Modelling approach in the terrestrial late countermeasures module, LCMT within RODOS 4.0

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Modelling approach in the terrestrial late countermeasures module, LCMT within RODOS4.0

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Management Summary

This document provides a description of the modelling approach adopted in the terrestrial late countermeasures module, LCMT within RODOS V4.0. The document also contains information on the program flow and logic of LCMT and gives a description of the input and output from the module. A summary of the default values for the supporting data used with the models is also provided. Details of the interfaces between LCMT and other modules of RODOS and the supporting database used are given elsewhere.

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1 Introduction

As part of an EC Project to develop a decision-aiding support system (RODOS) for emergency response in the EC, NRPB has developed models to assess the consequences of late countermeasures and have produced a Late Countermeasures Module called LCM. LCM comprises two main modules. The first considers countermeasures applied in the terrestrial environment; these are relocation, decontamination and agricultural countermeasures affecting food; the module for the terrestrial pathway is called LCMT. The second module considers countermeasures applied in the aquatic environment; this module is called LCMA. The endpoints calculated by LCMT include the doses saved by the introduction of the countermeasures, the time over which the countermeasures will be in force, and the areas of land, numbers of people and amount of food affected. These endpoints are calculated for various countermeasure criteria.

This document is a description of the modelling approach adopted in the LCMT module for version 4.0 of RODOS. The modelling approach for LCMA is described elsewhere[1]. LCMT is divided into several sub-modules considering the three areas of countermeasure modelling included in the module. In addition there is a control sub-module. This document contains information on the methodologies adopted for the modelling of relocation, decontamination and agricultural countermeasures. A description of the user–selected input, the results calculated and a summary of the output interfaces with other modules of RODOS are also given. A summary of the supporting data used in the models and the default values provided with LCMT is provided. Finally, there is a description of the program flow and logic of LCMT. Details of the input and output interfaces with other modules of RODOS are given elsewhere.[2]

1.1 Quality assurance in development of LCMT

The LCMT module has been developed under NRPB's Environmental Assessments Quality Assurance System for application in the area of computer code development and radiological impact assessment. The Department is ISO9001 accredited. The RODOS project QA standards were also adopted.

2 LCMT STRUCTURE

LCMT consists of a collection of subroutines which perform the calculations necessary for the five main options available to the user running LCMT as described below in sections 2.1.1 and 2.1.2. For ease of description and in a manner relating to the tasks they perform, the various subroutines have been grouped into four sub-modules, namely the overall control of LCMT and the three countermeasure options; food, relocation and decontamination. The relationship between these sub-modules is illustrated in Figure 1. The names and broad functions of each sub-module are:

LCMTC - controls and directs the other sub-modules

LCMTR - assesses the consequences of relocation

LCMTF - assesses the consequences of food countermeasures

LCMTD - assesses the consequences of decontamination

The structure of LCMT has been developed to enable the countermeasure options to be considered separately and provides a flexible structure into which other models or sub-modules could be added in the future.

2.1 AUTOMATIC AND INTERACTIVE MODES

RODOS is able to operate in two modes, an Automatic mode and an Interactive mode. LCMT has been developed to address the different calculations required in these two modes of operation.

In Automatic mode, the purpose of LCMT is to give the user an indication of the size of the accident in terms of the areas potentially affected by food restrictions and relocation of the public, and the time period over which there is likely to be a problem. There is no user-interface in this mode of operation. The calculation time for the Automatic mode is of the order of one minute.

In Interactive mode, the complete range of countermeasure options and criteria are available, allowing the user to choose a number of options and to customise the criteria on which the countermeasures are implemented through an interface comprising a number of user-windows and associated data files. The countermeasures cover those which may be implemented in the first few days following the accident to those implemented several years after the accident, some with permanent implications on the population and agricultural practices.

The rationale for the interactive mode is that the user should have the flexibility necessary to make an evaluation of the effectiveness of a range of countermeasure options within LCMT. LCMT provides the information for this evaluation to be made.

2.1.1 Automatic mode

In the automatic mode, the option RELOCATION and FOOD is run in LCMT. Decontamination is not considered. There is no interaction from the user, although the user can pre-set the criteria for relocation and food restrictions through data file entry. The calculations for FOOD are limited to green vegetables and milk which can be considered indicative of other crops and animal products.

2.1.2 Interactive mode

In the interactive mode, the user may select one of the following four options.

1	RELOCATION and FOOD **(default)**
2	RELOCATION only
3	FOOD only
4	DECONTAMINATION only

If option 2 is selected, LCMT assesses the impact of relocation with the option to estimate the impact on relocation of a user-selected decontamination strategy. If option 3 is selected, the system assesses the impact of large number of single agricultural countermeasures, including decontamination of agricultural land, for up to 40 foods. Option 1 is the combination of options 2 and 3. Option 4 allows the user to assess the impact on external and resuspension doses of a chosen decontamination strategy.

These 4 options form the *exploratory mode* which enables the full flexibility of LCMT to be accessed and all endpoints to be calculated. Single countermeasure options and selected combinations of options may be considered in any one run of LCMT. The influence of relocation on agriculture, i.e. changes in production and livestock management, can be considered within LCMTF. The identification of areas where relocation is required and the impact of decontamination of inhabited areas and previous evacuation on relocation are included within LCMTR.

