XA0201579

THE REHABILITATION STRATEGIES IN AGRICULTURE IN THE LONG TERM AFTER THE CHERNOBYL NPP ACCIDENT

S.V. FESENKO
Russian Institute of Agricultural Radiology and Agroecology, Obninsk, Russian Federation

Abstract

The experience gained in the aftermath of the severe radiation accidents shows that in the case of large-scaled radionuclide contamination the limitation of internal radiation doses to people by means of restoration of agricultural lands is more realistic than reduction of levels of external irradiation. Therefore, the problems connected with the optimal restoration strategies of agricultural land subjected to radioactive contamination after the Chernobyl accident are of crucial importance.
The justification of the approach for the estimation of the effectiveness of countermeasure strategies in the long term after the Chernobyl accident, based on the classification of farms by contamination density and risk of the exceeding of radiological standards, restricting the use of agricultural products, is presented. For each class of the farms the ranking of rehabilitation options and the time periods when their application would be of importance are given. Comparative analysis of the rehabilitation strategies, which are different in their effectiveness and cost, is provided.

1. INTRODUCTION

Countermeasures in agriculture hold a central position in the system of measures for liquidating consequences of the Chernobyl accident. The application of these countermeasures has considerably (5 to 10 times over the period 1987-1992) reduced the radionuclides content in products and, consequently, doses of internal irradiation in regions of active countermeasures implementation. The regions where countermeasures were applied on a limited scale saw a less pronounced reduction of the radionuclides concentration in products [1]. Overall, the introduction of countermeasures has practically led by 1996 to a minimum production of food stuffs which do not meet the radiological standards, as well as to a noticeable reduction in the exposure of the population living in the affected regions [1].

Each period after radioactive fallout is characterized by certain features, which define a particularity of agricultural production and countermeasures application in the affected areas. After a lapse of 10-12 years following the Chernobyl accident, a long-term period has come for the mitigation of the accident impact. The following peculiar features are typical for this period [2]:

- Radionuclides migration via the main trophic chains in the soil-plant-animal-agricultural products system is assuming properties of an equilibrium state–dominant are becoming relatively low processes of transformation of radionuclides forms in environmental objects and processes of involvement of radioactive substances into the sphere of biological cycling;

- A system of priorities is changing when assessing the effectiveness of countermeasures aimed at reducing exposure doses to the population (including countermeasures in agricultural industry). Radiological (doses averted due to countermeasure application) and economic-radiological (calculation of the cost of reduction in the unit collective dose, expressed in man-Sv per k Euros) indicators are in the forefront;

- Changes are being made from the temporary (accidental) to "peaceful" (more stringent) standards of the public exposure and permissible radionuclide concentration in foodstuffs [3].

The long term after the Chernobyl accident is marked by a severe economic crisis in Russia, which is responsible, in particular for a sharp decrease in the agricultural investment in the contaminated regions (including the reduced financing of agricultural countermeasures). A negative factor of the reduction (actually to full cessation) in countermeasure investment is a likely growth in ^{137}Cs concentration in farm products (as a result of limited fertilizing, discontinuance of liming, violation of crop cultivation technologies, etc.) [4].

A peculiar feature of the long term after the Chernobyl accident in the Russian Federation is the introduction in 1997 of the rigid standards regulating the permissible levels of radionuclide content in farm products [3]. For some products, milk in particular (50 Bq l^{-1}), these are more than a factor of 7 lower than the previously acting standard, DIL-93 (370 Bq l^{-1}). It is therefore necessary that the radiological situation in agriculture is assessed with the account of new criteria, as well as new methodological approaches to the justification of countermeasure options are developed.

2. METHODOLOGY

A distinguishing feature of milk contamination is time and space inhomogencity of the radionuclides content in products. Therefore, the analysis of different countermeasure options must use indicators of risk (probability) of SanPin-96 exceeding. Among the key factors responsible for the contamination levels of animal products are particularities of farming, including fodder land contamination levels, soil properties protective and remediation measures applied. On practice, a combined effect of these factors is usually observed, making it necessary to classify the farms.

Farm classification by the need in rehabilitation

An addressed rehabilitation aimed at achieving maximum effects of countermeasures with minimum additional investments should be based on the classification of farms which takes into account the following criteria of radiation safety in agricultural production (Table 1):

- risk (probability) of animal products production with ^{137}Cs concentrations above SanPin 2.3.2.560-96;

- contamination density of agricultural lands used for fodder production and live stock grazing.

