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A Guide to Countermeasures for Implemen-tation in the Event of a Nuclear Accident Affecting Nordic Food-Producing Areas

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Abstract

State-of-the-art information on methods for management of nuclear accidents affecting food-producing areas has been reviewed, evaluated and transposed to reflect conditions relevant to the Nordic countries. This data, describing in detail the various method-specific costs and benefits, is reported in a well-arranged format facilitating analyses in connection with decision-making. Guidance, recommendations and examples are given as to how the individual data sheets may be used in emergency preparedness planning.

Keywords

Radioactivity, caesium-137, strontium-90, iodine-131, contamination, countermeasures, intervention, deposition, particles, dose, dose rate, dose reduction, decontamination, clean-up, waste, agriculture, food industry, rural, soil, crops, animals, food, cost-benefit, data-sheet, strategy.

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A GUIDE TO COUNTERMEASURES FOR IMPLEMENTATION IN THE EVENT OF A NUCLEAR ACCIDENT AFFECTING NORDIC FOOD-PRODUCING AREAS

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1. Preface

The work reported was carried out as a part of the BOK-1.4 project (Countermeasures in Agriculture and Forestry) under the framework of the Nordic Nuclear Safety Research (NKS) Programme 1998-2001. In the previous NKS Programme period, 1994-1997, a background project, EKO-3.4, was carried out, describing e.g., the competent authorities and current regulations in relation to radiological emergencies affecting food-production in the Nordic countries. Also the use of countermeasures for the very earliest phase, before contaminant deposition occurs, is discussed in the report of EKO-3.4. The data sheet format applied in the present work was inspired by that applied in the report of the EKO-5 project in connection with description of countermeasures for application in the early phase after an accidental contamination of Nordic residential areas. The EKO-5 project was also carried out in the previous NKS Programme period.

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2. Summary

The core of the work reported is a series of data sheets describing in well-arranged format methods which are considered potentially applicable for reduction of radiation doses that would be received through consumption of contaminated food in the event of a major nuclear accident affecting Nordic areas. The three radionuclides ^{137}Cs, ^{90}Sr and ^{131}I are considered to have a special status in this context, as these have in the past (e.g., in connection with the Chernobyl accident) been found to have particularly great bearing on dose.

The methodological data sheets for countermeasures are shown in Chapter 6. Each of the data sheets contains a short general procedure description, as well as an estimate of the dose reductive effect of the measure, with respect to the above three isotopes. Further, cost elements are described in relation to personnel requirements, equipment and other remedies, as well as waste that may be generated by the method and must be treated and disposed of. Further, remarks are made in relation to particularly the practicability and acceptability of the measures, and literature is recommended for further information.

A categorisation system has been created to make it easier for decision-makers to quickly see which methods might have relevance in relation to the particular situation. This system is described in Chapter 4.

In Chapter 5, recommendations are given as to those simple measures that may be possible to implement during the earliest phase of an accident, where deposition has not yet occurred. Clearly, some such measures may be highly beneficial and monetary costs are here often not the determining restriction. However, the methods require early warning, so that there is sufficient time to carry out the work. Further, if it is not known when contamination may take place, the implementation of such measures may impose an extra risk on personnel carrying out the work.

In Chapter 7 a description is made of the type of criteria which may form the background for a decision as to whether or not countermeasures should be introduced. Recommendations are given in relation to how the radiological situation can be assessed, and a section describes the factors that locally determine the behaviour of contaminants after deposition in an area. The behaviour of contaminants in the food-producing environment is particularly important with respect to uptake through the food-chains. Also in Chapter 7, calculated data is given, which might be helpful in the critical early phase following contamination, in estimating the radiological impact and those pathways to consumption dose that are most important to consider in the formation of a strategy for dose reduction.

In Chapter 8, three examples are given of how the data sheets may be applied in the planning, e.g., through calculation of elements of direct costs and estimated value of benefits.

3. Introduction

In severe accident situations, where large amounts of radioactive matter are released to the atmosphere and subsequently deposited in food-producing areas, natural removal processes may well be insufficient in reducing the contamination to a level, which permits continuation of normal activities after an acceptable period of time. In such cases, countermeasures may be called for to mitigate adverse effects of the contamination. The major objectives in this context are that:

1. Doses to the population in the affected food-producing areas be reduced as much as is reasonably achievable. Here, significant dose contributions may be received both through consumption of contaminated food, external radiation from contaminated surfaces indoors and outdoors, and, particularly in the very early phase, external radiation from contaminants deposited to the human body, inhalation and external radiation from the contaminated cloud.
2. Contamination levels in food produced in the affected areas be kept under threshold values recommended for use, distribution or trade, so that the market for these products is at least not restricted for radiological reasons. If it is recognised that this can not be achieved other means of profitable application of the areas than food production may be sought. This may possibly prevent a desertion of the areas, provided that food to support inhabitants can be produced elsewhere.
3. Detailed information, comprehensible to the public, about the radiological situation and its implications as well as possible intervention practices be distributed to people working or living in the affected food-producing areas as well as to potential consumer groups. If this is not done very carefully, severe social, psychological and economic repercussions may be envisaged.

A strategy for dose reduction should address these three major points, and in connection with this, numerous other factors need to be taken into account. Further, it is important that the strategy is developed quickly, as some countermeasures, which would only be efficient if carried out in the early phase (days-weeks), may greatly affect long-term doses received.

The present report, which was developed in connection with the Nordic BOK-1.4 project, specifically aims at facilitating the decision making process in connection with the development of a strategy for dose-reductive treatment of contaminated Nordic food-producing (particularly agricultural) areas and their products. Although it has been sought to include factors characteristic to Nordic areas in the various considerations described, much of the content of the report is considered to be of relevance to a wider audience.

Ideally, the effect of all radionuclides, which might be released from all conceivable types of accidents should be considered in connection with a description of potentially applicable countermeasures. However, as this would be an immense task, it was decided early in the BOK-1.4 project to focus on those three radionuclides, which would be considered likely to be most important in connection with major releases from a nuclear power plant, i.e. ^{137}Cs, ^{90}Sr and ^{131}I. However, some of the described methods will also reduce dose contributions from other isotopes. It was also decided to focus on measures for reduction of consumption dose, as opposed to external dose.

4. The data sheet format

In connection with the description of details of relevance to the implementation of a countermeasure it is considered advantageous to as far as possible concentrate all important data in a single data sheet. This principle has been applied to all countermeasures considered potentially feasible and practicable in Nordic food-producing areas (including food processing industry and households) contaminated by radioactive matter.

The data sheet concept has the advantage that essentially all method-specific information required in decision-making is compiled and presented in a well-arranged form facilitating intercomparison of different techniques. If it is decided that a countermeasure is to be applied, central or local decision-makers can then copy single pages with method-data and distribute to relevant personnel (e.g., operators). In this way, the amount of irrelevant information is minimised, which may be of great importance in an emergency situation. Translation to local language as well as further instructions in relation to the particular situation would, however, often be necessary. It is strongly recommended that decision-makers intending to potentially use this report make themselves familiar with the contents of it - particularly Chapters 5-8 - well in advance of any application.

The data sheet format applied in BOK-1.4 (see Chapter 6), which is similar to that applied in the NKS/EKO-5 project (Andersson, 1996), contains a short description of the method, how it is carried out and where it is deemed practicable. In addition to this, the benefit in terms of expected dose reduction is expressed for those of the three major radionuclides (^{137}Cs, ^{90}Sr and ^{131}I), on which the method has an effect. This dose reductive effect is generally given relative to the dose that would have been expectable if no remedial action affecting doses were taken at all. This means that the possible effect of e.g. routine agricultural practice, such as ploughing and fertilising, is left out, as such practice would be likely to vary greatly between the Nordic countries. Application of some methods may be subject to seasonal limitations, and these, as well as other, possibly non-radiological, constraints and benefits are described. Finally, cost elements are detailed with respect to three main categories: personnel costs, costs of equipment (including consumables) and costs in relation to waste generated by the method (if any - calculated where possible from estimated costs of treatment, transport and storage). Manpower requirements are given in units of working time rather than in monetary units, as this makes the figures easier to apply in different countries with different typical worker wages. Further, working time units are not distorted by economical inflation. If further information is requested, each data sheet has a number of references to publications describing the particular method in greater detail.

The data in the data sheets represent 'best estimates' based on results of measurements, experimental campaigns, laboratory experiments, modelling and calculations, particularly made after the Chernobyl accident. Some special terms are applied in the data sheets. 'DF' is short for 'Decontamination factor' (contamination level of an object before relative to after decontamination). Similarly, DRF is the 'Dose reduction factor', by which a method reduces the particular dose contribution.

To further facilitate decision-making, all method description data sheets have in the upper left corner been assigned with a code. Techniques for application on soil areas with *vegetation* are given the codes V1 to V18, and techniques for application in animal *meat/milk* production are given the codes M1 to M11, whereas the techniques for dose reduction by *food* processing are given the codes F1 to F8. In brackets, a code starting with 'P' or 'A' is given, stating the stage in the accident preparedness, for which the method is considered to be relevant. Hereby, the planner can more easily determine which methods may be relevant at a certain time following contamination of the area. This 'stage' categorisation system is shown in Table 4.1. *Avoidance* of contamination may be achieved through action prior to contaminant deposition, whereas *early measures* must be implemented in the earliest phase after deposition (days-weeks) to be effective. *Long term measures* are those that could be expected to have a significant beneficial effect, even if they are implemented in later phases.

Table 4.1. Categorisation system for identification of accident 'stage'

stage	Plant food chain	Animal food chain	stage
P1	**Avoidance** of contamination of fields, crops, etc.	**Avoidance** of contamination of animals	A1
P2	**Early measures** to 'clean' fields for future crop production.	**Early measures** to 'clean' fields for future fodder production.	A2
P3	**Early measures** against short-lived isotopes (^{131}I)	**Early measures** against short-lived isotopes (^{131}I)	A3
P4	**Long term measures** to limit transfer of contamination from soil to edible crops	**Long term measures** to limit transfer of contamination from soil to fodder	A4
P5	**Long term measures** to limit contamination level in edible parts of 'raw' crops	**Long term measures** to limit animals' consumption of contaminated fodder	A5 -I
		Long term measures to limit uptake of contaminants from fodder to the animals	A5 -II
P6	**Long term measures** to limit contamination in crop-based food by preparation/processing.	**Long term measures** to limit contamination in animal-based food by preparation/processing.	A6
P7	**Long term changes** to production line of edible crops	**Long term changes** to production line of animal food	A7
P8	**Long term changes** to use of land/crops for other purposes than producing food	**Long term changes** to use of animals and fodder crop land for other purposes than producing food	A8

5. Simple methods to implement before deposition

In the very earliest phase of an emergency, before the contaminants from an airborne release have reached an area, some simple measures can be implemented, which can reduce the impact of the contamination (see e.g., Willdrodt, 1993). That is if the locals receive a sufficiently early warning.

Protecting animals

Animals' consumption of contamination in the early phase would be limited if field-grazing herds could be placed within a fenced area of small dimensions. Thereby, the grazing surface would be reduced, and thus the consumption doses in the first, perhaps critical, hours during deposition. It would of course be more advantageous if the animals could be placed indoors or at least under shelter against precipitation. Precipitation would generally be very efficient in 'washing' contamination out of the air, thus leading to high deposition levels. If possible, animals should be fed with stored uncontaminated fodder.

Covering areas or crops to protect against contamination

If any fodder or harvested crops or other food products could be covered during deposition, e.g., with plastic sheets, their contamination level would be greatly reduced. Sheets for covering should be waterproof, although at least in case of dry deposition, also synthetic fibre covers, which are perhaps more readily available, would have some effect. Although the primary objective is of course to prevent contamination of the ground, rather than of vegetation, it should be mentioned that use of plastic foils may in the summer lead to heat damages to vegetation. Covering of all crop areas would probably in general be impracticable. However, limited areas with particularly expensive crops may be possible to cover. Much cover material (preferably waterproof plastic) must be readily available, and the authorities should therefore inform farmers of these requirements well in advance of any contamination. If possible, also water resources should be covered, and surface water should not be applied until the situation is properly assessed.

Harvesting crop fields

Another method that might be considered is immediate harvesting of crop fields *before* contamination. Hereby, crop contamination would be avoided. However, unless edible crop parts can be harvested without significantly thinning the vegetation, it may well be more advantageous to instead harvest immediately *after* the contamination has occurred, as vegetation in a field may prevent contamination of the underlying soil with much more severe implications. This is particularly the case where contamination occurs practically without precipitation. Then, of course, the harvested crops may not be fit for consumption. Harvesting within such short time as would be expected to be available may well not be possible, and this, as well as the other methods mentioned above involving outdoor work, gives a possibly significant extra risk to workers, who may be exposed to direct deposition of contaminants to skin (this may be particularly high in precipitation) as well as inhalation of contaminants. Water-proof protective clothing covering the whole body, as well as effective respiratory protection would thus be *strongly* recommended. In addition to this extra radiological risk, a psychological impact of feeling 'unprotected' outdoors should enter the considerations forming the background for decision-making.

Keeping indoors

Keeping indoors with closed windows / air ducts would generally protect well against ^{131}I, depending on its chemical form. In connection with the Chernobyl accident, this also reduced strontium (associated with rather large particles) air concentrations in houses of good construction by a factor of 8-10, whereas caesium (associated with small particles) air concentrations were typically only reduced by a factor of ca. 2 compared to those outdoors (Andersson et al., 1999).

Further information on this very early accident phase can be found in the EKO-3.4 report (Preuthun et al., 1997).

6. Data sheets for countermeasures

The data sheets in this chapter are listed below:

Method number	Page number	Stage (see Table 4.1)	Short descriptions of methods in data sheets
V1	12	P2/A2	Early removal of vegetation
V2	13	P2/A2	Early removal of snow
V3	14	P3/A3	Storage of crops / grass
V4	15	P4/A4	Liming of soil
V5	16	P4/A4	Potassium fertilisation
V6	17	P4/A4	Ploughing
V7	18	P4/A4	Deep-ploughing
V8	19	P4/A4	Ploughing and K-fertilisation
V9	20	P4/A4	Repeated ploughing
V10	21	P4/A4	Skim-and-burial ploughing
V11	22	P4/A4	Phosphorus fertilisation
V12	23	P4/A4	Turf harvesting
V13	24	P7	Cultivating crops with low radionuclide uptake
V14	25	P7	Cultivating crops that can be processed
V15	26	P7	Change production from crops to animals
V16	27	P8	Use plants as fertiliser
V17	28	P8	Growth of industrial crops
V18	29	P8/A8	Change land use to forestry
M1	30	A3	Supply animals with stable iodine
M2	31	A3/A5I	Change slaughter time
M3	32	A4	Reduce animal intake of contaminated soil
M4	33	A5I	Clean fodder to animals before slaughter
M5	34	A5II	Prussian Blue salt licks/boli/addition
M6	35	A5II	Supplement fodder with micas or zeolites
M7	36	A5II	Addition of calcium to fodder
M8	37	A6	Prussian Blue filters for milk decontamination
M9	38	A7	Replace sheep/goats with cattle
M10	39	A7	Change from meat to milk production
M11	40	A8	Change animal production to non-consumption
F1	41	P3/A3	Manufacturing of food products to be stored for months
F2	42	P5/P6	Mechanical decontamination of fresh vegetables, fruit and cereals
F3	43	A6	Making cheese by Rennet method and replacing milk in diet with cheese
F4	44	P6	Change milling yield and use of least contaminated grain fractions
F5	45	A6	Light salting of meat
F6	46	A6	Light salting of fish
F7	47	P6	Parboiling mushrooms
F8	48	P6	Soaking dried mushrooms in water

Method V1 (P2/A2)	**Early removal of vegetation**
Description	Removal of growing crops from contaminated fields reduces ground contamination; on grass land also contamination of stubble and grass sward.
Target surface / product	Fields with rather dense vegetation, where the radionuclides are mainly retained in growing crops (dry deposited).
Time of application (number of days after deposition, season, etc.)	Removal of crops as soon as possible after fallout. Removal before the 1st rain shower after fallout is the optimal situation. Transfer of radionuclides from vegetation to soil has a half-life of about 15 days. Rainfall increases this transfer.
Expected effect: DF, DRF - internal DRF depends on diet	Reduction of external dose on contaminated fields and reduction of uptake of radionuclides in subsequently grown crops may be substantial (reduction by a factor up to 20).
Personnel requirements and costs (method time consumption)	Typically: 1 operator, ca. 0.2-0.3 man-days ha^{-1} for crop removal. Additionally: Loading, transport and waste disposal.
Equipment and other remedies - costs	Normally harvest equipment is available on the farms. For arable crops: anything from forage and swath harvesters (ca.10 000-20 000 EURO) to combines (ca. 200 000 EURO). For grass crops: tractors (ca. 50 000 EURO) with mowers (ca. 4 000 EURO). Petrol of the order ca. 10 l ha^{-1}.
Practicability	Achievable on a large scale. The limit is the number of workers and equipment locally available over a short period of time. The possibility to remove fallout from fields is usually best on grassland.
Waste	Removed crop material may, depending on contamination level, be used (after storage and/or preparation) or disposed of in repository. Costs of transportation of waste within 20 km : ca. 20 EURO m^{-3}.
Benefits	Reduction of external dose on treated fields may be substantial. Lower root uptake of nuclides due to less contamination of soils in following years.
Constraints	Sites for waste disposal and safe storage.
Remarks	Respiratory protection of workers may in some cases be radiologically necessitated.
References	CEC report EUR 12554 EN, ISBN 92-826-3272-5, 1991. NKS(97)18, BER6, ISBN 87-7893-017-0, 1997.