An additional mode of operation has been defined for FOOD called the *decision mode*. This forms Option 5. The *decision mode* applies only to the calculation of agricultural countermeasure effectiveness within LCMTF. The modelling of the influence of relocation on agricultural production is not included. In this mode, endpoints are produced for the evaluating sub-system of RODOS, ESY. Only one food may be considered in a *decision mode* run, with the underlying assumption that this food has been chosen on the basis of the results from previous *exploratory mode* runs. The user can only consider a single scenario, eg a particular deposition pattern in each run of the system. The program flow and logic is described in more detail in Appendix A.

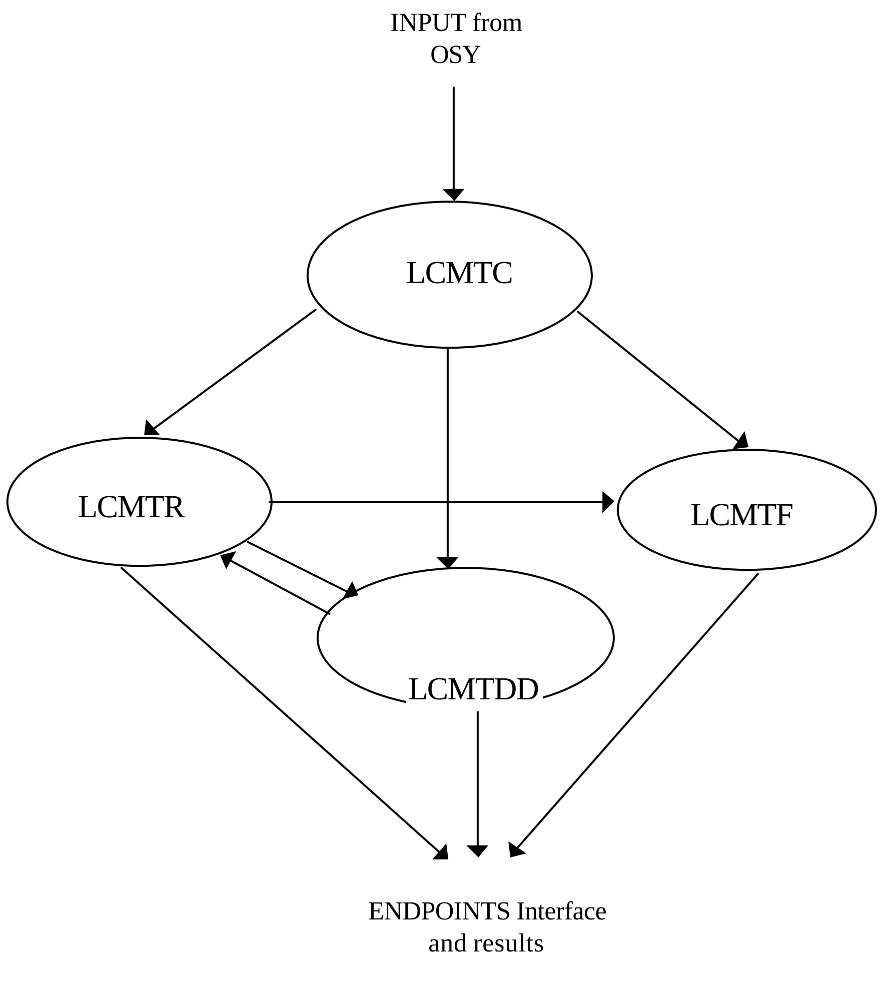
The selection of these options is handled by user-windows in RODOS.

2.2 DATA ORGANISATION

The operating subsystem (OSY) of RODOS allows data to be held in areas of shared memory. LCMT may use the same areas of memory as other modules of RODOS, so instead of explicitly reading data files produced by previous modules and writing data files for modules which follow, LCMT accesses the areas of shared memory which it requires for input and writes endpoints to other areas of shared memory.

There are two types of endpoints produced by RODOS modules. Interface endpoints are those generated by LCMT for use by another RODOS module or subsystem, eg output from LCMT for the ECONOMICS module. Results endpoints are generated if requested by the user.

Figure 1: Overall structure of LCMT



3 Relocation sub-module, LCMTR

The purpose of LCMTR is to calculate endpoints related to the imposition of relocation of the population in the presence or absence of land decontamination. Two types of relocation are considered, temporary and permanent. These are defined below:

Permanent Relocation is the removal of people from an area with no expectation of their return, however, the land may be released at a later stage and resettled by different individuals.

Temporary Relocation is the removal of people from an area for an extended but limited period of time.

The endpoints determined relate to the areas interdicted, the time periods over which this occurs, the numbers of people relocated, the doses received and saved as a result of relocation, and information on the areas decontaminated. Details of the program flow and logic for generating the required endpoints for relocation are given in Appendix A.

3.1 METHODOLOGY

Relocation is a countermeasure applicable in the post-release phase following an accident. The exposure pathways potentially of importance in this phase are: external irradiation from deposited activity, inhalation of resuspended material, and ingestion of contaminated food. Relocation is intended to protect against the first two. It is unlikely to be implemented to protect people against ingestion of contaminated food, since this can be more readily achieved by placing restrictions on the consumption of food. Therefore the doses compared with relocation dose criteria are the sum of the individual committed effective inhalation dose from intakes over a specified period, and the individual effective external gamma dose integrated over the same period. This summed dose is referred to as the 'individual effective dose'.

