Downloaded from orbit.dtu.dk on: Dec 19, 2017

Technical University of Denmark

Practical means for decontamination 9 years after a nuclear accident

Roed, Jørn; Andersson, Kasper Grann; Prip, Henrik

Publication date:
1995

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Roed, J., Andersson, K. G., & Prip, H. (1995). Practical means for decontamination 9 years after a nuclear accident. (Denmark. Forskningscenter Risoe. Risoe-R; No. 828(EN)).

DTU Library
Technical Information Center of Denmark

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

RISØ

Risø-R-828(EN)

Practical Means for Decontamination 9 Years after a Nuclear Accident

Editors J. Roed, K.G. Andersson, H. Prip

Risø National Laboratory, Roskilde, Denmark
December 1995

Practical Means for Decontamination 9 Years after a Nuclear Accident

Risø-R-828(EN)

Editors J. Roed, K.G. Andersson, H. Prip

Risø National Laboratory, Roskilde, Denmark
December 1995

Abstract. Nine years after the Chernobyl accident, the contamination problems of the most severely affected areas remain unsolved. As a consequence of this, large previously inhabited areas and areas of farmland now lie deserted. An international group of scientists funded by the EU European Collaboration Programme (ECP/4) has investigated in practice a great number of feasible means to solve the current problems. The basic results of this work group are presented in this report that was prepared in a format which facilitates an intercomparison (cost-benefit analysis) of the individual examined techniques for decontamination or dose reduction in various different types of environmental scenarios. Each file containing information on a method or procedure was created by the persons and institutes responsible for the practical trial. Although the long period that has elapsed since the contamination took place has added to the difficulties in removing the radioactive matter, it could be concluded that many of the methods are still capable of reducing the dose level substantially.

ISBN 87-550-2080-1
ISSN 0106-2840

Grafisk Service, Risø, 1995

Contents

Introduction

The files presented in this report are estimates of achievable 'local' dose reduction factors or decontamination factors and other important parameters (see definitions below) for different clean-up procedures in various types of environmental scenarios. The estimates were based on experimental work to assess the effect of dose reducing countermeasures in areas contaminated about 9 years ago by radioactive matter released during the Chernobyl accident.

Residential areas within the 30 km zone around the Chernobyl power plant are still unoccupied due to unacceptably high levels of radiation from radionuclides deposited on the ground and on various man-made surfaces in the environment. Also agricultural and forestry products contain high levels of radioactivity. The need for identification of effective means for reduction of the radiation dose to the population in the affected areas is therefore evident.

Nine years after the accident, the radioisotope of major concern is in most situations ^{137}Cs. This isotope therefore has a central position in the evaluation, and the effect of all procedures suggested for reduction of external radiation dose relates to ^{137}Cs.

The research was carried out under the framework of the EU radiation protection programme (ECP-4) with the ultimate goal of developing feasible strategies for clean-up of contaminated areas. A great number of feasible dose reducing methods for different areas have been suggested and investigated. The procedures that were found to be most promising after laboratory and other small scale tests were investigated further in field trials in the contaminated areas of Russia, Byelorussia and Ukraine. It is the experience from these trials, which were carried out by Danish, French, Greek, Russian, Byelorussian and Ukrainian scientists, that is presented in this report.

The work reported reflects an effort to guide decision-makers to obtain the maximum effect with the money available. Although they are to some degree directly related to the Chernobyl accident, the results could be used to estimate the effect, in a more general sense, of procedures for removal of aged contamination.

The report lists important features of the different methods so as to facilitate a comparison. The presentation is made as a series of tables or schemes which show the evaluation of the persons and institutes responsible for the investigation of the particular procedure. The aim was in this case to highlight the performance and effect of a procedure and not so much to describe the appearance and detailed function of the tools and methods applied. Such information can be found in other documents prepared by the ECP-4 project participants.

The idea of a scheme design was brought up by André Jouve at a meeting of the ECP-4 group in Russia. The idea was approved by all the participants and suggestions for the design were given. The final form of the scheme was reached at a meeting at Risø.

In the following is given an example of how to read and apply one of the schemes that were filled in. The scheme is shown in section 1.4 (sandblasting, wet).

1. Tool : mentions the tool and method in question. Remarks at the bottom of each page (below the scheme) often give more information on the design of the tool. In this case (wet sandblasting) the tool is fabricated by a Danish firm, KEW, and the remarks at the bottom of the page show that this is a high pressure water based cleaning equipment, to which a sandblasting device can be attached.

2. Target surface: this is the surface that we are dealing with (in this scheme it is walls).

2.1. Constraints: lists obvious constraints for the method and target. In this case it is indicated that scaffolding would ease the process and is often necessary.

3. Design (number of operators): gives some further details. It is indicated here, that the method mostly requires two operators.

3.1. Productivity: gives the speed by which the method is carried out. Usually, it is given as the number of square metres that can be treated by one tool in an hour. In this case this is 30.

4. Mode of operation: is in this case high pressure water with sand injected.

5. Cost: has been divided in the following different sub-sections:

5.1. Manpower (days per unit area) : gives the cost in man-days/unit area of the target surface. The reasons for which we have chosen man-days as indicators of costs instead of money are the following : a) the cost of man-power is very different in different countries, especially when considering the CIS countries compared with the EU countries. The users can therefore give their own local estimate of cost of labour force. b) the data can be used in the future as it is possible to include a cost estimate of labour force in a future situation.

5.2. Tool investment cost: gives the cost of buying or renting the tool. In this case the price of the tool is 2400 ECU.

5.3. Discount (ECU/year): gives the normal discount rate based on the investment costs and an assumed interest rate. In this case it can be seen that the equipment is fully discounted after 5 years.

5.4. Consumables: gives the most important consumables, in this case petrol, sand and water.

5.5. Overheads: is normally given in manpower per square meter. The overheads are in this case the work required for preparation of the tool, the normal cost of the administration of the firm in charge, etc.

5.6. Scale of application: gives the scale of application for normal operation - in this case 30 m^2 can be cleaned per hour and it is assumed that the tool can be operated 720 hours per year. This gives a total surface of 21,600 m^2 per year. From that it can be estimated how many tools are needed for a special operation. This is the reason why the item 'scale of application' has been placed under the 'cost' section

5.7.1.-5.7.3. are dose related costs.

5.7.1: Specific exposure: can be e.g. inhalation dose, β dose, etc. In this case it is indicated that there is only little dust (inhalation hazard), as it is greatly reduced by the water (wet sandblasting).

5.7.2. Inhalation/external dose relation: gives an estimate of the importance of inhalation dose when not protected. In this case it is estimated that the inhalation dose will be less than 1 % of the external dose.

5.7.3. Number of man-hours exposed: gives the number of man-hours where the operators are exposed on the contaminated working place.

6: Efficiency: has only one item (point 6.1). In most cases a decontamination factor has been quoted. The decontamination factor is defined as the concentration of the original contamination on a surface or in an object relative to what is left after a decontamination procedure. By some of the procedures, however, the contamination has not been removed (no actual decontamination), but for instance buried under a shielding layer of uncontaminated soil to reduce the dose rate. For such procedures another concept was introduced to evaluate the efficiency: the surface dose reduction factor, which is defined as the ratio of the dose rate before to that after a dose reduction action has taken place (e.g. deep ploughing) at a distance of 1 m from the surface, regarding the surface as having infinite dimensions, and assuming that no other sources are present. In most cases this factor must be calculated from measurements on a limited (finite) surface. By these concepts the decontamination factor for a surface is equal to the surface dose reduction factor, which can be used to find the 'total' dose reduction factor for a procedure in a given scenario. This 'total' dose reduction factor would be smaller (in some cases substantially smaller) than the surface dose reduction factor, due to the presence of other surfaces, objects and sources in the environment.

7. Wastes generated: point 7 deals with the wastes generated by the operation.

7.1. Solid (kg/m^2): this is the solid part of the waste, in this case sand and fragments of the wall that have been removed in the process.

7.2. Liquid (l/m^2): this is the residual waste after separation of the solid part from the liquid.

7.3. Waste activity (Bq/m^3 per Bq/m^2): enables a calculation of the concentration of radioactivity in the waste, when the contamination level per square meter of the surface is known.

7.4. Toxicity: deals with the toxicity (other than radioactivity) of the waste created.

8. Other costs: could be that the wall has to be repainted. In this case it is not found to be necessary.

9. Other benefits: in this case there are visual improvements.

10. Special remarks: could be that this method can not be used on wooden houses as the sand and water might then penetrate through the wall. In this case there are no special remarks.

The following scientists and organisations have contributed to this methodological evaluation :

Risø National Laboratory, Ecology Section, Environmental Science and Technology Department, DK-4000 Roskilde, Denmark (Risø):
J. Roed, K.G. Andersson, H. Prip

IPSN, DPEI/SERE CD/Cadarache, Batiment 159, 13108 Saint Paul lez Durance, France (IPSN):
A. Jouve

Laboratory of Ecology and Environmental Sciences, Agricultural University of Athens, 11000 Athens, Greece:
G. Arapis

A.A. Bochvar All-Russian Scientific Research Institute of Inorganic Materials, 5 Rogov st., 123060 Moscow, Russia (IIM):
L. Mamaev, G. Galkin, Rybakov, Ogulnik

Branch of St. Peterburg Institute of Radiation Hygiene, Karchevka, Novozybkov, Bryansk Region, 243000 Russia (BIRH):
V. Ramzaev

RECOM Ltd., 12-1 Schukinskaya st., 123182 Moscow, Russia (RECOM):
A. Chesnokov

Institute of Radioecological Problems, Academy of Sciences, 220109 Minsk, Sosny, Belarus (IRP):
N. Voronik

Institute of Power Engineering Problems, Academy of Sciences, Sosny 220109 Minsk, Belarus (IPEP):
A. Grebenkov

Chernobyl State Committee Belarus, 14 Lenin St., 220030 Minsk, Belarus (CSCB):
G. Antsypau

IGMOF AS Ukraine, Dept. of Radiogeochemistry of the Environment, 34 Palladin Avenue, Kiev 252142, Ukraine (IGMOF):
N. Movchan, Y. Fedorenko, A. Spigoun, B. Zlobenko

Belarus Institute of Agricultural Radiology, 16 Fedyuninsky st., 246007 Gomel, Belarus (BIAR):
S. Firsakova, A. Timoteev, A. Averin

Institute of Cell Biology and Genetic Engineering AS, 148 Zabolotnogo st., Kiev, Ukraine (ICBGI):
Y.Kutlakhmedov

Ukrainian Research Centre for Radiation Medicine, 53 Melnikova st., 254050 Kiev, Ukraine (UCRM):
I.P. Los

Institute of Geography AS of Ukraine, 44 Vladimirskaya st., 252034 Kiev, Ukraine:
V. Davydchouk

Belarus State University, Chemistry Dept., 4 Francisk Scorina Av., 220080 Minsk, Belarus:
G. Sokolik

Ukrainian Institute of Agricultural Radiology, 7 Mashinostroitelei st., Chabany, 255205 Kiev, Ukraine (UIAR):
L. Perepelyatnikova

Institute of Bio-organic Chemistry and Petrochemistry of Academy of Sciences, 50 Kharkovskoe shosse, 252160 Kiev, Ukraine (IBOChOCh):
V. Blagoev

1 Man-Made Surfaces in Urban and Rural Environments

This chapter reports the effect of experimental procedures to clean contaminated roof pavings, walls, roads, pavements, indoor surfaces and various other man-made surfaces. Decontamination of such surfaces is particularly difficult so long time after the accident, where the fixation of radiocaesium by micaceous substances that are present in many types of surface has become very strong. However, a substantial decrease in radiation dose rate has been found to be achievable by some of the reported methods. Also dismantling of buildings was considered as an option.

1.1 Fire hosing.

1) Tool	Fire hosing
2) Target surface	Roads
2.1) Constraints	-
3) Design (incl. number of operators)	Pump + 2 jet pipes
3.1) Productivity (units/h)	100 m^2/h
4) Mode of operation	Water rinsing
5) Cost	
5.1) Manpower (days/unit area)	0.0013 man-day/m^2
5.2) Tool investment cost, ECU	3000 ECU - if bought in Western Europe
5.3) Discount (ECU/year)	600 ECU/year
5.4) Consumables	10 l petrol per hour + 24 m^3 water per hour
5.5) Overheads	200 % of manpower (5.1)
5.6) Scale of application	72000 m^2 per year
5.7.1) Specific exposure	No inhalation hazard
5.7.2) Inhalation/external dose relation	0
5.7.3) Number of man-hours exposed	0.03 h/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	1.10 (probably less in heavily trafficked areas and more in Pripyat)
7) Wastes generated	
7.1) Solid kg/m^2	50-200 g/m^2 (impossible to collect)
7.2) Liquid l/m^2	0.25 m^3/m^2 (impossible to collect)
7.3) Waste activity Bq per m^3 per Bq per m^2	low
7.4) Toxicity (incineration, sulphate content in concrete solidification etc.)	None
8) Other costs (ECU)	-
9) Other benefits (renewing roof etc.)	-
10) Special remarks	-

Authors: Roed, Andersson, Prip Institution: Risø

As it is not always possible to find fire pumps in the area, it is assumed that a pump is needed. A pump can supply 2 jet pipes with water. It is assumed that the pump will also require an operator.

Reference: J. Roed and K.G. Andersson: 'Clean-up of Urban Areas in the CIS Countries Contaminated by Chernobyl Fallout', accepted for publication in J. Environ. Radioactivity, 1995.

1.2.a High pressure water hosing.

1) Tool	High pressure turbo nozzle
2) Target surface	walls/roofs
2.1) Constraints	-
3) Design (incl. number of operators)	1 person
3.1) Productivity (units/h)	37 m^2/h
4) Mode of operation	High pressure water hosing 120 bar
5) Cost	
5.1) Manpower (days/unit area)	0.0034 man-day per m^2
5.2) Tool investment cost, ECU	2350 ECU
5.3) Discount (ECU/year)	470 ECU/year
5.4) Consumables	4 l petrol per hour
5.5) Overheads	200 % of manpower (5.1)
5.6) Scale of application	(37 m^2/h* 720 h/y) 26500 m^2/year
5.7.1) Specific exposure	Because of water only a little dust
5.7.2) Inhalation/external dose relation	<1/100
5.7.3) Number of man-hours exposed	0.027 man-h/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	1.3(walls), 2.2(roofs), probably more in Pripyat
7) Wastes generated	
7.1) Solid kg/m^2	0.4 kg/m^2
7.2) Liquid l/m^2	20 l/m^2
7.3) Waste activity Bq per m^3 per Bq per m^2	2500 m^{-1} - solid
7.4) Toxicity (incineration, sulphate content in concrete solidification etc.)	None unless asbestos
8) Other costs (ECU)	-
9) Other benefits (renewing roof etc.)	Algae and moss removed. Nicer appearance
10) Special remarks	After precipitation the liquid contains 5 % of the radioactivity and can be disposed of

<u>Authors:</u> Roed, Andersson, Prip   Institution: Risø

Requirements: High pressure cleaning equipment, petrol driven. Working at 150 bar the turbo nozzle has an oscillating jet-stream.

<u>Reference:</u> J. Roed and K.G. Andersson: 'Clean-up of Urban Areas in the CIS Countries Contaminated by Chernobyl Fallout', accepted for publication in J. Environ. Radioactivity, 1995.

1.2.b High pressure water hosing.