Method V2 (P2/A2)	**Early removal of snow**
Description	If a field is covered by a thick layer of snow at the time of contamination, a removal of the snow before the first thaw will have the great advantage that the contamination will never reach the soil.
Target surface / product	Open areas that are covered by a thick layer of snow.
Time of application (number of days after deposition, season, etc.)	Before first thaw following the deposition of the contaminants.
Expected effect: DF, DRF - internal DRF depends on diet	Reduction of both external dose and ingestion dose contributions from all radionuclides may be great (by a factor of more than 20) if the operation is carefully and consistently carried out over a large area.
Personnel requirements and costs (method time consumption)	Typically entrepreneurs or municipal workers can remove the snow at a speed of 10^{-4}-10^{-3} man-days m^{-2}, using 'bobcats' or tractors mounted with shovel. Can also, much more slowly, be carried out manually by locals with shovels.
Equipment and other remedies - costs	Bulldozer (ca. 90000 EURO), 'bobcat' (ca. 40000 EURO) or tractor (ca. 50000 EURO) plus waste transport truck and petrol (ca. 0.04 l m^{-2} excluding waste transport).
Practicability	Achievable in large scale - the equipment is often readily available in the area.
Waste	Amount depends on thickness of removed snow layer. Costs for transport to the sea, where dumping may occur without raising contamination levels significantly (e.g., not in lakes used for drinking water), would be estimated to 2-5 EURO m^{-3}, depending on the transportation distance.
Benefits	Effective avoidance of soil contamination.
Constraints	Must be carried out before first thaw. Snowdrift may reduce effect.
Remarks	Can be carried out in all open areas covered by thick snow.
References	Qvenild, C. & Tveten, U.: 'Decontamination and winter conditions', Inst. for Energy Technology, Kjeller, Norway, ISBN 82-7017-067-4, 1984. Report NKS/EKO-5(96)18, ISBN 87-550-2250-2, 1996.

Method V3 (P3/A3)	Storage of crops/grass
Description	Harvest and storage of crop products to allow short lived radionuclides to decay, especially ^{131}I. Animal farms.
Target surface / product	^{131}I contaminated fields grown with cereals and with grass for silage/hay production.
Time of application (number of days after deposition, season, etc.)	Normal times for harvest of cereals and grass crops (1st or 2nd yield).
Expected effect: DF, DRF - internal DRF depends on diet	*Impact on ^{131}I:* The main factors determining efficiency will be the interval between deposition and harvest. Two months after the fallout ^{131}I has decayed to 1 %. Stored grass silage/hay may then be used for feeding dairy and beef cattle, grain also for feeding pigs.
Personnel requirements and costs (method time consumption)	The same number of personnel and cost is required as for normal harvesting of the crops.
Equipment and other remedies - costs	Normally the storage equipment is available on the farms. Cost of 1 kg hay/grain is 0.15 EURO.
Practicability	Achievable on a large scale during a fallout year.
Waste	None
Benefits	By storing contaminated crops they can be used as fodder instead of being disposed of.
Constraints	Uncontaminated fodder must be available for two months after fallout, or until the stored grain and/or grass products can be used as fodder.
Remarks	Respiratory protection of workers may in some cases be necessary for radiological reasons
References	IAEA, Technical report series No363, ISBN 92-0-100-894-5, 1994. CEC report EUR 16530 EN, ISBN 92-827-5195-3, 1996.

Method V4 (P4/A4)	**Liming of soil**
Description	Strontium behaves in soil like the macro nutrient Ca. Liming increases pH and reduces root uptake of ^{90}Sr. Effect of liming depends on actual pH or base saturation and on CEC of the soil. Liming releases K^+ to the soil solution and slightly reduces root uptake of ^{137}Cs.
Target surface / product	^{90}Sr contaminated fields from which vegetation enters the food chain by uptake.
Time of application (number of days after deposition, season, etc.)	Liming can be made at any time when it is possible to mix the lime material with soil by harrowing or ploughing.
Expected effect: DF, DRF - internal DRF depends on diet	*Impact on ^{90}Sr:* Liming from pH 5 to pH 7 may decrease plant uptake of ^{90}Sr by a factor 2 on sandy soils, 3 on loamy soils and 4 on clay soils, from pH 4 to pH 6 by a factor 6 on organic soils. Liming in excess of pH 7/6 has no effect. *Impact on ^{137}Cs.* Liming may also decrease uptake of ^{137}Cs by a factor 1.3-1.6 (max. ca. 3). Corrective liming lasts for at least 5 years. Maintenance liming every 5 years, to pH 7 on mineral soils and to pH 6 on organic soils, is recommended (0.5-2 tonnes CaO ha^{-1}).
Personnel requirements and costs (method time consumption)	1 operator ca. 0.2 man-days ha^{-1} plus loading and transport of lime.
Equipment and other remedies - costs	Tractor with spreading device (ca. 60000 EURO), petrol (10 l ha^{-1}), lime (1-8 tonnes CaO per ha).
Practicability	Achievable on a large scale and effective on acid soils.
Waste	None.
Benefits	Crop yield may be increased by solving acidity problems. Liming prevents some diseases that attack crops.
Constraints	Liming may induce manganese deficiency (oats).
Remarks	K- and Mg-fertilisation may be required to maintain optimal ionic equilibrium in soil and plant.
References	Rapport FOA 4 C-4395-28, Stockholm, 1969. Report 31, Radiobiology, Uppsala, ISBN 91-, 1975. Technical report series No363, ISBN 92-0-100-894-5, 1994.

Method V5 (P4/A4)	**Potassium fertilisation**
Description	Caesium behaves in the soil solution like the macro nutrient K. Binding of ^{137}Cs in soil is very complex. Fixation of carrier free fallout ^{137}Cs increases with content of clay and decreases with content of organic matter. K-fertilisation decreases plant uptake of ^{137}Cs.
Target surface / product	^{137}Cs contaminated fields from which vegetation enters the food chain by uptake.
Time of application (number of days after deposition, season, etc.)	K-fertilisation is mandatory and should be made as soon as possible after fallout both on grass land and arable soils; on arable soils together with soil management operations.
Expected effect: DF, DRF - internal DRF depends on diet	*Impact on ^{137}Cs and ^{134}Cs:* Effect of K-fertilisation on ^{137}Cs uptake by crops is highly dependent on the actual K-status in soil (most efficient on nutrient deficient peatlands). 'Typical' DRF: 1-3.
Personnel requirements and costs (method time consumption)	1 operator ca. 0.4 hour ha^{-1} including transport and loading.
Equipment and other remedies - costs	Tractor with spreading device (ca. 35000 EURO); Petrol (5 l ha^{-1}); Potassium fertiliser (100- 200 kg K ha^{-1})
Practicability	Achievable on a large scale.
Waste	None
Benefits	Crop yield increases on soils with originally low potassium status.
Constraints	K-fertilisation during growth season can usually only be made after removal of existing crop stand.
Remarks	Mg-fertilisation and liming may be required to maintain optimal ionic equilibrium in soil and plant. Fertiliser must not contain ammonium. Excess of potassium in feed for dairy cows should be avoided.
References	Rapport FOA 4 C-4557-A3, Stockholm, 1973. Technical report series No363, ISBN 92-0-100-894-5, 1994. SLU-REK-78, ISBN91-576-5134-5, 1996.

Method V6 (P4/A4)	**Ploughing**
Description	Ploughing with an ordinary tractor-driven mouldboard plough to a depth of about 25 cm reduces contamination for uptake from upper soil layers and reduces external exposure in the area.
Target surface / product	Large open areas of soil that have not been tilled since contamination
Time of application (number of days after deposition, season, etc.)	Unlimited period (as long as soil is not frozen). Soil should not be too dry
Expected effect: DF, DRF - internal DRF depends on diet	Internal DRF: All contamination in upper 10 cm can be reduced by typically a factor of ca. 5-10. Consumption dose reduction depends on e.g. root system of crop. *Specific for Cs*: External DRF : 3-6. Negligible effect on iodine contamination
Personnel requirements and costs (method time consumption)	One operator per plough : 0.15 man-days ha^{-1}.
Equipment and other remedies - costs	Tractor (ca. 50000 EURO), plough (ca. 2000 EURO), petrol (ca. 7 l ha^{-1})
Practicability	Achievable in large scale - ploughs are often readily available, if ploughing is possible in the area.
Waste	None
Benefits	Rapid way to reduce particularly external dose in large areas of soil.
Constraints	Subsequent ploughing may bring part of the contamination back to the surface. The method severely complicates contaminant *removal.* Soil should not be full of rocks. Application of fertilisers may be called for (not containing ammonium).
Remarks	Respiratory protection of operator should be considered under very dry conditions.
References	CEC report EUR 16530 EN, ISBN 92-827-5195-3, 1996. Risø report R-828(EN), ISBN 87-550-2080-1, 1995.

Method V7 (P4/A4)	**Deep ploughing**
Description	Ploughing with an ordinary tractor-driven single furrow mouldboard plough (ca. 24") to a depth of about 45 cm. The ploughing brings the contamination out of the zone of some plants' uptake and reduces external exposure in the area.
Target surface / product	Large open areas of soil that have not been tilled since contamination
Time of application (number of days after deposition, season, etc.)	Unlimited period (as long as soil is not frozen). Soil should not be too dry
Expected effect: DF, DRF - internal DRF depends on diet	Internal DRF: all contamination in upper 20 cm can be reduced by a factor of 10-20. Consumption dose reduction depends on e.g. root system of crop. *Specific for Cs*: External DRF : 6-10. Negligible effect on iodine contamination
Personnel requirements and costs (method time consumption)	One operator per plough : 0.2 man-days ha^{-1}.
Equipment and other remedies - costs	Tractor (ca. 50000 EURO), plough (ca. 2000 EURO), petrol (ca. 15 l ha^{-1})
Practicability	Achievable in large scale where ploughing is possible. Ploughs are in some Nordic areas readily available or can be delivered over a period of time.
Waste	None
Benefits	Rapid way to reduce both internal and external dose from large areas of soil. Subsequent ordinary ploughing (to ca. 25 cm) will normally not bring much contamination back to the surface.
Constraints	Subsequent deep ploughing may bring part of the contamination back to the surface. The method severely complicates contaminant *removal.* Soil should not be full of rocks. The method may greatly affect soil fertility and should be accompanied by use of fertilisers (not containing ammonium).
Remarks	Respiratory protection of operator should be considered under very dry conditions.
References	CEC report EUR 16530 EN, ISBN 92-827-5195-3, 1996. Risø report R-828(EN), ISBN 87-550-2080-1, 1995.

Method V8 (P4/A4)	**Ploughing and K-fertilisation**
Description	Ploughing with an ordinary tractor-driven mouldboard plough to a depth of about 25 cm reduces contamination for uptake from upper soil layers. K-fertiliser should be applied both before ploughing and before sowing.
Target surface / product	Large open areas of soil that have not been tilled since contamination
Time of application (number of days after deposition, season, etc.)	Unlimited period (as long as soil is not frozen). Soil should not be too dry
Expected effect: DF, DRF - internal DRF depends on diet	*Specific for* ^{137}Cs and ^{134}Cs reduction depends on e.g. root system of crop. The combined of effect ploughing and K-fertilisation is good.
Personnel requirements and costs (method time consumption)	One operator per plough: 0,15 mandays ha^{-1}. One operator of K- fertiliser ca. 0.4 hour ha^{-1} including transport and loading.
Equipment and other remedies - costs	Tractor (ca. 50000 EURO), plough (ca. 2000 EURO), petrol (ca. 7 l ha^{-1}). Tractor with spreading device (ca. 35000 EURO); Petrol (5 l ha^{-1}); Potassium fertiliser (2x100 kg K ha^{-1})
Practicability	Achievable in large scale if ploughing is possible in the area.
Waste	None
Benefits	The combined effect of ploughing and K-fertilisation reduce root uptake by a factor of about 10. Rapid way to reduce particularly external dose in large areas of soil.
Constraints	The method severely complicates contaminant removal.
Remarks	Respiratory protection of operator should be considered under very dry conditions.
References	Lönsjö, H., Haak, E. & Rosén, K. IAEA-SM-306/32, 151-162. (1990). CEC report EUR 16530 EN, ISBN 92-827-5195-3, 1996. Risø report R-828(EN) ISBN 87-550-2080-1, 1995. Rosén, K. *Sci. Total Environ.*, Vol. 182, 135-145. 1996.

Method V9 (P4/A4)	Repeated ploughing
Description	Repeated ordinary ploughing increases the contact between caesium and soil and decreases root uptake of ^{137}Cs effectively.
Target surface / product	Large open areas of soil that have not been tilled since contamination.
Time of application (number of days after deposition, season, etc.)	Unlimited period (as long as soil is not frozen). Soil should not be too dry.
Expected effect: DF, DRF - internal DRF depends on diet	*Specific for* ^{137}Cs and ^{134}Cs reduction. Internal DRF depends on number of ploughings.
Personnel requirements and costs (method time consumption)	One operator per plough. 0.15 mandays per ha and ploughing.
Equipment and other remedies - costs	Tractor (ca. 50000 EURO), plough (ca. 2000 EURO), petrol (ca. 7 l ha^{-1}).
Practicability	Achievable in large scale - mouldboard ploughs are readily available.
Waste	None
Benefits	Rapid way to reduce crop uptake of ^{137}Cs, in the first year(s) after fallout. The repea-ted ploughing may decrease the uptake by a factor of 10. The effect is especially good on grassland.
Constraints	The method severely complicates conta-minant removal..
Remarks	Respiratory protection of operator should be considered under very dry conditions.
References	Meisel, S., Gerzabek, M. & Muller, H. *Pflanzenerähr. Bodenk.,* 154, 211-215. 1991. Risø report R-828(EN), ISBN 87-550-2080-1, 1995. CEC report EUR 16530 EN, ISBN 92-827-5195-3, 1996. Rosén, K., Eriksson, Å. & Haak, E. *Sci. Total Environ.*, Vol. 182, 117-135. 1996.

Method V10 (P4/A4)	**Skim-and-burial ploughing**
Description	Reduction of plant contaminant uptake and external exposure with minimised fertility loss. 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 50 cm deep trench and places the lifted subsoil, which is not inverted, 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.
Target surface / product	Large open areas of soil that have not been tilled since contamination
Time of application (number of days after deposition, season, etc.)	Unlimited period (as long as soil is not frozen). Soil should not be too dry
Expected effect: DF, DRF - internal DRF depends on diet	Internal DRF: all contamination in upper 20 cm can be reduced by a factor of 10-20. Consumption dose reduction depends on e.g. root system of crop. *Specific for Cs*: External DRF : 6-15. Negligible effect on iodine contamination
Personnel requirements and costs (method time consumption)	One operator per plough : 0.4 man-days ha^{-1}.
Equipment and other remedies - costs	Tractor (ca. 50000 EURO), plough (ca. 4000 EURO), petrol (ca. 15 l ha^{-1})
Practicability	Achievable in large scale - ploughs can be delivered over a period
Waste	None
Benefits	This type of ploughing minimises fertility loss. Contaminants will not redistribute by subsequent ordinary ploughing (ca. 20-30 cm deep).
Constraints	The method severely complicates contaminant *removal.* Soil should not be very loose (sandy) nor full of rocks. Application of fertilisers may be called for (not containing ammonium).
Remarks	Respiratory protection of operator should be considered under very dry conditions.
References	Roed, J. et al: J. Environmental Radioactivity vol.33, no.2 pp. 117-128, 1996. Risø report R-828(EN), ISBN 87-550-2080-1, 1995.

Method V11 (P4/A4)	**Phosphorus fertilisation**
Description	P-fertilisation may decrease root uptake of strontium to some extent.
Target surface / product	^{90}Sr contaminated fields from which vegetation enters the food chain by uptake.
Time of application (number of days after deposition, season, etc.)	P-fertilisation, if needed, can be made at the same time as K-fertilisation.
Expected effect: DF, DRF - internal DRF depends on diet	*Impact on ^{90}Sr:* Application of soluble phosphate might reduce the availability of ^{90}Sr for plant uptake. P-fertilisation increases root depth on P-deficient soils.
Personnel requirements and costs (method time consumption)	1 operator ca. 0.4 hour ha^{-1} including transport and loading.
Equipment and other remedies - costs	Tractor with spreading device (ca. 35000 EURO); Petrol (5 l ha^{-1}); P-fertilizer (30-50 kg P ha^{-1})
Practicability	Achievable on a large scale and effective on P-deficient soils.
Waste	None.
Benefits	Crop yield increases on P deficient soils and may decrease uptake of ^{90}Sr by 50 %.
Constraints	P-fertilisation during growth season can usually only be made after removal of existing crop stand.
Remarks	
References	Rapport FOA 4A 4188-4623, Stockholm, 1961. Technical report series No363, ISBN 92-0-100-894-5, 1994. CEC report EUR 16530 EN, ISBN 92-827-5195-3, 1996.

