Local Strategies for Decontamination

Philippe HUBERT[1], Valeri RAMZAEV[2], Gennadyl ANTSYPOV[3], Emlen SOBOTOVICH[4], Lubov ANISIMOVA[5]

[1] Institut de Protection et de Sûreté Nucléaire, (IPSN), B.P. 6, 92265 Fontenay-aux-Roses cedex, France.

[2] Branch of Institute of Radiation Hygiene, Karchovka 243000 Novozybkov, Bryansk region, Russia.

[3] Chernobyl State Committee of the Republic of Belarus, 14 Lenin Str., 220030, Minsk, Belarus.

[4] Institute of Geochemistry, Mineralogy and Ore formation, 34 Palladin Av., 252680, Kiev-142, Ukraine.

[5] EMERCOM, Moscow, Russia.

Abstract. The efficiencies of a great number of techniques for decontamination or dose reduction in contaminated areas have been investigated by several teams of E.C. and CIS scientists (ECP4 project). Modelling, laboratory and field experiments, and return from experience allowed to assess radiological efficiencies (e.g. « decontamination factor ») and requirements for the operation of numerous practical solutions. Then, those data were supplemented with data on cost and waste generation in order to elaborate all the information for the optimisation of decontamination strategies. Results will be presented for about 70 techniques.
However, a technique cannot be compared to another from a generic point of view. Rather it is designed for a specific target and the best technology depends on the objectives. It has been decided to implement decision analyses on case studies, and the local conditions and objectives have been investigated. Individual doses ranged from 1 to 5 mSv, with contrasted contributions of internal and external doses. The desire to restore a normal activity in a partially depopulated settlement, and concerns about the recent increase in internal doses were typical incentives for action. The decision aiding analysis illustrated that actions can be usually recommended. Results are outlined here.

1. Introduction

In the aftermath of the Chernobyl accident, and the years immediately following the catastrophe, large scale decontamination actions and evacuations of populations have taken place. Meanwhile a series of restrictions were set-up, bearing on economic activities and on daily life. Therefore, six years after the accident, many of the critical areas had been decontaminated, the contamination could be considered as fixed, especially on urban objects and the social situation was felt to be stabilized.
Under those conditions, some questions remained without answer.
What is the efficiency of the « classical » decontamination techniques when contamination has been deposited years ago, or when previous countermeasures were applied?

Which specific techniques can be developed?
Is it sensible to undertake new decontamination actions?
The ECP 4 project was launched in order to look at the opportunities for further dose reduction actions in the contaminated territories of the three republics affected by the accident. The objective was to provide a local decision maker, faced with many alternatives for decontamination, with helpful informations related to the various objectives he may consider. The project involved teams from different disciplines. The techniques themselves, the assessement of their costs, the set up of a methodology for decision aiding and its application to case studies were studied.The main results are presented here.

1 Documenting decontamination techniques

1.1 Scope and organisation of the work

The project had a very broad objective. It surveyed usual techniques, techniques that had been designed within the framework of ECP4 (under assumption that they can be made effective at a full scale level), techniques that had been developed or examined by other Programmes(e.g. ECP2, ECP9, JSP2, JSP5...[1] [2] [3] [4]), and the « do nothing » option.

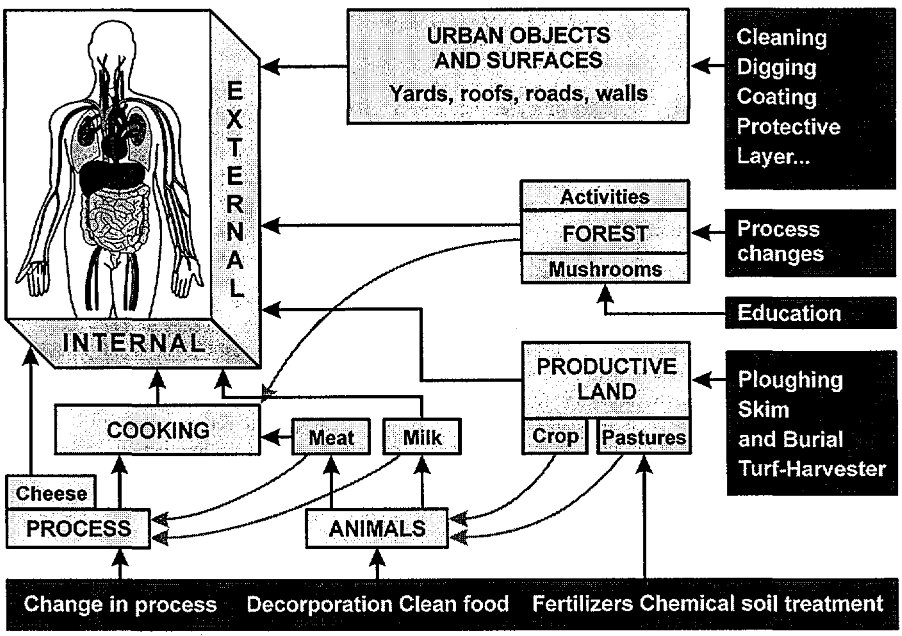

Figure 1 : **Exposure pathways and targets for countermeasures.**

Exhaustivity was searched for. Actions dealing with all sources and pathways were considered, and the tasks were divided in accordance with the type of sources on which it is possible to act (see figure 1). Five sub-projects dealing with techniques were set-up : decontamination of urban environment (walls, roofs, yards, roads...), soil decontamination

