REMEDIATION STRATEGIES FOR CONTAMINATED TERRITORIES RESULTING FROM THE CHERNOBYL ACCIDENT

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Abstract

The Directorate General for Environment of the European Commission has supported two projects on the issue of remediation strategies for contaminated territories resulting from the Chernobyl accident. The first one aimed at identifying and costing a set of additional countermeasures that would enable the reduction of the annual exposure of the inhabitants down to 1 mSv. The second one (still running) is developing a new rehabilitation approach based on the involvement of the local population in the decision taking process concerning the type of countermeasures to be applied (the ETHOS approach).

1. INTRODUCTION

Since 1995, the Directorate General for Environment of the European Commission is supporting projects dealing with the remediation of contaminated territories resulting from the Chernobyl accident [1]. The main aim of these activities is to help the CIS countries that are the most affected by the accident to take appropriate counter-measures and develop new policies in the field of site remediation. They could also be used as guidance for potential donor organisations and countries willing to improve the radiological situation around Chernobyl.

Following an international workshop that was organised by DG Environment in June 1998 in Brussels [2], two additional collaborative projects have been launched. The first one, which is just completed, aimed at optimising remediation strategies for contaminated territories [3], whereas the second one consists of scaling-up the so-called "ETHOS" approach from one village (Olmany in Belarus) to a district (the Stolyn district also in Belarus) [4].

2. ASSESSMENT OF REMEDIATION STRATEGIES

2.1 Current radiological situation in contaminated territories

In the contaminated rural areas of the Russian Federation, Belarus and the Ukraine 352 000 inhabitants would be receiving annual doses that are exceeding the legal threshold of 1 mSv due to the radioactive contamination of the environment resulting from the Chernobyl accident. This estimate is based on the official so-called catalogue doses issued in 1995 for Belarus and in 1996 for the Russian Federation and the Ukraine. The size of this population is considerably smaller than data published in the past in the literature for two main reasons:

- The radioactive decay of the main radionuclides and their migration in deeper layers of the ground;
- The mathematical models used to estimate this number have become in time more sophisticated and therefore less conservative.
- The breakdown of the population living in contaminated territories, where the annual exposure (due to the Chernobyl accident) is higher than 1 mSv, is showed in Table 1. A detailed analysis of the doses enables the rural population to be subdivided into three main categories:
  - 61.5% live in relatively low contaminated (37-185 kBq/m^2) areas and receive internal doses exceeding 0.5 mSv. Most of these live in the Ukraine;
  - 26.7% live in territories slightly more contaminated (185-555 kBq/m^2). Most of them have internal doses exceeding 0.5 mSv. This population is mainly distributed in Belarus and Russia;
  - 11.8% live in territories with a contamination level higher than 555 kBq/m^2. Here external doses play a major role. This population is mainly distributed in Belarus and Russia.

TABLE 1. PEOPLE RECEIVING ANNUAL EFFECTIVE DOSES THAT ARE EXCEEDING 1 mSv (FROM THE CONTAMINATION OF THE ENVIRONMENT DUE TO THE CHERNOBYL ACCIDENT) ACCORDING TO THE OFFICIAL CATALOGUE DOSES IN THE UKRAINE, RUSSIA AND BELARUS

Country	**Belarus**	**Russia**	**Ukraine**	**Total**
Urban areas	24 600	53 166	0	77 766
Rural areas	60 166	48 640	165 608	274 414
Total	84 766	101 806	165 608	352 180

Actually, most of the internal dose commitments are due to the consumption of privately produced foodstuffs (mainly milk and beef consumption) and to locally grown mushrooms. Therefore, these foodstuffs are giving the major radiological concern to the rural areas.

External doses are those arising from the contamination of the soil especially around houses.