Method V12 (P4/A4)	**Turf harvesting**
Description	Application of turf harvester to skim off in rolls or slabs a thin contaminated top layer from a meadow.
Target surface / product	Contaminated smooth open areas of soil with a mature grass mat. The areas must not have been tilled since contamination and must be free of rocks.
Time of application (number of days after deposition, season, etc.)	Applicable when soil is not frozen.
Expected effect: DF, DRF - internal DRF depends on diet	If carried out relatively early nearly all contamination will be removed with the upper 3-5 cm layer that is skimmed off. DRF depends on vertical contaminant distribution (typically DRF of 2-10 in relation to external exposure in the field and consumption dose from crops grown in the field).
Personnel requirements and costs (method time consumption)	Can be carried out by 2-3 operators at a speed of 0.14 man-days ha^{-1}.
Equipment and other remedies - costs	Turf harvester (ca. 8000 EURO), petrol (ca. 15 l ha^{-1}). Some turf harvesters require use of tractor (ca. 50000 EURO).
Practicability	Achievable in selected meadows. Turf harvesters are available in grass nurseries
Waste	Ca. 20-30 kg m^{-2} (solid), which must be transported away at a cost of ca. 1500 EURO per ha (if repository is less than 20 km away).
Benefits	Efficient reduction of both internal and external dose from areas of soil.
Constraints	Area must be smooth mature meadow without rocks. Machinery may well not be readily available.
Remarks	The method usually does not affect soil fertility.
References	CEC report EUR 16530 EN, ISBN 92-827-5195-3, 1996. Risø report R-828 (EN), ISBN 87-550-2080-1, 1995.

Method V13 (P7)	**Cultivating crops with low radionuclide uptake**
Description	Change from grass crops to cereal crops, and use of the cereal grain produced as fodder on the same farm.
Target surface / product	Long term measure on animal farms with some part of the acreage as organic and sandy soils.
Time of application (number of days after deposition, season, etc.)	During the fallout year the organic and sandy acreage of soils grown with grass crops, are limed, PK-fertilised and ploughed. Fodder cereals are cultivated in the following years.
Expected effect: DF, DRF - internal DRF depends on diet	The transfer of ^{137}Cs and ^{90}Sr to cereal grain will be one order of magnitude less than to grass, and even more compared to unploughed pastures.
Personnel requirements and costs (method time consumption)	Cost for extra ploughing, 50 EURO ha^{-1} (0.5 ha h^{-1}), and cost for liming and PK-fertilisation, to increase the nutrient status of the actual organic and sandy soils.
Equipment and other remedies - costs	During the fallout year some uncontaminated fodder must be available to keep the same livestock as before.
Practicability	Achievable in limited scale for use on animal farms with some acreage of organic and sandy soils of low nutrient status. If necessary the cereal grain produced on these critical soils can be reserved for feeding young dairy and beef cattle.
Waste	During the fallout year removal of growing grass on organic and sandy soils.
Benefits	It may be possible to keep the same live stock as before and feed them with the cereal grain from the organic and sandy soils.
Constraints	The fraction of organic and sandy soils of the total acreage on the farm.
Remarks	Change to other varieties of barley and ryegrass might decrease the uptake of ^{137}Cs.
References	Nordic Radioecology ed. H. Dahlgaard, ISBN- 0-444-81617-8, 1994. CEC report EUR 16530 EN, ISBN 92-827-5195-3, 1996.

Method V14 (P7)	Cultivating crops that can be processed
Description	Increased cultivation of crops, which, after processing, give nearly uncontaminated food items.
Target surface / product	Loamy and clay soils for sugar-beets and oil crops and sandy soils for industrial potatoes.
Time of application (number of days after deposition, season, etc.)	During a fallout year as well as later in a long-term situation.
Expected effect: DF, DRF - internal DRF depends on diet	*Impact on ^{137}Cs and ^{90}Sr*: Transfer of ^{137}Cs and ^{90}Sr to processed sugar, oil and technical alcohol products will be negligible.
Personnel requirements and costs (method time consumption)	There may be some extra cost for growing extra acreage with these crops.
Equipment and other remedies - costs	There may be extra cost for handling contaminated sugar-beets and oil seed at the factories.
Practicability	Achievable on a limited scale. Certain regions.
Waste	Removal of sugar-beet tops during the fallout year and deposition on special place.
Benefits	Fabricated sugar and oil products can be used for human consumption.
Constraints	Restricted to farms, on which sugar-beets and oil crops can be grown in rotation with fodder cereals. Monitoring of by products is needed (if utilised).
Remarks	Contamination with ^{137}Cs and ^{90}Sr of the by-products at processing sugar-beets and oil crops will be higher than those of cereal grain. Use of the by-products as fodder may therefore be restricted or combined with higher costs than normal.
References	Technical report series No363, ISBN 92-0-100-894-5, 1994. CEC report EUR 16530 EN, ISBN 92-827-5195-3, 1996.

Method V15 (P7)	**Change of production from crops to animals**
Description	A change from crop to animal production can greatly reduce the total amount of radioactivity in the produced food. Particularly if the biological half-life in the animals of the contaminants is short enough to enable a reduction of the meat contamination to an acceptable level by feeding with less contaminated fodder over a period prior to slaughter.
Target surface / product	Severely contaminated fields
Time of application (number of days after deposition, season, etc.)	Unlimited
Expected effect: DF, DRF - internal DRF depends on diet	The total contamination in the alternative product (meat) will be much less than that in the original product (crops), possibly by a factor of 10-100. The success increases if animals are fed with clean fodder for a period prior to slaughter. Whereas strontium will in animals concentrate in bones, caesium will concentrate in the soft tissue (meat). Generally, biological half-lives of caesium from beef, pork or lamb's meat are of the order of 2-3 weeks. Due to the short radiological half-life of ^{131}I (ca. 8 days) its effective half-life in animals will be short.
Personnel requirements and costs (method time consumption)	The production change requires availability (or education) of personnel with skills in relation to the new production.
Equipment and other remedies - costs	A requirement is the availability of meat animals and possibly e.g. stables.
Practicability	Achievable in large scale.
Waste	None.
Benefits	The method reduces the radiological impact from use of a contaminated field.
Constraints	Social and economic consequences may be significant. There must be a market for animal products. Product contamination levels must be monitored.
Remarks	The product must be meat, not milk.
References	Alexakhin, R.M. et al.: The Science of the total environment, 137, pp. 169-172 (1993).

Method V16 (P8)	Use plants as fertiliser
Description	Contaminated plants, which are not fit for consumption, may be applied as fertiliser without significantly raising soil contamination levels. The vegetation may either be ploughed directly down in the field, or harvested and silaged or burnt in a power plant before being applied in a field.
Target surface / product	Vegetation from contaminated areas
Time of application (number of days after deposition, season, etc.)	In principle unlimited. If contamination took place to a field with dense vegetation in absence of precipitation, the option should not be considered in the early phase (prior to first heavy rain-shower on the plants).
Expected effect: DF, DRF - internal DRF depends on diet	The method is mainly a means for disposal of contaminated vegetation. DRF dependent on the need for fertilising and amount of fertiliser crops spread over an area.
Personnel requirements and costs (method time consumption)	Depends on application method. By ploughing it down it can be considered an inherent part of agricultural routine practice. For other possibilities, see methods for crop removal/ fertilisation.
Equipment and other remedies - costs	Dependent on method. See methods for ploughing/ crop removal/ fertilisation.
Practicability	Achievable in large scale.
Waste	None.
Benefits	Mainly disposal of contaminated vegetation. Fertilisation of fields.
Constraints	Spreading of ash fertiliser in fields may negatively affect health of grazing animals and greatly reduce milk fat from grazing cows.
Remarks	If spread over an area corresponding to that harvested from, the increase in contamination level will usually be insignificant. Alternatively, e.g., grains/potatoes could be used as seeds.
References	H. Junker et al: "Chernobyl Bioenergy Project, Final Report, Phase 1", ELSAMPROJEKT report no. EP 8204, 1998. Dewes, H.F. et al: New Zealand Veterinary Journal 43:3, pp. 104-109, 1995.

Method V17 (P8)	Growth of industrial crops (incl. fibres for clothing)
Description	If an area of soil has become so heavily contaminated that it is deemed inapplicable for growing products for direct consumption, it may have a different application. For instance, rape or sunflower (for oil), cotton, flax or other industrial plants may be grown.
Target surface / product	Severely contaminated fields.
Time of application (number of days after deposition, season, etc.)	Unlimited
Expected effect: DF, DRF - internal DRF depends on diet	The method is strictly not a means of dose reduction, but rather a way to make use of heavily contaminated land without significantly increasing doses. The activity concentration in the product may be up to 100 times less than that in cereals from the same field, and the product may only give rise to external exposure.
Personnel requirements and costs (method time consumption)	The production change requires availability (or education) of personnel with skills in relation to the new production.
Equipment and other remedies - costs	A requirement is the availability of sowing/harvesting/refining equipment applied in the new production line.
Practicability	Achievable in large scale.
Waste	Depends on the product. E.g., refining may lead to waste generation, and the disposal of this waste must be considered in the evaluation of the method.
Benefits	The method represents an economically attractive alternative to abandoning large contaminated agricultural land areas. In communities with 'traditional' agricultural overproduction the method may be advantageous.
Constraints	External doses to personnel must not exceed limits. Social and economic consequences may still be significant. There must be a market for the new products. Food must locally be available from other areas.
Remarks	Product contamination levels should be monitored.
References	Alexakhin, R.M. et al.: The Science of the total environment, 137, pp. 169-172 (1993).

Method V18 (P8/A8)	**Change land use to forestry**
Description	If an area of soil has become so heavily contaminated that it is deemed inapplicable for growing products for consumption, forestry (for e.g. paper, furniture or energy production) may be one of few options for use of the area.
Target surface / product	Severely contaminated fields.
Time of application (number of days after deposition, season, etc.)	Unlimited
Expected effect: DF, DRF - internal DRF depends on diet	The method is strictly not a means of dose reduction, but rather a way to make use of heavily contaminated land without significantly increasing doses. The activity concentration in the wood is typically more than 100 times less than that in cereals from the same field.
Personnel requirements and costs (method time consumption)	The production change requires availability (or education) of personnel with skills in relation to the new production.
Equipment and other remedies - costs	A requirement is the availability of equipment applied in the new production line.
Practicability	Achievable in large scale.
Waste	Depends on the use of the forest. Energy forest wood is typically concentrated by a factor of 10-100 in wood ash waste.
Benefits	The method represents an economically attractive alternative to abandoning large contaminated agricultural land areas. Radioactive decay over the period before wood harvesting may be significant.
Constraints	External doses to personnel must not exceed limits. Social and economic consequences may still be significant. There must be a market for the new products (e.g., power plants).
Remarks	Product contamination levels should be monitored.
References	K.G. Andersson et al.: Rad. Prot. Dosimetry, vol. 83, pp.339-344 (1999). Final report of CEC project RECOVER (FI4-CT950021c): 'Relevancy of short rotation coppice vegetation for the remediation of contaminated areas', Mol, Belgium, 1999.

Method M1 (A3)	Supply animals with stable iodine
Description	As ^{131}I has a radiological half-life of only about 8 days, it is generally highly advantageous to store food products contaminated by ^{131}I. If cattle consume fodder contaminated by ^{131}I, much of this will be transferred to milk. However, the transfer of ^{131}I to milk may also be greatly reduced by supplying stable iodine to cattle fodder (isotopic dilution) at a daily rate of ca. 10 g of potassium- or sodium iodide per cow.
Target surface / product	Milk cattle fed with fodder contaminated with ^{131}I.
Time of application (number of days after deposition, season, etc.)	Must be initiated as early as possible to have a significant effect.
Expected effect: DF, DRF - internal DRF depends on diet	With the above administration rate, the effect is in most reported cases a reduction of the ^{131}I level in milk by a factor about 2-4.
Personnel requirements and costs (method time consumption)	The administration of stable iodine to cows would as such not be very time consuming. Transport of iodine to farms will require extra personnel dependent on the state of local availability and distribution network of iodine.
Equipment and other remedies - costs	Availability of stable iodine (chemical costs less than ½ EURO/day per cow).
Practicability	Achievable where stable iodine is available at short notice.
Waste	None.
Benefits	Reduction of radioiodine concentration in milk. Stable iodine transferred to milk will further reduce ^{131}I uptake to humans.
Constraints	The method only has effect on radioiodine. Administration of large amounts of stable iodine, particularly prior to the accident, may in some cases block the thyroid iodine uptake of cattle and thereby increase ^{131}I excretion, also to milk. Milk ^{131}I must be monitored. The method needs to be investigated further before a general recommendation of its implementation can be given.
Remarks	Distribution network and large amounts of stable iodine must be available. Stable iodine consumption by humans can further reduce the problem.
References	Voigt, G.: The Science of the Total Environment 137, pp. 205-225, 1993.

Method M2 (A3/A5I)	Change slaughter time
Description	Immediate slaughter before and/or close to time of deposition. Limiting the intake of Cs by: -slaughter reindeer/roedeer in September before turning them onto the more contaminated lichen which is the normal winter feed. -collect sheep earlier than usual from natural mountain and woodland pastures in years with abundant growth of mushrooms.
Target surface / product	Reindeer/roedeer and sheep meat from Cs contaminated areas
Time of application (number of days after deposition, season, etc.)	Medium and long term after deposition. Up to 10-20 year after contamination
Expected effect:	Impact on Cs: Can give a reduction of up to 50% in the meat.
Personnel requirements and costs (method time consumption)	Persons to collect herd. Depending on how large the herd is and the area from which to collect the animals.
Equipment and other remedies - costs	For collecting and slaughter of reindeer/roedeer: Equipment for slaughter at field (if needed 93750 Euro estimated for 300 animals) or Trucks for transport to slaughter place / helicopter and/or motorbikes (8500 Euro). Deep freezing facilities and storage rooms may be needed additionally.
Practicability	For reindeer: Achievable if mobile slaughtery or transport can be arranged at that time of year
Waste	None
Benefits	Reduced Cs in meat
Constraints	Reduced income due to lower slaughter weight on calves.
Remarks	When a place for slaughter in the field is at place, this can be used the next year and coming years and thereby give reduced costs later.
References	Brynildsen, L.I., et al., (1996) Health Physics 70(5): 665-672. IAEA-Technical Reports Series No. 363 (1994) IAEA.

Method M3 (A4)	**Reduce animal intake of contaminated soil**
Description	Intake of contaminated soil to grazing animals may be highly significant (0.1-1 kg per day). If, on the other hand, animals are fed with harvested forage, cutting the forage plants at greater height would significantly decrease the amount of attached contaminated soil.
Target surface / product	Animal farms on contaminated soil.
Time of application (number of days after deposition, season, etc.)	Not very useful before first heavy rain. Efficiency decreases over the first years.
Expected effect: DF, DRF - internal DRF depends on diet	The effect depends on soil type and vertical contaminant distribution (time, tilling), as well as on fodder crop species. A reduction in fodder ^{137}Cs content by a factor of 3 has been achieved few weeks after contamination by increasing cutting height of grass from 5 to 15 cm; for ^{131}I the factor was here found to be 10. In the long run the corresponding factor for ^{137}Cs would mostly be less than 2.
Personnel requirements and costs (method time consumption)	No extra requirements.
Equipment and other remedies - costs	Usually no extra requirements.
Practicability	Achievable in large scale.
Waste	None.
Benefits	Easy means for reduction of contaminant concentration in meat and dairy products.
Constraints	Shortly after a dry contaminant deposition, the method will often have no effect, since deposition to the rough plant surface is significantly greater than that to the underlying soil.
Remarks	Greatly varying reductive effect expectable. Depending on soil type (clay content) and time, soil-bound caesium may be less available for uptake in animals than is caesium from plants. Monitoring is needed to assure the effect.
References	Bertilsson, J. et al.: Health Physics 55, pp. 855-862, 1988. Burmann; F.J.: J. Dairy Sci. 50, pp. 1891-1896, 1967. Rafferty, B. et al.: Sci. of the Total Environment 153, pp. 69-76, 1994. Herlin, A.H. and Andersson, I.: Soil ingestion in farm animals, Sveriges Lantbruksuniversitet, report 105, ISBN SLU-JBI-R--105--SE, 1996.

Method M4 (A5I)	**Clean fodder to animals before slaughter**
Description	Give feed containing as little as possible of radiocesium to sheep, goats, cattle and reindeer for a pre-determined period (based on monitoring of a representative number of animals) before slaughter.
Target surface / product	Meat from animals grazing in contaminated areas.
Time of application (number of days after deposition, season, etc.)	Medium and long term after deposition. Unlimited period.
Expected effect:	Biological half-life, depending on animal species, is estimated to be from 9 to 18 days.
Personnel requirements and costs (method time consumption)	Personnel to collect the herd and to feed and monitor the animals in the time needed before slaughter. (8 hours for 30 days – 2500 to 6500 Euro)
Equipment and other remedies - costs	Indoor or enclosed areas where the animals can be given clean fodder and where monitoring can be done (875 Euro per year). Clean fodder for the needed feeding time (depending on activity levels in animals) (buying of fodder concentrates 0.6 – 0.8 Euro per kilo).
Practicability	Achievable if persons needed and areas for keeping animals exist.
Waste	Faeces and urine if highly contaminated.
Benefits	Reduced radionuclide activity in meat.
Constraints	Feed area used which are intended for use at other times of the year.
Remarks	The feeding period will usually last for 2 to 19 weeks, giving best results in the beginning of the feeding time.
References	Brynildsen, L.I., et al., (1996) Health Physics 70(5): 665-672 IAEA-Technical Reports Series No. 363 (1994) IAEA.