(arable soils and pastures) with chemical and physical approaches, decontamination of forests, protection and decontamination of machines and the decontamination of domestic and industrial food. They were associated with a sub-project on self-restoration in ecosystems. A specific sub-project was devoted to cost-benefit analysis which eventually made use of the data collected on techniques.
The first years of the project were devoted to laboratory and field experiments, often at a sensible scale. Among other results, it was proved that it is still possible to decontaminate walls and roofs on which Caesium was deposited almost 10 years ago (for example using water under pressure), or fields in which the fertile layer is too thin for ploughing (e.g. turf harvester), and that modifications of cheese making processes can achieve significant decontamination factors (e.g. the Phoenix cheese). During the last year, syntheses were made in order to build up an information that is of practical use in decision analysis.

1.2. Techniques and decontamination yields

Unless otherwise specified, the figures are related to the effectiveness considered several years after an accident and they apply to Caesium. Some figures are close to unity, suggesting a poor efficiency. Most often it traces a countermeasure of current use in the early stages of the accident, which was included here for the sake of completeness.
Urban decontamination and decontamination of machines have been assessed with different techniques such as Ammonium Nitrate, Water Hosing, Vacuuming, Sandblasting, Clay treatment, Polymer coatings, Sorbents, Roofwasher or special digging, in the towns of Pripyat and Vladimirovka (1992-1994) [5][6][7], Novozybkov and surrounding settlements (1993) [6] and Halch (September 1994) [7][8] (see Table 1).

Table 1: Decontamination yields of Techniques applying to urban objects

Technique	Target	D_f	Constraints	Comments
Turning flagstones manually	Flagstones	6	No	-
Set of tools for dismantling	Houses	∞	No	Need to build a new house
Road planing	Road	>100	No	Grinding off surface
Fire hosing	Roads	1.10	No	Water rinsing
Vacuum sweeping	Roads	1.4	No	Dust close to operator
Roof washer	Roof	2	No	Rot. brush, air compressor
Set of tools	Roof (Asbestos)	∞	Two ladders	Manual change of roof cover
ARS-14 with trailer	Roof, Wall	1.2-3.6	No	Dry & collect clay films
Electectric drill, steel wool or sand-paper	Roof (iron), wall (painted)	2-2.3	Possibly scaffolding	Grinding
High pressure turbo nozzle OM-22616	Roof, Wall, Asphalt & Concrete surface	1.3/2.2, 1.7-2.2	No	High pressure water hosing 120 bar
Detached polymer paste	Surfaces (smooth)	4-30	T > +5°C	Transports. Manual work
Sandblasting (dry or wet)	Wall	4 (dry) 5 (wet)	Scaffolding preferable	High-pressure with sand, Whole-body protect/air supply
Ammonium nitrate spraying	Wall	1.3	No	Surface rinsed with clean water
Vacuum cleaner, razors...	Walls (paper)	>100	No	Replacement of wallpaper
Polymer coatings	Walls (not wooden)	4-5	T=20-30°C	Humidity <80%
Manual electric cutting machine	Wooden wall	5	Residual nail remove	Upper layer mechanically removed (dust)

Among the techniques of decontamination of soils (see table 2), mechanical as well as chemical actions were tested. The yields of « classical » actions applying to undisturbed soils were also documented. Among others, the Turf Harvester was tested on meadows and arable lands, in Burakovka and Chistogalovska (1992) [5][6], in Millyachi and Savichi (1993, 1994) [5][6][7][8], Soil fractionation, in Karchovka (1993) [6]; Phytodesactivation in Burakovka (1994)[8].

Table 2:Decontamination yields of Techniques applying to soils in urban/rural environment

Technique	Target	Df	Constraints	Comments
Front loader / Bulldozer	Soil	28 / 10-100	No	Scraping top soil (10-30cm) Removes fertile soil layer
Grader	Top layer of ground	4-10	No	Scraping of soil surface
Shovel	Garden soil	6	Virgin soil	Digging to about 30 cm depth
Turf harvester (small)	Undisturb. grass. soils, priv. & forest pastures, urban grassed lands.	3-20	No or few stones	Removes the 3-5 cm top soil. No further intervention required
Turf harvester (industrial)	Undisturbed grassed soils	20 (grass & milk)	Few stones	Need to build a prototype
Lawn mower (mulcher)	Grassed areas in city	1(9 y after)	No	With other tech. (turf-harv.)
Showel (triple digging)	Garden soil	10-20	Virgin land	Burying top layer 30-40 cm
Mobile equipment for soil fractionation	Soil	4-6	-	Mechanical separation of the soil, Sand, sand clay (20%) soil
Ordinary plough and tractor	Arable soils	9-12(ext.)	Virgin land	Ploughing to 25-45 cm depth
Deep ploughing	Arable soils	2-4(crop)	Virgin land	Plough soil layer (25-35cm)
Skim-and-burial plough	Arable soils	10-20	Virgin land	5 cm topsoil buried at 45 cm
Liming (special trucks for spreading)	Acid arabic land	1.3-3	Soil pH = 4.5-5.5	Requires K addition, Persistent effect during 4-5 y.
Addition of potassium	Arable lands	1.3-3	No	K addition needed
Addition of phosphorus	Arable lands	0.8-1.3	With K,N	-
Organic amendment of soil	Arable soils	1.3	-	Yield and quantity increase
Radical improvement of Pasture (draining, cleaning, disking 3 times...)	Pastures	4-16(peat) 4-9 (podzol)	No	Yield increase
Disking, fertilising, liming and sowing new grass	Pastures	1.4-2.2 (Cs), 1.2-1.4 (Sr)	Repeat disking 4-6 times	Dilution of Cs and Sr in the soil profile, Yield and quantity increase
Liming and fertilising	Forest pastures	1.5	Manual	Poor soils Enriched by Ca, K
Ferrasin bol or Prussian blue	Cow	2-3	3 bolus/3 m.	Where Cs level > 1000 Bq/l
Clean fodder to animals before slaughter	Cow	2-3 on meat	2 m. before slaughter	Organisation of special animal feed before slaughter
Prussian blue salt licks	Cows and bulls	2-3		Salt lick duration= 3 months
Phytodecontamination	Soils (mixed)	1.1-1.3/y	7procedures	
Exchange of food crops with technical (industrial) crops	Arable lands	Exclusion food uptake	Plant /Crop processing	Use of contaminated area for crop production
Ferrasin filters for milk	Milk	ca. 10	Private farm	If milk contamination>400 Bq/l

