Fluxes of Radiocaesium to Milk and Appropriate Countermeasures

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Abstract. Radiocaesium contamination of milk persists in some areas of Belarus, Ukraine and Russian Federation which received fallout from the Chernobyl accident. In general, effective countermeasures have been used which ensure that radiocaesium activity concentrations in milk from collective farms does not exceed intervention limits. However, farming practices differ greatly between the large collective farms, and the small, family operated private farms which are responsible for a major part of the food consumed in many rural areas. As a result of comparative low rate of use of fertilizers and utilization of poor quality land ^{137}Cs activity concentrations in milk from family-owned cows continues to exceed intervention limits in some areas. It is therefore important to be able reliably to quantify the rates of transfer of ^{137}Cs to private milk, so that all areas where persistent problems occur are identified, and appropriate countermeasure strategies applied. Where there is considerable variation, within a few km^2, in both soil type and deposition, the ^{137}Cs content of private milk is highly variable. However, combining information about soil type, transfer rates for each major soil type, deposition, pasture size and grazing strategies can be a useful method of quantifying transfer of radiocaesium to milk. Geographical information systems provide a promising new tool to integrate these factors. Effective countermeasures are available to reduce radiocaesium transfer to private milk. Private farmers are more sceptical of such methods than the scientists, administrators and agriculturalists in their society, particularly those methods involving the use of chemical additives given to their animals. Increased information efforts on the local level appears to be a prerequisite for a successful implementation of necessary countermeasures.

Introduction

This paper briefly summarises some studies in ECP9 which have focused on the transfer of radiocaesium to milk and appropriate countermeasures in small selected study sites [1]. Milk is an important potential source of radiocaesium for humans. It has become evident after the Chernobyl accident that the extent of radiocaesium ingestion via milk by humans depends on a large number of ecological, agricultural and socio-economic factors. To be able to reliably quantify the intake of radiocaesium in milk all these factors need to be considered.

In the short and medium term after the Chernobyl accident the contamination of milk from collective farms was the focus of concern, because of its importance in contributing to collective dose. Much effort has been devoted to ensuring that radiocaesium contamination of collective milk supplies was below intervention limits. Furthermore, in heavily contaminated areas private dairy animals were removed from residents and replaced by supplying uncontaminated milk from central sources. Over the medium and longer term there has been a realization that radiocaesium activity concentrations in milk of private farmers living in villages in some less highly contaminated areas continues to exceed intervention limits.

Assessments need to be carried out on a large scale to give an estimate of the overall importance of milk as a source of radiocaesium in the contaminated areas for decision makers. However, it is helpful to carry out detailed studies in smaller areas to ensure that the focus of the modelling exercises is correct, and that they take into account all the important factors determining radiocaesium intake via milk. ECP9 has been focusing its studies in selected contaminated study sites in Ukraine, Russia and Belarus to try and quantify the contribution of different potential sources of radiocaesium to the diet of village residents. The study sites were centered on:

- Milyach village, Kolos and Kliporop collective farms, Dubrovitsa district, Rovno region, Ukraine
- Shelomi village and Rodina collective farm, Novosybkov district, Bryansk region, Russian Federation
- Savichi village, Bragin region, Belarus

Milk production in the study areas occurred both in large collective farms which were mainly responsible for the supplies to the towns in the area, and on the private farms in the villages where the workers on the collective farms live. Milk production on the collective was mechanized to a considerable extent. Herds were large (usually >200 dairy cattle) and milking, harvest and transportation carried out with the help of machines. Equipment for cooling and storage of milk was available. The private farmers produced milk for consumption in the family, each of which commonly have one cow. Milk yields were between 2000 and 2500 kg y^{-1} in both production systems.

This paper will summarize the information ECP9 has obtained on transfer and fluxes of radiocaesium to milk, and briefly report on a questionnaire which attempted to critically evaluate the attitudes of farmers and other relevant professionals towards potential countermeasures. Aspects of the transfer to milk will be illustrated using data from the Ukrainian study site, which was the most variable from a radioecological perspective, incorporating a wide variation in soil types and including both collective and private farming.