Method M5 (A5II)	**Prussian Blue salt licks/boli/addition**
Description	Place Prussian Blue salt licks in contaminated areas grazed by sheep, goats, reindeer, roedeer or cattle. Give sheep, goats, reindeer or cattle in contaminated areas Prussian Blue boli, or alternatively Prussian Blue administered in fodder. Prussian Blue binds Cs ions and reduces uptake to meat and activity in milk.
Target surface / product	Meat and milk.
Time of application (number of days after deposition, season, etc.)	Medium and long term after deposition. Unlimited period
Expected effect:	Reduction of Cs in meat and milk: -Salt licks: from 50 to 75% reduction. -Fodder administr.: 90 % red. in 1 week. -Boli (3 boli to each animal each 3 months): from 50 to 70% reduction. Reduction of Sr and I: None.
Personnel requirements and costs (method time consumption)	Salt licks/ fodder addition PB can be distributed in the contaminated area by the farmer. Time depending on the area. Lamb can be treated with boli by the farmer. Reindeer need assistance from veterinary. Time consumption is set to approximately 50 hours for farmers (300 animals) and 30 hours of 60 Euro for veterinary.
Equipment and other remedies - costs	Salt lick stones: 25 Euro per stone; Boli: 6 Euro for 3 boli; Fodder addition: Prussian Blue 1 Euro kg^{-1} (3 grammes per cow per day).
Practicability	It is easy to put up salt licks in the area if the area is limited. Boli have to be given to the animals before they go to the grazing areas.
Waste	None
Benefits	Reduction of Cs in meat and milk
Constraints	In a grazing flock there will always be some sheep, which will not lick the salt.
Remarks	The efficiency of the salt lick depends upon frequent visits to the licks. Animals must be treated with minimum two bolis to have the needed effect.
References	Brynildsen, L.I., et al., (1996) Health Physics 70(5): 665-672. IAEA-Technical Reports Series No. 363 (1994) IAEA. Hove, K., (1993) The Science of the Total Environment, 137, 235-248. Hansen, H.S., et al., (1996) Health Physics, 71(5): 705-712.

Method M6 (A5II)	**Supplement fodder with micas or zeolites**
Description	Give micas and/or zeolites as a supplement to fodder to reduce uptake of Cs in the animal by reducing absorption.
Target surface / product	Meat and milk
Time of application (number of days after deposition, season, etc.)	Medium and long term after deposition. Unlimited period
Expected effect:	A reduction of 50 – 80% in the transfer of radiocesium to milk and meat of cows, sheep and reindeer can be achieved at daily doses of about 500 mg – 2 g.
Personnel requirements and costs (method time consumption)	Personnel to collect the herd and to feed and monitor the animals. (8 hours for 30 days – 2500 to 6500 Euro).
Equipment and other remedies - costs	micas and/or zeolites
Practicability	Clay minerals cannot be fed directly in semi-natural ecosystems and are not sufficiently effective to be used in salt licks or boli.
Waste	None
Benefits	Reduce Cs in meat and milk
Constraints	Inappropriate for use as a countermeasure for freely grazing ruminants. Not easy to feed a longer time.
Remarks	Can be used during decontamination feeding.
References	Hove, K., (1993) The Science of the Total Environment, 137, 235-248, Andersson, I. (1989) Swedish J. Agr. Res. 19: pp. 85-92, Andersson, I. (1990) Swedish J. Agr. Res. 20: pp. 35-42.

Method M7 (A5II)	**Addition of calcium to fodder**
Description	Calcium is used as a dietary supplement to reduce the radiostrontium transfer to milk.
Target surface / product	Milk
Time of application (number of days after deposition, season, etc.)	Medium and long term after deposition. Unlimited period.
Expected effect:	Increasing the calcium content of the diet by 2-4 times reduces radiostrontium levels in milk by a factor of between 1.5 and 3 depending on the initial level of calcium nutrition. At least a reduction of 40 – 60% would be expected, where supplement has been 100-200 g per day.
Personnel requirements and costs (method time consumption)	Personnel to collect the herd and to feed and monitoring the animals. (8 hours for 30 days – 2500 to 6500 Euro).
Equipment and other remedies - costs	Calcium
Practicability	Calcium cannot be fed directly in semi-natural ecosystems.
Waste	None
Benefits	Sources of calcium supplements are numerous and inexpensive.
Constraints	If the Ca/P ratio of the fodder becomes too high it can affect animal health. Inappropriate for use as a countermeasure for freely grazing ruminants.
Remarks	Can be used during decontamination feeding.
References	IAEA-Technical Reports Series No. 363 (1994) IAEA. Howard, B.J., et al., (1997) Radiat. Environ. Biophys., 36, 39-43.

Method M8 (A6)	**Prussian Blue filters for milk decontamination**
Description	Filtering highly contaminated milk trough a Prussian Blue filter will bind the Cs and thereby reduce Cs content in the milk
Target surface / product	Milk
Time of application (number of days after deposition, season, etc.)	Medium and long term after deposition. Unlimited period
Expected effect:	A reduction of the radiocaesium content in milk by a factor of 5-10. No reductive effect on Sr and I.
Personnel requirements and costs (method time consumption)	Personnel to filter the milk before going to reprocessing. Ca. 0.02 man-days per filter. One filter can be used to clean 100 l of milk.
Equipment and other remedies - costs	Filters prepared with Prussian Blue. Estimated cost of one filter: ca. 5-10 EUROS. Filtering devices at dairies, or batch treatment facilities are needed.
Practicability	Achievable in large scale dependent on local availability of the filters.
Waste	Contaminated Prussian Blue filters
Benefits	Reduction of Cs in milk
Constraints	Large amounts of filters may not be readily available.
Remarks	The toxic impact on humans of use of Prussian Blue has been reported to be negligible.
References	Risø report R-828(EN), ISBN 87-550-2080-1, 1995.

Method M9 (A7)	**Replace sheep/goats with cattle**
Description	Replace small ruminants such as sheep/goats with cattle due to the fact that small ruminants accumulate higher radionuclide levels than cattle due to differences in metabolism for these animals.
Target surface / product	Meat and milk
Time of application (number of days after deposition, season, etc.)	Medium and long term after deposition.
Expected effect:	Variable. Depends on activity levels and animals. Can have up to fivefold reduction.
Personnel requirements and costs (method time consumption)	
Equipment and other remedies - costs	
Practicability	Achievable if infrastructure and knowledge of husbandry practices is at place.
Waste	None
Benefits	The pasture where sheep/goats were grazing can be used for cattle.
Constraints	The most efficient products, judged from the viewpoint of reducing radionuclide transfer, may not give the best economic returns.
Remarks	Small ruminants utilise low grade grassland better than cattle.
References	IAEA-Technical Reports Series No. 363 (1994) IAEA.

Method M10 (A7)	**Change from milk to meat production**
Description	In severely contaminated areas, a means for limiting the transfer of radioactivity to animal food products is to change the production line from milk to beef or e.g. pork.
Target surface / product	Animal farms in severely contaminated areas.
Time of application (number of days after deposition, season, etc.)	Unlimited
Expected effect: DF, DRF - internal DRF depends on diet	Analyses have shown that the method can reduce the *transfer* of radiocaesium from a field to animal food products by a factor of 5-10, thereby reducing *collective* dose. Further, as opposed to milk, which is produced continuously, meat is produced intermittently. This gives the possibility to avoid seasonal peak meat activity concentrations, and if it is possible to feed with clean fodder over a period prior to slaughter a considerable reduction in meat activity can be obtained (Cs biological half-life of ca. 2-3 weeks).
Personnel requirements and costs (method time consumption)	The production change has no special personnel requirements or costs.
Equipment and other remedies - costs	Clean fodder for use before slaughter would be advantageous.
Practicability	Achievable in large scale.
Waste	None.
Benefits	The method reduces the radiological impact from use of a contaminated field.
Constraints	Since meat cattle are generally slaughtered earlier than milk cattle, the meat production would be expected to increase, and there must be a market for this to be profitable. Product contamination levels must be monitored. Locally needed milk must be obtainable through other sources.
Remarks	External doses to personnel must not exceed limits.
References	Andersson, I. & Lönsjö, H.: Swedish J. Agric. Res. 18, pp. 195-206 (1988). Prister, B.S. et al.: The Science of the total environment, 137, pp. 183-198 (1993).

Method M11 (A8)	**Change animal production to non-consumption**
Description	In high contamination scenarios, where cleaner fodder is not available, it may not be possible to reduce animals' meat contamination sufficiently to allow consumption. However, use may still be made of e.g. sheep for non-food production (wool and leather). Also, e.g. riding horses may be kept.
Target surface / product	Animal farms in severely contaminated areas.
Time of application (number of days after deposition, season, etc.)	In principle unlimited, although particularly relevant in the first years after contamination.
Expected effect: DF, DRF - internal DRF depends on diet	The method is strictly not a means of dose reduction, but rather a way to continue animal farming in high contamination scenarios. The specific contamination in washed wool may be as little as one-fifth of that in meat from the same sheep, and will only give rise to external exposure. In sheep, the natural excretion half-life of caesium from wool is also shorter than that from meat.
Personnel requirements and costs (method time consumption)	The costs are mainly the loss of income from applying the consumable products. Although the production of e.g. wool may not be profitable without compensation, the social benefit from maintaining a local production may be considerable.
Equipment and other remedies - costs	The production of e.g. wool would as such be unchanged, and would not require new remedies.
Practicability	Achievable in large scale.
Waste	Animal bodies need to be disposed of.
Benefits	Continued local animal farming (local employment).
Constraints	External doses to personnel must not exceed limits. Social and economic consequences may still be significant. Market prices or compensation must be able to keep the production going.
Remarks	More profitable future animal production may be sought in e.g. mink farming, which would however require new skills and new equipment.
References	H.S. Hansen & K. Hove: J. Environ. Radioactivity 19, pp. 53-66 (1993).

Method F1 (P3/A3)	**Manufacturing of food products to be stored for several months**
Description	All methods of conserving fresh foodstuffs to be used several months later, as deep freezing, drying, making steam juice or marmalade of berries and fruit, making sauerkraut of cabbage, pickling of vegetables and mushrooms, fish and meat, manufacturing butter, etc.
Target surface / product	All types of fresh foodstuffs
Time of application (number of days after deposition, season, etc.)	Early phase of a fallout situation, during occurrence of short-lived radionuclides in several types of foodstuffs; mostly when fallout is received in plant growth period.
Expected effect: DF, DRF - internal DRF depends on diet	The effect is based on radioactive decay of short-lived radionuclides during storage time. ^{131}I decays in six weeks time to insignificant level. No significant reducing effect on long-lived ^{90}Sr and ^{137}Cs
Personnel requirements and costs	An issue of seasonal timing and personal capacity for private households, institutional kitchens and food industry. Saves time at households later when conserved products are used.
Equipment and other remedies - costs	Rationalisation of work means often additional utensiles and machines. Reasonable costs.
Practicability	Achievable in large scale
Waste	No new types of waste
Benefits	Eliminates intake of short-lived radionuclides from the foodstuffs conserved. DRF is very much dependent on actual case. Ensures usability of seasonal products. Reduces losses of milk and meat during contamination from short-lived nuclides.
Constraints	When also activities of long-lived radionuclides in foodstuffs are unacceptable, storage does not help.
Remarks	Some of the methods listed above may also have decontaminating effect, which is discussed in other sheets.
References	IAEA, Technical report series No363, ISBN 92-0-100-894-5, 1994

Method F2 (P5/P6)	**Mechanical decontamination of fresh vegetables & fruit, and cereal grains**
Description	Washing, brushing, peeling, removing outer leaves of cabbages or lettuce, additional cleaning of grains before milling.
Target surface / product	All types of fresh foodstuffs of vegetative origin.
Time of application (number of days after deposition, season, etc.)	Early phase (the first 1 or 2 weeks) of a fallout situation, during occurrence of external contamination of fallout radionuclides on crops. Only after a fallout received in growth period of plants.
Expected effect: DF, DRF - internal DRF depends on diet	The effect is based on removable surface contamination. The DRF varies by case, and the decontaminating effect gets weak rather soon due to rapid absorption and translocation of radionuclides in growing plants. In early phase the DRF for one type of food may reach some tens of percent, in late phase close to the fraction of mass loss due to the treatment.
Personnel requirements and costs	Some additional work.
Equipment and other remedies - costs	Adjustment of industrial processes. Household methods are usual. Costs due to mass losses of food products.
Practicability	Achievable in large scale.
Waste	Normal types of waste, but in increased quantities.
Benefits	Eliminates or reduces intake of the whole mixture of fallout radionuclides deposited on growing stands of vegetables and fruit just before harvest. DRF is very much dependent on actual case. Improves usability of seasonal products.
Constraints	No reducing effect on long-lived ^{90}Sr and ^{137}Cs transferred to plants via roots, except for products with higher uptake to peels or outer layers.
Remarks	Checking the efficiency of treatment by measurements before large scale campaigns to consumers or industry are reasonable.
References	IAEA, Technical report series No363, ISBN 92-0-100-894-5, 1994.

Method F3 (A6)	**Making cheese with rennet method and replacing milk in the diet with cheese**
Description	Manufacturing Emmenthal type cheese distributes radionuclides of milk into cheese and whey. Caesium is mainly transferred to whey, whereas Sr (like Ca) is found in cheese.
Target surface / product	Dairy milk
Time of application (number of days after deposition, season, etc.)	Unlimited period, as long as reduction of ingestion dose from ^{137}Cs in milk is needed
Expected effect: DF, DRF - internal DRF depends on diet	Internal DRF: Cheese contributes to dietary radiocaesium 6-10% of the activity received through milk needed for making the cheese. When used as main Ca source instead of milk, the DRF is the same. Specific for Cs. No significant dose reducing effect on radiostrontium.
Personnel requirements and costs (method time consumption)	Organising additional cheese-cooking in dairies specialised for this may add costs of dairy industry.
Equipment and other remedies - costs	Capacity of dairies manufacturing cheese is crucial.
Practicability	Achievable in large scale
Waste	Increased quantities of whey containing radiocaesium
Benefits	In situations when Cs dominates the food contamination milk can be used and stored in preserved form. Nutrient losses are small. The market price of cheese is comparable with the price of milk used for making same quantity of cheese.
Constraints	The use of whey as a constituent of human food should be excluded. The lactose used to sweeten e.g. biscuits, if originating from milk, should be separated from the caesium in whey. - Dietary advice and restrictions for groups with low milk fat diet for medical reasons.
Remarks	Cannot replace fresh milk in nutrition of babies and small children.
References	Pirhonen T, Uusi-Rauva E, Rantavaara A, Rauramaa A. The radioactivity of milk and milk products in Finland. Meijeritieteellinen aikakauskirja 1987; XLV: 62-75. McEnri C M, Mitchell P I, Cunningham J D. the transfer of radiocaesium from whole milk to milk products.

Method F4 (P6)	Change milling yield and use of least contaminated grain fractions
Description	The season of external contamination of cereal crops from deposited radionuclides has distinctive influence on the distribution of radionuclides in cereal grains after harvest. Different activity concentrations are found in flour, dark meal and bran. Only contamination occurring immediately before harvest is mostly found in bran. Control measurements of actual milling fractions will show the distribution of different long-lived radionuclides, and indicate what can be achieved by changing milling yield / reduced use of bran/dark meal for human foods.
Target surface / product	Wheat, oats and rye
Time of application (number of days after deposition, season, etc.)	First and sometimes second harvest after the distribution of fallout.
Expected effect: DF, DRF - internal DRF depends on diet	Internal DRF: Cereals can be heavily contaminated only when accidental fallout is received on growing crops. The DRF depends on changes of normal practices to be made. Some tens of percent of dietary radiocaesium (and a considerable part of radiostrontium) received from grains can be avoided by (modified milling and) adjusted use of milling fractions for human food.
Personnel requirements and costs (method time consumption)	The milling industry is well prepared for changes in milling yield, and also in changes of grain trade through eventual use of bran as feed. Additional transport costs will be caused. Additional personnel costs at mills are relatively low.
Equipment and other remedies - costs	Use of some milling fractions for feeds or composting will add transport and treatment costs.
Practicability	Achievable in large scale
Waste	Contaminated bran to be disposed.
Benefits	Doses received from cereals can be reduced by some tens of percent. The actual numbers vary by fallout situation.
Constraints	Before application the method should be tested, i.e. the distribution of activities in different milling fractions measured in the actual situation. Small differences in milling yields do not improve the DRF.
Remarks	Reduces intake of minerals which are normally received through whole grain/ bran. Alternatively, grains could be used as seeds.
References	Rajama J, Rantavaara A.: Report STL-A41. Helsinki: Institute of Radiation Protection. Voigt G, et al.: Proceedings of the Seminar on Radioactivity transfer during cooking and culinary preparation, Cadarache 1989. Report XI-3508/90, CEC, DG XI, 1990, p. 351-360.

