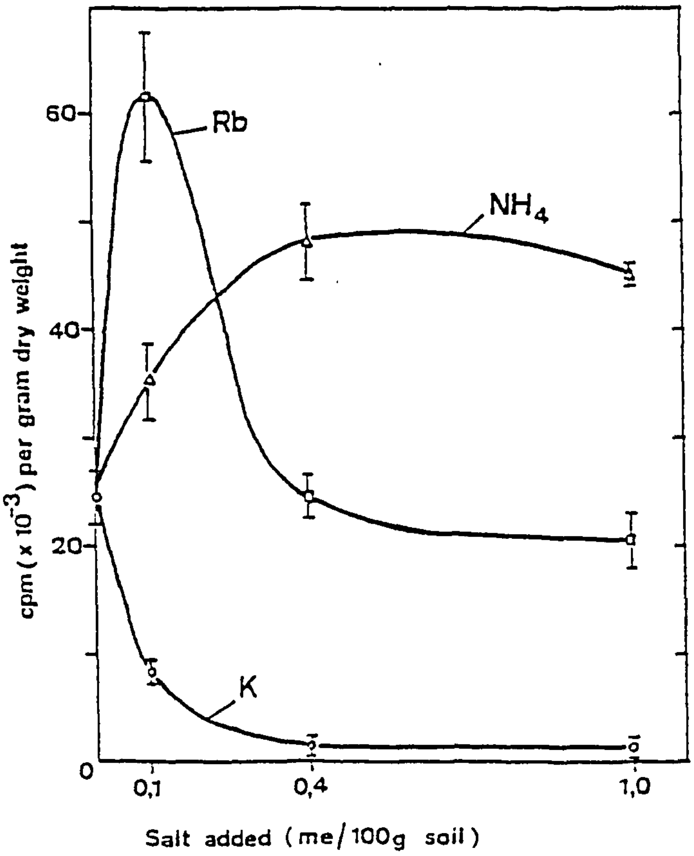


FIGURE 8

Response of Sr-uptake into red clover and rye-grass to the exchangeable Ca-concentration in the soil (ANDERSEN 1967)