Two types of dose can be considered, normal living doses and outdoor doses, the user selecting one or other of these. Outdoor doses are calculated assuming an individual is permanently outdoors; normal living doses take into account the time spent indoors and outdoors by individuals, making allowance for the shielding of buildings whilst an individual is indoors. The modification of the outdoor dose to allow for normal living is achieved using a location factor which may vary with spatial grid point. The choice of outdoor or normal living doses by the user determines the doses used throughout the calculations made in LCMTR and the endpoints calculated. If the user wants to calculate HEALTH endpoints, normal living doses should be chosen.

In line with current recommendations, effective dose is used to compare with the relocation criteria. The criteria are expressed in terms of doses integrated over a period which can be chosen by the user and for one of 5 age groups. The choice of criteria must be consistent with the choice of normal living or outdoor doses made for calculations and endpoints in LCMTR. The user also specifies the first time at which doses are to be compared with the implementation criterion, and the time delay after relocation starts at which relocation is modelled as completed.

To determine whether relocation should be imposed individual effective doses are summed over radionuclide and deposition event and are integrated over a number of exposure periods which is the length of the period specified by the criterion for imposition of relocation. The first exposure period begins when doses are first compared with the relocation criterion but because the dose may rise as a result of future deposition events the dose in sequential periods is calculated to ensure that all deposits have been included. If the individual effective dose received in the exposure period for the user specified age group is greater than or equal to the dose criterion then some form of relocation will be necessary. The start of the first time period when the relocation criterion is exceeded is taken as the start time for relocation. However, dose is also accrued for the period taken for relocation to be implemented which is specified by the user.

The relaxation criterion is sequentially compared against the individual effective dose received in the same time period, starting from when relocation begins and stepping through time in units of time defined by the relaxation criterion (ie if the criterion is x mSv in a month, then time is stepped through in monthly intervals). The exception to this is when the criterion for relaxation of relocation is expressed as the individual effective dose received from a lifetime's exposure. In this case the individual effective dose received is calculated initially for a lifetime's exposure beginning at the time relocation starts, but thereafter for a lifetime's exposure beginning at yearly intervals after the accident. In this way it is possible to find out if relaxation of relocation at this location. If the actual dose received drops below the criterion, then relaxation of relocation is permitted at the start of that time period. If the end of the time grid is reached before return from relocation is permitted then a warning message is issued. The duration of relocation is compared with the maximum duration of temporary relocation to determine the type of relocation necessary. If the relocation duration exceeds that specified by the user for temporary relocation, relocation is assumed to be permanent.

3.1.1 *Impact of evacuation on relocation implementation*

The user has the option of taking into account any previous evacuation that has taken place when looking at the impact of relocation on reducing individual effective doses. If this option is evoked and evacuation has occurred somewhere, the time when doses are first compared with the relocation criterion will be the time at which evacuation ends. If evacuation has not occurred, the time when doses are first compared with the relocation criterion will be the time chosen by the user. The individual effective doses potentially received for the time periods which fall into the period of evacuation are set to zero. Where a time period only partially falls in the evacuation period it will be assumed that the dose rate is uniform over that period and the fraction of the dose equal to the fraction of the period that overlaps will be set to zero.

3.1.2 *Impact of decontamination on relocation implementation*

The user can choose to consider the influence decontamination has on the need for relocation. Decontamination can be chosen to take place only at those locations where potential relocation (ie relocation in the absence of decontamination) is necessary or in the whole area that is contaminated. In the first case, the area requiring relocation is identified, decontamination is applied in this area and the need for relocation is then recalculated. In the second case, decontamination is implemented in the whole contaminated area prior to calculation of any required relocation area. The user can chose up to five decontamination strategies to be considered in a single run. A detailed description of the decontamination options is given in Section 5.

3.1.3 *Relocation and food restrictions*

If the user requests the consideration of both FOOD and RELOCATION options in the Interactive mode (see Section 2.1), the implications of relocation on food production and food countermeasures can be considered. This is considered within the LCMTF module and the approach adopted is described in Section 4.1.5. LCMTR is required to pass information on the areas affected and the time periods for which land is interdicted to LCMTF.

3.1.4 *Re-contamination of area due to long range dispersion*

If a location receives additional contamination due to the return of the plume, ie there are several deposition events at a location, the external and resuspension doses arising from each event are calculated and summed to give a total temporal profile of the individual doses prior to comparison with the relocation criteria and further calculations in LCMTR.

3.2 Input to LCMTR

LCMTR receives information from within LCMT and from other modules of RODOS. Specific details of the interfaces with other RODOS modules are given in reference 2.

LCMTR also requires information from the user via input-windows while running the RODOS system. These include selected criteria for the imposition and relaxation of relocation, information on decontamination options and the selection of options such as whether the impact of evacuation is to be considered. Default values have been given for all input information that can be selected by the user; the user is free to overwrite any of this information. The choice of default values is described in detail in reference 3. A summary of the information available for selection or for changing by the user for running LCMTR and the default values are given in Tables 1 and 2, respectively.

Selection of Input:	
Impact of evacuation	No impact Include impact of evacuation
Selection of relocation criteria	Normal living or outdoor doses Imposition dose criteria Relaxation dose criteria Time when relocation first considered Age group
Selection of decontamination options	No decontamination (default) Decontamination in relocated areas Decontamination at all contaminated locations
Selection of decontamination strategies (if option selected to decontaminate)[a]	Techniques Decontamination factors
Selection of other organs for dose calculations	

Note:

(a) See Section 5 for details on decontamination selection.