Method F5 (A6)	**Light salting of meat**
Description	Soaking of meat pieces (200 g) in dilute (5%) NaCl brine, using two successive treatments of 2 days each.
Target surface / product	Meat contaminated from radiocaesium
Time of application (number of days after deposition, season, etc.)	Unlimited period, as long as reduction of ingestion dose from meat is needed
Expected effect: DF, DRF - internal DRF depends on diet	Internal DRF: 20% of the radiocaesium in contaminated meat will remain in the edible fraction of meat.
Personnel requirements and costs (method time consumption)	Additional working time for the treatment
Equipment and other remedies - costs	Capacity of meat processing industry is assumed to be sufficient.
Practicability	Achievable in large scale
Waste	Brine containing Cs is mostly normal waste.
Benefits	Meat with close to normal taste can be distributed during unavoidable contamination. Method is applicable to both household cooking and food industry.
Constraints	Some vitamin and mineral losses cannot be avoided.
Remarks	DRF's 40-50% are achieved if meat is treated in larger pieces.
References	Petäjä E, Rantavaara A, Paakkola O, Puolanne E. Reduction of radioactive caesium in meat and fish by soaking. Journal of Environmental Radioactivity 16; 1992: 273-285.

Method F6 (A6)	**Light salting of fish**
Description	Fish is brined as file in dilute (5%) NaCl solution in cool or cold store for shorter (8 h) or longer (≤ 48 h) time. The brine is discarded after the treatment.
Target surface / product	Fresh fish
Time of application (number of days after deposition, season, etc.)	Unlimited period, as long as reduction of ingestion dose from fish is needed
Expected effect: DF, DRF - internal DRF depends on diet	Internal DRF: 20% of radiocaesium received from fish will remain in edible product after a treatment of 2 days; 50% after a treatment of 8 hours. Specific for Cs.
Personnel requirements and costs (method time consumption)	Additional working time for the treatment.
Equipment and other remedies - costs	Simple utensiles and salt are needed. Large scale treatment in industry needs facilities and cold stores.
Practicability	Achievable in large scale
Waste	Used brine is treated as waste in normal way
Benefits	During radiocaesium contamination of fish the consumption can continue. Small nutrient losses to brine.
Constraints	The product is not conserved, but should be cooked soon after the treatment.
Remarks	The method is convenient for e.g. persons who fish for their own use. - Deepfreezing and discarding the liquid from fish has similar influence
References	Petäjä E, Rantavaara A, Paakkola O, Puolanne E. Reduction of radioactive caesium in meat and fish by soaking. Journal of Environmental Radioactivity 16; 1992: 273-285.

Method F7 (P6)	**Parboiling mushrooms**
Description	Parboiling fresh mushrooms in excess of water (about fourfold volume of water compared to mushrooms). Boiling time at least 3 minutes, discarding the water and rinsing mushrooms with plenty of cold water. Major part, about 90% of radiocaesium will be removed from Lactarius type mushrooms. All species can be parboiled to remove caesium.
Target surface / product	Edible mushrooms to be parboiled or not after the normal instructions of consumer guidance.
Time of application (number of days after deposition, season, etc.)	Unlimited period, as long as additional reduction of ingestion dose from mushrooms is needed
Expected effect: DF, DRF - internal DRF depends on diet	Internal DRF: The fraction of initial activity remaining in edible part of mushrooms is about 10 %. With a repeated treatment the fraction becomes 5% or less. Specific for Cs, but all radionuclides will be removed to some degree.
Personnel requirements and costs (method time consumption)	Working time for the treatment of mushrooms increases, if species not parboiled normally are treated.
Equipment and other remedies - costs	Kettle with sufficient volume, cost for electricity
Practicability	Achievable in large scale
Waste	The waste waters can be drained normally.
Benefits	Consumption of mushrooms can continue after rather heavy fallout, if parboiling is used for most types of mushrooms.
Constraints	The volume ratio of water and mushrooms should be at least 4 to get the expected result. Mushroom species with thick and hard surface cover may need longer treatment than 3 minutes.
Remarks	The taste of mushrooms does not disappear, as the best aroma are not water soluble.
References	Rantavaara A. Proceedings of the Seminar on radioactivity transfer during cooking and culinary preparation, Cadarache 1989. Report XI-3508/90, CEC, DG XI, 1990, p. 69 - 94.

Method F8 (P6)	**Soaking dried mushrooms in water**
Description	When dried mushrooms are soaked in boiled water, which is poured onto mushrooms in a bowl, and the water is allowed to cool to room temperature. Discarding the water before cooking the mushrooms will reduce the radiocaesium activity of edible food significantly.
Target surface / product	Dried mushrooms
Time of application (number of days after deposition, season, etc.)	Unlimited period, as long as reduction of ingestion dose from mushrooms is needed
Expected effect: DF, DRF - internal DRF depends on diet	Internal DRF: Mushrooms contribute to the intake of radiocaesium after the treatment 10 - 20 % of the activity ingested without the treatment. Specific for Cs, but obviously all radionuclides are removed to some degree.
Personnel requirements and costs (method time consumption)	No essential costs.
Equipment and other remedies - costs	In household scale no specific utensils are needed.
Practicability	Achievable in large scale
Waste	Water containing radiocaesium can be drained normally.
Benefits	Close to normal practice of cooking. Applicable to different species of mushrooms.
Constraints	If used primarily for decontamination, takes more time than parboiling (due to drying).
Remarks	Not too great nutrient losses.
References	Rantavaara A. Transfer of radionuclides during processing and preparation of foods - Finnish studies since 1986. Proceedings of the Seminar on radioactivity transfer during cooking and culinary preparation, Cadarache 1989. Report XI-3508/90, CEC, DG XI, 1990, p. 69 - 94.

7. Strategical planning of countermeasures

7.1. General criteria for implementation of dose-reducing measures

The need for quick decisions
In the event of an accident, which may lead to a radioactive contamination of Nordic land areas, it is important to *quickly* assess the situation to determine the needs for countermeasures. This obviously relates to the pre-deposition phase (see Chapter 5), where estimates of the likelihood of significant contamination are crucial. Here, meteorological conditions may be of vital importance for the decision-making (Rosén, 1997). Further, after the deposition has occurred, some measures, such as early removal of vegetation from fields, may in some cases be very efficient in reducing the contamination level. A requirement to obtain a good result is, however, that the procedure is carried out within few days of the contaminant deposition. If the contamination descends practically in absence of precipitation, primarily to a dense vegetation cover, rather than to the soil, removal of the vegetation could be a great advantage before much of the contamination reaches the soil. If, on the other hand, contamination occurs in rain or accompanied shortly after by heavy rain showers, the effect of removing vegetation would be little, as much of the contamination would then have reached the soil. Both for ^{131}I, ^{137}Cs and ^{90}Sr, the transfer process of the contamination from vegetation to the underlying soil is reported to have an average half-life in the range of 2 weeks (Nielsen, 1981; Eriksson et al., 1998). This half-life naturally depends on the actual weather conditions after deposition, and early heavy rain showers can substantially shorten the duration of the process.

Optimisation principles
Whether or not action should be taken to reduce the dose rate in an area depends on whether it can be done in a way that is cost-effective. That is, not only in terms of the traditional cost-benefit elements (essentially monetary operation costs versus saved dose), but also including non-radiological factors that may influence the decision. In short, it can be said that any action should be justified. Small dose contributions may under some circumstances be easily and inexpensively averted, and if so, they should be averted, as it is generally considered that radiation dose has no lower threshold with respect to the detrimental effect of radiation. However, international *guidance* criteria have also been made solely addressing the level of contamination, to avoid doses of a magnitude, which is deemed unacceptable.

For instance, the ICRP in 1984 recommended dose-reducing action in an area if the annual dose to individuals exceeded 50-500 mSv. The so-called CEC Article 31 expert committee in 1992 recommended dose-reduction, or alternatively permanent removal of people, if the accumulated dose over a life-time (70 years) exceeds 1 Sv. Further, local recommendations have been formulated in some countries. In Sweden, for instance, annual individual doses from contamination exceeding 5 mSv are generally considered unacceptable.

The IAEA (1997) has issued a detailed recommendation concerning the need for action at various dose ranges, as summarised in Table 7.1.

Table 7.1. IAEA recommendations concerning the need for cleanup action in contaminated areas with dose levels in various intervals.

Average annual extra dose over a life-time, mSv	Extra annual mortality risk	Need for action at this level
	$\sim 10^{-2}$	Clean-up or prevent use
~100		
	$\sim 10^{-3}$	Clean-up or restrict use
~10		
	$\sim 10^{-4}$	Clean-up if justified
~1		
	$\sim 10^{-5}$	Clean-up unlikely unless constrained
~0,1		
	$\sim 10^{-6}$	Clean-up probably not necessary
~0,01		
	$\sim 10^{-7}$	Clean-up not necessary

In addition to such criteria, international or local guidelines concerning the maximum acceptable content of radionuclides in foodstuffs may apply. For instance, the Codex Alimentarius Commission of the FAO and WHO has set *guideline* threshold values for food moving in international trade. This level for general consumption is 1 kBq kg^{-1} with respect to e.g., ^{137}Cs, ^{134}Cs, and ^{131}I (see example 2 in Chapter 8), but 0.1 kBq kg^{-1} for ^{90}Sr. In milk and infant foods the level for ^{131}I is, however, only 0.1 kBq kg^{-1}. To comply with such guidelines it may be necessary to introduce measures. Further national or European criteria may apply. For instance, a number of national threshold values currently applied in Norway and Sweden are given in the report of the EKO-3.4 project (Preuthun et al., 1997). In a state of emergency, however, these may not apply. Current European thresholds are also reported by Preuthun et al. (1997), and are for the relevant isotopes similar to the Codex Alimentarius values.

It should again be stressed that the above values are only to be considered as recommendations, and that other factors and criteria in relation to the specific situation may greatly affect any decision on action.

7.2. The first assessments after deposition

In any case, an assessment of the radiological situation is an essential first step. This assessment must be based on the available information in relation to the contamination of the area, and this information will in the critical early phase often be sparse.

Typically, measurements of radionuclide surface contaminations will be made on a reference surface, such as a grassed field. Here, the grass in a well-defined area of the surface should be cut as close as possible to the soil surface and sampled. At the same time, a ca. 5 cm deep soil core covering the same surface area should be sampled (without vegetation on the top). These samples should be brought to a laboratory, where gamma-spectrometric measurements can be made. If the radionuclide content is greatest in the grass sample we are dealing with a dry deposition; otherwise we have a wet deposition. This information has, as indicated above, great importance for the choice of possible countermeasures to be implemented in the early phase after deposition.

The actual contamination level in a specific field relative to that on the grassed reference surface will depend mainly on the size of the aerosols deposited, the surface roughness of the receptor surface (different crop types) and the turbulence of the air, and is thus difficult to predict exactly. For a rough estimate, however, the measured values for the reference surface can be applied, since dry deposition velocities for the particle size range typically observed after the Chernobyl accident do not appear to vary by more than about a factor of 2 between grass, wheat and lettuce fields (Roed, 1990; Watterson & Nicholson, 1996). However, lettuce may in general be slightly more efficient at intercepting depositing particles (Watterson & Nicholson, 1996).

In relation to the single crop field it may well be necessary, if dry deposition has been detected, to estimate from a visual impression whether the vegetation seems sufficiently dense for much of a dry deposition to have occurred to vegetation rather than to soil. After the Chernobyl accident, the following deposition velocities to a grassed surface were measured in Denmark: Caesium: $4\ 10^{-4}$ m s^{-1}; Iodine: $22\ 10^{-4}$ m s^{-1}; Strontium: $6\ 10^{-4}$ m s^{-1} (Roed, 1990). The deposition (in Bq m^{-2}) can be roughly estimated by multiplication of the deposition velocity by the total time-integrated air concentration over the period of deposition (in Bq s m^{-3}), if available. However, direct contamination measurements on a surface should always be used in connection with the planning, since airborne caesium, strontium and iodine contaminants may in a future contamination scenario have completely different physical (size, shape) and chemical (particularly for iodine: aerosol, gas) forms than those observed in connection with the Chernobyl accident.

7.3. Parameters affecting contaminant behaviour after deposition

A variety of parameters may affect the consequences of a contamination of a food-producing area.

Soil type

One of the affecting parameters is the local soil type. This affects both the downward migration (and thus the shielding against external radiation) and the availability for uptake to plants as well as to animal food chains. In relation to this, an important mechanism is, specifically in relation to caesium contamination, the soil's clay content. It is well known that caesium is tenaciously retained by certain micaceous clay minerals. Indeed, the capacity of clays to extract caesium from aqueous solution, even in the presence of excessive amounts of cations, is exploited e.g. in the treatment of radioactive waste from nuclear fuel reprocessing plants and in underground storage of radioactive waste.

The main reason for this is that the caesium ion is very strongly bound at frayed edges at the interlayer spacing between unit layers of some clay minerals (Andersson & Roed, 1994). This applies to caesium specifically, since the caesium ion has a low tendency to hydration and has an ionic radius of 1.65 Å, which fits nicely with the size of the hexagonal openings formed by oxygen atoms at the clay unit layer surfaces. Ammonium and potassium ions have similar characteristics, but are somewhat smaller (radii of respectively 1.43 and 1.33 Å) and thus not quite so strongly bound as caesium. From the less selective ion exchange sites, however, fertilising with ammonium can lead to a desorption of cations (to some extent including caesium), thus potentially leading to an increased bio-availability of contaminants. Therefore, a general recommendation is that fertilisers containing ammonium should not be applied in contaminated fields (Renaud & Maubert, 1997).

The strong caesium fixation in clay will depend on the type of clay mineral (largely, the negative charge density of the clay layers). For common three-layer clays it increases in the order montmorillonite < vermiculite < illite. Caesium is also fixed to other soil minerals, although less selectively. Illites are very small and often well-mixed in a matrix with organic matter. In general, the fraction of organic matter combined with inorganic matter is less than 50 % only in some very sandy soils (Schnitzer & Kahn, 1978). Therefore, decomposition of organic matter may be responsible for some downward migration of contaminants fixed in mineral particles.

In some parts of the Nordic countries soils may contain particularly much organic matter. In these soils the effect of organic matter and organic compounds generated in the decay of organic matter, may, at least for some time, determine the behaviour also of caesium. It should, however, be stressed that it takes only very little soil clay to offer sufficiently many sites to strongly (virtually irreversibly) fix a caesium contamination at the trace amount concentrations that may be foreseen after a nuclear accident such as that at Chernobyl in 1986. Peat soils are often nutrient deficient, and would consequently have a high plant uptake rate of contaminants.

Strontium ions are divalent and are therefore held (chelated) less strongly, by organic compounds. The main influencing factor will here be the soil content of calcium, as this ion will in nature behave very similarly to strontium. Sandy soils will generally contain less calcium than will loamy and peaty soils.

The influence of soil type on the transfer of caesium and strontium to a variety of crops by uptake is described in detail by Eriksson (1997) in the final report of the Nordic BER-6 project, in a series of transfer factor data.

Source term

Another factor, which can affect the bio-availability of contaminants to both plants and the animal food-chain is the contaminant source term. Different release processes will create contaminant particles with different characteristics. High-temperature releases, such as the Chernobyl reactor explosion, will create particles of more different shapes and sizes than those created in connection with low temperature releases. Correspondingly, deposition patterns will vary. After deposition, e.g. in a field, the fate of the contaminants will depend on particle weathering and subsequent mobilisation of associated radionuclides (e.g. ^{90}Sr) depends on particle characteristics (size, structure, oxidation rate) and environmental factors (e.g., soil pH) (Salbu et al, 1998). Particles released under oxidising conditions (e.g., fire) will be more soluble, whereas in other cases (e.g., explosions) some contaminants may remain in particle form for years.

Bobovnikova et al. (1991) found during the fallout period of the Chernobyl accident that deposition of not readily soluble forms of ^{137}Cs was predominant at a distance of 18 km from the Chernobyl plant. The Chernobyl caesium that Tomasek et al. (1995) found on air filter samplers as far away as Prague also contained significant 'insoluble' caesium fractions ranging up to about 30 %. The relatively large 'insoluble' (or less readily soluble) particles would be expected to a greater extent to stay on the surface rather than penetrate to deeper soil layers. The reduced solubility will result in lower transfer to plants over some time.

Table 7.2 shows examples of observations of different processes leading to different contaminant characteristics in relation to various releases of radionuclides to the environment in the past.

If, for instance, cattle take in 'insoluble' particulate contamination by digestion of contaminated plants, particles can be retained in the gastro-intestinal tract for months. Furthermore, some methods, such as those involving the use of Prussian Blue, will not be effective if much of the contamination is associated with 'insoluble' particles, as the Prussian Blue has effect by binding soluble caesium. Similarly, transfer factors estimated for root uptake will not be valid until radionuclides are released from the particles.

Further, the relationship between amounts of different chemical species of iodine contamination (e.g., organic particulate or elemental gas) will greatly influence the deposition processes and thus the distribution pattern of radioiodine after an airborne release.