ECP9 evaluated historical data on transfer to milk for the study sites and carried out further directed sampling in 1994 and 1995 of soil, vegetation and milk. Transfer to milk was quantified using classical radioecological methods, but also considering spatial variation using geographical information systems (GIS) and total fluxes to milk by evaluating agricultural production methods.

Factors affecting radiocaesium transfer to milk

Many factors affect the extent to which milk will be contaminated by radiocaesium. The major factors include:

- Deposition rates of radiocaesium
- Soil type and consequent varying rates of transfer of radiocaesium to milk
- Rates of decline in radiocaesium activity concentrations in milk
- Production strategies
- Application of countermeasures

To understand the processes which are important for the transfer of radiocaesium, knowledge of the farming system is also required. In the study sites, the grazing season starts in May, and feeding is again necessary from the beginning of October. During the summer season both the collective and private cows obtain the most of their energy intake from grass, and no (private) or little grain or commercial concentrates are fed. In Table 1 the rations provided for the cattle in the two productions systems are given.

Table 1 Daily rations and ^{137}Cs content for dairy cattle in a collective farm and a typical private farm in the Dubrovitsa study area

Farm type		Grazing period		Feeding period	
Collective farm	^{137}Cs	May - September		October - April	
Feed	Bq kg^{-1} fw	kg d^{-1} fw	Bq d^{-1}	kg d^{-1} fw	Bq d^{-1}
Pasture		45			
Hay	1170	-		1	1 170
Straw (Rye)	230	-		4	920
Silage (grass, maize)	340	-		15	5 100
Concentrate (grain)	250	1	250	2	500
Total					7 690
Private farm	^{137}Cs	May - September		October - April	
Feed	Bq kg^{-1}	kg d^{-1}	Bq d^{-1}	kg d^{-1}	Bq d^{-1}
Pasture		45			
Hay	720	-		10	7 200
Concentrate	250	-		0.3	75
Total					7 275

Concentrated feeds were generally available only in small quantities to the private farmers, while the collective cows received 1-2 kg daily. Grass and roughages used by the collective cows were harvested on fields where extensive countermeasures had been undertaken. Private cattle grazed partly on improved and rough pastures, and also within forest clearings where ^{137}Cs activity concentrations in the grass was high compared with other pastures. Hay for winter feed was collected in forests and rough pasture. As a result, the ^{137}Cs activity concentration of winter hay for private cows was highly variable (range 41 - 1 299 Bq kg^{-1} dw in 1994 and 104 - 7700 Bq kg^{-1} dw in 1995). Some of the hay was exchanged for hay with a lower ^{137}Cs content by the collective farm as a way to reduce the ^{137}Cs content of locally produced milk.

Deposition rate

The deposition rate is commonly quantified on a large scale for planning purposes into broad categories, defined by mean deposition rates. However, it is well known that deposition of radiocaesium was heterogeneous, and can vary over more than one order of magnitude within a few metres. There is often good sample data, at a local level, on the variation in deposition in contaminated areas, and if such information is evaluated in a GIS, such as kriging and interpolation, then the areas of greatest uncertainity in the deposition measurements can be identified [2].This strategy has been used by ECP9 to direct sampling requirements to improve deposition information where it is most needed.

Soil type and consequent varying rates of transfer of radiocaesium to milk

It is well known that uptake rates of radiocaesium vary considerably with soil type. Whilst soil types can be classified broadly in large areas, local variations in soil types can give rise to great variability in transfer of radiocaesium to milk. It is fortunate that for many of the contaminated regions soil type has been classified precisely, and mapped within each collective farm. At the highly variable Ukrainian site, which has a wide variety of different major soil types, the transfer values measured for soil to plant transfer (Table 2) have been used to predict the activity concentrations in vegetation for each pasture used by collective and/or private cows.