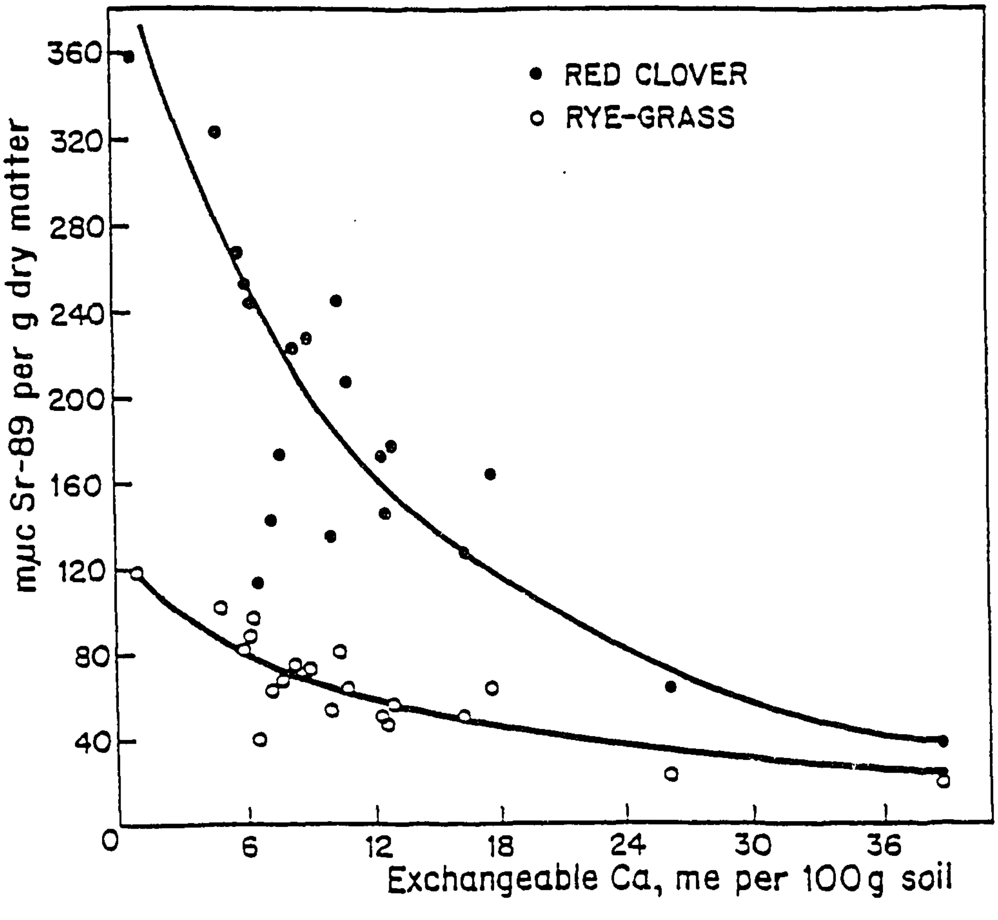
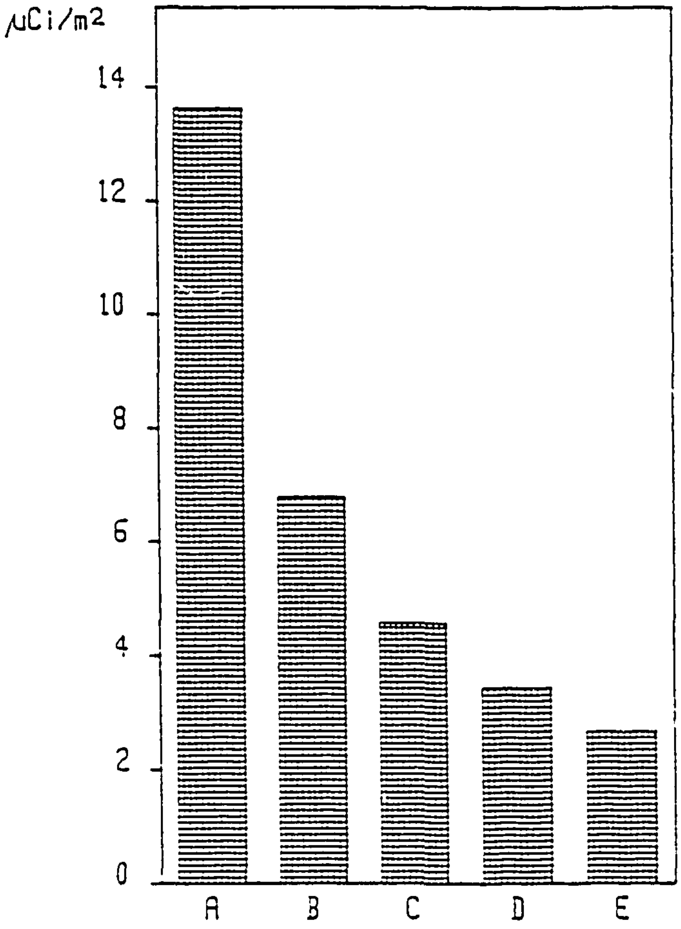


FIGURE 9

^{90}Sr taken up into barley, rye-grass, and red clover during a five years experiment

Distribution of the radionuclide:
A: 0-5 cm B: 0-20 cm C: 20-25 cm
D: 40-45 cm E: 80-85 cm (ANDERSEN 1967)