For the sub-project concerning the rehabilitation of forests techniques (see table 3) techniques such as Brushing Machine, Grinding, Tree Felling Machine, Wood Incineration, Gasification or Thermal and Chemical Treatment, were tested in Kopachi, Burakovka and in the Red Forest(Nov. 1992)[5], in Rovno region, in Kruki and in Savichi (1993, 1994)[6][8].

Table3: Decontamination yields of Techniques applying to forest environment and products.

Technique	Target	Df	Constraints	Comments
Mechanical brush	Forest litter	3.5-4.5		Not wet forest areas or forest < 30 y old. Litter layer removal
Grinding mower	Under-wood forest, shrubs	1.2	∅ wood stem < 8 cm	Not wet forest areas or forest <30 y old. Cleaning of underwood
Wood sawing plant 20-K63-2	Timber	2-4	No wet area	Mec. removal of bark and phloem
Twin-screw extruder	Contaminated wood	50-100	Preparation wood chips	Special wood pulp treatment, extracts Cs, Sr from wood pulp

The study of decontamination of food products was organized in field trips to 3 farms in the Ukraine (1991-1992, 1994)[5][7], in Chistogalovka and in Chernobyl zone (1993)[5] and it also took place in laboratory (see Table 4).

Table 4: Decontamination yields of techniques applying to food processing.

Technique	Target	Df	Constraints	Comments
Replace prod. Tvorog / prod. Phoenix cheese	Domestic and Industrial milk	5	Training required	Phoenix cheese has low transfer factor for Caesium
Exchange milk private plots / milk from collective farm	Industrial milk	6	Transport costs	Use privately produced milk for feeding young animal in coll.farm
Exchange feed(hay) private plots / feed collective farm	Industrial milk	1.3	Transport costs	Use privately produced feed for feeding animals on coll. farm
Use fat fraction, Convert skim to cheese	Industrial milk	complete	Transport costs	Contamination fed to animals does not directly re-enter the food chain
Separate milk into cream & skim milk fractions	Industrial milk	complete	Transport costs	Skim is returned to farm to be used as feed for young animals
Ion-exchange	Industrial milk	10	-	Minimal nutritional implications
Use of sorbents	Industrial milk	>20	-	Minimal nutritional implications
Brine meat (UIAR recommend.)	Industrial meat, Domestic meat	2.5	Training required	Increase Na content,decrease K, B12, Fe, Z, Niacin.
Replace wild / cultured mushrooms	Domestic mushrooms	complete	Training required	Role of education in implementation will be vital
Educate to pick less contaminated mushrooms	Domestic mushrooms	1.8-12.5	Training required	Cs transfer factor can vary greatly between species of mushrooms
Domestic salting of mushrooms	Domestic mushrooms	5	Training	
Parboil potatoes	Domestic potatoes	2	Training	20% of all potatoes in the diet.
Domestic pickle cabbage	Domestic vegetables	2	Training	
Dispose of berries while making compote	Domestic vegetables	2	Training required	Possibly some losses of nutrition associated with disposal of berries
Marinating meat / eating fresh	Domestic/industrial meat	2.5	Training required	Decrease of content of water soluble vitamins and minerals
Wet culinary techniques	Domestic meat	1.6	Training	Losses of Cs are less with dry tech.
Brine carrots/ consume fresh	Domestic vegetables	2	Training	

Self Restoration was followed on Chistogalovska site, Khojniki, Kormyany, and Cherikovskij region (1993)[5][6][8]. Radiological characterisation is an important step in the definition of strategies. Its cost cannot be neglected in the optimisation analysis. Design of measurement tools that are portable and usable in large scale characterisation were worked out and experimented. This was the case of an NaI detector which can at the same time count Caesium activity in the soils and estimate the depth under certain conditions (CORAD device from RECOM). This technique as well as classical methods were documented within the same format as decontamination techniques [9].