1) Tool	OM-22616
2) Target surface	Asphalt surfaces, concrete surfaces
2.1) Constraints	No
3) Design (incl. number of operators)	2 operators
3.1) Productivity (units/h)	1.5..2 m^2/h (1.0..1.8 m^2/h for concrete surfaces)
4) Mode of operation	High pressure water hosing
5) Cost	
5.1) Manpower (days/unit area)	0.15 ... 0.2 man-days/m^2
5.2) Tool investment cost, ECU	240 ECU
5.3) Discount (ECU/year)	80 ECU/year
5.4) Consumables	Power: 49 kW; Water 0.1 m^3/m^2
5.5) Overheads	160 % of wages
5.6) Scale of application	2 m^2/h * 720 h/year
5.7.1) Specific exposure	No
5.7.2) Inhalation/external dose relation	No
5.7.3) Number of man-hours exposed	1.0 ... 1.4 man-hour/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	1.7 ... 2.2 for concrete surfaces
7) Wastes generated	
7.1) Solid kg/m^2	No
7.2) Liquid l/m^2	Liquids are not collected
7.3) Waste activity Bq per m^3 per Bq per m^2	
7.4) Toxicity	No
8) Other costs (ECU)	No
9) Other benefits	Sanitary cleaning up
10) Special remarks	Large volume of water

Authors: Voronik, Grebenkov, Antsypau. Institution: IRP, IPEP, CSCB

1.3 Dry sandblasting.

1) Tool	Sandblasting equipment (dry)
2) Target surface	wall
2.1) Constraints	scaffolding preferable
3) Design (incl. number of operators)	High-pressure with sand (2 persons)
3.1) Productivity (units/h)	20 m^2 per hour
4) Mode of operation	High pressure air with sand injected
5) Cost	
5.1) Manpower (days/unit area)	0.012 man-day per m^2
5.2) Tool investment cost, ECU	4500 ECU
5.3) Discount (ECU/year)	900 ECU/year
5.4) Consumables	5 l petrol per hour and 2 kg sand per m^2. Dry sand - preferably quartz-sand (0.5-2 mm)
5.5) Overheads	200 % of manpower (5.1)
5.6) Scale of application	20 m^2/h * 720 h/year = 14400 m^2/year
5.7.1) Specific exposure	Dust: inhalation hazard
5.7.2) Inhalation/external dose relation	ca. 1/10 with proper mask
5.7.3) Number of man-hours exposed	0.1 man-h/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	4
7) Wastes generated	
7.1) Solid kg/m^2	2.5 kg/m^2 (impossible to collect)
7.2) Liquid l/m^2	-
7.3) Waste activity Bq per m^3 per Bq per m^2	800 m^{-1}
7.4) Toxicity	None
8) Other costs (ECU)	-
9) Other benefits (renewing roof etc.)	Visual improvement
10) Special remarks	Creates dust. Whole-body protect/air supply needed

Authors: Roed, Andersson, Prip Institution: Risø

Basic equipment: High pressure air compressor with sandblasting equipment and sand container

Reference: J. Roed and K.G. Andersson: 'Clean-up of Urban Areas in the CIS Countries Contaminated by Chernobyl Fallout', accepted for publication in J. Environ. Radioactivity, 1995.

1.4 Wet sandblasting.

1) Tool	Sandblasting with KEW equipment (wet)
2) Target surface	wall
2.1) Constraints	scaffolding preferable
3) Design (incl. number of operators)	High pressure water plus sand - 2 persons
3.1) Productivity (units/h)	30 m^2 per hour
4) Mode of operation	high pressure water with sand injected
5) Cost	
5.1) Manpower (days/unit area)	0.0083 man-day per m^2
5.2) Tool investment cost, ECU	2400 ECU
5.3) Discount (ECU/year)	480 ECU/year
5.4) Consumables	4 l petrol/h, 2.25 kg sand/m^2, 55 l water per m^2
5.5) Overheads	200 % of manpower (5.1)
5.6) Scale of application	30 m^2/h*720 h/year = 21600 m^2/year
5.7.1) Specific exposure	because wet only a little dust
5.7.2) Inhalation/external dose relation	<1/100
5.7.3) Number of man-hours exposed	0.067 h/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	5
7) Wastes generated	
7.1) Solid kg/m^2	2.5 kg/m^2
7.2) Liquid l/m^2	(55 l/m^2)
7.3) Waste activity Bq per m^3 per Bq per m^2	Solid 800 m^{-1} (liquid = almost 0)
7.4) Toxicity	None
8) Other costs (ECU)	-
9) Other benefits	Visual improvement
10) Special remarks	-

Authors: Roed, Andersson, Prip Institution: Risø

High-pressure water cleaning equipment supplied with a sandblasting device which injects sand in the water jet-stream.

Reference: J. Roed and K.G. Andersson: 'Clean-up of Urban Areas in the CIS Countries Contaminated by Chernobyl Fallout', accepted for publication in J. Environ. Radioactivity, 1995.

1.5.a Clay treatment improved with chemicals.

1) Tool	ARS-14 with trailer
2) Target surface	Wall
2.1) Constraints	No
3) Design (incl. number of operators)	3 persons
3.1) Productivity (units/h)	70 m^2/h
4) Mode of operation	Covering clay suspension, drying and collecting of clay films
5) Cost	Total cost estimate 0.7 ECU/m^2
5.1) Manpower (days/unit area)	0.007 man.day/m^2
5.2) Tool investment cost, ECU	57000 ECU
5.3) Discount (ECU/year)	11400 ECU/year
5.4) Consumables	gasoline 31 kg/h
5.5) Overheads	200 % of wages
5.6) Scale of application	max. area treated 45500 m^2/year
5.7.1) Specific exposure	Wet = no dust
5.7.2) Inhalation/external dose relation	> 0,00001
5.7.3) Number of man-hours exposed	$4.3 * 10^{-2}$ man.h/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	1.2 ± 0.1 - 3.6 ± 0.8
7) Wastes generated	
7.1) Solid kg/m^2	0.25 ± 0.05
7.2) Liquid l/m^2	
7.3) Waste activity Bq per m^3 per Bq per m^2	$5.7 * 10^3 - 1.2 * 10^4$
7.4) Toxicity	No toxicity
8) Other costs (ECU)	no
9) Other benefits	Improvement of consumable properties
10) Special remarks	

Authors: Movchan, Fedorenko, Spigoun, Zlobenko. Institution: IGMOF

#3. Design ARS-14 consists of:
3.1 Lorry SIL-131
3:2 Tank for water 2.5 m^3
3.3 pump 2.5 VS-3a
-productivity 30+300 l/min. - pressure 3-4.5 bar. - Trailer with vessel 3-4 m^3

3 persons: 2 operators + 1 driver.

1.5.b Clay treatment improved with chemicals.

1) Tool	ARS-14 with trailer
2) Target surface	Roof
2.1) Constraints	No
3) Design (incl. number of operators)	3 persons
3.1) Productivity (units/h)	90 m^2/h
4) Mode of operation	Covering clay suspension, drying and collect clay films
5) Cost	Total cost estimate 0.7 ECU/m^2
5.1) Manpower (days/unit area)	0.006 man.day/m^2
5.2) Tool investment cost, ECU	57000 ECU
5.3) Discount (ECU/year)	11400 ECU/year
5.4) Consumables	gasoline 31 kg/h
5.5) Overheads	200 % of wages
5.6) Scale of application	max. area possibly treated 58500 m^2/year
5.7.1) Specific exposure	Wet = no dust
5.7.2) Inhalation/external dose relation	> 0,00001
5.7.3) Number of man-hours exposed	$3.3 * 10^{-2}$ man-h/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	1.2 ± 0.1 - 2.6 ± 0.4
7) Wastes generated	
7.1) Solid kg/m^2	0.25 ± 0.05
7.2) Liquid l/m^2	
7.3) Waste activity Bq per m^3 per Bq per m^2	$4 * 10^3 - 2.8 * 10^4$
7.4) Toxicity	Non toxicity
8) Other costs (ECU)	no
9) Other benefits	Improvement of consumable properties
10) Special remarks	

Authors: Movchan, Fedorenko, Spigoun, Zlobenko. Institution: IGMOF

#3. Design: ARS-14 consist of:
3.1 Lorry SIL-131
3:2 Tank for water 2.5 m^3
3.3 pump 2.5 VS-3a
- productivity 30+300 l/min. - pressure 3-4.5 bar. - Trailer with vessel 3-4 m^3

3 persons: 2 operators + 1 driver.

1.6 Roof cleaning.

1) Tool	Roof washer
2) Target surface	Roofs
2.1) Constraints	None
3) Design (incl. number of operators)	Air driven rotating brush - 2 persons
3.1) Productivity (units/h)	18 m^2 per hour
4) Mode of operation	Rotating brush + rinsing water
5) Cost	
5.1) Manpower (days/unit area)	0.014 man-day/m^2
5.2) Tool investment cost, ECU	6000 ECU
5.3) Discount (ECU/year)	1200 ECU/year
5.4) Consumables	5 l petrol/h + 13 l/m^2 water
5.5) Overheads	150 % of man-power (5.1)
5.6) Scale of application	(18m^2/h*720 h/y) 12960 m^2/year
5.7.1) Specific exposure	0
5.7.2) Inhalation/external dose relation	0
5.7.3) Number of man-hours exposed	0.11 h/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	2 (probably higher in Pripyat)
7) Wastes generated	
7.1) Solid kg/m^2	0.2 kg/m^2 (in water)
7.2) Liquid l/m^2	13 l/m^2
7.3) Waste activity Bq per m^3 per Bq per m^2	77 m^{-1}
7.4) Toxicity	None unless asbestos
8) Other costs (ECU)	-
9) Other benefits	Roof cleaned for moss and algae
10) Special remarks	Can be used with special waste-collection system. Can be operated from ground level.

Authors: Roed, Andersson, Prip Institution: Risø

Rotating brush mounted on extendible rod allows operation from ground. Air compressor provides pressure for rotating the brush and tap water at ordinary pressure is needed for rinsing. A filter system can enable recycling.

Reference: J. Roed and K.G. Andersson: 'Clean-up of Urban Areas in the CIS Countries Contaminated by Chernobyl Fallout', accepted for publication in J. Environ. Radioactivity, 1995.

1.7.a Change of roof.

1) Tool	Set of tools
2) Target surface	Asbestos roof (mainly for private house)
2.1) Constraints	No
3) Design (incl. number of operators)	4 operators
3.1) Productivity (units/h)	12 m^2/h
4) Mode of operation	Change of roof
5) Cost	Sum estimated in Gomel Province (5.1+5.2+5.3+5.4+5.5): 1.5 ECU/m^2
5.1) Manpower (days/unit area)	0.05 man-days/m^2
5.2) Tool investment cost, ECU	100
5.3) Discount (ECU/year)	30
5.4) Consumables	12 m^2/h of new asbestos plates
5.5) Overheads	160 % of wages
5.6) Scale of application	12 m^2/h * 840 h/year
5.7.1) Specific exposure	Asbestos dust
5.7.2) Inhalation/external dose relation	<0.001
5.7.3) Number of man-hours exposed	0.27 man-hour/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	In principle infinite
7) Wastes generated	
7.1) Solid kg/m^2	12 kg/m^2
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	120 m-1
7.4) Toxicity	Asbestos
8) Other costs (ECU)	No
9) Other benefits	New roof, nicer looking
10) Special remarks	

Authors: Antsypau, Grebenkov Institution: CSCB, IPEP

1.7.b Change of roof.

1) Tool	Hammer, nail-taker.
2) Target surface	Roof (asbestos)
2.1) Constraints	needs 2 ladders
3) Design (incl. number of operators)	
3.1) Productivity (units/h)	2 m^2/h 800 h/year
4) Mode of operation	Manual changing of roof covering
5) Cost	
5.1) Manpower (days/unit area)	0.125 man.day/m^2
5.2) Tool investment cost, ECU	10 ECU
5.3) Discount (ECU/year)	10 ECU
5.4) Consumables	No
5.5) Overheads	150 %
5.6) Scale of application	2 m^2/h * 800h/y = 1600 m^2/year
5.7.1) Specific exposure	Dust + asbestos inhalation
5.7.2) Inhalation/external dose relation	1/1000 - 1/10000
5.7.3) Number of man-hours exposed	1 man-hour/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	>100
7) Wastes generated	
7.1) Solid kg/m^2	15 kg/m^2
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	100 - 200 Bq/m^3/Bq/m^2
7.4) Toxicity	Asbestos
8) Other costs (ECU)	1.5 ECU/m^2 of new asbestos
9) Other benefits	Renewing of roof
10) Special remarks	Especially effective in the case of old roof.

Authors: Ramzaev Institution: BIRH
Chesnokov RECOM

Removing old asbestos sheets manually and putting on new ones.

2 operators.

1.8 Road planing.

1) Tool	Road planer (grinding off 3 cm)
2) Target surface	Road
2.1) Constraints	-
3) Design (incl. number of operators)	Professional road planer (4 operators)
3.1) Productivity (units/h)	500 m^2/h
4) Mode of operation	grinding off surface which must be picked up
5) Cost	
5.1) Manpower (days/unit area)	0.0019 man-day/m^2
5.2) Tool investment cost, ECU	70.000 ECU
5.3) Discount (ECU/year)	12.500 ECU
5.4) Consumables	8 l/hour of petro-diesel
5.5) Overheads	200 % of manpower (5.1)
5.6) Scale of application	500 m^2/h*720h/y = 360000 m^2/year
5.7.1) Specific exposure	Dusty - but coarse particles
5.7.2) Inhalation/external dose relation	< 1/10
5.7.3) Number of man-hours exposed	0.016 man-h/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	>100
7) Wastes generated	
7.1) Solid kg/m^2	45 kg/m^2
7.2) Liquid l/m^2	none
7.3) Waste activity Bq per m^3 per Bq per m^2	22 m^{-1}
7.4) Toxicity	Asphalt (bitumen)
8) Other costs (ECU)	In some cases subsequent paving of the road - not necessary with the right machine
9) Other benefits	Planing of road
10) Special remarks	-

Authors: Roed, Andersson, Prip Institution: Risø

Contractor's machinery - large scale - a rotating 'drum' grinds off the asphalt top layer which must be removed.

1.9 Turning flagstones.

1) Tool	Turning flagstones manually
2) Target surface	Flagstones
2.1) Constraints	-
3) Design (incl. number of operators)	- 1 operator
3.1) Productivity (units/h)	12 m^2/h
4) Mode of operation	Manual
5) Cost	
5.1) Manpower (days/unit area)	0.02 man-day/m^2
5.2) Tool investment cost, ECU	None
5.3) Discount (ECU/year)	-
5.4) Consumables	-
5.5) Overheads	-
5.6) Scale of application	12 m^2/h * 720 h/y = 8640 m^2/year
5.7.1) Specific exposure	-
5.7.2) Inhalation/external dose relation	-
5.7.3) Number of man-hours exposed	0.2 man-h/m^2
6) Efficiency	
6.1) Surface dose reduction factor	6
7) Wastes generated	-
7.1) Solid kg/m^2	-
7.2) Liquid l/m^2	-
7.3) Waste activity Bq per m^3 per Bq per m^2	-
7.4) Toxicity	-
8) Other costs (ECU)	-
9) Other benefits	-
10) Special remarks	-

<u>Authors:</u> Roed, Andersson, Prip   Institution: Risø

<u>Reference:</u> Further description of the method can be found in : H.L. Gjørup, N.O. Jensen, P. Hedemann Jensen, L. Kristensen, O.J. Nielsen, E.L. Petersen, T. Petersen, J. Roed, S. Thykier Nielsen, F. Heikel Vinther, L. Warming, A. Aarkrog:' Radioactive Contamination of Danish Territory after Coremelt Accidents at the Barsebäck Power Plant, Risø National Laboratory, Risø-R-462, March 1982.