2.2 Shrinkage of the contaminated territory

Due to the decay of most radionuclides and their progressive dilution in the environment, there is shrinkage of the size of contaminated territories in time. An exponential decrease of the internal dose with a half-live of 15 years and of external dose with a half-life of 18.8 years has been assumed. Under these conditions, in the year 2002, the rural populations receiving an annual dose higher than 1 mSv drops from about 352000 to 190000. If further 13 years are elapsed, this population reduces to about 30,000 (see Fig. 1). Therefore, the extent of the remediation actions in contaminated territories depends very much on the time at which the decision of remediating is taken.

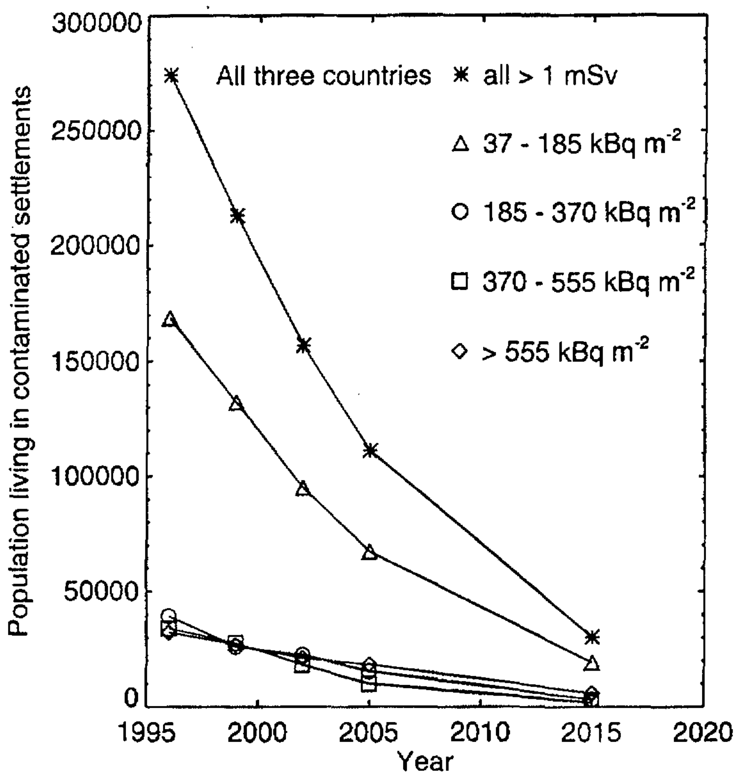

Fig. 1.

2.3 Goal of the project

The main goal of the project is to identify and cost remediation strategies-which are corresponding to a set of specific countermeasures-which could enable a reduction of the annual exposure resulting from the Chernobyl accident in rural areas below 1 mSv.

2.4 Methodology

On account of the large variety of exposure pathways which themselves very often depend on the agricultural practices, the type of soil, the level of contamination, etc. it is virtually impossible to define remediation strategies that could be applied to the whole territory of contaminated land. A subdivision of these territories in specific categories is therefore necessary. Eleven categories of contaminated land based on the surface specific activity (Bq/m^2) were defined. The annual radiation doses existing in each of these categories is given in Table 2.

To derive remediation strategies for these categories, 70 representative settlements (24 in Belarus, 25 in Russia, and 21 in the Ukraine) were selected for which extensive radioecological data were gathered (see Table 3).

TABLE 2. ANNUAL RADIATION DOSES IN THE ELEVEN CATEGORIES OF CONTAMINATED LAND IN 1995

Annual internal dose (mSv)	^{137}Cs contamination per unit area (kBq/m²)			
	37-185	185-370	370-555	>555
	Annual external dose (mSv)			
	0.06-0.4	0.3-0.8	0.6-1.2	>0.9
	Annual total dose			
<0.5	-	<1.3	0.6-1.7	>0.9
0.5-1	0.56-1.4	0.8-1.3	1.1-2.2	>1.4
>1	>1.06	>1.3	>1.6	>1.9