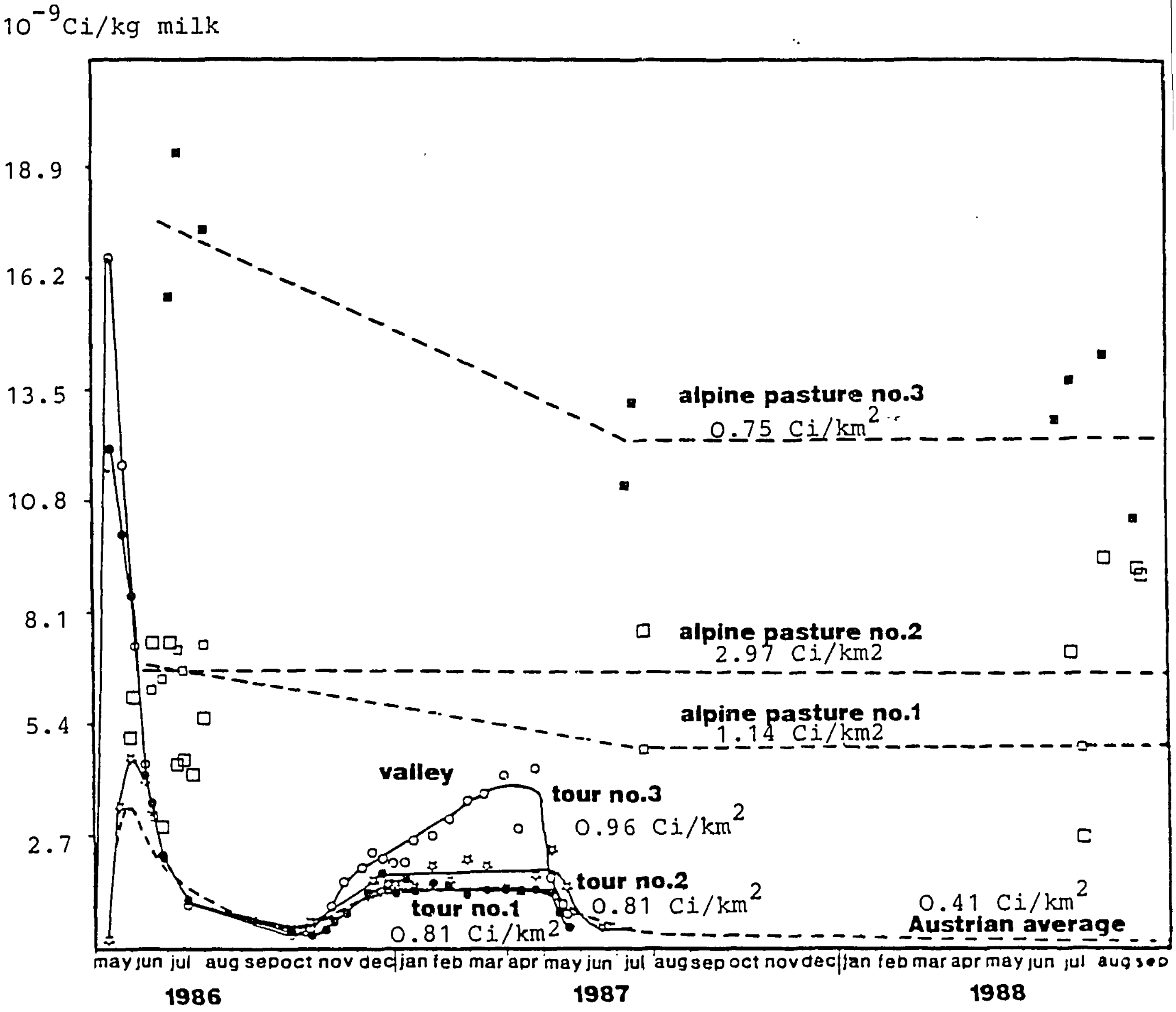


Figure 10: Variation in ^{137}Cs-activity concentration with time in six different areas within one province.