1.2. Logistic and economical aspects

Teams working on the techniques have been asked to document them according the needs of optimisation. Components of the costs were depicted in physical terms: direct manpower and overheads, skill requirements for workers, and needs in education for the public, transportation, consumables, loss of value for products, generation of wastes (solid and liquid volumes, activity and toxicity). They were slightly different for techniques bearing on surfaces [9] and for techniques bearing on food stuff [10].

Prices were necessary in order to assess costs. A short synthesis was made in order to know the prices of manpower (from 70 to 100 ECUs per month), consumables (e.g. 0.15 to 0.3 ECUs per liter for gasoline) and products (e.g. 0.25 to 0.4 ECUs per liter for milk). Prices are indeed fluctuant at the local scale but this task was necessary to provide default values and standard values when comparing case studies.

A specific study was then necessary in order to look at the costs associated with waste management, within the framework of Belarus regulations [11]. Wastes are normally in low or very low level (Conventionally Radioactive) categories and the costs were found to depend mostly on handling, transportation and process, which do not vary very much according to the category. The relative costs for disposal of radioactive waste range from about 70 ECU/ m3 for woody waste up to 700 ECU/m3 for liquid waste. Experience in decontamination showed that local options were retained in the past at lower costs (e.g. Kirov with a cost of 17000 Rb 1989 for 3000 m^3 [6]).

2 Principles for the definition of local strategies

2.1. From cost benefit analyses on individual techniques to local strategies

The costs and the savings associated with the application of a technique can be estimated at the scale of an «Intervention Element», that is an element which is homogeneous with respect to radiological characterisation, response to the application of a technique, and contribution to a collective dose (e.g. a particular culture on a given field). The radiological benefit is usually the collective dose, valuated on the basis of the cost of Man Sievert. Other benefits can be considered (e.g. increase in the crop production when fertilizers are used). Very often the cost of the countermeasure is a constant, while the efficiency increases as the contamination increases, for that simple reason that the effect is a multiplicative effect (see table 1 to 4). Thus for a given a priori value of the Man Sievert, one can determine a « Specific Intervention Level » (S.I.L.), that is contamination level above which a countermeasure is justified. Cost benefit ratio allows the ranking of a set of countermeasures that apply to the same target. CIEMAT experimented this approach on the basis of Intervention Elements having the characteristics of some soil types from Kirov [12]. The areas were agricultural areas devoted to pasture and potato production and the S.I.L. ranged from 550 to more than 8000 kBq per sq m (turf harvester, skim and burial, mineral fertilization, liming, organic fertilization, phytodesactivation).

Eventually decision analysis involved a more complex approach. When defining a strategy, a local decion maker needs to determine the best combination of countermeasures that would satisfy a series of criteria. This decision cannot be based solely on the cost-benefit ratio of individual techniques, because some techniques may interact at the level of their efficiencies, or of their costs. The main reason is that all actions must be considered simultaneously when looking at criteria such as individual doses, to which all Intervention Elements contribute simultaneously. Thus optimisation analysis is embodied in a global assessment of the radiological impact of a given situation.
The methodology was tested on case studies. At this level, problems that are encountered are complex, but their size is manageable and the alternatives are limited because the regulatory framework and other national provisions were considered as a given reference. Practical decision on the means for decontamination are also usually taken at this level. Key parameters such as behaviour of populations become meaningfull atthe scale of a « case ». Two type of cases were considered: decontamination of a settlement, reduction of the doses attached to a practice.
Selection of case studies aimed at representing typical situations. Consequently, the choice involved many criteria, such as soil type, importance and nature of previous actions, behaviour of the population, (diet, occupancy factors and professional activities), economic activities, and of course, contamination levels, actual doses and structure of the doses. At last the social situation is of interest, as some settlements are partially evacuated and some others do have the same life-style as before the accident. A second series of criteria was more pragmatic; availability of good quality data and involvement of local authorities.
Eventually 8 cases were developed, 5 of them bearing on settlements, 3 others dealing with the enhancement of the radiological situation in an activity. The settlements were Kirov and Savichi in Belarus, Millyachi and Polleskoe in Ukraine, Zaborie in Russia. Difficulties were encountered in the investigation of the case of Polleskoe (a partially evacuated little town, quite dependant on the forest industry, submitted to heterogeneous fall-out) so that results are not presented here. Some features of the settlements are outlined (see table 5).

Table 5: Some features of the case studies.

Cases	Reference Soil contamination (Ci/sq km)	Present population	% of pre-accident population	Dominant pathway	Previous actions
Zaborie	66	180	20%	External	Extensive
Kirov	30	500	40%	External	Extensive
Savichi	10	160	20%	External	Limited
Millyachi	5	3200	100%	Internal	Numerous

One other case dealt with work in the forest and in the wood industry, an activity of major importance in the Belarus economy. It considered the practical small scale actions that can improve the radiological situation. A recreational activity was investigated, associated with the use of a site of Karchovka, near Novozybkov. At last the approaches for the rehabilitation of a school in Halch were examined. A school is a limited object, but it is an important matter of concern in many areas.