TABLE 3. INFORMATION GATHERED FOR EACH OF THE 70 REPRESENTATIVE SETTLEMENTS SELECTED TO CHARACTERISE EACH CATEGORY OF CONTAMINATED TERRITORY

Number, name and country of settlement	Ratio of internal catalogue dose to model dose
Internal catalogue dose in 1996	Degree of application of Prussian blue to cows
Fraction of locally produced food stuff in diet, annual consumption and transfer factors	Degree of application of radical improvement
^{137}Cs activity per unit area in fields	Fraction of peat in the agricultural area
Annual dose due to the various food stuffs and external dose	Impact of various countermeasures on the averted doses
Geometric mean and geometric standard deviation of transfer factors	Cost of each individual countermeasure

For nine remedial actions, basic data on reduction factors, time periods of effectiveness and cost were reviewed. To reduce the ^{137}Cs activity in milk and beef of privately-owned cows, the main remedial actions considered were radical improvement of hay-land and meadows (agro-technical cultivation of soil and root mat by means of disking plus soil ploughing at a depth of 20-25 cm, and possible application of fertilisers and ameliorants), and addition of Prussian blue (^{137}Cs binder) to fodder for cows (Table 4). For the reduction of ^{137}Cs intake with other foodstuffs, the main remedial actions considered were feeding pigs with clean fodder before slaughter, use of mineral fertilisers for potato fields and restriction of mushroom consumption (Table 5). In addition, the distribution of radiometers for food monitoring and the removal of contaminated soil around the houses in the contaminated settlements were considered.

TABLE 4. AVERAGE REDUCTION FACTORS, TIME PERIODS OF EFFECTIVENESS AND COSTS IN 1998 FOR LARGE-SCALE APPLICATIONS OF REMEDIAL ACTIONS TO REDUCE THE ^{137}Cs ACTIVITY IN MILK AND BEEF OF PRIVATELY-OWNED COWS

Remedial action	Reduction factor	Time period	Cost per cow (€)
Radical improvement of soil (RI)	Milk and beef: 1.7-3.5	4 years	Belarus: 241 Russia: 338 Ukraine: 291
Wet peat drainage	Milk and beef: 2.7	Long term	8000
Feeding with Prussian Blue (PB)	Milk: 3 Beef: 2	Continuous application	Belarus: 28 Russia: 25 Ukraine: 25

TABLE 5. REMEDIAL ACTIONS INVESTIGATED, REDUCTION FACTOR FOR ^{137}Cs INTAKE, TIME PERIODS OF EFFECTIVENESS AND COSTS IN 1998 FOR LARGE-SCALE APPLICATIONS (IN EUROS)

Remedial action	Reduction factor	Time period	Cost per inhabitant (€)
Supply clean milk (SM)	Milk: 2	Continuous application	Belarus: 78/year Russia: 78/year Ukraine: 71/year
Clean feed for pigs (FP)	Pork: 3	Two months before slaughter	Belarus: 6.0/year Russia: 3.2/year Ukraine: 5.8/year
Mineral fertiliser for potato fields (MF)	Potatoes: 2	Yearly	Belarus: 1.2/year Russia: 2.6/year Ukraine: 0.6/year
Restrict mushroom consumption (RM)	Mushrooms: 3	Continuous	10/year
Distribute radiometers for food monitoring (FM)	1.2-2	4 years	30
Removal of soil (RS)	External dose: 1.35	Infinite	325

For most of the remedial actions considered, practical experience in the three CIS countries were sufficient to derive representative and reliable estimates of effectiveness and costs. A new model for calculating dose distribution in each of the representative settlement was established. On average, the 89 percentile of the dose distributions correspond to the catalogue values established by the CIS Ministries in charge of the Chernobyl after effects.

An algorithm was set up to optimise the impact of applying a set of countermeasures with respect to dose reduction and cost.