Table 2 Aggregated transfer coefficients (T_{ag}) (Bq kg^{-1} dw/Bq m^{-2}) for the dominant soil groups at the Dubrovitsa study site for 1994-1995

Soil type	Soil to grass T_{ag} (m^2 kg^{-1} x 10^{-3})	
	Range	Mean ± SD
Peaty - cms*	9.36 - 120.94	33.06 ± 30.89
Peaty + cms*	0.64 - 42.23	9.77 ± 9.64
Soddy podzols	<0.34 - 8.74	3.21 ± 2.50
Gleys	0.33 - 3.57	1.23 ± 1.01
Alluvium	0.11 - 0.72	0.24 ± 0.18

* - cms = without countermeasures, + cms = with countermeasures

There are obvious differences between transfer rates for pastures with different soil types, with T_{ag} values showing a large standard deviation comparable to the mean for all soil types. The effectiveness of countermeasures can be seen clearly for the peaty soils. Soil type varies within some pastures, and therefore T_{ag} values for only one soil type applied across whole pastures may be too simplistic and inaccurate, particularly for estimating transfer to milk since cows, by their grazing, will integrate over the whole pasture.

Predicted ^{137}Cs contents in grassy vegetation were calculated for each pasture used for collective and/or private dairy cows by combining information on deposition and the proportion of each soil type in each pasture with the respective T_{ag} values, taken as the mean value from Table 1, in a GIS. This provided a mean predicted radiocaesium activity concentration for grassy vegetation for each pasture which took account of the relative proportion of each major soil group in each pasture. Such an approach takes account of the total surface area of the ecosystem being assessed as recommended by [3]. Mean values were then calculated for ^{137}Cs deposition and vegetation activity concentration for all the pastures used by the two collective herds in the study site and these "weighted" values are given in Table 3. Such weighted values take into account the relative sizes of each of the pastures grazed by the collective cows which is an important consideration since pastures sizes can vary by a factor of ten, and averages taken for all pastures used by each herd would be inappropriate. In addition, the ^{137}Cs activity concentration of milk from the summer grazing period has been predicted by applying a concentration ratio for milk/grass of 0.13, based on recommended values for F_m and daily intake [4]. The independently predicted ^{137}Cs activivty concentration of milk is compared with that actually measured in Table 3.

Table 3 Weighted mean values for ^{137}Cs deposition and vegetation contamination for the pastures used by the collective cows, and predicted milk activity concentrations

Collective	Predicted mean ^{137}Cs values			Measured
	Deposition ($kBq\ m^{-2}$)	Vegetation ($Bq\ kg^{-1}$ dw)	Milk ($Bq\ l^{-1}$)	Milk ($Bq\ l^{-1}$)
Kolos	117	546	71	61
Kliporop	80	611	79	79

Measured ^{137}Cs activity concentrations for collective milk in 1994-95 varied from 50 to 104 Bq l^{-1} for Kolos cows and 42 to 103 Bq l^{-1} for Kliporop cows. The predicted values agree well with the observed and suggest that this approach has some merit. The spatial variation in predicted ^{137}Cs content of milk based on the predicted ^{137}Cs values in vegetation is shown in Fig. 1.

Fig. 1 Predicted ^{137}Cs content of milk over the Dubrovitsa study site

Similar calculations to that above have been carried out to estimate T_{ag} values comparing the weighted mean values for ^{137}Cs deposition and vegetation contamination with the mean measured ^{137}Cs activity concentration in milk over the summer grazing period (including all values from May to September 1995). The resulting T_{ag} values for Kolos and Kliporop are 0.52 and 0.98 $m^2\ kg^{-1}$ x 10^{-3} respectively. Such T_{ag} values, whilst giving an overall value for the herd, will be affected by the proportion of each soil type in each herds' pasture area. For the Kolos herd 75% of the pastures used by the herd have a gley type of soil, whilst the Kliporop cows graze pastures with 76% peaty soils.

Weighted mean values for ^{137}Cs deposition and vegetation activity concentration for all pastures used by the private cows in each village have been calculated and the values are given in Table 4, which also gives the predicted milk values, calculated as above, for comparison with measured values for 1994 and 1995. The division of Milyach into -cms and +cms is because some of the cows in this village graze a pasture which has not been ploughed or treated with fertilizers. All other pastures have been treated to reduce radiocaesium uptake by vegetation.