The farm classification by ^{137}Cs soil contamination density made use of the following grades: 37-185 kBq m^{-2}, 185-555 kBq m^{-2}, 555-740 kBq m^{-2}, and above 740 kBq m^{-2}. By risking to be in excess of SanPin 2.3.2.560-96, the following ranges were used: 0, 0-10, 10-50, 50-90 and above 90%.

With this classification, it may be expected that for the farms in each of the category an excess of SanPin 2.3.2.560-96 is determined by similar factors, thereby allowing the development of differential countermeasure strategies and ensuring the account of local conditions during their implementation. So, the classification proposed makes possible the realization of an addressed development of a system of necessary remediation and protective measures.

Criteria for the estimation of countermeasure effectiveness

Essential, when developing countermeasure strategies in agriculture and justifying the most effective ways of their implementation, is a cost-benefit analysis, i.e. a ratio between countermeasure cost and benefit in the farm of dose reduction. The criteria for such of analysis and comparison of various countermeasure combinations should include:

- Decline in risk of exceeding the standards for farm products;
- Decline in collective dose from the consumption of contaminated products;
- Averted doses resulting from the countermeasures application and cost of 1 man-Sv averted.

The first of the above criteria is especially important when the effectiveness of countermeasures in the collective sector is assessed. By this criterion a possibility to obtain foodstuffs which meet the radiological standards can be evaluated and time periods which need rehabilitation countermeasures foe zones with different contamination levels of animal products can be determined.

Other criteria are of a subordinate importance and are employed for the optimization of countermeasures with close effectiveness in reducing risk of animal products contamination since a similar effect in reducing levels of animal products contamination can be achieved through the use of a large number of various countermeasure combinations. In this case a decrease in the collective dose and cost of these countermeasures are considered as criteria, which ensure an optimum choice of adequate actions.

A parameter connecting the first two criteria is the cost of 1 man-Sv averted by the use of countermeasures. In particular, ICRP Publication 37 considers countermeasures as justified if the cost of reduction of the collective dose by 1 man-Sv as a result of their application is within a range of 10-20 thousand of US dollars (EURO).

Stages of justification of strategies for protective and rehabilitative measures

I. Assessment of the need in countermeasures application. The prime objective of this stage is to estimate the need or justification of countermeasures. At this stage the contamination levels of agricultural products are determined and farms are distributing between categories described earlier. To this end, factors are analyzed which are responsible for the contamination of animal products and effectiveness of countermeasures including:

- Levels of agricultural land contamination;
- Soil properties;
- Levels of farm products contamination;

II. Justification of potentially effective countermeasures. In case when the application of countermeasures is thought to be justified the most effective ways of their implementation are specified based on a preliminary analysis. The most effective rehabilitation options are identified for each category of farms considered based on the analysis of advantages and disadvantages of individual countermeasures. As criteria for comparing different countermeasures the following ones are regarded:

- Levels restricting the use of farm products with the account of the radionuclides content (SanPin 2.3.2.560-96);
- Collective dose from the consumption of products before and after the application of countermeasures, as well as dose reduction through the countermeasures application;
- Cost of 1 man-Sv averted by rehabilitation options application.

III. The prime objective of this stage is to identify for each category of the settlements site-specific combination of rehabilitation options, which allow reaching maximal effect from their application taking into account these criteria.

A comparative analysis of the effectiveness of countermeasure strategies. The main goal of this stage is to find the most effective strategies, i.e. countermeasure combinations throughout the whole period after radioactive fallout when the application of these countermeasures is justified. So at this stage, rational countermeasure combinations and time periods of their usage need to be specified for every year after the fallout. The effectiveness of each strategy is assessed based on the integral indices (or criteria) calculated for the entire time period when the use of countermeasures is recognized as necessary.

3. RESULTS

Since the Chernobyl accident, in all the affected regions the Russian Federation of Agriculture has been carrying out a program of ^{137}Cs content measurement in agricultural products. Formally, 21 regions in the Russian Federation were subject to radioactive contamination after the Chernobyl accident. For most regions typical are the contamination levels of no more than 37 kBq m^{-2}. In four (Bryansk, Kaluga, Ourel, Tula) regions, however, high levels were registered and these saw the most active measurements. The measurements show that in 17 regions of Russia the maximum ^{137}Cs levels in milk are not in excess of 50 Bq l^{-1}, the norm adopted by SanPin 2.3.2.560-96. It has also been found that in these regions ^{137}Cs concentration in grain and potato (as well as in other vegetables) do not exceed the new standards. Simultaneously it has been revealed that in six districts of the Bryansk region (Gordeyevsky, Klimovsky, Klintsovsky, Krasnogorsky, Novozybkovsky and Zlynkovsky) likely is the production of milk with ^{137}Cs content above 50 Bq l^{-1}.