1.10 Ammonium nitrate treatment.

1) Tool	Ammonium nitrate spraying
2) Target surface	wall
2.1) Constraints	
3) Design (incl. number of operators)	spraying with pump (1 person)
3.1) Productivity (units/h)	24 m^2/h
4) Mode of operation	Ammonium nitrate solution sprayed onto wall
5) Cost	
5.1) Manpower (days/unit area)	0.01 man-day /m^2
5.2) Tool investment cost, ECU	1000 ECU
5.3) Discount (ECU/year)	200 ECU/year
5.4) Consumables	6.25 l/m^2 of 0.1 M ammonium nitrate solution
5.5) Overheads	150 % of manpower
5.6) Scale of application	17280 m^2/year
5.7.1) Specific exposure	-
5.7.2) Inhalation/external dose relation	<1/100
5.7.3) Number of man-hours exposed	0.1 man-h/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	1.3 (probably higher in Pripyat)
7) Wastes generated	
7.1) Solid kg/m^2	None
7.2) Liquid l/m^2	6 l/m^2 - collectable, recyclable
7.3) Waste activity Bq per m^3 per Bq per m^2	55 m^{-1}
7.4) Toxicity	-
8) Other costs (ECU)	-
9) Other benefits	-
10) Special remarks	-

<u>Authors:</u> Roed, Andersson, Prip Institution: Risø

Ammonium nitrate is dissolved to 0.1 M (no significant effect improvement from stronger solutions) in water in a vessel. A pump (submersible) is used together with a hose to apply the solution. The surface is subsequently rinsed with clean water.

<u>Reference:</u> J. Roed and K.G. Andersson: 'Clean-up of Urban Areas in the CIS Countries Contaminated by Chernobyl Fallout', accepted for publication in J. Environ. Radioactivity, 1995.

1.11 Indoor decontamination (following dry deposition).

1) Tool	Vacuum Cleaner, razors, manual scraper, brush
2) Target surface	Walls covered with wall paper
2.1) Constraints	none
3) Design (incl. number of operators)	2 operators
3.1) Productivity (units/h)	7.5 m^2/h
4) Mode of operation	Changing of wallpaper
5) Cost	
5.1) Manpower (days/unit area)	0.03 man-day/m^2
5.2) Tool investment cost, ECU	70 ECU
5.3) Discount (ECU/year)	18 ECU/year
5.4) Consumables	0.0005 kWh/m^2
5.5) Overheads	100 %
5.6) Scale of application	7.5 m^2/h * 8h * 200 days = 12000 m^2/year
5.7.1) Specific exposure	No
5.7.2) Inhalation/external dose relation	< 0.0001
5.7.3) Number of man-hours exposed	0.07 man-hour/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	> 100
7) Wastes generated	
7.1) Solid kg/m^2	0.15 - 0.30 kg/m^2
7.2) Liquid l/m^2	None
7.3) Waste activity Bq per m^3 per Bq per m^2	10000 Bq/m^3 per Bq/m^2
7.4) Toxicity	None
8) Other costs (ECU)	0.2 ECU/m^2 for new wall paper etc.
9) Other benefits (renewing roof etc.)	wallpaper renewed
10) Special remarks	Replacement of wallpaper

Authors: Ramzaev, Chesnokov Institution: BIRH, RECOM (Russia)

1.12.a Coatings.

1) Tool	Detached polymer paste
2) Target surface	Smooth metal surfaces (painted)
2.1) Constraints	Effective at t>+5°C
3) Design (incl. number of operators)	1 operator
3.1) Productivity (units/h)	2 ... 6 m^2/h
4) Mode of operation	Cleaning of equipment, transports
5) Cost	
5.1) Manpower (days/unit area)	0.02 ... 0.07 man-days/m^2
5.2) Tool investment cost, ECU	0 ECU
5.3) Discount (ECU/year)	0 ECU/year
5.4) Consumables	Paste and ingredients: 0.4-0.7 kg/m^2, 1.7-2.5 ECU/kg
5.5) Overheads	160 % of wages
5.6) Scale of application	2-6 m^2/h * 500 h/year
5.7.1) Specific exposure	No
5.7.2) Inhalation/external dose relation	No
5.7.3) Number of man-hours exposed	0.12 ... 0.15 man-hour/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	4 ... 30
7) Wastes generated	
7.1) Solid kg/m^2	0.2 ... 1.8 kg/m^2
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	10 ... 20 m^{-1}
7.4) Toxicity	no
8) Other costs (ECU)	No
9) Other benefits	Sanitary cleaning up, improvement of consumable properties
10) Special remarks	Large volume of manual work

<u>Authors:</u> Voronik Institution: IRP

The polymer paste binds a surface contamination, being dried, and removes it, being detached. Some sorption and adhesive properties improve effectiveness of method. The technology provides the minimal decontamination factor (4- 7) while applying to rusted or painted metal surfaces. The technology provides the maximal decon-tamination factor (10 - 30) while applying to oiled or dirty metal surfaces.

1.12.b Coatings.

1) Tool	Polymer coatings
2) Target surface	Walls
2.1) Constraints	Temperature -20 - +30 °C, humidity < 80 %
3) Design (incl. number of operators)	
3.1) Productivity (units/h)	9 m^2/h, 560 h/year
4) Mode of operation	removing radionuclides from surface of wall
5) Cost	
5.1) Manpower (days/unit area)	0.014 man-day/m^2
5.2) Tool investment cost, ECU	14000 ECU
5.3) Discount (ECU/year)	1400 ECU/year
5.4) Consumables	0.56 kWh/m^2
5.5) Overheads	120 %
5.6) Scale of application	9 m^2/h * 560 h/year = 5040 m^2/year
5.7.1) Specific exposure	No data
5.7.2) Inhalation/external dose relation	< 1/10000
5.7.3) Number of man-hours exposed	0.11 man-hours/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	4-5
7) Wastes generated	
7.1) Solid kg/m^2	0.2 kg/m^2
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	5000 Bq/m^3 per Bq/m^2
7.4) Toxicity	No
8) Other costs (ECU)	Repainting of the walls 0.3 ECU/m^2
9) Other benefits (renewing roof etc.)	Renovation of walls
10) Special remarks	Can not be used on wooden walls

<u>Authors:</u> Mamaev, Galkin + assistance from Ramzaev, Chesnokov
Institution: IIM, BIRH, RECOM

The contaminated surface is coated by dissolving polyvinyl alcohol powder in water mixed with chemical agents and plastifier. After some time water and the components evaporate. The polymer coating is removed mechanically.

1.13 Vacuum sweeping.

1) Tool	Vacuum sweeping
2) Target surface	Roads
2.1) Constraints	-
3) Design (incl. number of operators)	Vacuum sweeper (1 person)
3.1) Productivity (units/h)	3500 m^2/h
4) Mode of operation	rotating brush and vacuuming
5) Cost	
5.1) Manpower (days/unit area)	$3.6 * 10^{-5}$ man-day per m^2
5.2) Tool investment cost, ECU	90000
5.3) Discount (ECU/year)	18000
5.4) Consumables	5-6 l/h of petrol
5.5) Overheads	150 % of manpower
5.6) Scale of application	3500 m^2/h * 720 h/y = 2520000 m^2/y
5.7.1) Specific exposure	Accumulated dust is brought close to the operator
5.7.2) Inhalation/external dose relation	Inhal. dose can be minimised by applic. of water
5.7.3) Number of man-hours exposed	$5*10^{-4}$ man-hours per m^2
6) Efficiency	
6.1) Decontamination factor (DF)	1.4 - depends on local traffic and particle size - probably higher in Pripyat
7) Wastes generated	
7.1) Solid kg/m^2	50-200 g/m^2
7.2) Liquid l/m^2	-
7.3) Waste activity Bq per m^3 per Bq per m^2	20000-5000 m^{-1}
7.4) Toxicity	-
8) Other costs (ECU)	-
9) Other benefits	Cleaning roads of litter
10) Special remarks	See attached sheet

Authors: Roed, Andersson, Prip Institution: Risø

Vacuum sweeping with a municipal seated Schöling street cleaning machine with a water nozzle to spray a fine mist of water onto the road prior to brushing with 3 rotating brushes and finally application of a vacuuming attachment. The street dust is accumulated in a vessel behind the operator, who can get a dose from this.

Reference: J. Roed and K.G. Andersson: 'Clean-up of Urban Areas in the CIS Countries Contaminated by Chernobyl Fallout', accepted for publication in J. Environ. Radioactivity, 1995.

1.14.a Scraping wooden surfaces and painted roofs.

1) Tool	Electric drill with steel wool or sand-paper
2) Target surface	Iron roofs/ painted walls
2.1) Constraints	Possibly scaffolding
3) Design (incl. number of operators)	Household equipment - 1 person
3.1) Productivity (units/h)	1 m^2/h
4) Mode of operation	Grinding
5) Cost	
5.1) Manpower (days/unit area)	0.125 man-day per m^2
5.2) Tool investment cost, ECU	100 ECU
5.3) Discount (ECU/year)	50 ECU
5.4) Consumables	Electricity 1 kW/h, steel wool 1 ECU/h
5.5) Overheads	150 % of manpower (5.1)
5.6) Scale of application	x-large due to simplicity
5.7.1) Specific exposure	inhalation dose
5.7.2) Inhalation/external dose relation	<1/10 with proper mask
5.7.3) Number of man-hours exposed	1 h/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	2-2.3
7) Wastes generated	
7.1) Solid kg/m^2	0.1 kg/m^2
7.2) Liquid l/m^2	None
7.3) Waste activity Bq per m^3 per Bq per m^2	5000 m^{-1}
7.4) Toxicity	yes if paint contains dangerous elements
8) Other costs (ECU)	-
9) Other benefits	Easy to repaint
10) Special remarks	No know-how is required - only due consideration

Authors: Roed, Andersson, Prip Institution: Risø

The equipment is what is usually applied to clean surfaces prior to painting.

1.14.b Scraping wooden surfaces and painted roofs.

1) Tool	Manual electric cutting machine
2) Target surface	wooden wall
2.1) Constraints	Residual nails in the wall must be removed
3) Design (incl. number of operators)	2 operators
3.1) Productivity (units/h)	1 m^2/h - 900 h/year per operator
4) Mode of operation	Mechanical removal of the upper layer
5) Cost	
5.1) Manpower (days/unit area)	0.08 man-day/m^2
5.2) Tool investment cost, ECU	50 ECU
5.3) Discount (ECU/year)	25 ECU/year
5.4) Consumables	0.6 kWh/m^2
5.5) Overheads	100-200 %
5.6) Scale of application	1 m^2/h * 900 h/year = 900 m^2/year
5.7.1) Specific exposure	Inhalation of dust
5.7.2) Inhalation/external dose relation	1/1000 - 1/10000
5.7.3) Number of man-hours exposed	1 man-hour/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	5
7) Wastes generated	
7.1) Solid kg/m^2	2.5-5.0 kg/m^2
7.2) Liquid l/m^2	None
7.3) Waste activity Bq per m^3 per Bq per m^2	300-500 m^{-1}
7.4) Toxicity	None
8) Other costs (ECU)	New painting : 0.3 ECU/m^2
9) Other benefits (renewing roof etc.)	Renovation of the walls
10) Special remarks	Removing the upper 0.3-0.5 cm with the tool.

Authors: Ramzaev, Chesnokov Institution: BIRH, RECOM

After dismantling the house, wooden walls can be used as a building material for new houses. In this case parts of wooden wall can be cleaned up separately in a master house. Two operators are needed as a 16 hour working day is assumed.

1.15 Dismantling houses to re-build.

1) Tool	Set of tools (See descriptions attached)
2) Target surface	House and shed
2.1) Constraints	No
3) Design (incl. number of operators)	8 operators
3.1) Productivity (units/h)	0.036 house/h
4) Mode of operation	Dismantling of a house
5) Cost	Sum estimated for Gomel Province (5.1+5.2+5.3+5.4+5.5): 700 ECU/house
5.1) Manpower (days/unit area)	25.5 man-days/house
5.2) Tool investment cost, ECU	Rent of machinery: 300 ECU/house
5.3) Discount (ECU/year)	No
5.4) Consumables	
5.5) Overheads	200 % of wages
5.6) Scale of application	0.036 house/h * 1120 h/year
5.7.1) Specific exposure	Dust
5.7.2) Inhalation/external dose relation	<0.0001
5.7.3) Number of man-hours exposed	200 man-hour/house
6) Efficiency	
6.1) Decontamination factor (DF)	In principle infinite
7) Wastes generated	
7.1) Solid kg/m^2	12 kg/m^2 of asbestos roof
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	120 m^{-1}
7.4) Toxicity	Asbestos dust
8) Other costs (ECU)	30000 (new house)
9) Other benefits	Remediation of territory
10) Special remarks	

Authors: Ansypau Institution: CSCB
Grebenkov IPEP

Attached descriptions:	Tools applied: 1 Crane, 1 Truck MAZ, 1 Bulldozer.	
Personnel of one team:	1 crane operator	2 man-days
	1 truck driver	3 man-days
	1 bulldozer operator	0.5 man-day
	5 workers, operating outdoors	4 days * 5 = 20 man-days

Territory does not include in any options
Dismantled house is not considered to be managed as radioactive waste except roof materials.
Dismantled house represents a single one-stored building and one wooden shed.

2 Soil Surfaces in Various Housing Environments

This chapter reports the effect of experimental procedures to reduce the dose rate from areas of soil in various types of housing environments. Various methods to remove the top soil layer were evaluated, since the major part of the radiocaesium is still in the uppermost few centimetres of the vertical soil profile 9 years after deposition. Also methods to bury the contamination and thereby greatly reduce the dose rate were investigated. Further, a method to extract soil particles and substances to which the radiopollutants are attached, was considered.

2.1.a Scraping off the top soil with a front loader.

1) Tool	Front Loader
2) Target surface	Soil
2.1) Constraints	No
3) Design (incl. number of operators)	1 operator
3.1) Productivity (units/h)	700 m^2/h
4) Mode of operation	Cutting of contaminated soil layer
5) Cost	
5.1) Manpower (days/unit area)	0.0002 man-day/m^2
5.2) Tool investment cost, ECU	20000 ECU
5.3) Discount (ECU/year)	2000 ECU
5.4) Consumables	Diesel oil: 0.03 kg/m^2
5.5) Overheads	160 %
5.6) Scale of application	700 m^2/h * 900 h/year = 630000 m^2/y
5.7.1) Specific exposure	No
5.7.2) Inhalation/external dose relation	< 1/10000
5.7.3) Number of man-hours exposed	0.0014 man-hours/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	28
7) Wastes generated	
7.1) Solid kg/m^2	75 kg/m^2
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	20
7.4) Toxicity	No
8) Other costs (ECU)	No
9) Other benefits (renewing roof etc.)	No
10) Special remarks	Land digging machine for periodic action.

Authors: Filled in by Person: Mamaev, Rybakov Institution: IIM, Russia

Removes fertile soil layer.

2.1.b Scraping off the top soil with a front loader.