2.5 Results

Application of the new model for dose distribution and the algorithm to each of the representative settlements showed that for:

- 14 of the settlements, model calculations give an annual dose below 1 mSv;
- For 45 of the settlements, remediation strategies could be derived;
- For 11 of the settlements, dose reduction down to 1 mSv can only be achieved through intensive decontamination works or relocation of the population due to high external exposure (outside the scope of the project).

Based on the optimised countermeasures set up for each representative settlement, it has been possible to derive remediation strategies for each of the 11 categories of contaminated land defined previously. These remediation strategies (extensively described in reference 13) highlighted the following conclusions:

- Application of radical improvement of private hay-land and meadows would be recommended in all rural settlements if this has not been applied during the last four years;

- Feeding cows with Prussian blue would be cheaper and as effective as radical improvement of soil provided that this remediation option is accepted by the rural population;
- Supplying clean milk should only be considered for the highest contamination /internal-dose category;
- Fertilising potato fields would be recommended for most settlements with a ^{137}Cs activity per unit area exceeding 555 kBq/m^2;
- Distribution of food monitors would be useful for all settlements in the highest contamination/internal-dose category, and for a significant part of the neighbouring categories with lower contamination or lower internal dose;
- Removal of contaminated soil would be required for all settlements with a ^{137}Cs activity per unit area exceeding 555 kBq/m^2, and for one quarter to one third of the settlements belonging to the category with a ^{137}Cs activity within the range 370-555 kBq/m^2;
- For the category of contaminated land with a Cs-activity higher than 555 kBq/m^2, approximately 30% of those settlements with internal catalogue doses below 0.5 mSv and 80% of those with internal catalogue doses exceeding 0.5 mSv cannot be fully remediated (the annual exposure cannot be reduced to 1 mSv with the selected countermeasures). These settlements are mostly located in Russia and Belarus. Identification of optimal ways to improve the situation in these settlements is the most difficult task and requires additional consideration.

2.6 Cost and averted doses resulting from the implementation of the remediation strategies

Total costs for the proposed remediation strategies for the whole contaminated territories have been calculated on the basis of the number of privately-owned cows and inhabitants, and on the set of countermeasures that have been determined for each main category of contaminated land. These would amount to 15.6 Million Euros in the year 2002 with the following breakdown: 4.1 Million Euros in Belarus, 4.7 Million Euros in Russia and 6.8 Million Euros in the Ukraine (see Table 6).

These costs established for the year 2002 are indicative of the total investment to be made, which is much lower than what is generally expected (less than 20 MEuros). In Belarus and Russia most of the remediation costs should be attributed to the removal of contaminated soil in heavily contaminated areas (higher than 555 kBq/m^2) with the aim of reducing external exposure. In the Ukraine, most remediation works should consist of reducing the contamination level of milk through radical improvement of meadows and hay-land. Whereas the decontamination works in Belarus and Russia should only have to be applied once, radical improvement in all three countries should be repeated every four years.

If the proposed remediation strategies are applied in 2002, then an effective dose of 2000 Sv could be averted in the three CIS countries.

However, the largest potential for averting doses is in the Ukraine.

TABLE 6. TOTAL COSTS, AVERTED DOSES AND COST PER AVERTED DOSES THAT WOULD RESULT FROM THE IMPLEMENTATION OF OPTIMISED REMEDIATION STRATEGIES IN THE CONTAMINATED TERRITORIES OF BELARUS, RUSSIA AND THE UKRAINE[a]

Country	Remedial actions	Costs (kEuros)	Averted dose (Sv)	Cost per averted dose (kEuro/Sv)
Belarus	RI, PB	1459	116	13
	SM, FP, MF, RM, FM, RS	2637	188	14
	Total	4096	304	13
Russia	RI, PB	1076	71	15
	SM, FP, MF, RM, FM, RS	3590	178	20
	Total	4667	249	19
Ukraine	RI, PB	6098	1034	6
	SM, FP, MF, RM, FM, RS	718	449	2
	Total	6815	1482	5
All three countries	RI, PB	8633	1221	7
	SM, FP, MF, RM, FM, RS	6945	814	9
	Total	15578	2035	8

[a]Those territories for which application of the proposed remediation strategies cannot reduce the annual exposure of the population below 1 mSv are not included in this calculation.