Table 7.2. Sources and characteristics of actinide containing particles (from Salbu, 1999)

Source	Site	Release conditions	Characteristics	Affected area
Weapons tests	Maralinga, Australia	Atmospheric and ground surface tests, safety trials	Submicrons to fragments, inter-action with soil	Desert area
	Marshall Island	Atmospheric and ground surface tests, safety trials	Submicrons to cm, inter-action with coral, device and shot dependent	Atoll, marine
	Mururoa, French Polynesia	Atmospheric and ground surface tests, safety trials	Submicrons to cm, inter-action with coral	Atoll, marine
	Nevada test site, US	Atmospheric, ground surface and under-ground	Submicrons to cm inter-action with soil, device and shot dependent	Desert area
	Semipalatinsk, Kazahkstan	Atmospheric, ground surface craters and underground tests	Localised heterogeneities	Desert area
	Novaya Zemlya, Russia	Atmospheric, surface, under-ground, under water	Localised heterogeneities	Arctic terrestrial and marine
Nuclear reactor accidents	Chernobyl, Ukraine	Explosion, reduced Fire	Reduced U-particles, Oxidised U-particles	Terrestrial and fresh water systems
	Windscale, UK	Corrosion Fire	Flakelike U-particles U-particles	Terrestrial and marine systems
Accidents with nuclear devices	Canada/Cosmos	Destruction of satellite reactor	Submicrons to fragments	Terrestrial, fresh water systems
	Palomares	Destruction of 2 nuclear weapons	Pu-particles	Desert, marine
	Thule	Destruction of 4 nuclear weapons	Pu-particles	Arctic marine and terrestrial
Dumping of waste	Novaya Zemlya Abrosimov/ Stepovogo fjord	Corrosion of dumped waste	^{60}Co-particles Pu retention in sediments	Arctic marine
Effluents	Sellafield La Hague Mayak	Effluent Effluents Effluents	Particles/colloids Particles/colloids Localised heterogeneities in sediments	Marine Marine Fresh water systems, terrestrial

7.4. Other general factors to be taken into account in post-deposition planning

Time of contamination
The potential importance of the time aspect has already been discussed above in relation to early introduction of countermeasures. However, naturally, the impact of time also has relevance in relation to season. Some of the methods suggested in Chapter 6 have restricted applicability, depending on the season of implementation. Obviously, this goes for the method involving removal of snow, but also for instance ploughing procedures require that the soil is not frozen. Considerations in relation to season of implementation are integrated in the individual data sheets in Chapter 6, where appropriate.

Local conditions
The suggested methods are considered to apply to the Nordic countries as a whole. However, local planners must of course evaluate if the methods are relevant to their specific local conditions. For instance, due to rock formations, a procedure such as deep ploughing will not be possible in some Nordic areas. Some areas may well also have too steep a slope to allow the use of such measures.

The size of the contaminated area
The size of a contaminated area may affect the policy for treatment. If the contaminated area is very large it may be necessary to prioritise treatment of some parts of the area before other. Factors governing this prioritising may well not be based entirely on radiological concern. Also, to some extent, locally and politically determined factors such as for instance the wish to reduce the contaminant level to a level, which justifies continuation of an area's traditional function with respect to agriculture and industry, may weigh rather heavily. The alternative may be deemed to be unacceptably high social costs.

Protection of children
It is particularly important that food products, which are primarily consumed by children, contain as little radioactive matter as possible. Children should be protected exceptionally well against radiation, as the probability of developing radiation induced fatal cancer is on average about twice as high for 0-10 year olds as for adults.

Psychology / public acceptance
Psychological effects of a contamination of land areas may be severe. Depending on the level of information, people may not want to work or live in contaminated areas, which would from a radiological point of view be considered safe. It is therefore of great importance that people living or working in the affected areas are thoroughly informed about the possible adverse health effects due to the contamination in the area. To agricultural producers, for instance, it is important to know which protective measures may possibly be recommendable in the daily work (see also example 2 in Chapter 8). Knowledge on what locals can do themselves to improve their conditions may have a great psychological value, and possibly prevent desertion of the affected areas.

One thing that individuals can do to reduce their individual doses is to take dietary advice. The responsible authorities should well in advance of any emergency write a leaflet with such advice, which could rapidly be distributed to the public. As can be seen from Tables 7.4 and 7.5, not all major dietary components contribute equally much to the consumption dose in a contamination scenario. Further, for instance mushrooms may accumulate very high levels of contamination and should in heavy contamination scenarios be avoided unless monitoring certifies that the contamination level is acceptable or can be made acceptable by treatment, e.g., as described in data sheets F7 and F8 in Chapter 6. In relation to this, it should be mentioned that a recent report (Salt et al., 1999) shows that 40 % of the Norwegian respondents to a questionnaire reduced their intake of wild mushrooms in the early phase after the Chernobyl accident. In the longer term, this figure was reduced to 24 %. The corresponding figures resulting from a questionnaire in Scotland were respectively 19 % and 10 %, indicating that risk perception may vary greatly between different communities, influenced not only by local conditions within the community, but also by the level of information given.

It is important that any countermeasures implemented are acceptable to the people affected by them. For instance, methods *removing* the contamination would often be more attractive (though perhaps not practicable) than those where the contamination remains at the site, but e.g. uptake is reduced.

Also consumers outside the directly affected areas should be informed carefully of the actual radiological risk. If this is not the case, foodstuffs produced in any contaminated area may be expected to be impossible to sell, regardless of the contamination level. Answers to a Norwegian questionnaire (Salt et al., 1999) indicate that well-educated people in general have a significantly lower risk perception than the rest of the population. This suggests that knowledge in general may reduce risk perception, and highlights the need for generally comprehensible information.

External dose contributions
Further, external doses to the populations in agricultural areas as well as doses to workers implementing countermeasures in the areas should be considered.

External doses to populations in residential areas and measures against these are described in connection with an earlier Nordic project (Andersson, 1996; Ulvsand et al., 1997; Andersson & Roed, 1999a). Some of these methods may also be important to implement in the agricultural environment, to protect the agricultural workers/residents. In general, the external dose per unit of surface contamination would be expected to be somewhat higher in agricultural areas than in urban areas, as the vertical urban surfaces shield against distant contamination, whereas in open agricultural areas there is often not much shielding. In this connection it should be mentioned that calculations have shown that with a typical distribution in soil of ^{137}Cs (which will be likely to be the radionuclide governing external exposure) only about 34 % of the dose rate in an infinitely large field is caused by contamination within a radius of 16 m, whereas 13 % comes from contamination at more than 64 m distance (Andersson, 1996).

Protection of workers / inhabitants
Some countermeasures described in the data sheets in Chapter 6 may under specific conditions require that workers take certain steps to protect themselves. Particularly

in the early phase, when the contamination is weakly held on the various surfaces, and in connection with dust-generating methods, such as harvesting of freshly contaminated vegetation, respiratory protection may be called for. This is mentioned in the data sheets, where relevant. However, calculations have shown that in areas, with a caesium contamination level of 1 MBq m^{-2}, typically corresponding to about 50 Bq g^{-1} of surface soil, inhalation doses from resuspended soil contamination will be small, even at high dust concentrations in air (Andersson et al., 1999b). For information on worker inhalation dose see also example 2 in Chapter 8. Typically, if workers are situated very near containers for storage of cut-off grass and other vegetation the dose rate they receive may be 5-10 times as high as that otherwise received by staying in the area. It may thus in strongly contaminated areas be recommended to minimise the number of individual working hours for some operations (Ulvsand et al, 1997).

Protective, waterproof clothes covering the whole body as well as respiratory protection may be recommended particularly in connection with implementation of early measures to reduce dose rate. At this stage, contaminant air concentrations may not be known. Measurements have shown that contaminated soil, e.g., under the soles of shoes, will often be the most important pathway of indoor contamination (Thatcher & Layton, 1994). Therefore shoes should in heavily contaminated areas be changed at entry. Daily hoovering would be recommended in the early phase, even though deposited particles may in some cases be so small that hoovering would have little effect. In such cases, at least some of the deposited particles would attach to larger house dust particles, thus becoming removable.

7.5. Rough evaluation of the radiological consequences of agricultural contamination

As stated in the above sections of Chapter 7, a number of factors influence both the dose-rates received after a nuclear contamination of agricultural areas and the choice of means for dose reduction.

As a first step, however, it can be useful to quickly be able to roughly estimate the doses we would be dealing with under what would be considered as 'likely', conditions, though of course not covering all conceivable scenarios.

In connection with the estimate described below it was assumed that the soil type was a sandy loam with 5-10 % clay, representative of many Nordic areas, though naturally far from all. A high solubility of deposited particles was here assumed. A further assumption is that the contaminated area is large, so that it covers production areas for virtually all dietary constituents. For simplicity, it is here assumed that all food consumed is locally produced. The average annual consumption rates in Denmark of the main dietary components are shown in Table 7.3. These are compared with the corresponding figures for Austria. As can be seen, the two sets of figures are similar.

Table 7.3. Important dietary components in Denmark compared with Austria.

Dietary component:	Annual consumption (kg) in Denmark*	Annual consumption (kg) in Austria**
Milk products	162	150
Beef	20	20
Pork	67	52
Mutton	1	2
Green vegetables	45	37
Potatoes	57	61
Grain products	95	65

* Figures derived from *Statistisk Årbog, Denmark, 1999.*
** Figures derived from *Mueck et al, 1992.*

The reason for this comparison is that a detailed analysis has been made in Austria of the influence of the season of contaminant deposition on ingestion doses received during the first year (Mueck et al., 1992). It was, as expected, found that such early dose contributions received in connection with deposition during the plant growth season were much greater than those received if the contamination took place outside the growth season.

Rough estimates of long-term dose contributions are shown in Table 7.4 from a contamination with the three radionuclides deemed to be of major concern. These calculations were performed with the European standard model COSYMA, implementing data specific to Danish conditions, where possible, e.g., in relation to dietary components, as given in Table 7.3. Only doses to adults are calculated. Doses to children would generally be somewhat higher.

If contamination occurs in the growth season, with very little precipitation, an additional early phase dose contribution should be added to the figures in Table 7.4 for the doses to individuals. That is if directly contaminated crops are used unrestrictedly for consumption / production of food products. These contributions, which are based on the Austrian work, are shown in Table 7.5.

Table 7.4. Long term dose contribution (integrated to year 50, to adults). Figures based on calculations made with the European COSYMA model.

Isotope	^{137}Cs	^{90}Sr	^{131}I
Individual dose (Sv/(Bq/m^2))	$2.1\ 10^{-8}$	$8.1\ 10^{-8}$	~0
Ingestion dose part (%)	59	100	-
Dose breakdown by important dietary components (%)			
Milk	23	18	-
Beef	14	0	-
Pork	2	0	-
Mutton	2	0	-
Green vegetables	50	38	-
Potatoes	3	6	-
Grain products	6	38	-

As can be seen from Table 7.4, the ingestion pathway part is for caesium contamination estimated to be only slightly more than half of the total life-time dose contribution. This is due to the large contribution from external radiation.

Table 7.5. Average additional committed dose contribution to adults if deposition occurs practically without rain, within the crop growth season. Figures based on calculations reported by Mueck et al, 1992.

Isotope	^{137}Cs	^{90}Sr	^{131}I
Individual dose (Sv/(Bq/m^2))	$6.3\ 10^{-8}$	$5.0\ 10^{-8}$	$2.5\ 10^{-9}$
Ingestion dose part (%)	100	100	100
Dose breakdown by important dietary components (%)			
Milk	34	46	30
Beef	27	0	0
Pork	3	0	0
Mutton	3	0	0
Green vegetables	21	50	70
Potatoes	5	0	0
Grain products	7	4	0

Naturally, dietary components will not for all Nordic areas be adequately represented by the figures in Table 7.3. However, a simple scaling using the dose breakdowns in Tables 7.4 and 7.5 would reveal the effect on dose of any dietary deviations. It should be stressed that leafy green vegetables are to a large extent in Denmark grown in greenhouses and may at least in wet deposition scenarios be practically unaffected by airborne contamination. In the example above these vegetables are assumed to grow outdoors in a field.

These tables may, particularly in lack of exact information on influencing factors, as would be expected in the early phase, be useful for a rough indication of expectable consequences of an emergency in an agricultural area. At least, they illustrate principles that can be adapted in the identification of consequences. By comparison of such data with criteria for implementation of dose-reducing measures, as described in the first section of this Chapter, the decision can be made as to whether action is called for.

The dose breakdown by dietary components gives indications as to which agricultural areas would generally be most important to treat by dose-reducing countermeasures. Thereby, a strategy can be made ensuring that any countermeasures implemented have the optimal effect in terms of dose reduction. As described above, non-radiological factors would, however, still need to be taken into account in the formulation of the strategy.

7.6. Implementation of data sheet information in choice of countermeasures

The data sheets in Chapter 6 are designed to describe possible countermeasures for the contaminated agricultural environment, and, as far as possible, to give information on dose reductive effect and elements of costs, constraints and other important aspects, thus facilitating decision-making. In the event of a nuclear contamination of a Nordic agricultural area, it is important to first find out if action is necessary to reduce dose. If this is the case, countermeasures should be identified, which can be applied to treat the type of areas or products affected. The categorisation system described in Chapter 4 may be useful in this context. Hereby, the 'emergency stage' is determined, and only a limited number of data sheets relevant to the particular stage need to be considered. For many of these methods, it will be possible to calculate a 'dose-reducing effect'.

Generally, an estimate of the collective long-term consumption doses received by intake of contaminated food may be based on a multiplication of the contamination level (usually in units of Bq m^{-2}) by the relevant transfer factor for transfer of the isotope from soil to the food species in question (usually in units of Bq kg^{-1} per Bq m^{-2}), the contaminant reduction factor by routine food preparation (if significant), the consumption rate (kg y^{-1}), the number of consumers supplied, and the dose response (Sv Bq^{-1}).

Alternatively, for instance, it may be calculated by multiplication of the contamination level (usually in units of Bq m^{-2}) by the relevant transfer factor for transfer of the isotope from soil to the food species in question (usually in units of Bq kg^{-1} per Bq m^{-2}), the contaminant reduction factor by routine food preparation (if significant), the mass of edible crop produced per m^2, the affected area (in m^2) and the dose response (Sv Bq^{-1}). The radiologically beneficial effect of introducing a countermeasure can then generally be calculated by multiplying this dose by any achievable reduction in food radionuclide content.

Concerning transfer factors the reader is referred to the detailed data given by Eriksson (1997) for transfer to a number of crops, assuming a variety of different soil characteristics. Such transfer factors are also reported by Nisbet & Woodman (2000). For transfer factors to beef and milk the reader is referred to the calculated values used in Example 2 in Chapter 8 of this report, or to e.g., the values reported by Voigt et al. (1988).

Also the IAEA Handbook of Parameter Values (IAEA, 1994b) give transfer factors for a wide range of foodstuffs, radionuclides and soils. However, these latter values are expressed in units of Bq kg^{-1} in foodstuff per Bq kg^{-1} in soil. Therefore, the application of these requires knowledge of the contamination level per kg of the part of the soil that is relevant to uptake through the particular crop root system, thus complicating things somewhat.

The contamination-reducing effect of routine cooking methods, if any, is described in detail by the IAEA (1994). The dose response is given by ICRP (1995) as a function of the exposed person's age. For adults this is 2.8 10^{-8} Sv Bq^{-1} for ^{90}Sr, 2.2 10^{-8} Sv Bq^{-1} for ^{131}I, and 1.3 10^{-8} Sv Bq^{-1} for ^{137}Cs.

For detailed data on the types and amounts of food products produced in specific areas, the planner should contact the responsible ministries, which may have relevant databases. It would be highly beneficial to have established this contact well in advance of any accident.

Some measures, such as for instance ploughing, may have an additional effect in terms of reduction of external exposure.

The beneficial effect of avoiding a Sv collective dose (usually termed a man-Sv) may be assigned a monetary value (see examples 1,2 and 3 in Chapter 8), which may be highly variable, both between Nordic countries and with time. It should be stressed that this monetary value is *politically* determined.

The cost element in direct connection with the countermeasure can normally also be evaluated from the data sheets, taking into account factors such as labour, remedies, consumables, transport and waste storage.

Waste storage principles described in connection with the NKS/EKO-5 project (Andersson, 1996) also apply for the types of waste generated by some of the methods described in Chapter 6 of this report, and costs indicated in data sheets are based on this simple, but safe type of repository design. A problem is here that current legislation in the Nordic countries may not permit simple storage of waste, and current waste practice for routine disposals would be considered impracticable in connection with large accidents.

Further, recent work has indicated the potential of applying contaminated biomass in safe energy production, minimising the amount of waste for storage (Junker et al., 1998; Roed et al., 2000).

In addition to the above direct costs, partly locally determined indirect costs (and benefits) must be considered. These may relate to social and psychological factors. The data sheets also give recommendations in relation to some non-radiological factors of concern in connection with implementation of the individual methods described. However, as described earlier in this Chapter, more, generally applying non-radiological factors need to be considered in the choice of countermeasures.

Some data sheets describe methods for which cost and benefit elements can not be readily expressed in monetary units. For instance for methods involving change of land use, the dose reduction benefit would be that the area is perhaps no longer used for food production (assuming food for the affected area can be produced elsewhere). The exact saved dose would then depend on the type of food normally produced, and can be calculated as described above. The costs in connection with a radical change of production would be determined mainly by local parameters, including the market and how it is influenced by the changes. Therefore, data sheets for such methods can often only qualitatively describe the techniques and factors that must be taken into account. Nevertheless, these types of techniques may be highly important and represent useful means of optimisation in relation to some categories of contamination scenarios.

It is very important not only to concentrate on the figures that can be derived from data sheets, but also to carefully read all accompanying text, e.g. in relation to constraints on the use of the methods.