1) Tool	Bulldozer
2) Target surface	Soil
2.1) Constraints	
3) Design (incl. number of operators)	1 operator
3.1) Productivity (units/h)	0.03 ha/h
4) Mode of operation	scraping of top soil with front loader (10-30 cm)
5) Cost	Total estimate: 190 ECU/ha (Ukraine)
5.1) Manpower (days/unit area)	4 man-days/ha
5.2) Tool investment cost, ECU	20000 ECU
5.3) Discount (ECU/year)	2000 ECU
5.4) Consumables	12 kg/h petro-diesel
5.5) Overheads	100 %
5.6) Scale of application	300 m^2/h * 800 h/y
5.7.1) Specific exposure	
5.7.2) Inhalation/external dose relation	0.001
5.7.3) Number of man-hours exposed	$1*10^{-5}$ man-hours/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	10-100
7) Wastes generated	
7.1) Solid kg/m^2	30-60 kg/m^2
7.2) Liquid l/m^2	-
7.3) Waste activity Bq per m^3 per Bq per m^2	3-10 m^{-1}
7.4) Toxicity	-
8) Other costs (ECU)	Loss of soil productivity
9) Other benefits (renewing roof etc.)	No subsequent treatment required
10) Special remarks	-

Authors: Kutlakhmedov, Blagoev   Institution: ICBGI, IBOChOCh

2.2 Scraping off the top soil with a grader.

1) Tool	Grader
2) Target surface	Top layer of ground
2.1) Constraints	No
3) Design (incl. number of operators)	1 operator
3.1) Productivity (units/h)	400-1000 m^2/h
4) Mode of operation	Scraping of soil surface
5) Cost	Sum estimated for Gomel Province (5.1+5.2+5.3+5.4+5.5): 1.38 ECU/m^2
5.1) Manpower (days/unit area)	0.00036 man-day/m^2
5.2) Tool investment cost, ECU	Rent of machinery: 100 ECU/day
5.3) Discount (ECU/year)	No
5.4) Consumables	24 kg/h
5.5) Overheads	200 % of wages
5.6) Scale of application	1000 m^2/hour * 720 h/year
5.7.1) Specific exposure	Dust in dry season
5.7.2) Inhalation/external dose relation	<0.0001
5.7.3) Number of man-hours exposed	0.001 man-hour/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	4 ... 10
7) Wastes generated	
7.1) Solid kg/m^2	180 ... 400
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	(4 ... 10)m^{-1}
7.4) Toxicity	No
8) Other costs (ECU)	Depends upon further utilisation of clean ground
9) Other benefits	Planing of territory
10) Special remarks	

Authors: Antsypau, Grebenkov Institution: CSCB, IPEP

2.3 Manual digging.

1) Tool	Shovel
2) Target surface	Garden soil
2.1) Constraints	the soil must be virgin soil
3) Design (incl. number of operators)	hand-digging (x persons)
3.1) Productivity (units/h)	4 m^2/h per man
4) Mode of operation	Digging to about 30 cm depth
5) Cost	
5.1) Manpower (days/unit area)	0.03 man-day per m^2
5.2) Tool investment cost, ECU	12 ECU
5.3) Discount (ECU/year)	24 ECU/year
5.4) Consumables	None
5.5) Overheads	100 % of manpower
5.6) Scale of application	Unlimited
5.7.1) Specific exposure	
5.7.2) Inhalation/external dose relation	
5.7.3) Number of man-hours exposed	0.3 man-hour per m^2
6) Efficiency	
6.1) Surface dose reduction factor	4-6
7) Wastes generated	
7.1) Solid kg/m^2	-
7.2) Liquid l/m^2	-
7.3) Waste activity Bq per m^3 per Bq per m^2	-
7.4) Toxicity	-
8) Other costs (ECU)	-
9) Other benefits	-
10) Special remarks	-

Authors: Roed, Andersson, Prip   Institution: Risø

Reference: J. Roed and K.G. Andersson: 'Clean-up of Urban Areas in the CIS Countries Contaminated by Chernobyl Fallout', accepted for publication in J. Environ. Radioactivity, 1995.

2.4 Turf harvester (small).

1) Tool	Turf harvester (small)
2) Target surface	Undisturbed grassed soils, small private pastures, forest pastures, urban grassed lands.
2.1) Constraints	No of few stones
3) Design (incl. number of operators)	4
3.1) Productivity (units/h)	800 m^2/h
4) Mode of operation	removes the 3-5 cm top soil
5) Cost	
5.1) Manpower (days/unit area)	0.0006 man-d/m^2
5.2) Tool investment cost, ECU	7200 ECU
5.3) Discount (ECU/year)	2400 ECU/year
5.4) Consumables	2 kg/h, gasoline (0.23 ECU/kg)
5.5) Overheads	100 %
5.6) Scale of application	800 m^2/h (720 h/year)
5.7.1) Specific exposure	External and internal doses
5.7.2) Inhalation/external dose relation	≤0.0001
5.7.3) Number of man-hours exposed	$6*10^{-4}$ man.day/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	3-20
7) Wastes generated	occupy 5 % of the decon. area
7.1) Solid kg/m^2	20-30 kg/m^2
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	
7.4) Toxicity	No
8) Other costs (ECU)	No
9) Other benefits	Improves pastures.
10) Special remarks	Decontamination definitely achieved, no further intervention required.

Authors: A. Jouve, A. Grebenkov, G. Antsypau, Y. Kutlakhmedov
Institutions: ISPN, IPEP, CSCB, ICBGI

The turf harvester is an existing technique used to produce turf mats from grass nurseries, that can be planted further away to fasten the creation of new lawns. When the grass mat is strong enough, this machine is capable of removing very precisely a soil layer of 1 cm, which is the usual thickness of the turf mats used for commercial purpose, or 5 cm in the trials carried out in the Chernobyl zone to decontaminate the soil. This technique is particularly well adapted to decontaminate peat bog soil pastures with a removal of a 5 cm layer of the organic horizon without compromising the fertility. It was however tested on a podzol with a 10 cm layer of the organic horizon without compromising the subsequent soil re-use. The machine produces flags of turf mats of 45 x 45 cm layer of the soil, which can be easily removed by hand using a fork and be put in a trailer to be disposed in a delimited area of the field which is decontaminated, or further away depending on the availability of disposal areas.

2.5 Turf harvester (large).

1) Tool	Turf harvester (industrial)
2) Target surface	Undisturbed grassed soils
2.1) Constraints	No of few stones, build a prototype, large fields (150mx150m), less than 20% of the area disturbed by wild pigs, remove bushes before on abandoned fields
3) Design (incl. number of operators)	1 (in case of an automatic conveyor)
3.1) Productivity (units/h)	1.25 ha/h
4) Mode of operation	removes and dispose the 3-5 cm top soil
5) Cost	170 ECU/ha
5.1) Manpower (days/unit area)	0.1 man-d/ha
5.2) Tool investment cost, ECU	600 kECU
5.3) Discount (ECU/year)	120 kECU/year
5.4) Consumables	30 kg/ha, gasoline
5.5) Overheads	100 %
5.6) Scale of application	12500 m^2/h (400-800 h/year)
5.7.1) Specific exposure	No
5.7.2) Inhalation/external dose relation	<0.000001
5.7.3) Number of man-hours exposed	$1.25*10^{-6}$ man.h/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	20 on grass and milk
7) Wastes generated	occupy 5 % of the decon. area
7.1) Solid kg/m^2	20-30 kg/m^2
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	20-30 m^{-1}
7.4) Toxicity	No
8) Other costs (ECU)	No
9) Other benefits	Destroys *Nardus stricta*, thus improves pastures. Possibility to make a map of the remaining contamination using on board CORAD system
10) Special remarks	Decontamination definitely achieved, no further intervention required.

Author: A. Jouve Institution: ISPN

The industrial turf harvester is based on the principle of the small turf harvester. It is composed of 3-5 modules of small turf harvesters driven together by a single engine and connected to a single frame. Each module has however an independent mobility to follow the curves of the soil relief. The turf mats that are produced are automatically conveyed into a trailer or a mobile conveyer which subsequently disposes the wastes on a delimited disposal area. Comparatively to the small turf harvester, this option decreases a number of operators involved in the decontamination procedure and allows a faster decontamination than the small turf harvester. However this machine which has been designed in a pre-project has never been constructed nor tested.

2.6 Lawn mower (mulcher).

1) Tool	Lawn mower
2) Target surface	Grassed areas in city
2.1) Constraints	-
3) Design (incl. number of operators)	1 operator
3.1) Productivity (units/h)	1000 m^2/h
4) Mode of operation	Large lawn mower (1 person)
5) Cost	
5.1) Manpower (days/unit area)	$1.3 * 10^{-4}$ man-days/m^{-2}
5.2) Tool investment cost, ECU	15000 ECU
5.3) Discount (ECU/year)	3000 ECU/y
5.4) Consumables	6 l/h of petrol
5.5) Overheads	100 % of manpower
5.6) Scale of application	$1000 * 720 = 720000$ m^2/y
5.7.1) Specific exposure	-
5.7.2) Inhalation/external dose relation	practically 0
5.7.3) Number of man-hours exposed	$1.5*10^{-3}$ man-h/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	1 after 9 years (no effect alone)
7) Wastes generated	
7.1) Solid kg/m^2	Depending on length of grass
7.2) Liquid l/m^2	0
7.3) Waste activity Bq per m^3 per Bq per m^2	0
7.4) Toxicity	-
8) Other costs (ECU)	-
9) Other benefits (renewing roof etc.)	-
10) Special remarks	The procedure is used in connection with other procedures such as turf-harvesting

Authors: Roed, Andersson, Prip Institution: Risø

Municipal petrol driven lawn-mower with seat. Collects grass in a vessel.

2.7 Triple digging.

1) Tool	Ordinary shovel (for triple digging)
2) Target surface	Garden soil
2.1) Constraints	Area must be surface dug or virgin land
3) Design (incl. number of operators)	unlimited
3.1) Productivity (units/h)	2 m^2/h per man
4) Mode of operation	Burying the soil top layer 30 - 40 cm down
5) Cost	
5.1) Manpower (days/unit area)	0.068 man-day/m^2
5.2) Tool investment cost, ECU	12 ECU
5.3) Discount (ECU/year)	24 ECU/y
5.4) Consumables	None
5.5) Overheads	100 % of manpower
5.6) Scale of application	unlimited
5.7.1) Specific exposure	a little dust
5.7.2) Inhalation/external dose relation	< 1/100
5.7.3) Number of man-hours exposed	0.7 h/m^2
6) Efficiency	
6.1) Surface dose reduction factor	4-15 depending on soil type
7) Wastes generated	
7.1) Solid kg/m^2	None
7.2) Liquid l/m^2	None
7.3) Waste activity Bq per m^3 per Bq per m^2	None
7.4) Toxicity	None
8) Other costs (ECU)	-
9) Other benefits (renewing roof etc.)	The area will be ready for new crops
10) Special remarks	instruction needed

<u>Authors:</u> Roed, Andersson, Prip Institution: Risø

The garden triple digging procedure can be used to dig a garden area in the same manner as that which is performed by a skim and burial plough. The principle is basically to manually bury a thin top soil layer containing the radioactive matter, whereby a shielding effect is obtained. The method is described in detail in:

<u>Reference:</u> J. Roed and K.G. Andersson: 'Clean-up of Urban Areas in the CIS Countries Contaminated by Chernobyl Fallout', accepted for publication in J. Environ. Radioactivity, 1995.

2.8 Soil size fractionation.

1) Tool	Mobile equipment for soil separation
2) Target surface	soil
2.1) Constraints	can be used for sand and sand clay (20 %) soil
3) Design (incl. number of operators)	
3.1) Productivity (units/h)	100 kg/h
4) Mode of operation	Mechanical separation of the soil
5) Cost	
5.1) Manpower (days/unit area)	0.025 man-day/kg
5.2) Tool investment cost, ECU	20000 ECU
5.3) Discount (ECU/year)	2000 ECU
5.4) Consumables	0.1 kWh/kg
5.5) Overheads	120 %
5.6) Scale of application	100 kg/h * 6 h/d * 120 days/y = 72000 kg/year
5.7.1) Specific exposure	No
5.7.2) Inhalation/external dose relation	< 1/10000
5.7.3) Number of man-hours exposed	0.02 man-hour/kg
6) Efficiency	
6.1) Decontamination factor (DF)	4-6
7) Wastes generated	
7.1) Solid kg/m^2	0.1 kg/kg
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	10000 m^{-1}
7.4) Toxicity	Nitric acid
8) Other costs (ECU)	Possible restoration of the soil
9) Other benefits (renewing roof etc.)	Decreasing amounts of waste
10) Special remarks	-

Authors: Mamaev, Ogulnik Institution: IIM, Russia

The equipment consists of the following units: 1. the unit for loading soil, 2. the unit for mixture preparation and removal of organic substances, 3. the unit for separation of the small fraction, 4. the unit for waste processing and collection. 2 operators are involved in the processes.

3 Forest Areas

The procedures presented in this paragraph are suggested for separation of the radioactive substances from wood. The use of the wood then becomes less restricted and great resources can be exploited.

3.1 Litter removal.

1) Tool	Mechanical brush
2) Target surface	Forest litter
2.1) Constraints	Cannot be used in wet forest areas or for forest less than 30 years old
3) Design (incl. number of operators)	2 operators
3.1) Productivity (units/h)	540 m^2/h
4) Mode of operation	Litter layer removal
5) Cost	
5.1) Manpower (days/unit area)	0.00053 man-days/m^2
5.2) Tool investment cost, ECU	5,000 ECU for brushing machine; Rent of BELARUS tractor: 50 ECU/day
5.3) Discount (ECU/year)	1,700 ECU/year for brushing machine
5.4) Consumables	Petrol-diesel: 30 kg/hour
5.5) Overheads	160 % of wages
5.6) Scale of application	540 m^2/h * 840 h/year
5.7.1) Specific exposure	Dust
5.7.2) Inhalation/external dose relation	<0.001
5.7.3) Number of man-hours exposed	0.0037 man-hour/m^2
6) Efficiency	
6.1) Decontamination factor (DF)	3.5 ... 4.5
7) Wastes generated	
7.1) Solid kg/m^2	30 ... 50 kg/m^2
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	15 ... 20 m^{-1}
7.4) Toxicity	Flammable
8) Other costs (ECU)	No
9) Other benefits	No
10) Special remarks	

Authors: Antsypau, Grebenkov Institution: CSCB, IPEP

Attached descriptions

This procedure represents the main on-site decontamination technology which provides sufficient dose reduction for forest workers. After removal of contaminated litter of 5-7 cm in thickness it is directed to the shallow ground/surface disposal or to a valorisation procedure. The main mechanism produced in France consists of the rotor with frequent firm elastic cores located on its cylindrical surface. The rotor is driven by hydraulic engine with reductor placed inside the rotor cavity. This mechanical brush is assembled on the frame together with a storage bin with volume of about 0.4 m^3 where the litter is collected. The bin and brush are covered with the roofing shelter. The litter collected in the bin can easy be unloaded into a trailer (or platform) with a help of hydro-cylinders/monitors. Soil depth of operating of the brush is controlled by means of a couple of wheels. The machine is connected to"BELARUS" tractor, and parameters of the hydraulic engine correspond to those of the tractor's oil-pump. Similar technique of large scale is also produced in the CIS. For example, МСП-1 type which supplied with loosener combined with pneumatic system. The mediate scale machines dflMTC type should be also noted.