Due to the shrinkage in the size of the contaminated territories with time, it is obvious that the corresponding remediation cost will also considerably decrease if these are postponed by several years (up to a factor of 5 by the year 2015) as showed in Table 7.

TABLE 7. VARIATION OF THE TOTAL COST FOR REMEDIATION OF CONTAMINATED TERRITORIES AGAINST TIME

Country	Total remediation cost in the year (kEuros)				
	1996	1999	2002	2005	2015
Belarus	6809	5424	4096	2742	914
Russia	6815	5863	4667	3764	1014
Ukraine	12 458	9581	6815	5131	1443
Total	26 081	20 867	15 578	11 638	3372

2.7 Conclusions

The project showed that rehabilitation of the contaminated territories resulting from the Chernobyl accident-based on the dose criteria (annual dose due to Chernobyl lower than 1 mSv)-can be achieved at a relatively low cost for most of the territories. However the remediation strategies to be implemented depend on the country considered. Agricultural countermeasures should be applied in all three countries. However, in Russia and Belarus large-scale decontamination works would also be of importance. In these two countries there is a considerable portion of the rural population who lives in the settlements with high levels of ^{137}Cs deposition densities and internal dose which at present cannot be fully remediated. The cost of countermeasure options estimated in the current project was not related to these settlements. However, it is obvious that remediation of heavily contaminated Russian and Belorussian settlements results in considerable additional cost in the total costs required for remediation of the rural settlements located on the contaminated territories.

Although the extent of the remediation activities to be performed strongly decreases in time, this should not be interpreted as an encouragement to apply the "do-nothing" option. Remediation still remains a prerequisite to restore the confidence of hundreds of thousands of people in the ability of their respective governments to address the rehabilitation of these territories in a proper way, either alone or with the support of the International Community.

3. SCALING-UP OF THE ETHOS APPROACH

3.1 The ETHOS approach

As showed in section 2.1 the radiological situation existing in the contaminated territories as a result of the Chernobyl accident is becoming less and less dramatic. However, even if the annual exposure of the population becomes lower than the legal threshold of 1 mSv, these territories cannot be considered as rehabilitated as long as their population remains anxious and stressed, and still regards the low exposure as unacceptable.

Numerous studies supported by the international community already showed that the most important consequence of the Chernobyl accident is a deterioration of the quality of life experienced by people living in the contaminated territories characterised by:

- Continuing stress which is contributing to enhanced morbidity;
- Scepticism towards efficacy of any restoration action;
- Need for public assistance and dependence of local economy in contaminated area on such assistance.

These effects are obviously preventing any possibility of returning these territories to a normal level of economic development and quality of life in both the short- and medium term. These problems will not be overcome easily but there is evidence that successful rehabilitation will require a decentralised approach in which the affected populations take much greater responsibility for the management of, and how they live in, the affected territories.

In the field of research, exploratory studies [5] (the ETHOS I project) focusing on one settlement (Olmany/1300 inhabitants in Belarus) already demonstrated that a substantial improvement can be achieved through the active involvement of the population in a number of actions e.g. in the:

- Production of uncontaminated milk for children;
- Control of the radiological exposure for children;
- Private production and marketing of clean meat;
- Education of children about risks of living in contaminated territories;
- Development of a risk culture amongst young people;
- Implementation of a radioactive waste management scheme.

3.2 The ETHOS II project

The launching in December 1999 of the ETHOS II project has two main objectives:

(1)To demonstrate that the success achieved with the use of a decentralised approach to rehabilitation can be extended to the level of a district;

(2)To develop guidance on how such an approach could be more widely disseminated in order to enable eventually the economic rehabilitation of all the contaminated territories in Belarus.