Table 1: Summary of Input Window Information for LCMTR

Input Window	Parameter	Default value
Impact of evacuation		No impact
Doses for comparing with criteria		Normal living
Relocation criteria	Imposition criteria	15 mSv
	Time period	365 days
	Relaxation criteria	15 mSv
	Time period	365 days
	Time when relocation first considered	1 day
	Implementation time: Temporary relocation Permanent relocation	 0 days 0 days
	Maximum duration of temporary relocation	730 days
Age group for criteria		Adult
Decontamination options		No decontamination

Table 2: Default input data for relocation

3.3 Endpoints available directly to the user

A number of endpoints are displayed graphically to the user; these are described below for the *automatic* and *interactive* modes. A summary of the endpoints for the *interactive mode* is given in Table 3.

3.3.1 Automatic Mode

Time when relocation ends

The time when relocation ends (days) for each spatial grid point is displayed to the user on a map.

The area relocated as a function of time (km^2)

The area relocated is calculated by summing up the area of each relocated spatial grid point at each time. If an area is resettled by new individuals following permanent relocation then the area is not included in this endpoint. This endpoint is displayed to the user as a graph.

The number of people relocated as a function of time

The number of people relocated as a function of time is calculated by summing up the number of people at each spatial grid point for which relocation is implemented at each time. If an area is resettled by new individuals following permanent relocation then this endpoint still includes those individuals who were originally relocated. This endpoint is displayed to the user as a graph.

3.3.2 Interactive Mode

Lifetime individual effective doses received

The individual doses are summed over all time periods to age 70 and over exposure pathway, radionuclide and deposition event to get the expected individual lifetime dose received, taking into account any relocation that has been implemented. The doses from each exposure pathway are also produced. Doses are presented for adults and up to 2 other ages and for effective dose and one other organ as specified by the user in the FDMT module of RODOS. No reduction in dose is assumed until the end of relocation implementation time which is defined by the user. The individual doses received at each spatial grid point is displayed to the user on a map.

Collective effective dose saved

The collective dose saved is calculated from the sum of the individual lifetime dose saved by relocation at each location multiplied by the number of people at each location and then summing over all spatial grid points for adults only. The doses from resuspension, external irradiation and the sum over exposure pathways are provided. This endpoint is displayed to the user as text.

Time when relocation ends

The time when relocation ends (days) for each spatial grid point is displayed to the user on a map.

The area relocated as a function of time (km^2)

See Section 3.3.1.

The number of people relocated as a function of time

See Section 3.3.1.

Map showing if decontamination has been implemented at each spatial grid point.

Total resources required for decontamination option chosen

The total resources required are calculated by multiplying the total area of decontaminated surface by the resource requirements per unit area. The area of the surface decontaminated is used which is a fraction of the total area of land. The total man hours of effort (man hours) and total waste produced (kg) are displayed as text. Section 5 gives more details of these endpoints.

3.4 Endpoints to other modules of RODOS

Endpoints are calculated for the HEALTH and ECONOMICS modules of RODOS. Details of the interfaces with these modules are given elsewhere[2]. A summary of the endpoints calculated is given in Table 3.

Graphical display	ECONOMICS MODULE	HEALTH MODULE (SIMPLE)	HEALTH MODULE (COMPLEX)[a]
Lifetime individual dose received as function of location, Sv (resuspension, external and total)	Maximum duration of temporary relocation, days	Lifetime adult individual effective dose saved as function of location, Sv	Individual dose saved (5 ages, 4 selected organs) integrated to a number of times as function of location
Total lifetime collective dose saved, manSv (resuspension, external and total)	Flag to indicate if relocation has occurred at any time and spatial grid point.		
Time when relocation ends, days	Relocation status (temporary, permanent or none) of each spatial grid point as function of time		
Area relocated as function of time, km^2	Number of people temporarily relocated as function of time		
Number of people relocated as function of time	Number of people permanently relocated as function of time		
Where decontamination implemented as function of location	Area interdicted as a result of temporary relocation as function of time, km^2		
Total resources required for relocation, effort (man hrs) and waste (kg)[b]	Area interdicted as a result of permanent relocation as function of time, km^2		
	Number of people normally resident at all locations which are decontaminated.		
	Area decontaminated, km^2		
	Time at which decontamination is implemented, days		
	Effort resources required for decontamination, man hr / m^2 [b]		
	Active area work efficiency factor		
	Waste generated from decontamination, kg m^{-2} [b]		
	Type of decontamination implemented		

Notes:

(a) Only generated if organs required passed from FDMT

(b) Only generated if decontamination technique option is chosen

Table 3: Summary of endpoints for RELOCATION OPTION

4 Agricultural countermeasures sub-module, LCMTF

The purpose of LCMTF is to calculate endpoints related to the imposition of countermeasures on food. The food countermeasures considered are: food disposal and stopping of production, food storage, food processing, supplementing animal feedstuffs with uncontaminated, lesser contaminated or different feeds, use of sorbents in animal feeds or boli, changes in crop variety and species grown, amelioration and change in land use. The foods that are considered in LCMTF are given in Table 4. The effects of relocation and decontamination of agricultural land on the imposition of food bans are also considered. Appendix A describes more fully the interaction of LCMTF with the other sub-modules of LCMT and the general program flow of this sub-module.