TABLE 1: Mean values for soil to plant transfer factors (HAUNOLD, HORAK and GERZABEK 1987)

	cereals	fodder plants	vegetables (leaves)	vegetables (tubers) fruits
Fe	0,0001	0,0008	0,0004	0,0001
Co	0,001	0,01	0,009	0,002
Sr	0,06	1,0	0,8	0,2
Ru	0,01	0,04	0,02	0,002
Cd	0,1	0,2	0,1	0,04
Sb	0,002	0,01	0,01	0,002
Cs	0,005	0,02	0,03	0,01
Pm	0,001	0,004	0,002	0,001
Tl	0,001	0,01	0,01	0,002
Ra	0,06	1,0	0,8	0,2
Th	0,0001	0,0008	0,0004	0,0001
U	0,0001	0,0008	0,0004	0,0001
Pu	0,000004	0,0002	0,0001	0,00001
Am	0,00002	0,001	0,0005	0,0005
Cf	0,00002	0,001	0,0005	0,0005

REDUCTION OF CESIUM LEVELS IN THE DIET THROUGH MANAGEMENT OF FOOD

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1. Introduction

In the past a large number of studies emphazised on the radionuclide transfer from soil to plant and plant to animal. However, the discrimination of radionuclides during food processing and culinary preparation can yield a significant dose reduction and is therefore worthwhile discussing. Most of the literature available was published in the sixties. This short paper is focussed on old data as well as on results obtained after the Chernobyl accident with special emphasis on cesium.

2. Definitions

Figure 1 gives the basic concept of discrimination processes from the raw material to the diet (QUINAULT 1989). In the case of direct use no further reductions in radionuclide contents of the diet are to be expected. The change in radioactivity due to food processing is defined by the F_p value, which can be calculated as the total amount of radionuclide in processed food divided by the total amount of this radionuclide in the original raw food (NOORDIJK 1989, QUINAULT 1989, Figure 2). Therefore, the F_p value is the fraction of the radionuclide remaining in the food after processing.

In a similar way QUINAULT (1989) defined reduction factors for the culinary preparation (Figure 2).

The figures presented in the following part of the paper are mean values or have been obtained by laboratory experiments. It should be taken into account that reduction factors may differ from this literature values due to other technologies used. Therefore measurements cannot be replaced by using this mean factors.

3. Milling of cereals

Since cereal kernels have a low mineral content (1.9-2.6%), the soil to plant uptake of radionuclides into the grains is lower than into the straw.'

The kernel of cereals consists of three main parts, the endosperm (83% of the kernel), the bran (14.5%) and the germ (2.5%). Germ and bran have ash contents of 4.5 to 5% in the case of wheat, the endosperm only 0.7% (GEISLER 1980). These figures indicate the nonuniform distribution of mineral nutrients in the kernel. Therefore, the discrimination of radionuclides during milling is not very surprising. Table 1 gives the results of measurements conducted in Austria in the years 1986 and 1987 (MÜCK et al. 1988). The activity concentration ratio between grains and flour was in all cases below 1, especially in white flour, which is characterized by low ash contents (480 mg ash/100g). ^{90}Sr yielded higher reduction than ^{137}Cs comparing the figures for winter wheat 1986. This may be explained by the different behaviour of cesium and strontium concerning the foliar uptake into plants. From the presented figures it may be assumed that cesium has been taken up to a greater extent from the fallout than strontium. Therefore, the strontium concentration of grains was mainly due to external contamination. This resulted in a significantly higher reduction factor. The activity concentration in bran was significantly higher than in the grains. The results presented are in good aggreement with data from VOIGT et al. (1989). Table 2 shows mean F_p values from a literature review conducted by NOORDIJK (1989). Milling of cereal grains to white flour led on average to a 50% decrease of the total cesium content. The F_p values depend on the yield of the product. Therefore the conclusion that transfer of Cs and Sr to dark wheat flour is lower than transfer to white flour is not justified as the yield of dark flour is much lower.

Processing bran with warm saline water (40°C, 1M NaCl) in a batch type procedure can reduce the contamination level by 75-90%, making bran available for either human diet products or animal feeding (APOSTOLATOS and HADJIANTONIOU 1989).