3.2 Grinding mower.

1) **Tool**	Grinding mover
2) **Target surface**	Under-wood forest; shrubs
2.1) Constraints	Diameter of wood stem must be less 8 cm. Cannot be used in wet forest areas or for forest less than 30 years old
3) **Design (incl. number of operators)**	1 operator
3.1) Productivity (units/h)	1500 ... 2000 m^2/h
4) **Mode of operation**	Cleaning and grinding of underwood
5) **Cost**	
5.1) Manpower (days/unit area)	0.0001 man-days/m^2
5.2) Tool investment cost, ECU	5,800 ECU for grinding machine "Norevert" or ODI-1; Rent of BELARUS tractor: 50 ECU/day
5.3) Discount (ECU/year)	1900 ECU/year
5.4) Consumables	Petrol-diesel: 30 kg/h
5.5) Overheads	160 % of wages
5.6) Scale of application	2000 m^2/h * 840 h/year
5.7.1) Specific exposure	Dust
5.7.2) Inhalation/external dose relation	<0.001
5.7.3) Number of man-hours exposed	0.0005 man-hour/m^2
6) **Efficiency**	
6.1) Decontamination factor (DF)	DF = 1.2
7) **Wastes generated**	
7.1) Solid kg/m^2	20 ... 50 kg/m^2
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	7 ... 20 m^{-1}
7.4) Toxicity	Flammable
8) **Other costs (ECU)**	No
9) **Other benefits**	Forest management
10) **Special remarks**	Method represents preliminary operation for furtherapplication of item 3.1

Authors: Antsypau, Grebenkov Institution: CSCB, IPEP

Attached descriptions : The debris which is left on a place of felling and constitutes the most contaminated part of wood undergoes collection and grinding. Then it is directed to following possible handling: (i) Scattering around place of felling in order to restore a litter of forest; (ii) Removing for further disposal; (iii) Removing for further valorisation. Options (i) and (iii) can be justified from ecological and economical points. Technique represents a drum grinder with knifes. It is placed onto platform of tractor which is supplied with manipulator and storage bin. This technology proceeds removing a forest litter, but this is also ordinary technology to care forest. The procedure presents cutting and grinding the underwood (bushes, young trees). The equipment (ODI-1) is assembled to the arm of excavator of EO-2621 typemade on a base of "BELARUS" tractor. The grinding mechanism consists of the head equipped by rotor with free hanging incisors and cutting blades. It rotates by means of hydro-mover connected to tractor's hydro-driving system. The grinding machine provides cutting the bushes and underwood of diameter of less than 10 cm. Width of the head is about 1.1 m. The chips after grinding are left on a place of cleaning. Similar machine ("Norevert") produced in Sweden is assembled to the shaft of "BELARUS" tractor.

3.3 Debarking wood.

1) Tool	Wood sawing plant 20-K63-2
2) Target surface	Timber
2.1) Constraints	Should be used as a soil mulch. Not in wet forest areas
3) Design (incl. number of operators)	3 operators
3.1) Productivity (units/h)	30 ... 50 m^3/h
4) Mode of operation	Mechanical removal of bark and phloem
5) Cost	Sum estimated in Gomel Province (5.1+5.2+5.3+5.4+5.5): 1.5 ECU/m^3
5.1) Manpower (days/unit area)	0.0048 man-days/m^3
5.2) Tool investment cost, ECU	3000 ECU
5.3) Discount (ECU/year)	1000 ECU/year
5.4) Consumables	
5.5) Overheads	160 % of wages
5.6) Scale of application	50 m^3/h * 1400 h/year
5.7.1) Specific exposure	Dust
5.7.2) Inhalation/external dose relation	<0.0001
5.7.3) Number of man-hours exposed	0.02 man-hour/m^3
6) Efficiency	
6.1) Decontamination factor (DF)	2 ... 4
7) Wastes generated	
7.1) Solid kg/m^2	10 ... 20 kg/m^3
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	10 ... 20 m^{-1} (50 ... 100 m^3/m^3)
7.4) Toxicity	Flammable
8) Other costs (ECU)	No
9) Other benefits	Possible valorisation of waste
10) Special remarks	

<u>Authors:</u> Antsypau, Grebenkov Institution: CSCB, IPEP

Attached descriptions

In the zone of contamination level of 5-15 Ci/km^2 raw wood after felling requires bark stripping that may removes 7% of biomass and 60-70% of radioactivity. Valuable wood trunk received in this zone may be used without any limitation.
In the zone of 15-40 Ci/km^2 the control of quality of wood must be provided and, even stripping bark, valuable wood trunk is, along with this, recommended not to be directly used but only if it is sawed into the beams. Phloem layers of 2-3 cm thick have to be stripped too, so the average size of square beam would not exceed 70% of stem diameter. Since the most contaminated part of wood is bark and external layers these elements of the technological chain of radioactive wood decontamination is necessary to reduce the level of wood's activity to that met the permissible limits.

3.4 Special wood pulp treatment.

1) Tool	Twin-screw extruder
2) Target surface	Contaminated wood
2.1) Constraints	Only for preparation of wood chips
3) Design (incl. number of operators)	10
3.1) Productivity (units/h)	5 t/h
4) Mode of operation	extracts Cs and Sr from wood pulp
5) Cost	0.9 MECU/year
5.1) Manpower (days/unit area)	0.25 man/t of wood
5.2) Tool investment cost, ECU	6 MECU
5.3) Discount (ECU/year)	0.6 MECU/year
5.4) Consumables	Electricity 1400 kW/h, Nitric acid 2 % of wood, Sodium sulphite 2 % of wood.
5.5) Overheads	100 %
5.6) Scale of application	26400 t/y of wood (16 h/day)
5.7.1) Specific exposure	No
5.7.2) Inhalation/external dose relation	<0.0001
5.7.3) Number of man-hours exposed	1.25 man.d/h
6) Efficiency	
6.1) Decontamination factor (DF)	50-100
7) Wastes generated	
7.1) Solid kg/m^2	
7.2) Liquid l/m^2	1000 l/t of wood (recycling to some extent)
7.3) Waste activity Bq per m^3 per Bq per m^2	95 % of wood activity
7.4) Toxicity	sulphates
8) Other costs (ECU)	No
9) Other benefits	Selling cardboard, 18400 t/y i.e. 11MECU
10) Special remarks	Decreases electric power consumption compared to chemical pulp factories by 30 %, decreases the waste production.

Author: A. Jouve. Institution: IPSN

The Twin-screw extruder produces wood pulp from raw wood. The mechanical defibrillation of wood replaces the chemical digestion commonly used in pulp factories. This procedure results in decreasing by about 30% the quantity of liquid waste and electric consumption. It is therefore suitable to decrease contaminated waste in case of using contaminated wood. It may decontaminate wood, since the mechanistic effect of pressure and acidic treatment of the wood is similar to the procedure tested in laboratory which decontaminated wood samples from the Chernobyl forest with a decontamination efficiency of up to 95 % for Cs and Sr. However, this technique has never been tested with contaminated wood. It is only mentioned as a reference scenario to provide economical information for the technique which has been tested at laboratory scale. The decontamination efficiency refers to the laboratory experiment assuming that similar results would be obtained if the procedure is applied using the twin-screw extruder. Similar decontamination factors were observed in classical wood processing plants in Sweden.

4 Virgin Soil in Rural Areas

This chapter reports the effect of experimental procedures to reduce the external dose rate and plant uptake in agricultural areas of virgin soil.

4.1 Ordinary ploughing.

1) Tool	Ordinary plough and tractor
2) Target surface	rural land
2.1) Constraints	Virgin land only
3) Design (incl. number of operators)	1 operator
3.1) Productivity (units/h)	9000 m^2/h
4) Mode of operation	Ploughing to a depth of 25 cm
5) Cost	
5.1) Manpower (days/unit area)	$1.4 * 10^{-5}$ man-days/m^2
5.2) Tool investment cost, ECU	2000 (plough) and 50000 (tractor)
5.3) Discount (ECU/year)	400 (plough) and 10000 (tractor)
5.4) Consumables	petrol : 6 l/h
5.5) Overheads	100 % of manpower
5.6) Scale of application	9000 m^2/h * 720 h/y = $6.48 * 10^6$ m^2/y
5.7.1) Specific exposure	Dust resuspension can be limited by water applic.
5.7.2) Inhalation/external dose relation	<1/10
5.7.3) Number of man-hours exposed	$1.1 * 10^{-4}$ man-h/m^2
6) Efficiency	
6.1) Surface dose reduction factor	3-6 (external)
7) Wastes generated	
7.1) Solid kg/m^2	-
7.2) Liquid l/m^2	-
7.3) Waste activity Bq per m^3 per Bq per m^2	-
7.4) Toxicity	-
8) Other costs (ECU)	Transport of equipment (depending on distances)
9) Other benefits (renewing roof etc.)	Ploughing of fields, reduction of plant uptake by a factor of up to 4 depending on the plant type
10) Special remarks	-

<u>Authors:</u> Roed, Andersson, Prip Institution: Risø

Ordinary 25 cm deep ploughing with tractor-driven Bovlund single-furrow 24” plough (type 9H-70).

<u>Reference:</u> J. Roed, K.G. Andersson, H. Prip: ‘The skim and burial plough: a new implement for reclamation of radioactively contaminated land’, accepted for publication in J. Environ. Radioactivity, 1995.

4.2.a Deep ploughing.

1) Tool	Ordinary plough + tractor
2) Target surface	Rural land
2.1) Constraints	Virgin land only
3) Design (incl. number of operators)	1 operator
3.1) Productivity (units/h)	7000 m^2/h
4) Mode of operation	Ploughing to a depth of 45 cm
5) Cost	
5.1) Manpower (days/unit area)	$1.8 * 10^{-5}$ man-days/ m^2
5.2) Tool investment cost, ECU	2000 (plough) and 50000 (tractor)
5.3) Discount (ECU/year)	400 (plough) and 10000 (tractor)
5.4) Consumables	Petrol: 10 l/h
5.5) Overheads	100 % of manpower
5.6) Scale of application	7000 m^2/h * 720 h/y = $5.04 * 10^6$ m^2/y
5.7.1) Specific exposure	Dust resuspension can be limited by water applic.
5.7.2) Inhalation/external dose relation	<1/10
5.7.3) Number of man-hours exposed	$1.43 * 10^{-4}$ man-h/m^2
6) Efficiency	
6.1) Surface dose reduction factor	6-10 (external)
7) Wastes generated	
7.1) Solid kg/m^2	-
7.2) Liquid l/m^2	-
7.3) Waste activity Bq per m^3 per Bq per m^2	-
7.4) Toxicity	-
8) Other costs (ECU)	Transport of equipment (depending on distances)
9) Other benefits (renewing roof etc.)	Ploughing of fields, reduction of plant uptake by a factor of up to 10 depending on plant type
10) Special remarks	Draw-back: Possible burial of fertile soil layer

Authors: Roed, Andersson, Prip Institution: Risø

Deep ploughing to 45 cm using a tractor-driven Bovlund single-furrow 24" plough (type 9H-70).

Deep ploughing will substantially reduce the root uptake to most plants and thereby reduce the dose received from locally produced food. Also, the radioactive matter will have been placed sufficiently deep in the soil profile that it is not redistributed by subsequent ploughing.

Reference: J. Roed, K.G. Andersson, H. Prip: 'The skim and burial plough: a new implement for reclamation of radioactively contaminated land', accepted for publication in J. Environ. Radioactivity, 1995.

4.2.b Deep ploughing.

1) Tool	Deep ploughing
2) Target surface	Decontamination of soil (plant production)
2.1) Constraints	deep ploughing of soil (25-35 cm)
3) Design (incl. number of operators)	1 operator
3.1) Productivity (units/h)	0.2 ha/h
4) Mode of operation	Deep ploughing upper soil layer (25-35 cm)
5) Cost	Total estimate: 120 ECU/ha
5.1) Manpower (days/unit area)	0.6 man-day/ha
5.2) Tool investment cost, ECU	20000 ECU
5.3) Discount (ECU/year)	2000 ECU/year
5.4) Consumables	15 kg/h petro-diesel
5.5) Overheads	100 %
5.6) Scale of application	2000 m^2/h * 720 h/year
5.7.1) Specific exposure	-
5.7.2) Inhalation/external dose relation	0.001
5.7.3) Number of man-hours exposed	$1*10^{-5}$ man-hours per m^2
6) Efficiency	
6.1) Surface dose reduction factor	2-4
7) Wastes generated	No
7.1) Solid kg/m^2	No
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	No
7.4) Toxicity	-
8) Other costs (ECU)	-
9) Other benefits (renewing roof etc.)	-
10) Special remarks	-

Authors: Kutlakhmedov, Perepelyatnikov Institution: ICBGI, UIAR

4.3.a Skim and burial ploughing.

1) Tool	Skim-and-burial plough and tractor
2) Target surface	Rural land
2.1) Constraints	Virgin or surface ploughed land
3) Design (incl. number of operators)	1 operator
3.1) Productivity (units/h)	3000 m^2/h
4) Mode of operation	skim and burial ploughing (see footnote)
5) Cost	
5.1) Manpower (days/unit area)	$4.16 * 10^{-5}$ man-days/m^2
5.2) Tool investment cost, ECU	50000 ECU (tractor) and 4125 ECU (plough)
5.3) Discount (ECU/year)	10000 ECU (tractor) and 825 ECU (plough)
5.4) Consumables	Petrol: 10 l/h
5.5) Overheads	100 % of manpower
5.6) Scale of application	$3000\ m^2/h * 720\ h/y = 2.16 * 10^6\ m^2/y$
5.7.1) Specific exposure	Dust resuspension can be limited by water applic.
5.7.2) Inhalation/external dose relation	<1/10
5.7.3) Number of man-hours exposed	$3.33 * 10^{-4}$ man-h/m^2
6) Efficiency	
6.1) Surface dose reduction factor	6-15
7) Wastes generated	
7.1) Solid kg/m^2	-
7.2) Liquid l/m^2	-
7.3) Waste activity Bq per m^3 per Bq per m^2	-
7.4) Toxicity	-
8) Other costs (ECU)	Transport (depending on distances)
9) Other benefits (renewing roof etc.)	Ploughing without significant loss of soil fertility, reduction of plant uptake by a factor of at least 10
10) Special remarks	See below

Authors: Roed, Andersson, Prip Institution: Risø

A skim coulter first places the upper 5 cm of soil in a trench made by the main ploughshare. In one movement, the main ploughshare then digs a new trench and places the lifted subsoil on top of the thin layer of topsoil in the bottom of the trench of the previous run. The skim coulter simultaneously places the top layer from the next furrow in the new trench. In this way, the 5-50 cm soil layer is lifted only about 10-15 cm and the power requirements minimised. The advantage of the method is that only a very thin layer (5 cm) of topsoil is buried at 45 cm, and the 5-45 cm layer is not inverted.

Skim and burial ploughing will eliminate the root uptake to most plants and thereby reduce the dose received from locally produced food. Also, the radioactive matter will have been placed sufficiently deep in the soil profile that it is not redistributed by subsequent ploughing.

Reference: J. Roed, K.G. Andersson, H. Prip: 'The skim and burial plough: a new implement for reclamation of radioactively contaminated land', accepted for publication in J. Environ. Radioactivity, 1995.

4.3.b Skim and burial ploughing.

1) Tool	Skim and burial ploughing
2) Target surface	soil
2.1) Constraints	Virgin or surface ploughed land
3) Design (incl. number of operators)	1 operator
3.1) Productivity (units/h)	0.2 ha/h
4) Mode of operation	Upper 5 cm layer cut off and put under ploughed horizon of soil
5) Cost	Estimate: 160-280 ECU/ha (Ukraine)
5.1) Manpower (days/unit area)	0.6 man-day/ha
5.2) Tool investment cost, ECU	25000 ECU
5.3) Discount (ECU/year)	2500 ECU/year
5.4) Consumables	20 kg/h petro-diesel
5.5) Overheads	100 %
5.6) Scale of application	2000 m^2/h * 720 h/y
5.7.1) Specific exposure	
5.7.2) Inhalation/external dose relation	0.001
5.7.3) Number of man-hours exposed	$1*10^{-5}$ man-hour/m^2
6) Efficiency	
6.1) Surface dose reduction factor	6-15
7) Wastes generated	
7.1) Solid kg/m^2	20-30 kg/m^2
7.2) Liquid l/m^2	-
7.3) Waste activity Bq per m^3 per Bq per m^2	15-20 m^{-1}
7.4) Toxicity	No
8) Other costs (ECU)	
9) Other benefits (renewing roof etc.)	
10) Special remarks	The waste is buried under the ploughed soil horizon

<u>**Authors:**</u> Kutlakhmedov, Roed, Blagoev Institution: ICBGI, Risø, IOChOCh

5 Agricultural Environment

This chapter reports the effect of experimental procedures to deal with radiological problems specific to the agricultural environment. The main tasks are to limit the content of radioactivity in locally grown crops and the contamination level in animal and dairy products.