The endpoints calculated relate to the areas of land and quantities of food affected, the time periods over which countermeasures are implemented and the doses saved as a result of the various food countermeasures.

Foods		
spring wheat (whole)	leafy vegetables	goat's milk
spring wheat (flour)	root vegetables	sheep's milk
spring wheat (bran)	fruit vegetables	beef (cow)
winter wheat (whole)	fruits	beef (bull)
winter wheat (flour)	berries	veal
winter wheat (bran)	cow's milk	pork
rye (whole)	condensed milk	lamb
rye (flour)	cream	chicken
rye (bran)	butter	roe deer
oats	cheese (rennet)	eggs
potatoes	cheese (acid)	beer

Table 4: Foods considered in LCMTF

4.1 METHODOLOGY

Food countermeasures may be implemented within a few days of the accident and over long periods of time. The exposure pathways of importance during these phases are external exposure from deposited activity, inhalation of resuspended material and ingestion of contaminated food. The banning of food is intended to protect against the last of these.

In LCMTF, countermeasure options that could be effective in the short and medium term in reducing activity concentrations in food can be studied. LCMTF can also be used to provide an indication of options that may be effective in the longer term. It is not envisaged, however, that LCMTF will be used in isolation in the long term for the evaluation of agricultural countermeasure strategies; these will be largely based on measurements in the environment and experimental research into countermeasure effectiveness.

4.1.1 Implementation of food restrictions

The first calculation that is performed in LCMTF is a comparison of the activity concentrations in each food with the activity concentration criteria for imposition of food bans to determine if the banning of food would be required in the absence of countermeasures for each spatial grid point that is contaminated. Foods for which activity concentrations are passed to LCMT from FDMT for the raw food form, eg. milk, are compared directly with the criteria. Activity concentrations in foods in their processed form, eg. butter are also calculated in FDMT and these concentrations include the effect of radioactive decay, delay times and processing losses. The activity concentrations in these processed foods are also compared with the criteria. The banning of food in the absence of countermeasures is assumed for the length of time activity concentrations are above the criteria and during this time the food is not available for consumption unless countermeasures are implemented which reduce the activity concentrations below the criteria. If the activity concentrations in a particular food drop below the criteria and then rise above it at some later time, eg. milk concentrations rising due to cattle being fed stored feed during the winter, the assumption is made that, in the absence of countermeasures, the food is banned from the start of the imposition until the last time at which the activity concentrations fall below the criteria. The banning of animal feeds is not considered.

If food restrictions are not required for any of the foods considered, no further calculations in LCMTF are performed. If a ban is required in the absence of countermeasures for a particular food the spatial and temporal extent of the affected area is calculated.

If the banning of a food is required in the absence of countermeasures, a number of food countermeasure options can be considered in the Interactive mode to explore if the need for the food ban can be avoided or its severity reduced; these are outlined below.

4.1.2 Inhalation by Animals

Contamination of animal products may occur from either ingestion of contaminated feeds or from inhalation whilst the radioactive plume is passing. The effects of inhalation by animals on the endpoints calculated by LCMTF have been included for completeness to take into account situations where the products may be contaminated via the inhalation pathway while animals are not consuming contaminated feed. This situation might arise if the animals are indoors eating uncontaminated fodder while the plume passes. In this situation, the deposition pathway would be zero and the inhalation pathway would be the only contribution to the activity concentrations in the animal product. The activity concentrations in the animal are likely to be low from this pathway, but, at least in theory, the situation could arise where the inhalation of the plume could give rise to the activity concentrations exceeding the ban criterion for a short period.

If the animal products are contaminated via the ingestion pathway, the relative contribution to the time-integrated activity concentration from any inhalation will only be small. Any period of intake by inhalation will occur during the release phase and will be relatively short compared to that over which intakes from ingestion occur. The length of contribution to the activity concentrations does, however, depend on the half-life of the radionuclide in the animal's body. There is also the possibility that the ingestion of radionuclides may not start until some weeks after the accident, in which case enhanced activity concentrations in animal products, due to inhalation alone, may be observed at early times.

There are only a few countermeasures which are suggested in some emergency plans which can be undertaken in order to reduce the activity concentrations in animals resulting from inhalation of radionuclides. Moving the animals from the plume may or may not be practical, depending on the number of animals involved. The prime purpose of any animal movement would be to prevent the animals eating contaminated pasture, but this may also reduce the inhaled component. Sheltering the animals 'indoors' may or may not reduce the inhalation component, depending on how low the air exchange rates in the farm buildings are. However, none of the countermeasures currently considered in RODOS would achieve reductions in activity concentrations resulting from inhalation of radionuclides. Of the countermeasures currently considered in LCMTF, only the countermeasure 'disposal and stopping production' can be used to prevent the activity concentrations in the animal product resulting from inhalation reaching the human food chain.

A simple approach has been adopted in LCMTF to include the pathway of inhalation by animals. The activity concentrations in foods arising from animals inhaling are included in the activity concentrations compared with the ban criteria to see if any action is required. If the option of 'disposal and stopping of production' is considered, the inhalation component is taken into account in the estimation of the reduction in activity concentrations achieved. All other countermeasures considered in LCM, of relevance to animals, involve the reduction in the contamination arising from ingestion of feeds. For these countermeasures, the inhalation component is not included in the calculation of the effectiveness of the countermeasure in reducing activity concentrations.