4. Vegetables, potatoes and fruits

A view reports are available in the case of iodine fractionation during processing. MURAMATSU et al. (1989) observed a significant reduction of radioiodine content of leaf vegetables due to washing and boiling (Table 3). The removal of radioactivity depends largely on the amount of radionuclides in the dust on the leaves, which can easily be washed off. The laboratory experiment with spinach contaminated with CH_3I led to a similar result as the samples contaminated with Chernobyl ^{131}I. This indicates that the gaseous ^{131}I from Chernobyl was mainly in an organic form.

Table 4 show the great variability of F_p values obtained for various plants and processes (NOORDIJK 1989). Focussing on the cesium data it becomes evident that boiling, blanching and washing yield a significant reduction of cesium in the end product. Obviously all these procedures are more effective in the case of an outer contamination. The F_p values for strontium are comparable with those obtained for cesium.

Special attention should be drawn to the significant effect of boiling mushrooms in 2% NaCl solution. It is well known that mushrooms are highly contaminated since the Chernobyl accident (GERZABEK et al. 1988).

Smaller effects of food processing were detected for root crops (Table 5). Peeling prior to boiling seems to be efficient for decreasing the cesium content of potatoes. In the case of actinides peeling yields an extremely low F_p value. Actinides show an exceedingly low soil to plant transfer. Therefore, soil adhesion is the main source for contamination and peeling the best countermeasure.

5. Meat processing

Table 6 gives mean literature F_p values for meat (NOORDIJK 1989). There does not seem to be a great variation due to the animal type. Only fish processing yields significantly lower radionuclide reductions. All F_p values are based on the assumption that the cooking or frying liquid is removed. The best effect in decreasing the cesium content of meat gave boiling or pickling. Boiled meat and bone are 60% and 75% lower in their cesium activity than the raw material, respectively. The effect of a combination of pressurized cooking and salting may be even higher (DRAGANOVICH and MICIC 1989, Table 7). Removal of strontium and iodine from bone is extreemly low due to boiling.

Marinating wild game is highly effective and may reach a Cs-decontamination of 90% (HECHT 1987). However, a significant influence of the marinade has been observed. The highest effect was obtained by acetic acid, followed by tartaric acid, red wine and buttermilk.

6. Dairy processing of milk

Milk and milk products are one of the principal ways by which food borne radionuclides are ingested. Furthermore the great importance of milk in childrens nutrition create high sensibility in the population.

In Austria the ^{137}Cs concentration in milk reached a maximum of app. 3.10^{-9}Ci/kg (average) 30 days after the Chernobyl fallout. However, in many cases the intervention level of 5.10^{-9}Ci/kg was significantly exceeded. Therefore considerable amounts could not be used as market milk and an alternative utilization had to be chosen.

In 1963 LAGONI et al. published data on the quantitative distribution of radionuclides in milk products. From figure 3 significant differences are observable. Cream and especially butter is depleted in cesium and strontium contents. Butter fat is free from these radionuclides. On the other hand skimmilk is enriched, particularly in strontium. Significant differences arise due to the casein production. In rennet casein ^{90}Sr is concentrated, while acid casein shows an only small enrichment. In both cases cesium is depleted as compared to the skimmilk. Cesium, a highly soluble monovalent cation has a tendency to concentrate in the more aqueous fraction during physical separation procedures, the high fat fractions are depleted in cesium. Data obtained after the Chernobyl fallout have a good agreement with the older literature (McENRI et al. 1989). Nevertheless up to 90% of the total cesium activity was observed in the whey. It requires app. 35 kg of whole milk to produce 1 kg of whey powder, the concentration factor for cesium is at least 30.

To minimize the level of radiocesium in dairy products from contaminated milk, production should be directed away from whole milk powder and towards cream, butter and buttermilk (McENRI et al. 1989).

Another possibility to reduce cesium in the diet derived from milk products is to remove it directly by the use of ion exchange resins. GIESE et al. (1989) conducted experiments with reliquified and ultrafiltrated whey, which was high in cesium (80 - 160.10^{-9}Ci per kg dry weight) due to the Chernobyl fallout. Four to five cycles through the exchange material (ammonium-copper-hexacyano-ferrate) were needed to decrease the cesium concentration below 1.10^{-9}Ci/L. The decontaminated spray dried product is intended for animal mixed feeds. More decontamination cycles would render it siutable in principle for human consumption (GIESE et al. 1989).