2.3. Implementationof case studies

The work on case study required preliminary steps : identification of the local goals for decontamination (lowering average or group specific individual doses, bringing food or

wood contamination level below thresholds, restoring an activity...); collection of data (demography, contamination levels, surfaces according to land use and soil types, productions, diets & occupancy factors); structuration of this information in order to put forward the « Intervention Elements » on which specific actions can be applied.
On those bases, the computation of the effectiveness of countermeasures required models combining both dose prediction and cost computation. In addition, it was necessary to use very flexible tools in order to simulate the efficiencies of countermeasures that could modify almost any of the steps in the chain of dose build-up, and in order to be able to look at very different outputs. For example, individual doses, doses to a critical group, collective doses, « exported » collective dose, contamination of food, volume of food above various levels, time span before reaching desired thresholds have been used in case studies. In contrast with this structural complexity, simplifications were made (e.g. grouping subpopulations or intervention elements whose behaviours are similar, reduction in the number of « in house » localisations ...), and it was decided to use the simplest dose computation models (transfer factors in the food chain, « influence » factors for computing external dose rates in given locations).
Some standardisation took place between the teams (CIEMAT and IPSN), in order to ensure comparability, as was done for costs. For example « recommended figures » worked out by JSP5 for dosimetric predictions have been used as a starting point ([4] and further recommendations), and they were modified only in the case they were contradicted by observations.
Indeed, observed figures in case studies were often available at two levels: foodstuff contaminations and dose rates in various locations on one side, body contents and data from individual dosimeters on the other. They were compared to "predicted doses" and the reasons for the differences were searched for. Whenever a correct explanation was found, basic coefficient such as transfer factors were modified. For example, in Zaborie [15], milk and crop contaminations were lower than predicted by about a factor of two. This was found to be consistent with the fact that previous countermeasures such as ploughing were extensively applied. Nevertheless, alterations were limited because there are many "free parameters" in such models (categorization of areas and populations, diets, occupancy factors, fraction of imported food ...). Therefore, it is always possible to reconstruct observed doses, but non documented modifications, aiming only at improving the fit, may lead to a fallacious accuracy. Preference was given to the robustness of a predictive tool which must be used in simulations. Modelled and observed figures are provided here (see table 6).

Table 6 : Mean individual dose 1993-1995 from Cs 137-134 ($\mu Sv.y^{-1}$):

	EXTERNAL			INTERNAL		
	Values based on predicted model	Dose rate+ Occupancy factor	Individual measurement	Values based on predicted model	Activity in food + diet	Whole Body Counting
Zaborie	4.15***	4.264***	3.098***	1.2***	1.05***	1.3***
Kirov	1.8•	1.570*		0.7•	0.96*	1.5•
Savichi	0.8•	0.510*		0.2•	0.092*	0.42♦
Millyachi	0.445**	No data	No data	2.83-3.1***	5-8	0.23-0.7

*- Predicted by Dr.M. Savkin [14]; **- [15]; ***- Predicted by IPSN in 1995
•- From passport 94 [16][17]; ♦- From passport 93 [17].

The "do nothing" option was the reference, so experimental work took place within ECP4. At first, ECP4 programme was focused on horizontal migrations, in contrast with the numerous studies on vertical migration. In the 1995 programme both aspects were considered [18] [19]. Ideally the self-restoration or, more properly, the reduction in the local exposures, depends on many factors and it is quite difficult to define a generic reduction parameter. Effective half life from 10 (external exposures) to 20 (internal exposures) were suggested by JSP5 [4]. The latest figure was kept for all cases; although this simplification goes along with some uneven treatment depending on pathways (external exposures from natural soils, urban objects and internal exposures).
The time scale for comparison and for computation of "averted collective dose" was taken as 50 years, leading, with the previous assumption to about 25 "effective years". It was shorter when the life time of a source of exposure was shorter, for instance for asbestos roofs which are to be replaced anyway before 50 years. A time scale of 100 years was discarded, because predictions on the behaviour of population, a major parameter for dose computation, was quite uncertain, and because the difference in "effective years" was small.

3. Lessons from case studies

3.1. Goals and criteria for decontamination

When dealing with the settlements, no cases were found in which decontamination was desired in order to meet one unique target. The overall idea is a desire for a return to a normal life style, by suppressions of interdictions in the formally "evacuated" areas (Savichi, Zaborie) or by alleviation of restrictions in villages in the other areas (Kirov, Millyachi).
Individual doses are a matter of concern that was put forward in the four main case studies, but criteria were heterogeneous. Average population dose is a criterion in Zaborie, to be compared with 5 mSv per year. Critical groups of workers have been identified in Zaborie, Kirov; Millyachi, whose doses are still to be compared with 5 mSv (e.g. forestworkers, cowboys,...). Reference to 1 mSv for the average population is also quoted (e.g. Belarus "Passports" on settlements). Most often 1 mSv is not a direct target, rather it is an indication that normal life is possible, and the length of time that is necessary to reach 1 mSv is often estimated. Individual doses are also adressed in Millyachi. It seems that the concern is rather a "potential for exposure" to high internal doses, than a limitation on actual average doses. Indeed, the presence of high transfer factors in peat-bog marshy soils results in observation of high contamination levels in some samples (especially milk). Together with mushroom consumption, internal doses to a family whose diet relies on those particular food chain can reach more than 5 mSv, although body content measurements on the average population failed to show such high figures (see table 6).
Not that the possibility for relatively high individual doses from « extreme » diets is not specific of Millyachi, especially as regards mushrooms and other "gifts of nature". Increases in individual doses in products that were noticed in 1993-1994 in Kirov and Zaborie may result from a lower vigilance of inhabitants.
The need to be less dependant on the restrictions to life style is not a quantified criterion but it is a clearly expressed goal. It has been said that population stayed or came back in evacuated territories. Direct observations also showed that prohibited land can be used either by the people from the settlement or by neighbours.