For every farm in these districts data have been collected on ^{137}Cs content in milk (1996-1999) and farming conditions (levels of agricultural land contamination, livestock, manufactured products, scales of countermeasures and their costs).

3.1 Analysis of factors responsible for ^{137}Cs content in milk

Among the key factors responsible for the radionuclides content in farm products are: density of agricultural land contamination, soil properties and countermeasures aimed at reducing mobility of radionuclides in food chains.

Contamination of haylands and pastures

The average levels of ^{137}Cs contamination of haylands and pastures defining largely the risk of exceeding the standards vary from 37 to 1400 kBq m^{-2}. It should however be noted that no clear correlation is observed between the milk contamination levels and ^{137}Cs land contamination which is connected with the use of countermeasures and properties of soils used for fodder production and cattle grazing.

Countermeasures

Because of the economic crisis, the application of countermeasures in the affected regions during the period discussed (1996-1999) was of a limited character and confined only to the use of ferrocyn compounds. Table 1 summarizes mean values for the effectiveness of countermeasures in terms of risk reduction of producing milk above SanPin 2.3.2.560-96 estimated on the basis of actual data.

TABLE 1. REDUCTION FACTORS FOR RISK OF EXCEEDING STANDARDS (50 BQ.l^{-1}) AS A RESULT OF APPLICATION OF FERROCYNE COMPOUNDS IN 1996-1999

Risk of exceeding standards in products, %	^{137}Cs contamination density of fodder lands, kBq m^{-2}			
	37-185	185-555	555-740	>740
0-10,0	1	1	1	1
10,0-50,0	1	1	1	1,01 (1-1,13)
50,0-90,0	1	1,12 (1-1,63)	1,15 (1,13-1,17)	1,33(1-1,72)
> 90	1,5	1,01 (1-1,15)	1,29 (1,03-1,67)	1,33 (1,03-1,99)

These data show that caesium binders were applied in larger scale in farm with high milk contamination. However, there are farms with high risk of exceeding normative of SanPin-96 in milk where these countermeasures were not applied.

Soil properties

The analysis of the data obtained should include effects of the soil properties on the contamination levels of milk. Fig. 1 illustrates doses of internal exposure normalized to ^{137}Cs contamination density as a function of portion of peat-boggy soils on the agricultural land adjacent to the farms considered. It is seen that depending on soil properties transfer factors from soil to milk in the area where light soddy-podzolic and peaty soils are widespread can vary by factors of 5 to 7, thereby dictating the extent for the need in countermeasures. This is mainly explains the fact of the occurrence of farms with a high risk of exceeding ^{137}Cs standards in milk in areas with low levels of contamination (Table 1).

3.2 Assessment of the need for countermeasures application

Data for 1996-1999 were used as the basic information to estimate a risk of exceeding ^{137}Cs levels in milk. Since by definition risk is a stochastic quantity, such a period of data generalization allows an account in the calculations of variability in weather conditions and associated variations in milk contamination. Distributions of products contamination obtained for each of the farms, typical for this period, were recalculated based on the effective half life period of ^{137}Cs decrease in milk equal to 15 years (Table 2).

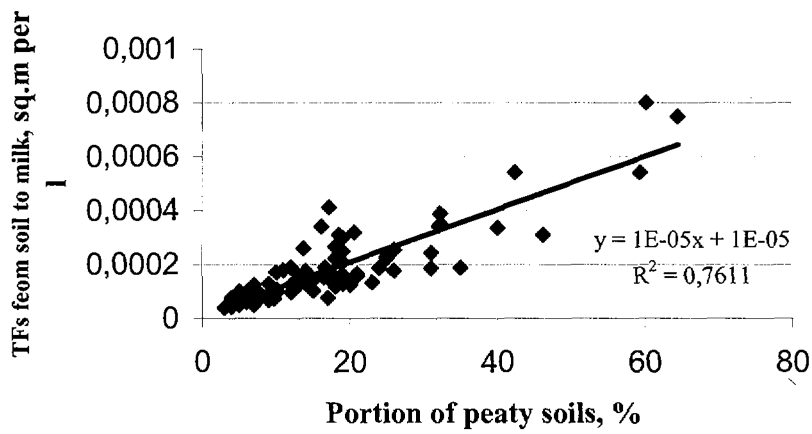

FIG. 1. Soil to milk TFs as a function of portion of peaty soils in the soil cover of haylands and pastures.