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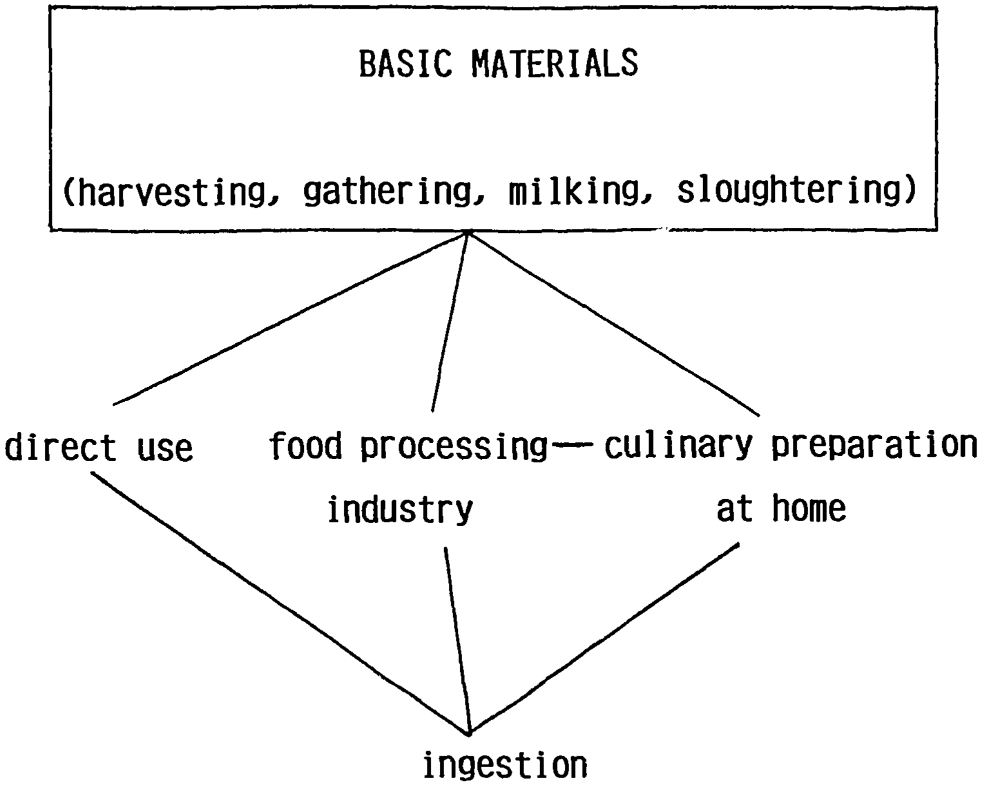
FIGURE 1: CONCEPTS (QUINAULT 1989)



The result of one process is expressed as a percentage of the activity of the starting material.

FIGURE 2: Simple models for the calculation of the activity concentration reduction (QUINAULT 1989).

A) Food processing

$$F_p = \frac{C_{final}}{C_{starting}}$$

$F_p > 1$ starting material not homogeneous, or effect of drying

$F_p < 1$ dilution or loss

$$C_{product} = \sum_i F_p(i) \cdot C_{basic\ material}(i)$$

B) Culinary preparation

$$P_p = \frac{C_{final}}{C_{starting}}$$

$$C_{final} = \underset{\text{mass losses}}{P_p} \times \underset{\text{washing}}{P_p} \times \underset{\text{cooking}}{P_p} \times C_{starting\ product}$$

TABLE 1

Influence of milling on the activity concentration ratio between flour and grain (MÜCK et al. 1988)

cereal	milling intensity	concentration ratio ^{137}Cs	^{90}Sr
winter wheat 1986	bran	2.89	4.42
	W 700	0.70	0.17
	W 480	0.47	0.11
spring wheat 1986	W 700	0.46	0.62
winter rye 1986	R 960	0.64	0.68
	R 500	0.36	0.24
winter wheat 1987	W 700	0.64	0.35
	W 480	0.35	0.24