Improvement of agriculture activity corresponds to another sort of criteria : Diminution of production above standards is a criterion in Kirov an Millyachi. Volume out of range or duration before everything is below standards can be used alternatively. Collective exported dose was also a criterion. Restoration of competitivity for local products was also quoted by local authorities. It can result from the demonstration that activities are permanently low.

More complex goals can be associated with a decision on "rehabilitation". People may have a prejudice on the activity that should be restored, but such a choice is sometimes an expected result from the decision analysis. In this respect, comparison with past situations cannot serve as a reference. Almost 10 years after, a reorganisation took place, abandonned equipments may have been destroyed, the economic context is quite different. It is believed that case studies are a valuable input to such analyses, but discussion with decision makers did not take place yet on this point.
No objectives were assessed in terms of collective dose. Nevertheless, the gain in collective dose was considered as the best criterion to assess the efficiency of a countermeasure. Cost effectiveness was measured by the « cost of averted Man Sievert ». It was admitted that the most cost effective measure should be applied first in the strategy ; so the decision making process is actually an optimisation under the contraints associated with the above mentioned goals and criteria.
The problem faced with the forest industry was close to the one discussed in settlements : need to alleviate restrictions on the activity, issue of individual doses to forest workers (to be brought down to 5 mSv); contamination in wood depending on the use, collective doses associated with the uses. The decontamination of a school in Halch was associated with targets in doses received during attendance. At last, in Karchovka, the goal was to reopen the area for the citizens of Novozybkov city. Contribution to individual doses to members of critical groups (anglers, mushroom collectors and .... leisure) were considered, on the basis of time spent. Collective doses were also considered.

3.2. Elements from the decision analysis

Results from the case studies were contrasted, as could be expected from the differences in radiological situation, soil types and other factors.
In Zaborie, application of countermeasures was limited by the fact that extensive decontamination took place so that options like ploughing were pointless. However, calculated doses being only slightly higher than 5 mSv, many countermeasures would allow to go below this figure ; cleaning yards, education on mushroom consumption, but also combination of agricultural countermeasures. Actions dealing with yards (Front leader or Bulldozer cleaning) or educational programmes yield to a cost of averted Man Sievert below 2000 ECU, and they would be used first in applying a strategy. The most effective action was the cleaning of the yards surrounding houses, provided that a local solution for waste disposal is accepted, as was done in the neighbouring settlement of Yalovka. Should generic costs be applied (see §1) it would be 50 times less effective. Education on mushroom was priced on the basis of one visit per year to each family. Liming, in spite of a poor global impact, has a good cost-efficiency ratio and deserves to be included in the strategy. Costs and impacts on collective dose of individual or combined options are displayed below. Options leading to an individual dose below 5 mSv are underlined (see figure 2). Some options yield very high costs for averted Man Sievert, others are limited in their scale of application, because areas fitted for them are limited (e.g. Turf harvester).

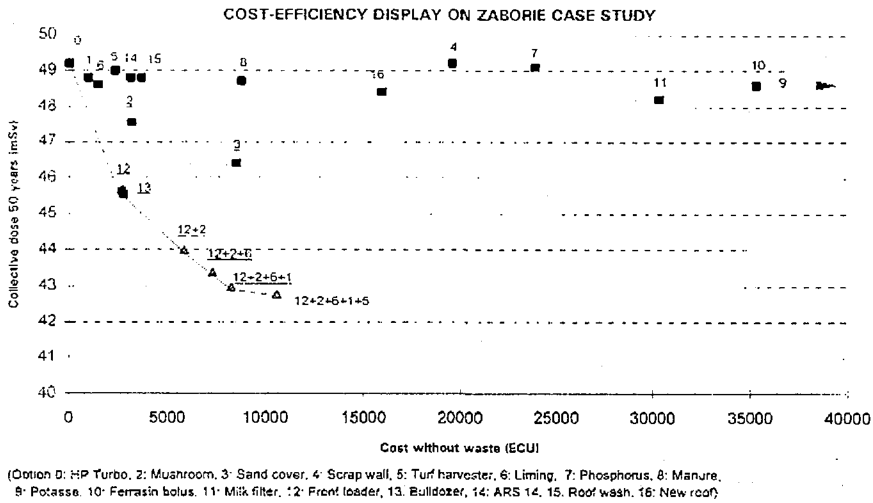

Figure 2: Cost-efficiency display on Zaborie Case study.

Situation in Savichi is such that the effectiveness of countermeasures is usually lower, simply because the contamination levels are lower. Most countermeasures yielded cost of avoided Man Sievert higher than 8000 ECUs. Actions on yards and liming are ahead as in Zaborie, but when benefits are taken into account (i.e. increase in the yields), application of fertilizers such as liming and potassium chloride are indicated. It was said that their efficiency has actually decreased due to previous applications, but they might prove useful again, after they have been stopped. Radical improvement of meadows and pastures can be proposed. In parallel with the cost benefit analysis, the classification of Savichi as a prohibited settlement was reconsidered

The collective farm in Kirov accounts for significant differences with the two previous case studies, as regards goals. Cleaning gardens is efficient (3000 ECUs per Man Sievert), followed by cleaning roofs. Although with a better efficiency due to higher levels of contamination, agricultural countermeasures have rankings similar to those in Savichi.