TABLE 2. CLASSIFICATION OF COLLECTIVE FARMS IN SIX DISTRICTS OF THE BRYANSK REGION BY RISKINESS OF MILK PRODUCTION WITH ^{137}CS CONTENT ABOVE 50 BQ.l^{-1} (BASED ON 1996 DATA)

Risk of exceeding 50 Bq.l^{-1} ^{137}Cs content in milk, %	^{137}Cs contamination density of fodder lands, kBq/m^2			
	37-185	185-555	555-740	>740
2001 y				
0	12	19	0	0
0-10.0	3	9	0	0
10.0-50.0	8	21	5	3
50.0-90.0	3	7	4	8
> 90	0	2	0	0
2009 y				
0	18	33	1	1
0-10.0	3	12	1	1
10.0-50.0	3	10	6	5
50.0-90.0	2	3	1	5
> 90	0	0	0	0
2030 y				
0	24	55	8	7
0-10.0	1	0	0	1
10.0-50.0	1	3	1	4
50.0-90.0	0	0	0	0
> 90	0	0	0	0

The analysis of the results shows that the area where risk to produce milk which exceeds the adopted limits is above 50% includes 24 farms, in 8 of which the contamination density of fodder lands is more than 740 kBq m^{-2}. On 31 farms all the milk will meet the standards. The application of countermeasures is required to a variable extent in 55 farms, of which 14 farms need them for a long period of time.

3.3. Comparative analysis of countermeasure strategies in the long term after the Chernobyl NPP accident

For five remedial actions the data on reduction factors, time periods of effectiveness and cost were reviewed, including radical improvement of hay-land and meadows (RI); administration of Cs binders in the forms of bolli (BO) and bifege (BIF); production of maize silage on arable soil to reduce portion of contaminated hay consumed by cows in winter period (SIL); replacement of cattle grazing on pastures with a combined breeding, based on use of cultivated pastures and feeding the cattle (up to 50%) with green fodder, so called "green conveyor" principle (GC).

TABLE 3. REHABILITATION OPTIONS IN AREAS WITH VARIOUS RISK OF EXCEEDING SANPIN-96

Risk of exceeding 50 Bq l^{-1} ^{137}Cs in milk	^{137}Cs contamination density of fodder lands, kBq m^{-2}			
	37-185	185-555	**555-740**	>740
0-0,1	RI 0,84	RI 0,79	-	-
0,1-0,5	RI 1	RI 0,72; (RI+BO) 0,12; (RI+BIF) 0,06	RI 0,74; (RI+BO) 0,26	RI 0,35; (RI+BIF) 0,65
0,5-0,9	(RI or LDCP+BO) 1	(RI+BO) 1	(RI+BO) 0,19; (RI+BIF) 0,81	(RI+BO) 0,51; (RI+BIF) 0,3; (RI+BIF+GC) 0,19
>0,9	(RI or LDCP +BO) 1	(RI+BIF) 0,38; (RI or LDCP+BIF+GC) 0,62	(RI+BIF) 0,32; (RI+BIF+GC) 0,68	(RI+BIF+GC+SIL) 1

Based on a comparative analysis of the effectiveness of these options, combinations of countermeasures have been identified for every category of farms which ensure the maximum effect in reducing risk to produce milk above the standard values (Table 3):

(1)Radical improvement of haylands and pastures organisation of long-duration cultivated pastures on arable land (RI);

(2)Application of ferrocyn compounds – boli (BO);

(3)Application of FC–bifege (BIF);

(4)Organization of maize production for silage (SIL);

(5)Organization of animal feeding by the "green conveyor" principle (GC).

All the measures have been arranged based on their cost and effectiveness. A set of countermeasures was considered to be sufficient if it ensured that the production of agricultural stuffs completely met the SanPin-2.3.2.560-96 standards. When combining countermeasures, radical improvement (RI) or organisation of long-duration cultivated pastures (LDCP) came first. The reason is that in this case a decrease in the products contamination is accompanied by a marked increase in the land productivity, thereby providing (in addition to reduced milk contamination) a supplementary income from the raised livestock productivity.