Any component of the total activity concentrations in animal products arising from animals inhaling is included in the calculation of the dose endpoints calculated in LCMTF.

4.1.3 Food Countermeasure Options

4.1.3.1 Food disposal or stopping of food production

If foods with activity concentrations which exceed the food banning criteria are harvested, disposal of that food may be necessary. Within LCMTF one countermeasure option considered is the disposal of all food produced which exceeds the criteria and this can be applied to all foods considered. It is assumed that disposal is continued for the duration that the activity concentrations exceed the criteria and the quantities of food affected are calculated. In practice, however, it is unlikely that disposal will be implemented in the long term. Therefore, within LCMTF stopping of food production is also considered. The assumption is made that food is only disposed of for a specified period following the accident which can be selected by the user via the Input Windows. If the activity concentrations exceed the criteria beyond this time food production is stopped for the remaining length of time that the criteria are exceeded.

4.1.3.2 Food processing

Food processing is only considered for cows milk and whole wheat which can be processed into milk products and flour, respectively. The options for other foods are freezing, drying or canning and this implicitly implies storage which is considered as a separate option. The activity concentrations in canned or frozen foods will not be significantly different from those in the fresh produce and so the problem reduces to one of storage.

Processing is only considered if there would be a ban on the fresh food but the concentrations in the processed food do not exceed the ban criteria under normal processing conditions.

The processing routes considered are :

cows milk into cheese (acid and rennet), butter, cream, condensed milk

summer wheat (whole) into summer wheat flour and bran

winter wheat (whole) into winter wheat flour and bran

rye (whole) into rye flour and bran

The assumption is made that there are no differences between processing as a countermeasure and processing food under normal conditions in terms of the activity concentrations in the processed food. Delays between production of the raw food and consumption of the processed food are included. A further option of chemically decontaminating milk can be considered and a factor can be applied to the activity concentrations in milk to express the reduction in concentration that could be obtained. Decontamination of milk can be applied on its own or in conjunction with processing. This option is set in the LCMT data files[4] (see Appendix C).

At the time the processed food is ready for consumption it will be competing in the market with processed food that has been produced under normal practices and hence the amount of food could outweigh the demand. The model does not include detailed assumptions about the distribution of the additional processed food made due to the countermeasure.

4.1.3.3 Food Storage

For long lived radionuclides storage is unlikely to be a viable option because of the length of time storage would be required and also the problems of social acceptance of the consumption of stored food when fresh food is available. There is, however, some argument for considering storage for short-lived nuclides such as iodine-131, where storage for short periods of time could reduce activity concentrations significantly. This option is considered for all foods considered with the restrictions outlined below.

Storage on its own is only considered for wheat and milk stored as milk products (cheese, butter and condensed milk) via normal processing procedures. Processing followed by storage will be considered for all other foods that cannot be stored in their fresh form without perishing but can be processed, ie canned, dried or frozen. The assumption is made that no activity concentration loss is obtained due to the processing procedure and the two options, storage, and processing + storage will be treated similarly with a flag identifying those foods which have been processed. The costs and equipment associated with the two options will obviously be different.

Storage or storage + processing is only considered if the countermeasure is effective in reducing concentrations below the banning criteria over the duration of the potential ban in the absence of any other countermeasures. All activity concentrations between the time when they first exceed the criteria and the end of the specified storage time are subject to normal radioactive decay whilst being stored. The user can choose two maximum storage times for fresh and processed foods in the Input Windows. A maximum limit of 5 years is set which has the effect of limiting storage to lengths of time that are practicable both in terms of the 'shelf life' of processed or fresh foods. In practice this also has the effect of only considering storage when the release comprises short-lived nuclides. Following storage any further food ban will not be required.

4.1.3.4 Removal of animals from contaminated feed

This option can either represent the removal of animals from contaminated pasture or the substitution of contaminated feed with uncontaminated feed. The animals and food products that are considered for this option are: lactating cow (milk and beef); lactating goat (milk); lactating sheep (milk); beef cattle (beef); pigs (pork); sheep (lamb); hen/chicken (chicken and eggs).

Two situations are considered: the first is when animals are removed from contaminated feed at the time of the accident and the second is when animals are removed from contaminated feed at some time after the accident.

a) Removal at time of accident.

In this situation, no contamination of the animal products has taken place. Three times during which uncontaminated feed is given can be selected by the user via the Input Windows. If the countermeasure is successful at reducing the activity concentrations below the criteria, the sub-module chooses the shortest feeding time required, after which the animal will return to its normal feeding regime.

b) *Removal at some time after the accident.*

In this situation, the animal product will already be contaminated, and following its removal from contaminated feed, the animal will retain activity which will decay depending on the biological turn over in the body. The user can choose the starting time for removal and three times during which uncontaminated feed is given via the Input Windows. The shortest duration of feeding uncontaminated feed is chosen by the sub-module.

4.1.3.5 Reduction in contaminated feed

This option represents the replacement of part of the animals normal contaminated diet with uncontaminated feed. The animals and food products that are considered for this option are: lactating cow (milk and beef); lactating goat (milk); lactating sheep (milk); beef cattle (beef); pigs (pork); sheep (lamb); hen/chicken (chicken and eggs).