In Millyachi, the importance of internal dose and the high transfer coefficients increase the efficiency of agricultural countermeasures in comparison with urban countermeasures. Education for the mushroom consumption remains highly efficient. Many agricultural measures have cost efficiency around 1000 ECUs per averted Man Sievert, but cleaning yards still remains efficient. One may also notice that those yields are averaged and that targeting the areas where contamination is the highest and where soils are peat or peat-marshy soils results in even lower costs per averted Man Sievert.

The study of the forest industry appears to be connected with other case studies in which a critical group, was made of forest workers. Tree falling machine, removal of litter targeted on working areas, brushing and grinding equipment were considered for dealing with the dose to forest workers. A figure of 3000 ECUs per avoided Man Sievert was quoted for removal of litter, while a quite high figure applied to tree falling machine (3-4 Million ECUs). In the latest case the question is rather associated with the move to a capital intensive production approach. Other options for wood decontamination were considered, but their goal was not mostly associated with workers doses [20].

The recreational zone of Karchovka is a good example where several decontamination techniques deserve implementation now. For example, the cost of avoided Man Sievert, for litter removal and for litter and soil removal is respectively of 3300 and 3500 ECUs. Deep ploughing has the best efficiency (around 200 ECUs per Man Sievert), altough it leads to some reorganization of the beaches that surround the ponds of this area [21].
The case of Halch school is the only one in which the costs of averted dose is high with all options (10^6 to 10^7 ECU per avoided ManSievert). This is due to somewhat low contamination of the walls and roofs [22].

3.3. Generic lessons

In spite of the contrasted situations, generic lessons can be drawn. First, in all cases but one, there are actions with a reasonably low cost for averted dose. Should Man Sievert be valuated to 5000 ECUs or even 2000 ECUs, there are indications for application of countermeasures. Of course there is a decrease in the cost efficiency ratio, and ambitious targets in individual doses (e.g. 1 mSv) would imply the use of techniques of poor economic efficiency. Besides, it has been confirmed that actions on non disturbed land are among the most efficient and that they are limited in the present case studies.
Within a given family of techniques, the hierarchy remains quite unchanged through the various case studies. On the other hand, hierarchies between families of techniques are subject to changes from one case study to another. The techniques bearing on agricultural production are more efficient where internal dose are more important than external doses. This is hardly a surprise but it was worthwhile to quantify this point. The cost effectiveness ratio, vary significantly from one study to an other, even when differences in contamination are accounted for. Differences in diets, or in use of the products can explain those differences , but cost components are also subject to changes. As an example, the cost of averted dose for turf harvester ranged from 100 [23] to 15000 ECUs, and liming ranges from benefit to negative values when the effect on yields is denied.

The case study approach still suffers from four limitations. First, not all techniques were included and domestic and industrial food processes have not been systematically introduced in the simulations. Second, the treatment of wastes was not fully mastered. Generic solutions, local solutions and absence of treatment are three possibilities, actually used and also simulated, but the differences are impressive. In principle, waste treatment should be incorporated in the optimisation as part of the technique. Third, the case studies were performed in areas in which radiological characterization was well advanced. In other areas, the costs assiociated with the acquisition of information must be taken into account. At last, consideration of Strontium would lead to propose new specific actions; however, it would also increase the efficiencies of the present ones.

4. Conclusion

The necessity to undertake new decontamination actions or other dose reduction actions almost one decade after the Chernobyl accident raised serious doubts when the programme was launched. The goals for such actions were unclear, the availability of large scale efficient techniques was questionned and their costs were felt to be prohibitive. Today, a global programme for decontamination of all the contaminated territories is still out of reach. Nevertheless the studies that were undertaken have demonstrated that there are clear

indications for action in practical cases. Case studies put forward two aspects : availability of cost effective actions, eventhough limited, in most cases, and confirmation of practical demands and goals at the local level. Moreover they demonstrated that a thorough investigation of a case is necessary before decision, because indications for techniques is highly dependant on a situation.
The feeling that there are opportunities seems to be shared by the local authorities that were involved in the case studies. Some achievements of the programme contributed to this evolution (development of new technologies or adaptation of classical techniques, development of a synthetic information on techniques, practical implementation of case studies). Side aspects of the project cannot be neglected either. A reciprocal training took place between the teams dealing with the technical and decisional aspects of radiation protection and it mitigated the lack of mutual awareness wich was a major difficulty in the development of the project. Implication of authorities did have a similar effect, as shown by the development of decisional aspects in the Radiation Passport in Belarus.
Other incentives for decontamination do not arise from the programme but from the evolution of the situation in the contaminated areas where demands for rehabilitation are getting stronger in "partially evacuated" areas and where it is more and more difficult to maintain the efficiency of restrictions on the life style and activities.