In the event when after the application of radical improvement the risk to exceed standard values in products remains above zero, a supplementary measure such as FC application was considered. In deciding between the two {bifege (BIF) and boli (BO)}, risk of products contamination after their use was the criterion. Should it remained high after the use of boli, the combination of RI+BIF was considered instead of RI+BO. If the risk to exceed standard values persisted after the application of radical improvement and ferrocyn compounds, a further measure was used, such as green conveyor (RI+BIF+GC) or organisation of maize production for silage (RI+BIF+SIL), to reduce contamination of products in the indoor period. The derived combinations of countermeasures, generalised for farm categories with different risks of SanPin-96 exceeding and different levels of haylands and pastures contamination, are summarised in Table 3 which shows the percent ratio of countermeasures proposed for every category.

Table 4 presents corresponding data on the cost of 1 man-Sv averted through the use of the recommended options in areas with different risks of SanPin-96 exceeding.

TABLE 4. COST OF 1 MAN-SV AVERTED THROUGH THE USE OF THE RECOMMENDED COUNTERMEASURES IN AREAS WITH DIFFERENT RISKS OF SANPIN-96 EXCEEDING, KEUROS

Risk of exceeding 50 Bq l^{-1} ^{137}Cs in milk, %	^{137}Cs contamination density of fodder lands, kBq m^{-2}			
	37-185	185-555	555-740	>740
0-10.0	96	101	-	-
10,0-50,0	77	63	60	57
50,0-90,0	45	38	35	25
>90	24	23	20	18

The minimum cost of 1 man-Sv averted is reported for the categories with the highest risk of SanPin 2.3.2.560-96 exceeding (Table 4). At the same time the cost of man-Sv averted for the categories with the risk below 50% (28-56 k Euros per 1 man-Sv) is noticeably higher values than the levels recommended by the ICRP. As it can be expected, the necessity in more effective combination in remedial options are increased with the growth of risk of exceeding normative of SanPin-96 in milk. Similar dependence (however much less expressed) is also found for contamination density of fodder lands.

Five strategies varying in cost and effectiveness, thereby allowing an analysis of various options of animal production with the account of resources allocated for their implementation were under consideration:

- **Strategy A**. No countermeasures are applied.
- **Strategy B**. Application of countermeasures on the 1996-1999 scales.
- **Strategy C**. It is based on the use of ferrocyn compounds (bifege) for periods with elevated content of radionuclides in products (critical periods) on all the farms where the risk of SanPin-96 exceeding is above 5%.
- **Strategy D**. This strategy is based on a system of organizational and agrotechnical measures. The evaluation of the radiological improvement effectiveness considers differences in the efficiency of measures for different soils and the potential effectiveness of these countermeasures is calculated individually for each farm with the account of local peculiarities of livestock production. On farms where flood plain haylands and pastures are used or where radical improvement failed to achieve a necessary effect, long-term cultivated pastures are supposed to be organized on arable land.
- **Strategy E.** It includes a minimum set of possible for each farm countermeasures ensuring a guaranteed obtaining of products which meet SanPin 2.3.2.560-96. Since this strategy is the most effective one reducing risk to obtain products inconsistent with the standards and contains elements of strategies **C-B**, it requires the highest costs.

So, the range of strategies discussed covers all possible variants of action, from the termination of countermeasures to their application on scales allowing the production in compliance with the standards, starting with 2003. The scenarios described cover a wide range of potential activities. Since their main aim is to reduce ^{137}Cs content in animal products, indicators such as dynamics of the reduction in products contamination in the south-western districts of the Bryansk region and cost of countermeasures were used as criteria in the comparison of strategies (Fig. 2).