The Stolyn district that was selected for the project comprises five villages: Belausha, Terejov, Gorodnaya, Olmany and Retchitsa. It covers a population of about 15,000 inhabitants.

During the first semester, most of the work focused on the conclusion of an agreement with the Belarus authorities on the implementation of the ETHOS II project; the information of the local population and administration through the organisation of a seminar; and the setting up of networks to group local participants in four dedicated task forces: radiometry, agriculture, health, and pedagogy.

3.3 The radiometry network

One person per village volunteered to participate together with the responsible persons for the measurements of the radioactivity in the dairy, in the slaughterhouse, and in the packinghouse, in the setting up of a network aiming to improve the collection of radiological data, and the presentation of the data in a way understandable for a lay-man. Four radiometers for measuring external irradiation and five computers were delivered to this network. Training courses were organised in the summer.

3.4 The agriculture network

This group is made up of three to six people who have responsibilities in the management of state-owned collective farms. Their first task would be to draw up a map of "contaminated milk" in order to identify those meadows which should not be used, and to improve the quality and the production of "clean" potatoes in order to decrease the intake of contaminated foodstuffs by the local population. In more general terms, the main task of this network is to improve the production, processing and marketing of agricultural products of good radiological quality (mainly milk and meat) with the active involvement of the private farmers.

3.5. The health network

About fourteen doctors would animate this network whose aim is to advise mothers on those actions in the home that could decrease the exposure of members of their families, in particular their children. This could be done by drawing up the map of contamination inside each house, and through exchange of information on the most contaminated foodstuffs produced locally.

3.6 The pedagogy network

This network would be made up of two to fifteen persons per village (school directors and teachers). The participants in this network would develop a practical risk culture among the children at school through the implementation of specific projects to be defined by each school.

3.7 Progress to-date

So far, the implementation of the project has been quite successful. The Belarus authorities are fully supporting the ETHOS approach. The creation of dedicated networks benefits from the help and support from the local administration of the Stolyn district. These networks are expected to become fully operational by the end of the year 2000. Based on the results obtained in 2001, a plan for extending the application of the ETHOS approach to the whole contaminated territory of Belarus should be established.

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DISCUSSION AFTER THE PRESENTATION OF S.V. FESENKO

K. MÜCK (Austria): If I extrapolate from deposition levels in Austria (which were on average 15 kBq/m^2 of ^{137}Cs), assuming a decrease in activity levels and in external exposures as I presented in Session 2, I find no area with a dose of more than 1 mSv nowadays for 555 kBq/m^2; in fact, I obtain substantially lower values. Where are the discrepancies? Do you have different effective half-lives? (They do not seem to be different in papers by you and Balonov which I have read.) Or is there a difference in foodstuff consumption patterns?

S.V. FESENKO (Russian Federation): For the conservative estimates of half-lives in the study we used 15 years for internal exposures and 18.8 years for external ones. The properties of the soil can vary widely, resulting in a large variation in the transfer factor values. The most contaminated areas are characterized by high availability of caesium. There are also large areas with wet peat soils (for instance the Rovno region in Ukraine) which are extremely sensitive to ^{137}Cs contamination. Other factors which influence the internal dose are the composition of the feeds of domestic animals and the rate of consumption of agricultural and natural products by the population. All these parameters are quite specific for the area considered and can result in an increased internal dose. The data are summarized in a report entitled "Remediation strategies for contaminated territories resulting from the Chernobyl accident" (FE 78404) to be published by the European Commission before the end of this year.

M. GOLDMAN (USA): Given the emotional history of this population with regard to the Chernobyl accident, how will you assess whether your efforts to explain risk are appropriate or are simply adding to the problem? How do you know that what you are doing is the right thing for this population?

S.V. FESENKO (Russian Federation): The ETHOS project was introduced in several stages. During the first stage, actions were implemented in a single settlement. The population of the settlement was directly involved in evaluating the actions, and only those actions which were positively evaluated by the population were tested at district level during the second stage of the project.