5.1.a Liming.

1) Tool	Liming (special trucks for spreading) (ORUP-8)
2) Target surface	Acidic arable land (pH 4.5-5.5)
2.1) Constraints	Requires also potassium addition to maintain ionic equilibrium
3) Design (incl. number of operators)	1.3 (per distribution unit) (Dolomite powder)
3.1) Productivity (units/h)	1 ha/h
4) Mode of operation	Competitive uptake, yield increase
5) Cost	Total estimate: 55 ECU/ha
5.1) Manpower (days/unit area)	0.15 Man-day/ha
5.2) Tool investment cost, ECU	13000 ECU
5.3) Discount (ECU/year)	1625 ECU
5.4) Consumables	Gasoline 12.5 l/ha, lime (ca. 1t/ha)
5.5) Overheads	200 %
5.6) Scale of application	No limitation
5.7.1) Specific exposure	No
5.7.2) Inhalation/external dose relation	No exposure to workers
5.7.3) Number of man-hours exposed	No exposure to workers
6) Efficiency	
6.1) Decontamination factor (DF)	1.3-1.6 (depends on soil pH)
7) Wastes generated	
7.1) Solid kg/m^2	No
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	No
7.4) Toxicity	No
8) Other costs (ECU)	No
9) Other benefits (renewing roof etc.)	Increases crop yield + quality of fodder
10) Special remarks	Specific equipment in CIS, but other tools may be used. Effect persistent during 4-5 years.

Authors: Firsakova Institution: BIAR

The general features of the method are described in the IAEA Technical Report Series No. 363 on Guidelines for agricultural countermeasures following an accidental release of radionuclides, ISBN 92-0-100894-5, 1994.

5.1.b Liming.

1) **Tool**	Liming of soils
2) **Target surface**	Decontamination of plants
2.1) Constraints	
3) **Design (incl. number of operators)**	2 operators
3.1) Productivity (units/h)	0.4 ha/h
4) **Mode of operation**	Liming of soil for decreasing uptake of radionuclides in plant production
5) **Cost**	13 ECU/ha (Ukraine)
5.1) Manpower (days/unit area)	0.6 man-day/ha
5.2) Tool investment cost, ECU	12000 ECU
5.3) Discount (ECU/year)	1200 ECU/y
5.4) Consumables	10 kg/ha petro-diesel, 300-800 kg/ha lime
5.5) Overheads	200 %
5.6) Scale of application	4000 m^2/h * 720 h/y
5.7.1) Specific exposure	
5.7.2) Inhalation/external dose relation	0.0001
5.7.3) Number of man-hours exposed	$5*10^{-4}$ man-hours/m^2
6) **Efficiency**	
6.1) Decontamination factor (DF)	2-3
7) **Wastes generated**	No
7.1) Solid kg/m^2	No
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	No
7.4) Toxicity	No
8) **Other costs (ECU)**	-
9) **Other benefits (renewing roof etc.)**	Increasing productivity of plants - 1.5-2 times
10) **Special remarks**	-

Authors: Kutlakhmedov, Perepelyatnikov Institution: ICBGI, UIAR

5.2.a Addition of potassium chloride.

1) Tool	Addition of potassium chloride
2) Target surface	Decontamination of plants on arable lands
2.1) Constraints	
3) Design (incl. number of operators)	2 operators (driver of truck and lorry)
3.1) Productivity (units/h)	0.2 ha/h
4) Mode of operation	Decreasing accumulation of radiocaesium in plants
5) Cost	Total estimate: 20 ECU/ha
5.1) Manpower (days/unit area)	0.12 man.day/ha
5.2) Tool investment cost, ECU	20000 ECU
5.3) Discount (ECU/year)	2000 ECU
5.4) Consumables	240 kg/ha KCl;20 kg/h Gasoline
5.5) Overheads	200%
5.6) Scale of application	2ha/h x 400 h/year
5.7.1) Specific exposure	
5.7.2) Inhalation/external dose relation	0.0001
5.7.3) Number of man-hours exposed	1 man.hour/ha
6) Efficiency	
6.1) Decontamination factor (DF)	2-3
7) Wastes generated	No
7.1) Solid kg/m^2	No
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	
7.4) Toxicity	
8) Other costs (ECU)	
9) Other benefits	Possibly increasing of harvest.
10) Special remarks	

Authors:		Institution:	
	Kutlakhmedov		ICBGI
	Perepelyatnikov		UIAR

The general features of the method are described in the IAEA Technical Report Series No. 363 on Guidelines for agricultural countermeasures following an accidental release of radionuclides, ISBN 92-0-100894-5, 1994.

5.2.b Addition of potassium chloride.

1) Tool	Addition of potassium
2) Target surface	arable lands
2.1) Constraints	
3) Design (incl. number of operators)	1.2 operators (driver of truck and loader)
3.1) Productivity (units/h)	1.5 ha/h
4) Mode of operation	Enrichment of soil by K
5) Cost	
5.1) Manpower (days/unit area)	0.1 d/ha
5.2) Tool investment cost, ECU	18000 ECU
5.3) Discount (ECU/year)	3000 ECU
5.4) Consumables	150 kg/ha KCl; 15 l/h Gasoline
5.5) Overheads	160 %
5.6) Scale of application	4800 ha.
5.7.1) Specific exposure	
5.7.2) Inhalation/external dose relation	<1/100
5.7.3) Number of man-hours exposed	0.8 man-hour/ha
6) Efficiency	
6.1) Decontamination factor (DF)	1.3 - 1.6
7) Wastes generated	No
7.1) Solid kg/m^2	No
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	
7.4) Toxicity	
8) Other costs (ECU)	
9) Other benefits	Possibly increase of yield.
10) Special remarks	Additional application of K is 0.5-1.0 of usual dose and depends of soil saturation by potassium.

Authors: Firsakova, Antzipov, Timoteev Institution: BIAR

5.3 Addition of phosphorus.

1) Tool	Addition of phosphorus
2) Target surface	Decontamination of plants on arable land
2.1) Constraints	
3) Design (incl. number of operators)	2 operators (driver of truck and lorry)
3.1) Productivity (units/h)	0.2 ha/h
4) Mode of operation	Decreasing accumulation of radiostrontium in plants
5) Cost	Total estimate: 40 ECU/ha
5.1) Manpower (days/unit area)	0.15 man.day/ha
5.2) Tool investment cost, ECU	20000 ECU
5.3) Discount (ECU/year)	2000 ECU
5.4) Consumables	550 kg/ha NaH(PO4)2; 20 kg/h Gasoline
5.5) Overheads	200%
5.6) Scale of application	1.5 ha/h x 400 h/year
5.7.1) Specific exposure	
5.7.2) Inhalation/external dose relation	0.0001
5.7.3) Number of man-hours exposed	1.2 man.hour/ha
6) Efficiency	
6.1) Decontamination factor (DF)	0.8-1.3
7) Wastes generated	No
7.1) Solid kg/m^2	No
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	No
7.4) Toxicity	No
8) Other costs (ECU)	
9) Other benefits	
10) Special remarks	Not recommended separately but in combination with other fertilisers (K,N)

Authors:	Kutlakhmedov	Institution:	ICBGI
	Perepelyatnikov		UIAR

The general features of the method are described in the IAEA Technical Report Series No. 363 on Guidelines for agricultural countermeasures following an accidental release of radionuclides, ISBN 92-0-100894-5, 1994.

5.4 Organic amendment to soil (Cattle manure and peat).

1) Tool	Organic amendment of the soil
2) Target surface	arable soils
2.1) Constraints	
3) Design (incl. number of operators)	1.2/ha (1 operator)
3.1) Productivity (units/h)	0.7 ha/h
4) Mode of operation	Binds Sr, complexes Cs and Sr
5) Cost	Total estimate: 60 ECU/ha (60 t/ha)
5.1) Manpower (days/unit area)	2 ECU/ha (0.4 man-day/ha)
5.2) Tool investment cost, ECU	11328 ECU
5.3) Discount (ECU/year)	1416 ECU/year
5.4) Consumables	Fuel: 8 l/ha, manure: 40 ECU/ha
5.5) Overheads	200 %
5.6) Scale of application	No limitation
5.7.1) Specific exposure	negligible (U, Th, Ra)
5.7.2) Inhalation/external dose relation	No
5.7.3) Number of man-hours exposed	No
6) Efficiency	
6.1) Decontamination factor (DF)	DF=1.3 for Cs and Sr
7) Wastes generated	
7.1) Solid kg/m^2	No
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	No
7.4) Toxicity	No
8) Other costs (ECU)	No
9) Other benefits (renewing roof etc.)	Yield and quantity increase
10) Special remarks	KH_2PO_4

Authors: Firsakova Institution: BIAR

5.5 Pasture improvement by ploughing and fertilising.

1) Tool	Radical improvement of pasture (draining, cleaning; disking (3 times) Fertilising; Ploughing; Sowing new grasses realised in Ukraine 1994. In 1987-1993 was used 2-3 procedures.
2) Target surface	Decontamination of crops and milk
2.1) Constraints	
3) Design (incl. number of operators)	9 operators (6 procedures)
3.1) Productivity (units/h)	0.125 ha/h
4) Mode of operation	The decreasing of accumulation of radionuclides in plants and milk
5) Cost	343 ECU/ha (6 procedures)
5.1) Manpower (days/unit area)	8.3 man.day/ha
5.2) Tool investment cost, ECU	65000 ECU
5.3) Discount (ECU/year)	6500 ECU
5.4) Consumables	80 kg/ha seeds;50 kg/h Petro-diesel, fertiliser
5.5) Overheads	160 %
5.6) Scale of application	0.12 ha/ x 700 h/year
5.7.1) Specific exposure	
5.7.2) Inhalation/external dose relation	0.004
5.7.3) Number of man-hours exposed	66 man.hour/ha
6) Efficiency	
6.1) Decontamination factor (DF)	4-16 for peaty soils, 4-9 for podsol soils
7) Wastes generated	No
7.1) Solid kg/m^2	No
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	No
7.4) Toxicity	No
8) Other costs (ECU)	
9) Other benefits	The increasing of harvest.
10) Special remarks	In 1987-93 were realised only 2-3 procedures of 6, but in 1994 all 6 procedures were used in Rovno district on 92 thousands ha.

Authors: Y. Kutlakhmedov Institution: ICBGI
G. Perepelyatnikov UIAR

5.6 Soil disking followed by ploughing and fertilising.

1) Tool	Disking, fertilising, liming and sowing new grass
2) Target surface	Pastures
2.1) Constraints	Need to repeat disking 4-6 times
3) Design (incl. number of operators)	0.8 operators per ha
3.1) Productivity (units/h)	0.25 ha/h
4) Mode of operation	Dilution of Cs and Sr in the soil profile
5) Cost	Total estimate: 150 ECU/ha
5.1) Manpower (days/unit area)	2 ECU/ha (0.4 man-day/ha)
5.2) Tool investment cost, ECU	11328 ECU
5.3) Discount (ECU/year)	1416 ECU/year
5.4) Consumables	Fuel: 8 l/ha, Phosphorus: 12 ECU/ha
5.5) Overheads	200 %
5.6) Scale of application	Availability of manure limited to cultivated crops
5.7.1) Specific exposure	
5.7.2) Inhalation/external dose relation	<1/100
5.7.3) Number of man-hours exposed	
6) Efficiency	
6.1) Decontamination factor (DF)	1.4-2.2 for Cs and 1.2-1.4 for Sr
7) Wastes generated	
7.1) Solid kg/m^2	No
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	No
7.4) Toxicity	No
8) Other costs (ECU)	-
9) Other benefits (renewing roof etc.)	Yield and quantity increase
10) Special remarks	

Author: Firsakova Institution: BIAR

5.7 Liming and fertilising forest pasture soil without ploughing.

1) Tool	Liming and fertilising forest pastures
2) Target surface	forest pastures
2.1) Constraints	Use of traditional machines not possible
3) Design (incl. number of operators)	2.5 operators
3.1) Productivity (units/h)	0.3 ha/h
4) Mode of operation	Enrichment of poor soil by Ca, K, P
5) Cost	
5.1) Manpower (days/unit area)	1 man-day/ha
5.2) Tool investment cost, ECU	- (manual operation only)
5.3) Discount (ECU/year)	-
5.4) Consumables	Lime, KCl, Superfosfate
5.5) Overheads	160 % of wages
5.6) Scale of application	1 ha / cow in settlements, surrounded by forest
5.7.1) Specific exposure	external
5.7.2) Inhalation/external dose relation	No
5.7.3) Number of man-hours exposed	20 man-hours/ha
6) Efficiency	
6.1) Decontamination factor (DF)	less than or equal to 1.5
7) Wastes generated	
7.1) Solid kg/m^2	no
7.2) Liquid l/m^2	no
7.3) Waste activity Bq per m^3 per Bq per m^2	no
7.4) Toxicity	no
8) Other costs (ECU)	-
9) Other benefits (renewing roof etc.)	Increases pasture productivity
10) Special remarks	only for villages surrounded by forests, when other pastures are impossible to use

<u>Authors:</u> Firsakova, Antsipov Institution: BIAR, CSCB

5.8.a Use of bolus in private farms.

1) Tool	Ferrasin bolus (boli applicator)
2) Target surface	Decontamination of milk from ^{137}Cs
2.1) Constraints	
3) Design (incl. number of operators)	2 operators
3.1) Productivity (units/h)	2 cows per hour
4) Mode of operation	
5) Cost	0.04 ECU/l or 19.2 ECU/cow
5.1) Manpower (days/unit area)	0.125 man-day/cow
5.2) Tool investment cost, ECU	8 ECU
5.3) Discount (ECU/year)	2 ECU/year
5.4) Consumables	3 bolus/cow = 19.2 ECU/cow
5.5) Overheads	200 %
5.6) Scale of application	1500 cows/year
5.7.1) Specific exposure	No
5.7.2) Inhalation/external dose relation	No
5.7.3) Number of man-hours exposed	No
6) Efficiency	
6.1) Decontamination factor (DF)	2-3 (on milk)
7) Wastes generated	
7.1) Solid kg/m^2	No
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	No
7.4) Toxicity	-
8) Other costs (ECU)	-
9) Other benefits (renewing roof etc.)	-
10) Special remarks	3 bolus included in a cow each 3 months. The use of bolus increases the milk price by 13 %. The method should be used where Cs level is higher than 1000Bq/l.

Authors: Kutlakhmedov, Perepelyatnikov Institution: ICBGI, UIAR

The general features of the method are described in the IAEA Technical Report Series No. 363 on Guidelines for agricultural countermeasures following an accidental release of radionuclides, ISBN 92-0-100894-5, 1994.

5.8.b Use of bolus in private farms.