TABLE 2: F_p values for the processing of cereals

raw material	method of processing	Sr	Cs	Pu/Am
wheat grain	milling to white flour	0.2	0.4	0.1-0.2
	milling to dark flour	0.1-0.2	0.1	
	milling to bran	0.6-0.9	0.6	
rye grain	milling to white flour	0.6	0.5-0.6	0.2
barley grain	milling to white flour	0.5	0.4-0.6	0.1-0.2
oats grain	milling to white flour	0.3	0.4	0.4

after NOORDIJK (1989)

TABLE 3

decontamination of radioiodine from vegetables

	washing	boiling	residue
(A)			
spinach	12%	58%	30%
shungiku (Chrysanthemum coronarium)	8%	70%	22%
leaf beet		80%	20%
(B)			
spinach (I_2)		33%	67%
spinach (CH_3I)		58%	42%

(A) Chernobyl samples
(B) laboratory experiment

after MURAMATSU, UCHIDA, SUMIYA, YOSHIDA and OHMOMO (1989)

TABLE 4

F_p Values for the Processing of Vegetables and Fruit

plant	method of processing	Sr		Cs		I
			outer c.		outer c.	outer cont.
spinach	washing	0.4-1.0	0.2	0.6	0.2	0.07-0.8
	washing and blanching	0.4-1.0	0.4-0.7	0.5	0.2-0.9	
	canning	1.0				
cabbage	removing inedible parts				0.9	0.5
	washing	0.3	0.07	0.9	0.09	0.4
	cooking and rinsing	0.8				0.2 -0.5
	canning	0.4		0.2		
beans	washing	0.1				0.7
	blanching	0.5	0.3	0.7	0.3	0.2
	canning	0.3-0.8		0.4-1.0		
	froth flotation	0.4-0.6	0.4	1.0	0.4	
onions	removing inedible parts				0.2	0.2
	washing				0.3	0.2
	peeling&wash.&boiling	0.5				
mushrooms	boiling	0.7-0.9		0.5		
	boiling in 2% NaCl	0.2		0.2	0.3	
	canning	0.5				
cucumbers	pickling			0.15		
	canning	0.35		0.06		
peaches	peeling	0.5				
	canning	0.5				
	lye peeling	0.09		0.03		
strawberries	rinsing	0.7		0.6		

after NOORDIJK (1989)

TABLE 5

F_p values for the processing of potatoes and carrots

raw material	method of processing	Sr	Cs	Pu/Am
potato tuber	boiling with peel	0.9-1.0		
	peeling	0.8	0.7	0.03-0.04
	peeling and boiling	0.7-0.8		
	frying	0.6		
	canning	0.7	1.0	
	decontamination	0.5	0.05-0.2	
carrot	scraping and washing and boiling	0.8		
	canning	0.8		

after NOORDIJK (1989)

TABLE 6

F_p Values for Meat Processing

Raw material	method of processing	Sr	Cs	I	Ru
meats of mammals (cow, pig, sheep, deer, rabbit)	boiling meat	0.5	0.4	0.6	0.3
	boiling bone	0.999	0.2-0.3	0.98	0.7
	frying meat	0.8	0.7-0.8		
	pickling wet		0.1-0.6		
	dry		0.8		
	marinate		0.1-0.6		
	sausage production		0.4-1.0		
birds	boiling meat	0.5			
fish	boiling	0.9	0.9		
	frying meat		0.9		

after NOORDIJK (1989)