Fig. 1 Predicted Cs-137 activity concentrations in milk calculated by field for the Dubrovitsa study site, Ukraine

Table 4 Weighted mean values for ^{137}Cs deposition and predicted vegetation content for pastures used by each village and comparison with predicted and measured ^{137}Cs content of milk

Village	Predicted mean ^{137}Cs values			Measured
	Deposition ($kBq\ m^{-2}$)	Vegetation ($Bq\ kg^{-1}$)	Milk ($Bq\ l^{-1}$)	Milk ($Bq\ l^{-1}$)
Villages within the Kliporop farm				
Milyach - cms	111	3587	466	414
Milyach + cms	75	576	75	238
Lugovoye	95	305	40	159
Bila	194	1128	147	208
Villages within the Kolos farm				
Vilun	224	545	71	33
Zagreblya	153	1072	140	20

The agreement between predicted and measured milk activity concentrations is again reasonable, but not as good as for the collective herd. The observed discrepancies are probably due to the more variable grazing conditions of private cows and to sampling of milk from sub-herds at a single time, which would not be representative for the total pasture available to each herd over the summer grazing season. This emphasizes the importance of ensuring that samples are collected in a representative manner. For instance, the private cow milk in Zagreblya was sampled from cows which graze an area of the pasture dominated by alluvium soils, which have a comparatively low T_{ag} value. However, the total pasture at Zagreblya has more peaty soil than alluvium and therefore the predicted value is higher than that measured. Nevertheless the general trend where all the villages associated with the Kliporop collective farm have higher contamination levels in milk, even though the pastures which they graze are less contaminated. This is due to the predominance of peaty soils on the Kliporop farm. In contrast the two villages in the Kolos area have higher deposition of ^{137}Cs, but lower milk contamination because of the predominance of gley soils.

In addition, the data in Table 4 has been compared with measured ^{137}Cs levels in milk to calculate T_{ag} values which take account of all pastures grazed by the private cows of each village. These T_{ag} values are given in Table 5, and are compared with the dominant soil types for each villages pastures.

Table 5 T_{ag} values for private milk comparing weighted mean values for all pastures used by the cows with predicted and measured ^{137}Cs in milk

Transfer parameter	Village					
	Milyach -cms	Milyach + cms	Lugovoye	Bila	Vilun	Zagreblya
Predicted milk T_{ag} ($m^2\ kg^{-1} \times 10^{-3}$)	4.20	1.00	0.42	0.76	0.32	0.92
Measured milk T_{ag} ($m^2\ kg^{-1} \times 10^{-3}$)	3.73	3.17	1.67	1.07	0.15	0.13
Dominant soil type in pastures	Peat bog -cms	Peat bog + cms	Soddy podzol	Peat bog + cms	Gley	Alluvium & peat bog

Using an approach of calculating T_{ag} values with predicted vegetation contamination for all pastures and measured milk values results in estimated transfer parameters which appear to be unrealistically high (eg. in Milyach + cms, Lugovoye) or low (eg Zagreblya), presumably for the same reasons as those discussed below Table 4.

Rates of decline in radiocaesium activity concentrations in milk

It has proved particularly difficult to quantify changes in radiocaesium levels in milk with time in any generic way, because most contaminated pasture has been treated to minimise radiocaesium transfer to milk. Consequently measured radiocaesium levels reflect both time-dependent changes and responses to countermeasures and calculated half-lives will be site specific.

A comparison has been made of the changes with time in transfer to collective and private cow milk, using milk data for Milyach private cows which graze the peaty-soil pasture which has never received countermeasures (Fig. 2). Radiocaesium activity concentrations in the collective milk declined most rapidly in 1988, when extensive countermeasures were used at the site. For the private milk the decline in ^{137}Cs content of milk has occurred gradually over 1991 to 1995, with the exception of a flooding event in 1993. The calculated ecological half-lives, discounting the 1993 temporary rise, are 3.8 y for the private milk and 2.7 y for the collective milk with R^2 values of 0.96 and 0.77 respectively.