1) Tool	Use of Prussian Blue boli in private farm
2) Target surface	Cows (milk)
2.1) Constraints	The Prussian Blue boli production
3) Design (incl. number of operators)	2 operators
3.1) Productivity (units/h)	3 cows per hour
4) Mode of operation	Binding of ^{137}Cs in the gastrointestinal tract
5) Cost	
5.1) Manpower (days/unit area)	0.08 days/cow
5.2) Tool investment cost, ECU	10 ECU (boli applicator)
5.3) Discount (ECU/year)	2.5 ECU
5.4) Consumables	Boli (Prussian Blue, wax, $BaSO_4$ + press mixer)
5.5) Overheads	
5.6) Scale of application	2000 treatments per operator per year
5.7.1) Specific exposure	No
5.7.2) Inhalation/external dose relation	No
5.7.3) Number of man-hours exposed	0.66 man-hours per cow
6) Efficiency	
6.1) Decontamination factor (DF)	2-3 for milk, meat
7) Wastes generated	
7.1) Solid kg/m^2	no
7.2) Liquid l/m^2	no
7.3) Waste activity Bq per m^3 per Bq per m^2	no
7.4) Toxicity	no
8) Other costs (ECU)	no
9) Other benefits (renewing roof etc.)	no
10) Special remarks	The application of boli repeated every 2-3 months. Cost of one treatment per animal = 3 ECU

Authors: Firsakova, Antsipau, Averin Institution: BIAR, CSCB

The general features of the method are described in the IAEA Technical Report Series No. 363 on Guidelines for agricultural countermeasures following an accidental release of radionuclides, ISBN 92-0-100894-5, 1994.

5.9.a Clean fodder to animals before slaughter.

1) Tool	Clean fodder before slaughter.
2) Target surface	Decontamination of meat
2.1) Constraints	
3) Design (incl. number of operators)	Without special operators
3.1) Productivity (units/h)	
4) Mode of operation	The organisation of special feedings of animal by clean food before slaughter
5) Cost	From 10 to 30% increasing of price of meet (0,2-0,5 ECU/kg additionally)
5.1) Manpower (days/unit area)	
5.2) Tool investment cost, ECU	
5.3) Discount (ECU/year)	
5.4) Consumables	
5.5) Overheads	
5.6) Scale of application	
5.7.1) Specific exposure	
5.7.2) Inhalation/external dose relation	
5.7.3) Number of man-hours exposed	
6) Efficiency	
6.1) Decontamination factor (DF)	2 - 3 (for Ukraine)
7) Wastes generated	No
7.1) Solid kg/m^2	No
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	No
7.4) Toxicity	No
8) Other costs (ECU)	Radiation Control, live dosimetry 0.5 ECU/animal/ year
9) Other benefits	
10) Special remarks	

Authors: Y. Kutlakhmedov Institution: ICBGI
G. Perepelyatnikov UIAR

5.9.b Clean fodder to animals before slaughter.

1) Tool	Clean fodder before slaughter.
2) Target surface	Cattle
2.1) Constraints	
3) Design (incl. number of operators)	No additional operators
3.1) Productivity (units/h)	
4) Mode of operation	The elimination of ^{137}Cs from muscles
5) Cost	Transportation costs (0.2 ECU/t per km) + Costs of clean feed
5.1) Manpower (days/unit area)	
5.2) Tool investment cost, ECU	
5.3) Discount (ECU/year)	
5.4) Consumables	
5.5) Overheads	
5.6) Scale of application	
5.7.1) Specific exposure	
5.7.2) Inhalation/external dose relation	
5.7.3) Number of man-hours exposed	
6) Efficiency	
6.1) Decontamination factor (DF)	3.0
7) Wastes generated	No
7.1) Solid kg/m^2	No
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	No
7.4) Toxicity	No
8) Other costs (ECU)	Radiation Control, live dosimetry 0.5 ECU/animal/ year
9) Other benefits	
10) Special remarks	During 2 months before slaughter animals are supplied by clean fodder from arable land of the collective farms. Such feed is in any collective farm, so maize silage and concentrate are usual rations of cattle.

Authors: Firsakova Institution: BIAR
Antsipov CSCB
Averin

5.10 Salt licks for animals.

1) Tool	Use of Prussian Blue salt-licks
2) Target surface	Cows and bulls
2.1) Constraints	Prussian Blue salt-lick production
3) Design (incl. number of operators)	2 operators
3.1) Productivity (units/h)	15 salt-licks/h
4) Mode of operation	Binds ^{137}Cs in gastrointestinal tract.
5) Cost	
5.1) Manpower (days/unit area)	0.016 man-day/salt lick
5.2) Tool investment cost, ECU	-
5.3) Discount (ECU/year)	-
5.4) Consumables	gasoline 10 l/day, Prussian Blue, NaCl, press equipment
5.5) Overheads	
5.6) Scale of application	12000 salt-lick distribution
5.7.1) Specific exposure	
5.7.2) Inhalation/external dose relation	No inhalation
5.7.3) Number of man-hours exposed	0.128 man-hr/salt-lick
6) Efficiency	
6.1) Decontamination factor (DF)	2.0-3.0 for milk, meat
7) Wastes generated	
7.1) Solid kg/m^2	None
7.2) Liquid l/m^2	None
7.3) Waste activity Bq per m^3 per Bq per m^2	None
7.4) Toxicity	None
8) Other costs (ECU)	None
9) Other benefits (renewing roof etc.)	Providing of NaCl
10) Special remarks	The duration of use by animal of 1 salt-lick is 3 months. Annual cost for 1 animal: 6 ECU

Authors: Firsakova, Antsipov, Averin Institution: BIAR, CSCB

The general features of the method are described in the IAEA Technical Report Series No. 363 on Guidelines for agricultural countermeasures following an accidental release of radionuclides, ISBN 92-0-100894-5, 1994.

5.11 Production of phytomass with enhanced contamination.

1) Tool	Production of phytomass with enhanced contamination (Phytodecontamination of soils)
2) Target surface	Decontamination of soils(mixed)
2.1) Constraints	This method includes 7 procedures: special treatment of seeds; ploughing; sowing crops; fertilising; irrigation; harvesting; harrowing. Only 3 procedures appears additional to traditional scheme: treatment of seeds; irrigation; harrowing after harvesting.
3) Design (incl. number of operators)	9 operators
3.1) Productivity (units/h)	
4) Mode of operation	The using of additional procedures (treatment of seeds; irrigation; harrowing) with aim creating of conditions for significant increasing transfer factor and harvest of biomass. The harvest of biomass can be used for feeding of animals and then using clean fodder before slaughter.
5) Cost	34 ECU/ha (0,2-0,5 ECU/kg additionally)
5.1) Manpower (days/unit area)	1 man.day/ha
5.2) Tool investment cost, ECU	On 3 additional procedures 10000 + 8000 + 12000 = 30000
5.3) Discount (ECU/year)	100 + 800 + 3000 = 3900 ECU/year
5.4) Consumables	50 kg/ha seeds; 5.000 t/ha water; 15 kg/h diesel.
5.5) Overheads	160%
5.6) Scale of application	0,12 ha/h x 400 h/year
5.7.1) Specific exposure	
5.7.2) Inhalation/external dose relation	0.001
5.7.3) Number of man-hours exposed	1 man.hour/ha
6) Efficiency	
6.1) Decontamination factor (DF)	1.1-1.3 (per year)
7) Wastes generated	No
7.1) Solid kg/m^2	No
7.2) Liquid l/m^2	No
7.3) Waste activity Bq per m^3 per Bq per m^2	No
7.4) Toxicity	No
8) Other costs (ECU)	
9) Other benefits	The receiving of food for feeding animals and then clean fodder before slaughter = 15 ECU/ha.
10) Special remarks	This is important possibility of phytodecontami-nation - using of phytomass for feeding animals.

Authors: Y. Kutlakhmedov	Institution: . ICBGI
G. Perepelyatnikov	UIAR

5.12 Industrial crops (rape, sugar beet, lignocelluloses, for oil fuel, etc.).

1) Tool	Exchange of food crops with technical (industrial) crops
2) Target surface	Contaminated arable lands
2.1) Constraints	crop processing plant
3) Design (incl. number of operators)	
3.1) Productivity (units/h)	
4) Mode of operation	Use of contaminated area for crop production
5) Cost	
5.1) Manpower (days/unit area)	
5.2) Tool investment cost, ECU	
5.3) Discount (ECU/year)	
5.4) Consumables	
5.5) Overheads	
5.6) Scale of application	10 % of arable land on contaminated area
5.7.1) Specific exposure	
5.7.2) Inhalation/external dose relation	
5.7.3) Number of man-hours exposed	
6) Efficiency	
6.1) Decontamination factor (DF)	Exclusion of food uptake
7) Wastes generated	
7.1) Solid kg/m^2	None
7.2) Liquid l/m^2	None
7.3) Waste activity Bq per m^3 per Bq per m^2	None
7.4) Toxicity	None
8) Other costs (ECU)	Purchase of special tools and creation of processing base
9) Other benefits (renewing roof etc.)	Development of industry
10) Special remarks	Large additional Government investments in agriculture will be possible

Authors: Firsakova, Antsipov Institution: BIAR, CSCB

The rape production is more realistic, several collective farms grow its crop and rape oil plant is treated in Gomel area.

The general features of the method are described in the IAEA Technical Report Series No. 363 on Guidelines for agricultural countermeasures following an accidental release of radionuclides, ISBN 92-0-100894-5, 1994.

5.13 Ferrasin filters for milk decontamination.

1) Tool	Ferrasin filters for milk
2) Target surface	Decontamination of milk from ^{137}Cs
2.1) Constraints	Used on private farms only
3) Design (incl. number of operators)	1 operator
3.1) Productivity (units/h)	40 filters per hour (0.01 filter/l milk)
4) Mode of operation	Filtration of milk through filter
5) Cost	0.006 ECU/l or 0.8 ECU/cow, 10 days (32 ECU/y)
5.1) Manpower (days/unit area)	0.02 man-day per filter
5.2) Tool investment cost, ECU	plastic system for filtration of milk (4 ECU)
5.3) Discount (ECU/year)	1 ECU/year
5.4) Consumables	Gasoline 4 kg/h, 0.01 filter/l milk
5.5) Overheads	100 %
5.6) Scale of application	40 filters/h * 320 h/y
5.7.1) Specific exposure	None
5.7.2) Inhalation/external dose relation	None
5.7.3) Number of man-hours exposed	None
6) Efficiency	
6.1) Decontamination factor (DF)	ca. 10
7) Wastes generated	
7.1) Solid kg/m^2	None
7.2) Liquid l/m^2	None
7.3) Waste activity Bq per m^3 per Bq per m^2	-
7.4) Toxicity	None
8) Other costs (ECU)	-
9) Other benefits (renewing roof etc.)	-
10) Special remarks	This method should be used under conditions where the milk contamination is 400 Bq/l or more

Authors: Kutlakhmedov, Los Institution: ICBGI, UCRM

6 Self-Restoration

Quantitative/qualitative evaluation of self-restoration

By: Arapis, Davydchouk, Sokolik,
Athens University, Kiev Inst. of Geography, Belarus State University.

Introduction:

To undertake any recovery action in natural and semi-natural ecosystems nine years or earlier after the accident it is of great importance to know the exact natural evolution of the radiological situation of these affected areas. This knowledge will facilitate the choice of the decision-makers of appropriate decontamination strategies.

Aim:

The goal of this technique is to evaluate the efficiency of the processes of self-restoration for natural and semi-natural ecosystems.

Methodology:

In order to do this the following example could be followed.

1. Evaluation of the self-restoration processes:

The evaluation of radiological balances of affected large areas in the Ukraine and Belarus was made. Using cartography, short and long term positive, neutral or negative radioecological balances of the 30 km zone were elaborated. Similar work was done for the Khoiniki, in order to cover an important part of the contaminated territory of these two republics.

The presentation of the radiological situation is made by maps of ^{137}Cs iso-lines of soil contamination and maps of the above mentioned balances. The velocity of vertical migration of radionuclides was calculated. The influence of different types of soil on the migration of ^{137}Cs and ^{90}Sr was studied. The migration ability of the radionuclides was measured for representative soils in Belarus and the results were presented in maps. Similar measurements and cartography are made for Ukrainian soils.

2. Evaluation of self-restorative dose reduction

The efficiency of self-restoration is evaluated in terms of dose reduction as a function of the vertical migration of radionuclides. The dose rate at 1 m above the surface was calculated from different ^{137}Cs depth distributions in different types of soil by the Monte Carlo method.

Table 6.1 shows - for 1993 and for non-covered forest soils - the calculated exposed dose rates (EDR) as a function of ^{137}Cs vertical migration, for five groups of migration velocities (from < 0.25 to > 1.2 cm/year) and for nine different levels of contamination (from 10 to 200 μCi/m^2). It is important to observe that eight years after the accident a significant (> 30%) EDR reduction was calculated in soddy - and peat-gley soils (group V) which types represent a relatively important part of the contaminated territories.

Table 6.1. Means of EDR for different migration velocity of ^{137}*Cs in soils (for density1.5 g/cm*^{3}*).*

Group of migration rate	Linear rate, cm/year	Soil deposit of Cs-137, μCi/m^2								
		5	10	15	20	25	30	50	100	200
		Value of EDR, μR/h								
	0	36.8	58.5	80.3	102.0	123.8	145.5	232.5	450.0	885.0
I	<0.25	34.6	54.1	73.7	93.2	112.8	132.3	210.5	406.0	797.0
II	0.25-0.5	32.4	49.8	67.2	84.6	102.0	119.4	189.0	363.0	711.0
III	0.5-0.7	29.6	44.2	58.8	73.4	88.0	102.6	161.0	307.0	599.0
IV	0.7-1.2	28.3	41.5	54.8	68.0	81.3	94.5	147.5	280.0	545.0
V	>1.2	25.7	36.4	47.1	57.8	68.5	79.2	122.0	229.0	443.0

7 Equipment for Measurement of the Effect of Treatments

This chapter describes an evaluation of the measurement procedures and measurement equipment which might be useful in assessments of radioactivity levels in connection with development of strategies to deal with the contamination problems.

7.1.a Gamma spectrometry in situ.

1) Tool	Intrinsic Ge-detector, Multichannel analyser, Lead shielding.
2) Target surface	Measurement of roof, wall, soil in situ
2.1) Constraints	Not able to measure depth distribution profile
3) Design (incl. number of operators)	
3.1) Productivity (units/h)	1 point per hour
4) Mode of operation	Measurement of surface contamination level
5) Cost	
5.1) Manpower (days/unit area)	0.25 man-day per point
5.2) Tool investment cost, ECU	30000 ECU
5.3) Discount (ECU/year)	6000 ECU
5.4) Consumables	0.5 kW, + Liquid N_2
5.5) Overheads	250-300 %
5.6) Scale of application	8 points per day * 90 = 720 points per year
5.7.1) Specific exposure	no
5.7.2) Inhalation/external dose relation	-
5.7.3) Number of man-hours exposed	2 man-hours per point
6) Efficiency	
6.1) Decontamination factor (DF)	
7) Wastes generated	
7.1) Solid kg/m^2	none
7.2) Liquid l/m^2	none
7.3) Waste activity Bq per m^3 per Bq per m^2	none
7.4) Toxicity	none
8) Other costs (ECU)	none
9) Other benefits (renewing roof etc.)	Can determine all gamma emitters
10) Special remarks	Special knowledge required

Authors: Roed, Andersson, Prip Institution: RISØ

The lead shielding is established on the site, in order to measure a defined area on the wall, ground or roof. a pre-made calibration is used to quantify the result in to Bq/m^2 of the different isotopes, on the different surface types. Minimum 2 well skilled persons are required.