For further information on how the data sheets may be applied to calculate *some* important figures in the event of a contamination of a food-producing area, three examples have been made (see Chapter 8).

8. Examples of rough calculations of cost-effectiveness analysis elements based on data sheets

Example 1. Contaminated potato field:

Consider a potato field, characterised as a sandy loam with 10 % clay, to which a deposition of 10 MBq m^{-2} ^{137}Cs occurs in the month of July, in absence of precipitation. For this soil type, a transfer factor of 1.40 10^{-3} m^2 kg^{-1} (dw) has been reported by Eriksson (1997). Potatoes contain about 20 % dry matter. At this time of the year, the potato plants will cover the ground well, and probably at least 90 % of the deposition will have occurred to the vegetation, rather than directly to the ground.

If the vegetation is harvested and removed within few days after contamination, a rather conservative estimate of the effect could therefore be a reduction of the contamination level of the area by a factor of 10. If the vegetation is not harvested early the contamination will typically over a few weeks be transferred to the ground, depending on the amount of precipitation. Assume here that the weather forecast says that prolonged rain is expected in about two days. Assume further, that an ordinary person has a daily consumption of 0.3 kg potatoes (raw weight), and that these potatoes are peeled and boiled.

Saved dose over the 1st season after the deposition year, to one ordinary inhabitant by early harvest of the potato field (assuming that a very great area has been contaminated, and that alternative food can not be imported in sufficient amounts):

10 MBq m^{-2} * 9/10 (early harvesting) * 1.40 10^{-3} m^2 kg^{-1} * 0.2 (dry matter part) * 0.3 kg d^{-1} * 365 d y^{-1} * 0.6 (peel+boil DF) * 1.3 10^{-2} Sv MBq^{-1} = 2.2 mSv y^{-1}.

Due to the radiological half-life of 30 y, this corresponds to ca. 80 mSv over a life-time (70 y). However, the availability of the caesium (TF) will decrease somewhat with time (assuming deposited particles are not 'insoluble'), due to stronger clay fixation and possibly downward migration beyond the root zone. This means that the individual averted life-time dose could be of the order of 50 mSv, or less.

A Danish potato field can give a total annual yield of ca. 36 t/ha. This is sufficient for 36000 / (0.3 *365) ≈ 300 people. Some of these potatoes will probably be wasted or used for other purposes than direct consumption by man, but perhaps 200 individuals can be supplied with potatoes from 1 ha.

This means that the early harvesting of vegetation from a 1 ha of potato field can give an averted collective dose over a life-time of some 10 man-Sv. A value of an averted man-Sv may, e.g., be derived from figures currently applied by Danish Ministries in connection with cost analyses of other types of accidents, for instance casualties in traffic. If such a monetary 'casualty' figure were multiplied by 0.05 Sv^{-1} (the current ICRP estimate of the probability of developing fatal, radiation-induced cancer), the result would be an estimated value of an averted man-Sv of about 300,000 DKK. This would make the dose averted by treatment of a ha worth some 3 mill. DKK over a life-time.

From the data sheet for harvesting shortly after contamination it can be seen that the harvesting of 1 ha can be accomplished by one operator with a harvester, in about 3 hours. The manpower costs for this, including overheads to have the equipment brought to the field and mounted, etc. would thereby be some 1000 DKK. In addition to this, about 100 DKK worth of petrol would be required, and the discount on equipment during the 3 hours of use would be of the order of 500 DKK. Further, the removed vegetation would need to be disposed of. There may be about 100 m^3 of waste, and if it can be disposed of within 20 km, it would cost somewhere of the order of 2000 EURO = ca. 15,000 DKK. This makes the total cost estimate about 17000 DKK, which is not much, e.g. in comparison with the monetary loss, if the field can not be used to grow crops in the future. Further, there would be likely to be very strong non-radiological (psychological/political) reasons to treat the area.

Example 2. Contaminated cattle farm area:

Assume here that we have a situation, where an area including cattle farms is contaminated by 1 MBq m^{-2} of ^{137}Cs and 5 MBq m^{-2} of ^{131}I in heavy rain. We are in the month of May, where the cattle are grazing freely in the fields until the accident. After news of the accident the cattle are placed in a stable. The question is now: how should the cattle farm area be treated ? As the contamination descended in rain, removal of the vegetation from the area would not be expected to have great effect on the contamination level of the field. Much of the contamination will already have been washed down into the soil. In other words: we have gone past stage A2 (see Chapter 4).

If we look at the stage A3 options, for instance storage of fodder crops for some weeks could significantly reduce the radioiodine contamination level. However, it will take some days for significant amounts of radioiodine to be taken up from the soil to the grass crops anyway, and this will reduce the importance of the radioiodine contamination somewhat (assuming that the heavy rain was efficient in washing practically all ^{131}I into the soil, as would be expected from the work of Roed (1987) and Jacob et al. (1993)). Further, as the area is also significantly contaminated with the long-lived isotope ^{137}Cs, this option can not be expected to make the crops growing in the area much more suitable for cattle fodder. An effort should therefore be made to supply uncontaminated fodder to the farms, ideally as soon as possible.

Assume in this example that this can not be readily achieved, possibly due to the large size of the area affected by the accident. The cattle must then be fed with the contaminated locally produced fodder for some time. As we then already have contaminated cattle, we would be looking at a A5I situation, where a recommended option would be to feed animals with uncontaminated fodder over at least a period of time prior to slaughter, so as to reduce the meat contamination level by exploiting the animals' natural excretion (biological half-life) of contaminants. This method is described in data sheet M4.

Assume that a cattle farm has 400 animals, and that the fodder for these is locally produced in an area of ca. 100 ha. A run of the EU FARMLAND model with standard Western European parameters, assuming that the cattle are fed with grass from the contaminated pasture, shows that the relationship between specific caesium activities of cow's meat and grass is ca. 1.6 (the corresponding relationship for strontium is 0.013). If we assume that the soil is a sandy loam with 10 % clay, the caesium transfer factor for uptake from soil to grass of 4.5 10^{-3} m^2 kg^{-1} has been reported by Eriksson (1997). The dose contribution from direct deposition to the grass cover would be low compared with that from the soil uptake to grass, since the heavy rain showers would as mentioned above wash the contamination into the soil. Further, the half-life of the natural transfer process of caesium deposits from grass to soil would be only ca. 2 weeks. This means that the meat contamination level, which would in the long run result from the accident, without dose-reducing action, would be expected to amount to

$4.5\ 10^{-3}\ m^2\ kg^{-1} * 1.6 * 1\ MBq\ m^{-2} = 7.2\ kBq\ kg^{-1}$.

This is assuming that the slaughter will not take place the first few months after deposition, after which ^{131}I dose contributions will at any rate be insignificant.

According to the Codex Alimentarius Commission, the *guideline* threshold value for food moving in international trade is 1 kBq kg^{-1} with respect to ^{137}Cs (and also e.g. ^{134}Cs, and ^{131}I). It should be stressed that this guideline level was set to facilitate international trade in food, and should be regarded as a level 'below regulatory concern'. Levels above this do not necessarily constitute a health hazard, and it is up to the competent national authority to decide the threshold value for action. However, if the local beef producers in the area seek to avoid possible economical penalties from trade restrictions by complying with the guideline value, the beef contamination level should be reduced by at least about 8 times. This could be accomplished by feeding the cattle with clean fodder over a period corresponding to 3 biological half-lives. According to data sheet M4 this corresponds to ca. 40-50 days. According to the data sheet, the price of imported uncontaminated fodder concentrates, if available, would be of the order of 0.6-0.8 Euro per kg. If a cow eats 4 kg per day over 45 days, the cost will thus be some 125 EURO, which is little compared with the total value of the animal. Stables were assumed to be available in this example, but a relatively small amount of money would, as mentioned in the data sheet, need to be added per cow, for monitoring.

The benefit in terms of averted dose to humans per cow fed with uncontaminated fodder over 45 days (assuming that some 300 out of ca. 400 kg of meat on a cow are somehow consumed by humans) would be

$7.2\ kBq\ kg^{-1} * 7/8 * 300\ kg * 1.3\ 10^{-5}\ Sv\ kBq^{-1} = 25\ mSv$.

The value of an averted man-Sv may currently be set to 300,000 DKK (see example 1). This makes the dose averted by treatment of a cow worth some 7,500 DKK ~ 1000 EURO, which is much more than the costs of the operation as calculated above. If practicable, it would be desirable to feed the cattle with clean fodder for much longer than 45 days.

It should, however, be stressed that it may well under all circumstances be difficult to avoid future trade restrictions, as markets are governed by the public opinion, which will to a great extent mirror the point of view taken by the press. It will take only very little scepticism to cause consumers to avoid these products 'for safety's sake', if possible. It is therefore of paramount importance to inform the consumers that action has been taken where required, and the contamination levels are not considered to constitute a health hazard. Particularly the farmers and workers in the food production line should be well informed about the actual implications of the situation.

For instance, workers may, in lack of information, instinctively seek to protect themselves against any inhalation risks in connection with their work. In relation to this the ICRP has expressed the following general view:

'The use of personal respiratory protection is likely to reduce the general working efficiency and hence result in longer work times to complete tasks. The resulting increase in external radiation exposure and any risks from conventional safety hazards should be taken into account in the decision to use such equipment'.

Worker doses would in general under the circumstances described in this example not differ significantly from the doses received by the general public in the areas.

When supply of fodder is established from other areas, the pasture area can be treated, so that the radionuclide content in future fodder crops grown in the area is acceptable. Here, for instance various types of ploughing may be considered. As the fields need not be ploughed immediately, for instance 'skim-and-burial' ploughing might be achievable. Alternative or supplementary options could in this context be potassium fertilisation, turf harvesting (if practicable in the area) and/or feeding fodder cut with an increased height compared with normal practice.

If this is also a milk-producing farm, separate methodology for treatment of milk may be needed, and for evaluation of cost and effect of the recommended methods in relation to the particular situation (stages A5II/A6), the data sheets can again be used. For that purpose it can be assumed that the relationship between specific caesium activities of cow's milk and grass is ca. 0.32 for caesium (and 0.078 for strontium, which is in this case not present).

Example 3. Milk contaminated with ^{131}I:

Consider a situation, where a contamination of a milk cattle farm with 400 animals has occurred, and has been detected by increased levels of ^{131}I in the milk produced. It has been found that the radioiodine was not accompanied by measurable amounts of any long-lived radioisotopes, and the ^{131}I level in milk has been measured to be 2 kBq l^{-1}. This is twice as much as the threshold guideline value set by the Codex Alimentarius Commission (see example 2) for food moving in international trade (if the milk is to be used for infant food, it is 20 times the recommended threshold value).

Naturally, here an effort should be made to trace the source of the radioiodine at the farm, so that appropriate measures can be taken (e.g. storage of crops/grass as described in data sheet V3, if clean fodder can be obtained for use until radioactive decay has reduced the radioiodine level sufficiently). There could be a contamination of the whole farm, or it could be that only fodder, perhaps produced outside the farm, was contaminated. As can be seen from Table 7.5 in Chapter 7, radioiodine contamination will mainly give doses from consumption of milk products and fresh green vegetables, so it would be recommended to find out if any nearby areas where green vegetables are grown are also contaminated with radioiodine.

At the cattle farm, more drastic measures, such as category A4 options (see Chapter 4), should in this case, where there are only short-lived isotopes present, not be considered.

Nevertheless, the contaminated milk needs treatment. For this purpose we will be looking at the category A3 options (protection against short-lived isotopes) in the data sheets. In data sheet F1 (manufacturing of food products to be stored for several months), it is mentioned that generally, ^{131}I will in six weeks time decay to an insignificant level. More specifically in this case, as ^{131}I has a radioactive half-life of about 8 days, the milk products would only need to be stored for a week or two to comply with the international trade guidelines. However, it would be beneficial to store them for longer periods, if possible, to save dose. The storage could be accomplished in several ways.

Other products generally more suitable for storage over longer periods could be manufactured from the milk (e.g., butter and cheese). An alternative would be to UHT (ultra high temperature) treat the milk. After heating the milk to some 135-150°C for 1-4 seconds, the milk will, if remaining in unopened packing, easily be storable for 3 months at room temperature. This treatment may, however, somewhat affect the flavour of the milk. In comparison, ordinary Pasteurised milk is typically heated to 72°C for 15 seconds, so the differences in the manufacturing process (and thereby the additional costs) would be likely to be small.

As mentioned under 'Remarks' in data sheet F1, some of the methods listed above may also have a decontaminating effect, which is discussed in other sheets. If, for instance, there were any radiocaesium in the milk, cheese manufacturing according to the Rennet method would reduce this by at least a factor of 10.

Assume that each of the 400 cows produce 20 l of milk per day, and that the radioiodine contamination in the milk decreases exponentially in the future with a half-life of ca. 8 days (this should be monitored continuously; there may not yet have been established an 'equilibrium' between radioiodine levels in fodder and milk). The collective committed dose averted by using the milk from the farm to produce storable food (which is consumed when the radioiodine level is negligible, instead of drinking the milk fresh) is then of the order of:

$2 \text{ kBq l}^{-1} * 400 * 20 \text{ l per day} * 2.2\ 10^{-5} \text{ Sv kBq}^{-1} * (8 \text{ days}/\ln 2) = 2.8 \text{ Sv}.$

This is assuming that all the milk would be consumed by humans.

The value of an averted man-Sv may currently be set to 300,000 DKK (see example 1). This makes the dose averted worth some 840,000 DKK ~ 110,000 EURO, which is considered to be very much more than any costs in connection with the change in production, assuming that the needed facilities are available, as they would at least be for some storage options. For reference, it should also be mentioned that the total market value of the milk produced at the farm over the critical period (a few weeks) would amount to some tens of thousands EURO.

9. Conclusions

9.1. Conclusive remarks and recommendations

This report describes countermeasures for implementation in connection with a nuclear accident contaminating food-producing areas with the isotopes ^{137}Cs, ^{90}Sr and ^{131}I. The report primarily addresses countermeasures in agriculture, but also takes into account possible reductions in food contamination level achievable by methods that can be used in the food industry (e.g., dairies) and by ordinary consumers (including e.g., restaurants) in food preparation.

The overall objective of the report is to describe potentially applicable methods in a short and well-arranged format, which can facilitate decision-making. All values given in the report are to be considered as 'best estimates', based on the available knowledge, and some deviations from these may be expected in values assessed in connection with any specific emergency. A number of parameters governing some of this variation are described in the report.

Some of the described methods are highly efficient, though in some cases somehow restricted in use. As time may be a major restriction, the planners should make themselves familiar with the content of the data sheets, so that it will be easier for them to survey an emergency and quickly start strategy formation and implementation of countermeasures.

Decision-makers and planners should also find out well in time if the needed equipment, remedies, potential waste repository sites and manpower exist in the area, and to which extent it can be readily applied in an emergency situation. Also local demographic data sources should be identified and incorporated in strategies well in time, to optimise the effect of an operation. Further links should be established facilitating consultation of regional advisory organisations and agricultural experts to determine the local feasibility of the methods in relation to a particular emergency situation before including them in the intervention plan.

The methods described in this report focus on reduction of doses received from consumption of contaminated food. However, the populations will typically also be subjected to other dose contributions, particularly through external radiation from contamination in the environment. These latter dose contributions may also call for dose-reducing action. In this context, methods described in the earlier NKS project EKO-5 may be useful.

Other aspects than the traditional cost and benefit elements need to be considered. Not only the contamination as such, but also some of the methods suggested for mitigating its effect may have serious adverse psychological and social implications, which may under some circumstances be unacceptable. It is important that such implications are considered in the planning. Some psychological effects may be minimised through information, and it is therefore very important that such information reaches the public at an early stage. An important psychological benefit may be achieved if the local farmers or inhabitants can somehow actively improve their own situation. Many of the methods described enable this.

In the event of an accident, distribution of data-sheets may be an important means of quickly transferring knowledge to people in charge of implementing procedures.

9.2. Recommendations for further work

A more detailed categorisation system than that described in Chapter 4 has been suggested, representing the methodological data in relation to two parameters: 'time after release' (before deposition, short term, 1st season, long term) and 'stage of transfer through ecosystem' (snow, soil, vegetation, animals, food products, man). To this system, it is further suggested to introduce information on generally recommended priorities as a function of the time after release. Although the implementation of such a system would require further detailing of e.g. method-parameters with respect to time, it is considered that use of the system in connection with the creation of an electronic representation of the data and information designed for use on the internet would form an attractive tool to secure the dissemination of the project's results.

The future work could benefit from the results of the STRATEGY project, in which a decision framework will be established for selection of remediation strategies for e.g., contaminated rural areas. The STRATEGY project has recently obtained funding through the CEC 5th Framework, and has several participants among the authors of this report.

10. References

Alexakhin, R.M., Frissel, M.J., Schulte, E.H, Prister, B.S., Vetrov, V.A. & Wilkins, B.T.: Change in land use and crop selection, The Science of the Total Environment 137, pp. 169-172, 1993.

Andersson, I. & Lönsjö, H.: Transfer of Cs-137 in 2 farm ecosystems - calculated effects of countermeasures following a postulated fallout land contamination, Swedish J. Agric. Res. 18, pp. 195-206, 1988.

Andersson, I.: Transfer of Cs-137 from feed to lambs meat and the influence of feeding bentonite, Swedish Journal of Agricultural Research, 19: (2) 85-92, 1989.