TABLE 7

F_p values obtained in decontamination experiments for Cs (lamb, veal)

lamb

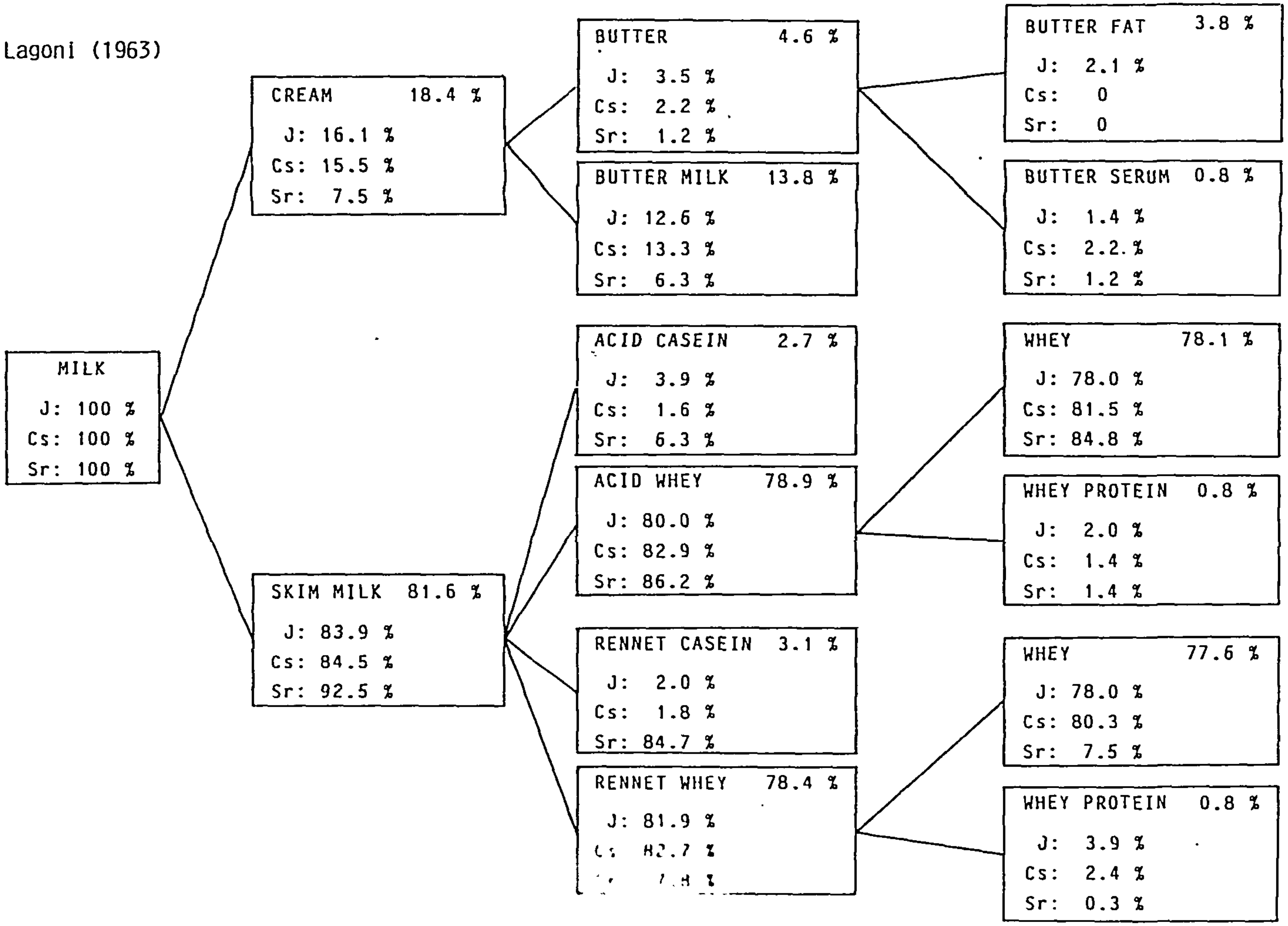
salted meat	salted and cooked
0.17 - 0.62	0.09 - 0.49

veal

soured meat	pressure cooked meat
0.10 - 0.14	0.02 - 0.08

after DRAGANOVIC and MICIC (1989)

FIGURE 3: Quantitative distribution of radionuclides in milk products.



Lagoni (1963)

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