7.1.b Gamma spectrometry in situ.

1) Tool	Pure Ge-detector, 4096 channel analyser
2) Target surface	Measurement of roof, wall, soil in situ
2.1) Constraints	Can not measure depth distribution profile
3) Design (incl. number of operators)	
3.1) Productivity (units/h)	1 point per hour
4) Mode of operation	measurement of surface contamination level
5) Cost	
5.1) Manpower (days/unit area)	0.25 man-day per point
5.2) Tool investment cost, ECU	25000 ECU
5.3) Discount (ECU/year)	5000 ECU
5.4) Consumables	0.5 kW
5.5) Overheads	250-300 %
5.6) Scale of application	8 points per day * 90 = 720 points per year
5.7.1) Specific exposure	no
5.7.2) Inhalation/external dose relation	-
5.7.3) Number of man-hours exposed	2 man-hours per point
6) Efficiency	
6.1) Decontamination factor (DF)	
7) Wastes generated	
7.1) Solid kg/m^2	none
7.2) Liquid l/m^2	none
7.3) Waste activity Bq per m^3 per Bq per m^2	none
7.4) Toxicity	none
8) Other costs (ECU)	none
9) Other benefits	Can determine all gamma radiation
10) Special remarks	Special knowledge required

Authors: Ramzaev, Chesnokov Institution: BIRH, RECOM (Russia)

The quantum flux is measured by pure Ge-detector (energy resolution < 2 keV for 662 keV radiation) and multichannel analyser in situ. The total measured quantum flux is recalculated into specific and surface activity of the measured surface. 1 scientist and 1 field worker are needed for the measurements.

7.2 Gamma spectrometry in the laboratory.

1) Tool	Pure Ge-detector 4096 channel analyser
2) Target surface	Measuring of samples of roofs, walls, soil
2.1) Constraints	Laboratory conditions are needed
3) Design (incl. number of operators)	
3.1) Productivity (units/h)	1 sample per hour for total activity and 0.1 sample per hour for depth distribution profile
4) Mode of operation	Measuring sample activity
5) Cost	
5.1) Manpower (days/unit area)	0.25 man-day/sample
5.2) Tool investment cost, ECU	25000 ECU
5.3) Discount (ECU/year)	5000 ECU
5.4) Consumables	0.5 kW
5.5) Overheads	250-300 %
5.6) Scale of application	8 samples/day * 220 days = 1760 samples/year
5.7.1) Specific exposure	none
5.7.2) Inhalation/external dose relation	none
5.7.3) Number of man-hours exposed	2 man-hours per sample, 20 man-hours per profile
6) Efficiency	
6.1) Decontamination factor (DF)	
7) Wastes generated	
7.1) Solid kg/m^2	-
7.2) Liquid l/m^2	none
7.3) Waste activity Bq per m^3 per Bq per m^2	-
7.4) Toxicity	none
8) Other costs (ECU)	transport of samples to laboratory- 2 ECU/sample
9) Other benefits	All gamma radiation could be determined
10) Special remarks	Special knowledge required

Authors: Ramzaev, Chesnokov Institution: BIRH, RECOM

The total sample activity measured at laboratory conditions is recalculated into specific and surface activity of substances. The sample activity is measured by pure Ge-detector (energy resolution < 2keV for 662 keV radiation) and multichannel analyser. 1 scientist and 1 field worker are required for the whole procedure.

7.3 Beta counter measurements in situ.

1) Tool	Beta counter
2) Target surface	Various surfaces in situ
2.1) Constraints	At least 10 kBq/m^2 on surface
3) Design (incl. number of operators)	Portable, 1 operator
3.1) Productivity (units/h)	
4) Mode of operation	ca. 10 points per hour (depending on surface type and orientation)
5) Cost	
5.1) Manpower (days/unit area)	0.01 man-day per point
5.2) Tool investment cost, ECU	3500
5.3) Discount (ECU/year)	700/y
5.4) Consumables	Negligible (gas, battery)
5.5) Overheads	200 %
5.6) Scale of application	7200 points per year
5.7.1) Specific exposure	-
5.7.2) Inhalation/external dose relation	-
5.7.3) Number of man-hours exposed	0.08 man-hours per point
6) Efficiency	
6.1) Decontamination factor (DF)	-
7) Wastes generated	-
7.1) Solid kg/m^2	-
7.2) Liquid l/m^2	-
7.3) Waste activity Bq per m^3 per Bq per m^2	-
7.4) Toxicity	-
8) Other costs (ECU)	-
9) Other benefits	Easy to handle in situ on walls and roofs
10) Special remarks	Instruction required

<u>Authors:</u> Roed, Andersson, Prip Institution: Risø

CONTAMAT FHT 111 M beta counter. Portable, battery operated butane gas proportional counter measuring a surface area of 166 cm^2.

7.4 Ion chamber measurements in situ.

1) Tool	Ion chamber. (Reuter Stokes)
2) Target surface	Environmental monitoring in situ
2.1) Constraints	None
3) Design (incl. number of operators)	Portable, 1 operator
3.1) Productivity (units/h)	5 Measurements/h
4) Mode of operation	Tissue equivalent dose metering.
5) Cost	
5.1) Manpower (days/unit area)	0.025 man-day/measurement.
5.2) Tool investment cost, ECU	17000 ECU
5.3) Discount (ECU/year)	3300 ECU/y
5.4) Consumables	Negligible (battery)
5.5) Overheads	200 %
5.6) Scale of application	8000 points per year
5.7.1) Specific exposure	-
5.7.2) Inhalation/external dose relation	-
5.7.3) Number of man-hours exposed	-
6) Efficiency	-
6.1) Decontamination factor (DF)	-
7) Wastes generated	-
7.1) Solid kg/m^2	-
7.2) Liquid l/m^2	-
7.3) Waste activity Bq per m^3 per Bq per m^2	-
7.4) Toxicity	-
8) Other costs (ECU)	-
9) Other benefits (renewing roof etc.)	Results in: R, rem, rad, Sv, Gy.
10) Special remarks	Instruction required

Authors: Roed, Andersson, Prip Institution: Risø

Reuter Stokes Ion Chamber is considered as the reference instrument in environmental dose measurement.

7.5.a In situ spectrometry with sodium iodide detector.

1) Tool	NaI counting system
2) Target surface	Various surfaces in situ
2.1) Constraints	Min. 1 kBq/m^2 on surface
3) Design (incl. number of operators)	NaI counter + MCA 1 operator
3.1) Productivity (units/h)	ca. 10 points per hour depending on surface type and orientation
4) Mode of operation	In situ measurements with NaI detector
5) Cost	
5.1) Manpower (days/unit area)	0.01 man-day per measurement point
5.2) Tool investment cost, ECU	8000 ECU
5.3) Discount (ECU/year)	1600 ECU/year
5.4) Consumables	-
5.5) Overheads	200 %
5.6) Scale of application	7200 points/year
5.7.1) Specific exposure	-
5.7.2) Inhalation/external dose relation	-
5.7.3) Number of man-hours exposed	0.08 man-h/point
6) Efficiency	-
6.1) Decontamination factor (DF)	-
7) Wastes generated	-
7.1) Solid kg/m^2	-
7.2) Liquid l/m^2	-
7.3) Waste activity Bq per m^3 per Bq per m^2	-
7.4) Toxicity	-
8) Other costs (ECU)	-
9) Other benefits	-
10) Special remarks	Instruction required

Authors: Roed, Andersson, Prip Institution: Risø

Portable 3"*3" NaI detector system with multichannel analyser.

7.5.b In situ spectrometry with sodium iodide detector.

1) Tool	CORAD
2) Target surface	soil
2.1) Constraints	0.1 μCi/m^2 - 400 μCi/m^2 of ^{137}Cs soil contam.
3) Design (incl. number of operators)	
3.1) Productivity (units/h)	10-12 points per hour
4) Mode of operation	Measurement of ^{137}Cs deposit and penetration
5) Cost	
5.1) Manpower (days/unit area)	0.01-0.0125 man-day per point
5.2) Tool investment cost, ECU	4000 ECU
5.3) Discount (ECU/year)	800 ECU/year
5.4) Consumables	Portable (0.1 kW for battery)
5.5) Overheads	250-300 %
5.6) Scale of application	80-100 points/d *90 = 7200-9000 points/year
5.7.1) Specific exposure	None
5.7.2) Inhalation/external dose relation	None
5.7.3) Number of man-hours exposed	0.08-0.10 man-hours per point
6) Efficiency	
6.1) Decontamination factor (DF)	
7) Wastes generated	
7.1) Solid kg/m^2	none
7.2) Liquid l/m^2	none
7.3) Waste activity Bq per m^3 per Bq per m^2	none
7.4) Toxicity	none
8) Other costs (ECU)	none
9) Other benefits	Device allows to estimate ^{137}Cs penetration depth
10) Special remarks	Special knowledge required

Authors: Ramzaev, Chesnokov Institution: BIRH, RECOM

The measured quantum flux restricted by the lead collimator is recalculated into surface activity of soil. The quantum flux is measured by NaI detector (energy resoln. < 10% for 662keV radiation) and 256 channel analyser. 1 operator should work after some education. Portable device.

7.6 Laboratory spectrometry with sodium iodide detector.

1) Tool	NaI counting system with lead shielding
2) Target surface	Various surfaces in situ
2.1) Constraints	Max. sample size : 20cm * 20cm * 20cm
3) Design (incl. number of operators)	1 operator
3.1) Productivity (units/h)	ca. 10-20 samples per hour depending on source strength
4) Mode of operation	Lead shielded NaI crystal measurements in lab.
5) Cost	
5.1) Manpower (days/unit area)	0.005-0.01 man-day/sample
5.2) Tool investment cost, ECU	8000 ECU (detector system) + 2000 (lead bricks)
5.3) Discount (ECU/year)	1800 ECU/y
5.4) Consumables	-
5.5) Overheads	200 %
5.6) Scale of application	7200-14400 samples/year
5.7.1) Specific exposure	-
5.7.2) Inhalation/external dose relation	-
5.7.3) Number of man-hours exposed	-
6) Efficiency	-
6.1) Decontamination factor (DF)	-
7) Wastes generated	-
7.1) Solid kg/m^2	-
7.2) Liquid l/m^2	-
7.3) Waste activity Bq per m^3 per Bq per m^2	-
7.4) Toxicity	-
8) Other costs (ECU)	-
9) Other benefits	-
10) Special remarks	Instruction required

Authors: Roed, Andersson, Prip Institution: Risø

Lead shielded 3”*3” NaI detector system with multichannel analyser for laboratory use.

Conclusion

A catalogue of feasible techniques for reduction of the radiation dose nine years after an accidental contamination of different environments has been made. The catalogue is based on recent experimental research and therefore describes the effect and limitations of the investigated methods in relation to the current situation in the areas affected by the Chernobyl accident. However, the reported results could be used to guide clean-up operations in other scenarios involving aged contamination.

The format of the files describing the individual techniques facilitates a comparison on many different features, so that the most suitable technique for a special operation can be selected on the basis of a weighing of details such as for instance the dose reducing effect, scale of application, tool investment costs, labour costs, cost of consumables, overheads, exposure of operators and amounts and types of generated wastes. The selection of techniques can thus be made on the background of detailed analysis to ensure that the maximum effect is obtained for the costs that can be afforded.

It is often difficult to describe labour costs in monetary units, as such expenses will be greatly dependent on the local wages. Also, due to the currently high inflation rates in the former Soviet Union, a monetary evaluation of such costs would not be valid for very long time. Therefore, it was chosen to describe the labour costs in terms of the amount of time required to treat an area of surface or a standardized object.

An overall examination of the files shows that it is still possible to substantially reduce the radiation dose nine years after an accidental contamination, although it would certainly have been easier immediately following the deposition of the radioactive matter.

Bibliographic Data Sheet **Risø-R-828(EN)**

Title and authors

Practical Means for Decontamination 9 Years after a Nuclear Accident

Editors J. Roed, K.G. Andersson, H. Prip

ISBN	ISSN
87-550-2080-1	0106-2840
Dept. or group	Date
Environmental Science and Technology Department	December 1995
Groups own reg. number(s)	Project/contract No(s)

Pages	Tables	Illustrations	References
82	1		

Abstract (Max. 2000 characters)

Nine years after the Chernobyl accident, the contamination problems of the most severely affected areas remain unsolved. As a consequence of this, large previously inhabited areas and areas of farmland now lie deserted. An international group of scientists funded by the EU European Collaboration Programme (ECP/4) has investigated in practice a great number of feasible means to solve the current problems. The basic results of this work group are presented in this report that was prepared in a format which facilitates an intercomparison (cost-benefit analysis) of the individual examined techniques for decontamination or dose reduction in various different types of environmental scenarios. Each file containing information on a method or procedure was created by the persons and institutes responsible for the practical trial. Although the long period that has elapsed since the contamination took place has added to the difficulties in removing the radioactive matter, it could be concluded that many of the methods are still capable of reducing the dose level substantially.

Descriptors INIS/EDB

AGRICULTURE; BUILDINGS; CHERNOBYLSK-4 REACTOR; CLAYS; COST BENEFIT ANALYSIS; DECONTAMINATION; DOMESTIC ANIMALS; DOSE RATES; EFFICIENCY; FARMS; FORAGE; FORESTS; RADIATION PROTECTION; RADIOECOLOGICAL CONCENTRATION; REACTOR ACCIDENTS; REMEDIAL ACTION; SOILS; SURFACE CLEANING

Available on request from Information Service Department, Risø National Laboratory, (Afdelingen for Informationsservice, Forskningscenter Risø), P.O.Box 49,
DK-4000 Roskilde, Denmark.
Telephone +45 46 77 46 77, ext. 4004/4005
Telex 43 116. Telefax +45 42 36 06 09

RISØ

Objective

The objective of Risø's research is to provide industry and society with new potential in three main areas:

- *Energy technology and energy planning*
- *Environmental aspects of energy, industrial and plant production*
- *Materials and measuring techniques for industry*

As a special obligation Risø maintains and extends the knowledge required to advise the authorities on nuclear matters.

Research Profile

Risø's research is long-term and knowledge-oriented and directed toward areas where there are recognised needs for new solutions in Danish society. The programme areas are:

- *Combustion and gasification*
- *Wind energy*
- *Energy technologies for the future*
- *Energy planning*
- *Environmental aspects of energy and industrial production*
- *Environmental aspects of plant production*
- *Nuclear safety and radiation protection*
- *Materials with new physical and chemical properties*
- *Structural materials*
- *Optical measurement techniques and information processing*

Transfer of Knowledge

The results of Risø's research are transferred to industry and authorities through:

- *Research co-operation*
- *Co-operation in R&D consortia*
- *R&D clubs and exchange of researchers*
- *Centre for Advanced Technology*
- *Patenting and licencing activities*

To the scientific world through:

- *Publication activities*
- *Co-operation in national and international networks*
- *PhD- and Post Doc. education*

Key Figures

Risø has a staff of just over 900, of which more than 300 are scientists and 80 are PhD and Post Doc. students. Risø's 1995 budget totals DKK 476m, of which 45% come from research programmes and commercial contracts, while the remainder is covered by government appropriations.

Risø-R-828(EN)
ISBN 87-550-2080-1
ISSN 0106-2840

Available on request from:
Information Service Department
Risø National Laboratory
P.O. Box 49, DK-4000 Roskilde, Denmark
Phone +45 46 77 46 77, ext. 4004/4005
Telex 43116, Fax +45 46 75 56 27
http://www.risoe.dk
e-mail: risoe@risoe.dk