Two situations are considered: the first is when the diet is supplemented with uncontaminated feed at the time of the accident and the second is when the diet is supplemented with uncontaminated feed at some time after the accident. The user can select the starting time (if not the time of deposition), three feeding durations and the fraction of the contaminated diet that is replaced via the Input Windows.

The same approach is adopted for the length of time uncontaminated feed is given as for the countermeasure option where all feed is replaced with uncontaminated feed, see 4.1.2.4.

4.1.3.6 Addition of sorbents to animal feeds/animal gut

Sorbents can be added to animal feedstuffs or directly to the animal's gut in the form of boli.

The animals and food products that are considered for this option are: lactating cow (milk and beef); lactating goat (milk); lactating sheep (milk); beef cattle (beef); pigs (pork); sheep (lamb); hen/chicken (chicken and eggs).

The effectiveness of the sorbent is modelled by reducing all activity concentrations in the animal by a factor during application if sorbents are added to feedstuffs, or for the length of time boli are effective in the animal's gut. The user is able to set the start of application and the duration of application in the Input Windows. The choice of considering the use of sorbents added to feed or the use of boli and the concentration reduction factor to be used for each animal can be made in the LCMT data files[4] (see Appendix C).

4.1.3.7 Substituting different feedstuffs in animal diets

Components of an animals diet can be changed, the relative quantities changed, or a component can be replaced by another feed that is uncontaminated. The impact of these changes on the resultant concentrations in animal products can be investigated using this option. Within a single run of LCMT, only a single feeding regime can be considered; the user can chose a starting time for implementation of this countermeasure to match the feeding period of his choice via the Input Windows. The default starting time is the feeding regime in place 7 days after deposition. If, however, the feeding regime changes within the first two weeks following deposition, the calculations are performed for this next feeding regime period. This avoids evaluating the effectiveness of the countermeasure for a feeding regime that is about to be changed under normal practices. Up to 8 feedstuffs can be considered in the diet for each animal and the diets can be radioecological region dependent. The changes to the diets can be made in the LCMT data files (see Appendix C). LCMT provides endpoints to enable the impact on the activity concentrations during this feeding period to be assessed.

Changes in the diet during a feeding regime, eg cows grazing grass, will influence the activity concentrations that could be expected in future feeding periods, eg when cows are subsequently fed hay indoors during the winter. This will depend on the contributions to the animals' intake from the new feeding regime compared to the residual activity in the animal from the previous feeding regime. Within the scope of RODOS it is not possible to look at successive changes in animal diets; however, it is recognised that it may be useful to consider the need to change animal diets in later feeding regimes when the duration of a ban in the absence of any countermeasures is long. To facilitate this, it is necessary to rerun FDMT with the revised diet for the first (or more) feeding regimes to revise the predicted activity concentrations in the food and then use LCMT to look at changing the diet in the next feeding period.

The activity concentrations in the animal products from the 'new diet' are estimated by scaling the activity concentrations by the ratio of the total activity ingested from the new diet to the total activity ingested from the original diet in each time period. The assumption is made that the activity concentrations in the animal reflect the change in the diet instantaneously. This is an approximation because in reality the activity in the animal from the original diet will contribute to the overall activity concentrations in the animal for a few weeks. This approach does, however, give an indication of the likely reductions in activity concentrations that could be expected.

The animals and food products considered are: lactating cow (milk and beef); lactating goat (milk); lactating sheep (milk); beef cattle (beef); pigs (pork); sheep (lamb); hen/chicken (chicken and eggs).

4.1.3.8 Amelioration

Amelioration is the treatment of soils to improve their quality and reduce the uptake of radionuclides by plants. This option is not considered until a minimum of 1 year after the accident in LCMTF. The crops that can be considered are: spring and winter wheat, rye, oats, potatoes, leafy vegetables, root vegetables and fruit vegetables. Following amelioration, the uptake of activity by plants is reduced by a factor representing a chosen soil treatment. The user can change the time of each application and the time over which each technique is effective via the Input Windows. Default values are provided for the reduction in activity concentration achieved in the LCMT data files[4] (see Appendix C). The concentration reduction factor is assumed to apply to the original concentrations such that it only modifies the activity concentrations for the duration of the application to which it applies. Concentration reduction factors which are radionuclide dependent may be specified for up to 5 element groups. It is assumed that activity concentrations in plants will be reduced immediately following application. By choosing suitable values, the user can look at the effectiveness of repeated applications. It is assumed that amelioration is carried out during the normal cultivation cycle and that no produce is lost.

4.1.3.9 Change of crop species or variety

The criterion for considering the change of crop species or variety is that the activity concentrations in the crop exceed the banning criteria over a user chosen period (default values of 2 years for crop variety and 10 years for crop species). These times can be selected by the user in the Input Windows. The assumption is made that this option would only be considered if by growing another crop the activity concentration could be reduced to below the ban criteria. This option is not considered until a minimum of 1 year after the accident. The crops that can be considered are: spring and winter wheat, rye, oats, potatoes, leafy vegetables, root vegetables and fruit vegetables.

The change of crop variety, ie the use of a different variety of the same crop, is a more straightforward countermeasure to implement with fewer implications for the economy and agricultural production than changes in the species of crop grown. A database of factors representing the difference in root uptake between crop varieties is interrogated to determine if any other crop variety could be grown to avoid the need to ban the crop[4]. If another crop variety can be grown the reduction in concentration is calculated. No allowance is taken of any delay between the harvesting of the two crops as it is assumed that the crop variety will be changed during the fallow period. If another crop variety could be grown then this is selected for the calculation of endpoints. The user can specify when the countermeasure takes place after 1 year via the Input Windows, and the assumption is made that the crop change will be continued on an annual basis until such time that the preferred original variety can be grown again.