Obviously, some developments are still needed for the improvement of decision. For example, specific questions linked with Strontium were not dealt with extensively, some conditions require adoption of techniques and some differences in the fied experiments must still be explained. The case study approach can be applied to other situations in order to give an exhaustive picture of the possibilities and needs. Among the questions that deserves most interest is the characterisation of contamination. Its global cost must be taken into account in the optimisation, and besides, its efficiency can still be increased.

References

[1] Anonymous, Transfer of radionuclides through the terrestrial environment to agricultural products including the evaluation of agrochemical practices. Final report for the period 1st November 1993 - 31st October 1994 for the Experimental Collaboration Project N°2 (ECP2). COSU-CT93-0040.

[2] Anonymous, Fluxes of radionuclides in rural communities in Russia, Ukraine and Belarus. Transfer of radionuclides to animals, their comparative importance under different agricultural ecosystems and appropriate countermeasures. ECP9 Annual Report. Nov 93-Dec 94.

[3] Anonymous, Joint Study Project N°2, Decision-aiding System for the Management of Post-Accident Situations, 1993-1994 Annual Report, 1995.

[4] Anonymous, Joint Study Project N°5. Pathway analysis and dose distributions. Contract COSU-CT93-53, Report for period Nov 93 to Oct 94. February 1995.

[5] A. Jouve, Decontamination strategies: Project N°4. Agreement on the consequences of the Chernobyl accident. Report for the period 1 November 1992 - 1 Marsh 1994. European Commission. 1994.

[6] Anonymous, CEU/CIS Agreement on the consequences of the Chernobyl accident; ECP/4, decontamination strategies, report on the work done in 1993, part two, CIS contribution. European Commission, 1994.

[7] Anonymous, Agreement on the consequences of the Chernobyl accident; Projet N°4: Strategies of decontamination, Part One, Contribution of EU institutes. Final report on the work done in 1994,. European Commission, 1995.

[8] Anonymous, Agreement on the consequences of the Chernobyl accident; Projet N°4: Strategies of decontamination, Part Two, Contribution of CIS institutes. Final report on the work done in 1994,. European Commission, 1995.

[9] J. Roed, K.G. Andersson, H. Prip, Practical Means for Decontamination 9 Years after a Nuclear Accident. RISØ Report, 1995.

[10] Anonymous, ECP4, Sub-project 5, Decontamination by Food Frocessing, Food Decontamination Methodologies, Radiological Protection Institute of Ireland, August 1995.
[11] A. Grebenkov, K. Rose, Management of Low Level radioactive Waste arising from ECP-4 Decontamination Techniques. Technical Report on the work done in 1995, AEA Technology, England, September 1995.
[12] C. Vazquez, J. Gutiérrez , R.Guardans, B.Robles, M.Savkin, Optimization of intervention strategies for the recovery of radioactively contaminated environments. Application to a case study : Kirov (Belarus). ECP4 Annual Progress Report (Oct. 1992-Oct. 1993) Second version. CIEMAT/IMA/UGIA/M5A 22/02/94, 1994.
[13] L.I. Anisimova, V.P. Ramzaev, V.I. Kovalenko, A.V. Ponomarev, V.A. Trusov, C.V. Krivonosov, A.V. Chesnokov, A.P. Govorun, O.P. Ivanov, B.N. Potapov, S.B. Shcherbak, Zaborie: NonStop Relocation ? A Russian case study, Novozybkov Branch of Institute of Radiation Hygiene, Novozybkov, 1995.
[14] M. Savkin, Savichy case study, General informations, 1995.
[15] Y. Kutlakhmedov, G. Perepelyatnikov, L. Perepelyatnikova, V. Pronevich, I. Los, Millyachi Case Study, A short report, 1995.
[16] S. Firsakova, V.S. Averin, Yu.M. Zhouchenko, Social-Economic and Radiation-Hygienic Passport on Kirov, Belarussian research Institute of Agricultural Radiology, 1995.
[17] S. Firsakova, V.S. Averin, Yu.M. Zhouchenko, Social-Economic and Radiation-Hygienic Passport on Savichi, Belarussian research Institute of Agricultural Radiology, 1995.
[18] V. Davydchuk, Project ECP-4, Geographic Assistance of Decontamination Technologies Trials and Decontamination Strategy Evaluation,Laboratory of Landscape and Ecological Problems of Chernobyl, Kiev, 1995.
[19] G. Arapis, ECP4/ Sub-project 7, Self-restoration of Contaminated Territories, Report 1995, Agricultural University of Athens, 1995.
[20] A. Jouve, F.A Tikhomirov, A. Grebenkov, M. Dubourg, M. Belli, N. Arkhipov, Management of Contaminated forests, Minsk Conference, 1996.
[21] V. Ramzaev, V. Kovalenko, A. Ponomarev, E. Ponomareva, A. Kacevich, V. Trusov, S. Krivonosov, I. Gorbovskaya, J. Roed, K.G. Andersson, Recreation Zone: Karchovka, a russian Case Study, ECP4 Report, 1995.
[22] N. Voronik, A. Bykov, Evaluation of the decontamination efficiency of school in Khalch village, Lazurny meeting, 1995.
[23] Jouve A. Technical and economic study of the use of a turf hrarvester for decontaminating permanent pastures in the Chernobyl affected areas , Rapport IPSN/DPEI/SERE Cadarache 1995.