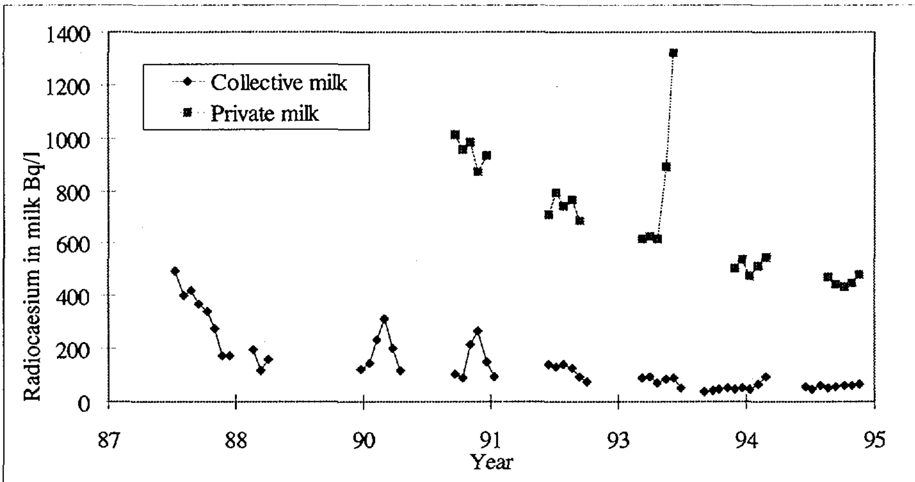

Fig. 2 Comparison of the changes with time in ^{137}Cs content in collective cow milk and private milk from cows grazing untreated pasture.

Production strategies

The extent to which radiocaesium is transferred to milk depends on the agricultural procedures used in the contaminated area. The type of land used, its management, and the consequent transfer of radiocaesium to milk differs between the collective and private farming systems, as previously indicated. Major differences in radiocaesium intake in the two production systems are related to the type of land used for production of feeds, ie. improved pastures and fields for the collective as opposed to a certain amount of unimproved and forest land for the private sector.

Transfer of radiocaesium from soil to hay on the collective fields was typically 2 to 10 times higher than the transfer to rye. Per unit of land used for production, cattle which are fed grains would therefore receive less ^{137}Cs than those which graze or feed on hay. Cattle on the collective farm received about 18% of the dietary energy from grains, while 36% of the energy requirements were covered by pasture and the remaining 46% from roughages given during the indoor feeding season. The private farms had little grain to give their animals; more than 95% of the energy came from pasture and hay. This feeding pattern with a low intake of grains made private cows more likely to produce milk with a high ^{137}Cs content than collective cows, especially when hay is cut on unimproved rough pasture and forest clearings.

Although plant productivity has been maintained at a reasonably high level during the years after the Chernobyl accident, partly as an effect of the deliberate use of fertilizers as a countermeasure, the nearly complete lack of mineral fertilizers which has been experienced by the collective farms during 1994 and 1995 will have a strong effect on plant productivity in the coming years, and may also lead to increased transfer of ^{137}Cs to vegetation. Mineral fertilizers were only available to the private farmers in very limited quantities; instead these farmers depend heavily on the use of cattle manure for their plots. The continued application of comparatively highly contaminated cattle manure may increase the ^{137}Cs content of soil in the private vegetable gardens.

In a study of the fluxes of energy and radiocaesium which has been carried out on the basis of the production figures from the collective farms, it is apparent that a large proportion of the energy (77% of the brutto production in plant crops) is either undigestible or is being used for maintenance of the production animals (Table 6). Likewise, only 12% of the radiocaesium in the plant crops is contained in grains and other products exported from the farm. The remaining 88% is recycled via manure and compost to the collective fields.