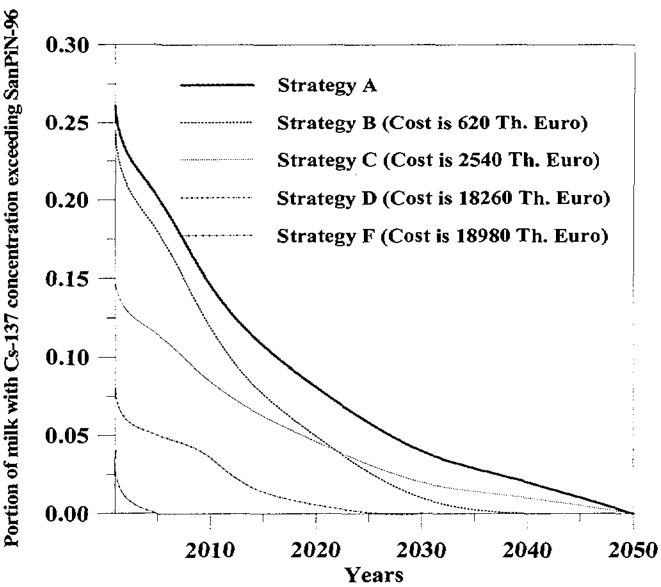

FIG. 2. Dynamics of reduction in milk with ^{137}Cs content above SanPin-96 on farm in the south-western districts, Bryansk region, for different rehabilitation strategies.

The results given in Figure 2 show that the best results by year 2003 can be achieved with the strategy **E**, which, however, needs the largest countermeasure expenses. Effective enough, by this criterion, is strategy C based on a large-scale application of ferrocyn compounds. Although the cost of this strategy amounts to 54%, it should be taken into account during the comparison that the farms may have an additional income resulting from the improved productivity of fodder lands.

A comparison of the two most costly strategies, which include a wide application of radical improvement, indicates that a rational use of other options on its background considerably increases the effectiveness of countermeasures and makes it possible to reach in the shortest time ^{137}Cs levels in products which meet the standards.

Noticeably lower effectiveness is shown by strategies **B** (use of ferrocyn compounds on farms with the highest contamination levels) and **D** (application of ferrocyn compounds on farms where SanPin Exceeding is most likely) which include the application of ferrocyn compounds in periods with high levels of milk contamination. The production in compliance with the standards will be achieved in 2025 and 2020 for strategies **B** and **D**, respectively. So, the existing countermeasure options and their combinations aimed at reducing contamination of animal products provide great scope for achieving the contamination levels in compliance with SanPin-96. However the choice of one or another kind of strategy is dictated by the funds allocated for their implementation.

CONCLUSIONS

Overall, the obtained results allow the conclusion that application of countermeasures in a long term period after the accident of the ChNPP, on considerable territories of Russia countermeasures will be necessary an large scales, which shows a need for optimisation of countermeasure implementation. Even in the long-term after the ChNPP accident, application of countermeasures in collective farms located on the most contaminated territory will require considerable expenses.

It may be concluded that the situation in the most affected districts of Bryansk, region requires a non-forced switch to the standards of a "normal" (non-accidental) period (SanPiN-96). In this respect, specific measures need to be scheduled for every settlement and every farm to provide agricultural production in accordance with the new radiation safety standards (50 Bq l^{-1}) for ^{137}Cs.

REFERENCES

[1] FESENKO, S.V., ALEXAKHIN, R.M., SPIRIDONOV, S.I. and SANZHAROVA, N.I. Dynamics of ^{137}Cs Concentration in Agricultural Production in Areas of Russia Subjected to Contamination After the Accident at the Chernobyl Nuclear Power Plant. Radiation Protection Dosimetry, 60(2) (1995). 155-166.

[2] ALEXAKHIN R.M. In: Proc. Sci. Conf. "Problems of agricultural production on radioactively contaminated agricultural lands in the long term after the Chernobyl accident". Moscow, 1999, P. 4-7.

[3] SanPin-96. Sanitary safety requirements for raw food and foodstuffs. Sanitary code. SanPin 2.3.2. 560-96, M. 1996.

[4] MARKINA, Z.N., KURGANOV, A.A., VOROBYEV, G.T. Radioactive contamination of plant production of Bryansk region. Bryansk. BGSXA (1997) 241 p. (In Russian)

DISCUSSION AFTER THE PRESENTATION OF S.V. FESENKO

S.M. VAKULOVSKY (Russian Federation): What dose will be received by a person from the consumption of contaminated milk in a contaminated area if he or she lives for one year on produce with radioactivity levels corresponding to the maxima permitted by the health regulations?

S.V. Fesenko (Russian Federation): The dose will depend on the milk consumption rate. Nowadays, the consumption of milk is much lower, and for a consumption rate of about 100 litres/year of raw milk the contribution of the milk will amount to about 0.05 mSv/year. The maximum value which could result from the consumption of milk with radioactivity levels corresponding to the maximum permitted by the health regulations (50 Bq/litre) is about 0.15mSv/year.