Andersson, I., Teglof, B. & Elwinger, K.: Transfer of Cs-137 from grain to eggs and meat of laying hens and meat of broiler-chickens, and the effect of feeding bentonite, Swedish Journal of Agricultural Research, 20: (1) 35-42, 1990.

Andersson, K.G.: Evaluation of Early Phase Nuclear Accident Clean-up Procedures for Nordic Residential Areas, NKS Report NKS/EKO-5(96)18, ISBN 87-550-2250-2, 1996.

Andersson, K.G. & Roed, J.: The Behaviour of Chernobyl Cs-137, Cs-134 and Ru-106 in Undisturbed Soil: Implications for External Radiation, J. Environ. Radioactivity 22, pp. 183-196, 1994.

Andersson, K.G., Fogh, C.L., Byrne, M.A., Roed, J. & Goddard, A.J.H.: Radiation doses from contaminant aerosol deposition to the human body, in proceedings of the 12th ordinary meeting of the Nordic Society for Radiation Protection, Skagen, Denmark, pp. 177-180, published by IRPA, printed at Risø, ISBN 87-550-2617-6, 1999.

Andersson, K.G. & Roed, J.: A Nordic Preparedness Guide for Early Clean-up in Radioactively Contaminated Residential Areas, J. Environmental Radioactivity vol. 46, no. 2, pp. 207-223, 1999a.

Andersson, K.G., Fogh, C.L. & Roed, J.: Occupational Exposure at a Contemplated Belarussian Power Plant Fired with Contaminated Bio-mass, Radiation Protection Dosimetry vol. 83, No. 4, pp. 339-344, 1999b.

Bertilsson, J., Andersson, I. & Johanson, K.J.: Feeding green-cut forage contaminated by radioactive fallout to dairy cows, Health Physics 55, no.6, pp. 855-862, 1988.

Bobovnikova, C.I., Machonko, K.P., Siverina, A.A., Rabotna, F.A., Gutareva, V.P., Volokitin, A.A.: Atomnaya Energiya 71, 1991, p.449, as referenced by Tomasek et al., J. Radioanalytical Nucl. Chem. letters 201 (5), pp. 409-416, 1995.

Brynildsen, L.I., Selnaes, T.D., Strand, P. & Hove, K.: Countermeasures for radiocesium in animal products in Norway after the Chernobyl accident - Techniques, effectiveness, and costs, Health Physics 70(5), pp. 665-672, 1996.

Burmann, F.J.: Influence of grazing intensity on cesium-137 levels in milk, J. Dairy Science 50: 1891-1896, 1967.

Dahlgaard, H. (ed.): Nordic Radioecology - The transfer of radionuclides through Nordic ecosystems to man, Studies in Environmental Science 62, Elsevier, ISBN 0-444-81617-8, 1994.

Desmet, G. (ed.): Improvement of practical countermeasures: The agricultural environment: Post-Chernobyl action. Final report, ISBN 92-826-3272-5, EUR-12554, 1991.

Dewes, H.F., McLeay, L.M. & Harfoot, C.G.: Fly-ash, basic slag and Glenbrook slag toxicity in cattle, New Zealand Veterinary Journal 43: (3), pp. 104-109, 1995.

Eriksson, Å.: The cultivated agricultural environment, Part 2 of the NKS report 'Reclamation of contaminated urban and rural environments following a severe nuclear accident' (eds. P. Strand, L. Skuterud and J. Melin), NKS (97) 18, 97-10-10, ISBN 87-7893-017-0, 1997.

Eriksson, Å, Rosén, K. & Haak, E.: Retention of simulated fallout nuclides in agricultural crops, Report SLU-REK-R--80--SE, ISBN 9926554431, Sveriges Lantbruksuniversitet, 1998.

Fredriksson, L. , Eriksson, Å. & Haak, E.: Studies on Plant Accumulation of Fission Products under Swedish Conditions. II: Influence of Lime and Phosphate Fertilizer on the Accumulation of 89Sr in Red Clover Grown in 29 Different Swedish Soils Försvarets Forskningsanstalt, Rapport FOA 4A-4188-4623, 1961.

Fredriksson, L., Haak, E. & Eriksson, Å.: Studies on plant accumulation of fission products under Swedish conditions, XI. Uptake of 90Sr by different crops as influenced by liming and soil tillage operations. Försvarets forskningsanstalt avdelning 4. Report C 4395-28, Stockholm, 1969.

IAEA: Guidelines for agricultural countermeasures following an accidental release of radionuclides, Technical report series no. 363, ISBN 92-0-100894-5, International Atomic Energy Agency, Vienna, 1994.

Haak, E & Eriksson, Å. Studies on Plant Accumulation of Fission Products under Swedish Conditions XIV: Uptake of 137Cs by Wheat and Timothy from Six Different Soils as Influenced by Rate of K-Fertilization and by Type of N-Fertilization in Pot Experiments. Försvarets Forskningsanstalt, Rapport FOA 4 C-4557-A3, 1973.

Herlin, A.H. & Andersson, I.: Soil ingestion in farm animals, Sveriges Lantbruksuniversitet (JBT), Rapport 105, ISBN SLU-JBI-R--105--SE, 1996.

Hansen, H.S. & Hove, K.: The effect of exercise on Cs-134 retention in lambs, J. Environ. Radioactivity 19, pp. 53-66, 1993.

Hansen, H.S., Hove, K. & Barvik, K.: The effect of sustained release boli with ammoniumiron(III)-hexacyanoferrate(II) on radiocesium accumulation in sheep grazing contaminated pasture, Health Physics 71(5), pp. 705-712, 1996.

Hove, K: Chemical methods for reduction of the transfer of radionuclides to farm animals in semi-natural environments, The Science of the Total Environment, 137, pp. 235-248, 1993.

Howard, B.J., Beresford, N.A., Mayes, R.W., Hansen, H.S., Crout, N.M.J. & Hove, K.: The use of dietary calcium intake of dairy ruminants to predict the transfer coefficient of radiostrontium to milk, Radiation And Environmental Biophysics 36: (1) 39-43, 1997.

Hubert, P., Annisomova, L., Antsipov, G., Ramsaev, V. & Sobotovitch, V. (editors): Strategies of decontamination, Experimental collaboration project 4, CEC report EUR 16530 EN, ISBN 92-827-5195-3, 1996.

IAEA: Guidelines for agricultural countermeasures following an accidental release of radionuclides. A joint undertaking by the IAEA and FAO. Technical reports series no. 363, International Atomic Energy Agency, Vienna, 1994a.

IAEA: Handbook of parameter values for the prediction of radionuclide transfer in temperate environments, Technical report series no. 364, International Atomic Energy Agency, Vienna, 1994b.

IAEA: Application of radiation protection principles to the cleanup of contaminated areas - Interim report for comment, IAEA Tecdoc-987, International Atomic Energy Agency, Vienna, December 1997.

ICRP: Age-dependent doses to members of the public from intake of radionuclides: part 5 - Compilation of ingestion and inhalation dose coefficients, ICRP Publication 72, Pergamon Press, Oxford, 1995.

Jacob, P., Müller, H., Pröhl, G., Voigt, G., Berg, D., Paretzke, H.G. & Regulla, D.: Environmental behaviour of radionuclides deposited after the reactor accident of Chernobyl and related exposures, Radiation and Environmental Biophysics 32: (3), pp. 193-207, 1993.

Junker, H., Jensen, J.M., Jørgensen, H.B., Roed, J., Andersson, K.G., Kofman, P.D., Bøllehuus, E., Baxter, L., Grebenkov, A.: Chernobyl Bioenergy Project, Final Report, Phase 1, Elsamprojekt report no. EP 8204, 1998.

Lönsjö, H & Haak, E. Uptake of ^{90}Sr by agricultural crops as influenced by soil type, liming rate and PK-fertilization in a long term microplot experiment. Report 31, Radiobiology, Uppsala, 1975.

Lönsjö, H., Haak, E. & Rosén, K. Effects of remedial measures on the long-term transfer of radiocaesium from soil to agricultural products as calculated from Swedish field experimental data. Proceedings. FAO/IAEA/UNEP/WHO International Symposium on Environmental Contamination Following a Major Nuclear Accident, 16-20 October 1989, Vienna, Austria, pp 151-162, 1990.

McEnri C. M., Mitchell P. & Cunningham, J. D.: The transfer of radiocaesium from whole milk to milk products. in proceedings of the CEC-seminar 18.-21. September 1989, Cadarache, France. Report of CEC DG XI, and IPSN, France, 1990.

Meisel S., Gerzabek M.H. & Muller H.K.: Influence of plowing on the depth distribution of various radionuclides in the soil, Pflanzenerähr. Bodenk., 154(3), 211-215, 1991.

Mueck, K, Suda, M., Gerzabek, M. & Kunsch, B.: Ingestion dose response to the deposition date in the first year after radionuclide deposition, Rad. Prot. Dosimetry vol. 42, No. 2, pp. 103-114, 1992.

Nielsen, O.J.: A literature review on radioactivity transfer to plants and soil, Risø-R-450, Risø National Laboratory, 1981.

Nisbet, A.F. & Woodman, R.F.M.: Soil-to-plant transfer factors for radiocaesium and radiostrontium in agricultural systems, Health Physics, vol. 78, no. 3, pp. 279-288, 2000.

Petäjä, E., Rantavaara, A., Paakkola, O. & Puolanne, E.: Reduction of radioactive caesium in meat and fish by soaking, J. Environ. Radioactivity 16, pp. 273-285, 1992.

Pirhonen T, Uusi-Rauva E, Rantavaara A & Rauramaa A.: The radioactivity of milk and milk products in Finland. Meijeritieteellinen aikakauskirja 1987; XLV: 62-75, 1987.

Preuthun, J., Brink, M., Rantavaara, A., Runólfsson, H. & Salbu, B. (eds.): Från jord till bord - EKO-3.4 Rapport 1997 (in Swedish), NKS Report NKS/EKO-3.4(97)TR1, ISBN 87-7893-041-3, 1997.

Prister, B.S., Perepelyatnikov, G.P. & Perepelyatnikova, L.V.: Countermeasures used in Ukraine to produce forage and animal food products with radionuclide levels below intervention limits after the Chernobyl accident, The Science of the Total Environment, 137, pp. 183-198, 1993.

Qvenild, C. & Tveten, U.: Decontami-nation and winter conditions, Inst. for Energy Technology, Kjeller, Norway, ISBN 82-7017-067-4, 1984.

Rafferty, B., Dawson, D.E. & Colgan, P.A.: Seasonal variations in the transfer of 137Cs and 40K to pasture grass and its ingestion by grazing animals, The Science of the Total Environment 145, pp. 125-134, 1994.

Rajama, J. & Rantavaara, A.: Radioactivity in Finnish cereals from 1962 to 1980, STL-A41, Säteilyturvallisuuslaitos (currently: STUK, Radiation and Nuclear Safety Authority), 1982.

Rantavaara A.: Transfer of radionuclides during processing and preparation of foods - Finnish studies since 1986. Proceedings of the CEC-seminar 18.-21. September 1989, Cadarache, France. Report of CEC DG XI, and IPSN, France, pp. 69-94, 1990.

Renaud, Ph. & Maubert; H.: Agricultural countermeasures in the management of a post-accidental situation, J. Environ. Radioactivity, vol. 35, No. 1, pp. 53-69, 1997.

Roed, J.: Run-off from and weathering of roof material following the Chernobyl accident, Rad. Prot. Dosimetry vol. 21, no. 1/3, pp. 59-63, 1987.

Roed, J.: Deposition and removal of radioactive substances in an urban area, Final report of the NKA project AKTU-245, NKA, ISBN 87 7303 514 9, 1990.

Roed, J., Andersson, K.G. & Prip, H. (editors): Practical means for decontamination 9 years after a nuclear accident, Risø National Laboratory, Report Risø-R-828 (EN), ISBN 87-550-2080-1, 1995.

Roed, J., Andersson K.G. & Prip, H.: The Skim and Burial Plough: a New Implement for Reclamation of Radioactively Contaminated Land, J. Environmental Radioactivity vol.33, no.2 pp. 117-128, 1996.

Roed, J., Andersson, K.G., Fogh, CL., Olsen, S.K., Prip, H., Junker, H., Kirkegaard, N., Jensen, J.-M., Grebenkov, A.J., Solovjev, V.N., Kolchanov, G.G., Bida, L.A., Klepatzky, P.M., Pleshchenkov, I.G., Gvozdev, A.A., & Baxter, L.: Power production from radioactively contaminated biomass and forest litter in Belarus - Phase 1b, Risø-R-1146(EN), ISBN 87-550-2619-2, 2000.

Rosén, K.: Field studies on the behaviour of radiocaesium in agricultural environments after the Chernobyl accident. Pp 1–65. Report SLU-REK-78. Uppsala, 1996a.

Rosén, K.: Transfer of Radiocaesium in Sensitive Agricultural Environments after the Chernobyl fallout in Sweden. II. Marginal and semi-natural areas in the county of Jämtland. Sci. Total Environ, Vol. 182. Nos. 1-3, pp 135-145, 1996b.

Rosén, K.: Underlag för utarbetande av myndigheternas rekommendationer till lantbrukare i händelse av en kärnenergiolycka - Efter ett larm, men före nedfallet av radioaktiva ämnen, Rapport SLU-REK-79, Uppsala, pp. 1-24 (in Swedish with English summary), 1997.

Rosén, K., Eriksson, A. & Haak, E.: Transfer of radiocaesium in sensitive agricultural environments after the Chernobyl fallout in Sweden .1. County of Gavleborg, Sci. Total Environ. 182: (1-3) 117-133, 1996.

Salbu, B., Krekling, T.& Oughton, D.: Characterisation of radioactive particles in the environment, Analyst, May 1998, vol. 123, pp. 843-849, 1998.

Salbu, B.: Actinides associated with particles. J. Environ. Radioact. Booklet. In press, 1999.

Salt, C.A., Grande, J., Hanley, N., Solheim Hansen, H., Lettner, H., Kirchner, G., Rekolainen, S., Bärlund, I., Baumgartner, R., Berreck, M., Culligan Dunsmore, M., Ehlers, H., Ehlken, S., Gastberger, M., Haselwandter, K., Hormann, V., Hosner, F., Peer, T., Pintaric, M., Tattari, S. & Wilson, M.: Countermeasures: Environmental and socio-economic responses, Final report of the project CESER, co-funded by the Nuclear Safety Programme of the European Commission, Contract FI 4P-CT95-0021, University of Stirling, UK, 1999.

Schnitzer, M. & Khan, S.U.: Soil organic matter, Elsevier, 1978.

Statistisk Årbog 1999, Danmarks Statistik, Sejrøgade 11, DK-2100 København Ø, 103. årgang, ISBN 87-501-1070-5, 1999.

Strand, P., Skuterud, L. & Melin, J. (editors): Reclamation of contaminated urban and rural environments following a severe nuclear accident, NKS report NKS (97) 18, 97-10-10, ISBN 87-7893-017-0, 1997.

Thatcher, T.L. and Layton, D.W.: Deposition, resuspension and penetration of particles within a residence, Atmospheric Environm. vol. 29, No. 13, pp. 1487-1497, 1994.

Tomasek, M., Rybacek, K., Wilhelmova, L.: Chemical fraction of radioactive cesium in atmospheric aerosol in Prague after the Chernobyl accident, J. Radioanalytical Nucl. Chem. letters 201 (5), pp. 409-416, 1995.

Ulvsand, T., Andersson, K.G., Holst Hansen, J., Preuthun, J., Sinkko, K., Svennerstedt, G., Uhnger, S.: Tidiga åtgärder vid sanering efter kärnkraftsolyckor, riktlinjer för planeraren (in Swedish), FoU rapport P21-209/97, Räddningsverket, Karlstad, Sweden, ISBN 91-88891-16-X, 1997.

Vandenhove, H. (editor): RECOVER - Relevancy of short rotation coppice vegetation for the remediation of contaminated areas, Final report of CEC project F14-CT950021c (PL 960 386), Belgian Nuclear Research Centre, Mol, Belgium, 1999.

Voigt, G., Henrichs, K., Pröhl, G., Paretzke, H.G.: Measurements of transfer coefficients for ^{137}Cs, ^{60}Co, ^{54}Mn, ^{22}Na, ^{131}I and ^{95m}Tc from feed into milk and beef, Radiat. Environ. Biophys. 27, pp. 143-152, 1988.

Voigt, G., Müller, H., Pröhl, G. & Paretzke, H.G.: Cesium activity distribution of cereals after milling processes, in proceedings of the Seminar on Radioactivity Transfer during Food Processing and Culinary Preparation, held by the Commission of the European Communities DGXI in Cadarache, France, 18-21 September, 1989, CEC, 1990.

Voigt, G.: Chemical methods to reduce the radioactive contamination of animals and their products in agricultural ecosystems, The Science of the Total Environment, 137, pp. 205-226, 1993.

Watterson, J.D. & Nicholson, K.W.: Dry deposition and interception of 4-22 μm diameter particles to a lettuce crop, J. Aerosol Sci. vol. 27, No. 5, pp. 759-767, 1996.

Willdrodt, C.: Agrotechnical countermeasures to be applied before and during deposition of radioactive fallout, The Science of the Total Environment, 137, pp. 21-29, 1993.