Table 6 Estimate of fluxes of energy and ^{137}Cs through the collective farms at the Dubrovitsa study site during a one year production cycle. Energy is calculated as the net energy available from the feeds after digestion and absorption

	Energy ($TJ\ y^{-1}$)	^{137}Cs Flux ($GBq\ y^{-1}$)
Total plant production	167	8.5
Use of plant production:		
Grains to state	27.4	0.54
Grains/potato to private	5.5	0.3
Animal feeds	131.0	7.7
Animal production:		
Milk and meat sold to state	6.5	0.22
Meat sold to private	0.2	0
Recycled (manure and compost)	124.0	7.5

The average private farm cultivates an area of 0.3 to 0.4 ha to grow a variety of vegetable crops. On each farm there are on average 3.4 adults and 2.3 children below 16 years of age. A variety of domestic animals were kept: with means of 1.3 dairy cows, 0.1 goat, 10 chickens, 2.8 pigs, 2.2 geese, 2.7 rabbits, 1.9 turkeys and 1.2 ducks. The calculated energy content of the products from these animals were 11.5 GJ, from which 9.1 GJ or 79% can be attributed to milk. The total plant production on the farm was 29.5 GJ, mainly from potatoes and grain. A large, but undetermined part of this plant produce was used to feed the animals on the farm. In particular, a significant part would have to be used for the yearly production of about 240 kg of pork (17% of animal produce). However, the major feed energy in the private farming system was hay and pasture for the dairy cows (85 GJ per year). With an estimated mean concentration of ^{137}Cs of 400 Bq kg^{-1} in samples of winter hay for the 1994-1995 season which were measured in 18 private farms in 1994, and an average pasture contamination of 3587 Bq kg^{-1} (Milyach -cms, Table 4) roughages represented the dominating flux (9.3 MBq y^{-1}) of ^{137}Cs in the private farming system. Comparable figures for the families in Milyach where countermeasures were applied was 2.3 MBq y^{-1}. Although uncertainty is involved in the estimation of radiocaesium concentrations in the winter feeds, as demonstrated in samples taken towards the end of the winter feeding season (which had average values from 700 to 2300 Bq kg^{-1}) roughages used to feed dairy cattle were by far the most significant influx of radiocaesium to the private farms. For comparison, plant produce from the private plot contained 313 kBq, and animal produce excluding milk a total of 34 kBq y^{-1} of ^{137}Cs. In the villages of Vilun and Zagreblya, with low concentrations of ^{137}Cs in milk, a total of 100 kBq y^{-1} was produced, while in the farms in Milyach which used pastures where no countermeasures had been performed, the milk produced contained 760 kBq y^{-1}. Berries, fungi and other forest products, which were used for human consumption, contributed 16 kBq y^{-1} on the average farm.

Food energy from vegetables, potatoes, grains and animal products were sufficient to maintain a family of 10 adults. Thus there is a substantial food production potential in the private farms, and the production per unit area in the vegetable gardens are generally higher than in the collective fields. The large fraction of food energy from milk clearly emphasizes the crucial importance of the dairy cow in providing animal products for the rural population in this study site. Since milk is also a major contributor to the flux of ^{137}Cs, countermeasures which can limit the transfer of radiocaesium to milk will be particularly important in reducing radiocaesium intake by the rural farming population.

Application of countermeasures

In the ECP9 study area a variety of different countermeasures had been implemented. Deep ploughing and reseeding of all pastures was carried out during 1987-1988. Fertilizers were used on all fields in the collective farms. Both vegetable- and grass crops received 1.5 times the pre-Chernobyl rate of K during 1988-90. New schemes for crop rotations which were beneficial with respect to reducing ^{137}Cs transfer were devised. A radiology service was established in Milyach since 1992 which monitored milk and meat from the collective farm, and food products from the private farms in the villages. The reduction factors obtained with the available countermeasures are shown in Table 7.

Table 7 Use of countermeasures in agricultural production at Chapayev collective farm during 1988-93, and observed reduction factor

Countermeasure	Area (ha)	Number of animals	Total use	Reduction factor
Deep ploughing	990			1.3-2
Mineral fertilizer	720		360 t	2-2.5
Liming	420		1260 t	1.5-2.5
Fertilizer, pasture	250		75 t	2.5-3
Fertilizer + Sapropel*, pasture	440		13200 t	1.7-1.9
Prussian Blue boli for animals	-	80	250 boli	2.2-2.8
Prussian Blue powder	-	65	3250 g	1.5-1.9

* Sapropel - organic deposits with some clay minerals from reservoir bottom sediments

A questionnaire was completed with 14 of the private farmers involved in the agricultural survey in Milyach to collect information on the actual use of countermeasures. The results showed that only small changes in agricultural practices had taken place in the village after the Chernobyl accident. Partly as a result of international studies, caesium binders had been used for the private cattle on the farms where interviews were carried out. In 1995 mineral fertilizers were used on less than half of the farms, and countermeasures were only needed for the few remaining cows which gave milk with ^{137}Cs activity concentrations above the intervention limits (Table 8).

Table 8 Results from interviews with owners of 14 private farms in Milyach and Vilun on the use of countermeasures to control ^{137}Cs contamination of agricultural produce

Countermeasures	Yes N	No N	Comments
A) Countermeasures used in 1986-94			
Additional soil treatment practices	0	14	
Mineral fertilizers	12	2	Manure used on all farms
Special chemicals in any form	0	14	
Changes in plant production	0	14	Fields changed, but not crops
Changes in animal production	0	14	
Caesium binders for animals	12	2	Hexacyanoferrate powder, humalite
B) Countermeasures in use in 1995			
Additional soil treatment practices	0	14	
Mineral fertilizers	6	8	Manure used on all farms
Liming	5	9	Planned for autumn 1995
Caesium binders for animals	3	11	Limited current need
Apply restrictions in grazing of cattle	0	14	

It is evident that the usefulness of countermeasures is dependent not only on their radiological effectiveness, but also on other factors such as practicality (including availability, cost and effort) and acceptability [5]. ECP9 has used a questionnaire with a range of different types of people to evaluate attitudes to countermeasures which could be used for village residents.

The range of countermeasures incorporated included all methods which ECP9 participants considered to be potentially useful for reducing radiocaesium contamination levels in private produce. The countermeasures were sub-divided into three categories: pasture-based, animal-based and household-based.

Pasture-based countermeasures included two approaches, one of pasture improvement, ranging from radical improvement including deep or surface ploughing, reseeding and fertilization to less intensive procedures such as surface fertilization only. The second approach considered was exchange of pastures. It is possible to allocate land to private farmers which is either less contaminated, or produces less contaminated vegetation due to the soil type.

Animal-based countermeasures considered five approaches, one of "clean feeding" when uncontaminated feed can be provided to animals, and four involving the use of radiocaesium binders to reduce gut uptake of radiocaesium, thereby reducing radiocaesium contamination levels in milk and meat. The binders considered were Prussian blue provided as a powder, in a boli which resides in the rumen and release the binder for a period of 4-8 weeks [6] or within a salt lick. A further binder, clay minerals, which can be given together with fodder or incorporated into concentrate was also included.

Household-based countermeasures considered four approaches. The first two were selling contaminated private produce to state enterprises or the collective (or swapped for less contaminated equivalents) and local radiometric inspection of food. The last two approaches were dietary advice and advice on methods of cooking food to reduces the intake of radiocaesium.

The questionnaire was used for five different groups of five people in each republic:

- Private farmers - people who were resident in the respective study sites
- Collective farm managers (not Russia)
- Agricultural scientists
- Administrators, who deal with the Chernobyl problem at a local level
- Radioecologists - individuals who were not directly involved in ECP9.

For each countermeasure the participant was asked to give a rating from 0-5 (least to most positive) on four different aspects concerning the practical use of these countermeasures. Respondents were asked to comment on the effectiveness, effort required and availability of each of the 11 categories. In addition, the participant was also asked to answer "Would you do it?" on the same scale. Therefore, the maximum possible total score for each countermeasure over all classes was 20, and for all 11 countermeasures, 220.

All questionnaires were completed as intended with the exception of collective farm managers in Russia. Household-based measures were scored very differently in the three republics with Ukrainians giving high scores and Belarussians relatively low scores. Selling foodstuffs scored lowest for most groups, presumably because the people are subsistence farmers and need to keep all the food they produce for themselves. Overall the highest scores were given, in declining order, for:

pasture improvement > provide clean feed > local radiological inspection of food

and the lowest overall scores were given, in declining order, for:

salt licks > boli > selling contaminated produce

It is fundamentally important whether the private farmers, to whom these countermeasures are directed, will consider applying the countermeasures. There was a tendency among them to be more reluctant to use countermeasures involving the direct treatment of their animals, probably because of the overriding importance to the private farmers of their cows. The total scores are compared for each groups in Fig 3. Private farmers in Russia and Belarus scored consistently lower than the other respondent groups, but this was not the case for the Ukrainians, possible because they were familiar with many of the measures because they are living in an area which has been the focus of much research activity, and many of them have personal experience of the countermeasures.

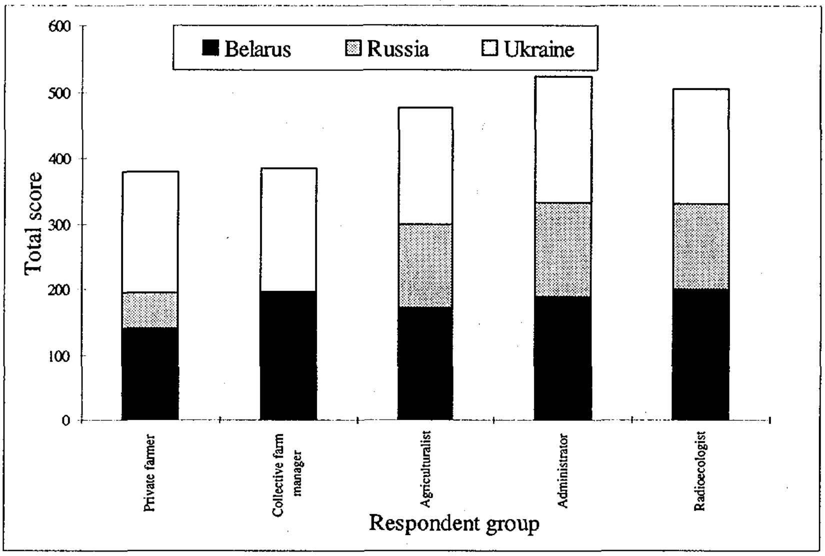

Fig 3 Comparisons between total scores of the different respondent groups.

Such assessments of countermeasures may be a useful tool and these initial results suggest that effort needs to be devoted to involving and informing the private farmers themselves.

Conclusion

There are a wide variety of ecological and production strategy factors which determine the extent of radiocaesium contamination of both collective and private milk. Because there is detailed information available on soil types within most of the contaminated area it should be possible to combine information on deposition rates, soil type and grazing strategies to identify the areas where pasture grass or fodder would have the highest radiocaesium activity concentrations. However, if there is considerable variation in the spatial distribution of major soil groups and deposition within a few km then it is likely that transfer to milk will also vary significantly within a small area and it will be difficult, and probably inappropriate, to make generalizations.

To predict radiocaesium contamination of private milk it is important to have good information on transfer rates between the different soil groups and grass, and to ensure that sampling strategies for soil, vegetation and milk are representative. It is of particular importance to be able to monitor the winter feeds, which may be highly variable in radiocaesium content. The criteria used to amalgamate soil types and quantify appropriate soil to plant transfer is a crucial element in modelling at the small scale and merits critical evaluation.

Many effective countermeasures are available to reduce radiocaesium activity concentrations in milk and such countermeasures could still be of value in the study areas. For local use in contaminated rural villages it is important to inform and involve the private farmers adequately about the methods to maximize their use and effectiveness.

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