If no other variety can be grown to satisfy the criterion for changing the crop variety grown, a change of crop species is considered, if the appropriate criterion is met. If this countermeasure is implemented, the assumption is made that the crop change will be continued for all future time following implementation. If no other crop can be grown the option is abandoned. If several other crop species may be grown then one of these species will be selected for the calculation of endpoints in this version of LCMTF. This selection is based on a list of crops such that similar crop species are considered first, eg. if the crop to be changed is spring wheat, other types of cereals will be considered before vegetables. The user is also informed of all the other species that may be grown. In this version of LCMTF the option of changing the growing of food crops to animal feed crops is not considered.

The assumption is made that there is no food produced prior to the time that the countermeasure is implemented. The calculation of dose saved also includes the dose saved from stopping the production of food prior to implementation of the countermeasure.

4.1.3.10 Change in land use

Only one land use change is considered in this version of LCMTF, the change of agricultural land to forestry. The criteria for the consideration of this option is that the land cannot produce food at activity concentrations below the criteria for a user-chosen time period, which is selected in the Input Windows. If this is the case, the land use is changed to forest and written off for food production. It is assumed that there is no food production from the time of the accident and, therefore, no account is taken of the potential need to dispose of food prior to any decision to stop the production of food on the land.

4.1.4 Decontamination of agricultural land

A robust approach to the modelling of decontamination of agricultural land has been taken in LCMTF. The effectiveness of decontamination of agricultural land is represented by a single reduction factor applied to concentrations in food grown on that land. Decontamination by ploughing and soil removal have been considered for arable crops and undisturbed pasture. A summary of the possible techniques and their effectiveness is given in reference 3.

The decontamination concentration reduction factor is defined as the fraction of activity remaining in any foodstuff growing on the land following decontamination compared with that in the absence of decontamination.

The user can choose the time of decontamination and a period after decontamination when food production is lost due to the land being unproductive, for example, after soil removal, in the Input Windows. The decontamination concentration reduction factor can be changed in the LCMT data files. If the user is considering decontamination of land supporting animals, it is their responsibility to define within the data file which animal products are contaminated via the animals consumption of pasture based on the feeding regimes that have been implemented in the food module, FDMT. The approach adopted for decontamination of agricultural land in LCMT does not allow the user to look at the effect of decontamination on the different diets of animals at different times of the year.

The assumption is made that there is no food produced until the time that the decontamination is implemented. The calculation of dose saved also includes the dose saved from stopping the production of food prior to implementation of the countermeasure.

4.1.5 Relocation

A simple and robust method has been adopted to consider the implications of relocation on the production and management of arable crops and livestock and to allow for the fact that a relocated workforce may have a direct negative impact on the agricultural production in a region. For areas with *temporary relocation*, it is assumed that crop production and livestock management are unaffected for the duration of relocation. Only areas with *permanent relocation* may have the normal agricultural production interrupted. For both arable crops and livestock production, the model allows the consideration of three options; the continuation of pre-accident production; production of crops and/or livestock ceases; production is continued only for specified foods. The endpoints calculated enable some judgement to be made as to the amount of man-power required for the continuation of food production in a relocated area and therefore whether it is feasible to continue farming an area using a relocated workforce.

The model also assumes that agricultural land is being farmed to capacity and that there is therefore no room for production to be moved from the relocated region to other regions.

In the first option, it is assumed that the permanently relocated workforce can return to the land for sufficient time to allow the continuation of production and harvesting at the original location for all foods. In the second option, the relocated workforce is unable to return. The livestock/crop production is not moved to an area outside the relocated area and hence production of all food ceases at each location in the relocated area. In the third option, the relocated workforce may return to the areas permanently relocated to continue the production of selected foods. The rationale behind this option is that for short periods of time farm workers may be allowed into the relocated area to tend extensively farmed crops and animals, i.e. those which probably do not require daily attention, or at times of harvest. Intensive farming requiring daily intervention is however, likely to stop. The foods for which farming and hence production are stopped can be chosen, with the constraint that production ceases in all locations within the relocated area for the relocation duration.

4.2 Agricultural countermeasure combinations

The overall effectiveness of individual agricultural countermeasures on reducing the activity concentrations in food depends on the amount of contamination, the time when the countermeasure is applied and withdrawn, and the effectiveness of the techniques employed in reducing the activity concentrations in arable crops and animal products. In some cases, the need for restricting foods may not be completely removed by an individual countermeasure, or the duration of the intended countermeasure may lead to an unacceptable cost, be it monetary or other, for a given level of benefit. The objective of undertaking a combination of two countermeasures must be to remove the need for or further reduce the duration of a food restrictions where using only one of the countermeasures failed to remove the food restrictions completely.

The effects of combining two countermeasures are considered, so that the user may investigate the effectiveness of countermeasure combinations in order to remove the need for food restrictions or reduce their duration.

4.2.1 General Approach

A countermeasure combination is defined as a countermeasure strategy for a single food which involves two individual countermeasures, where each countermeasure in some way affects the activity in the food. One example is the processing of a food, which in itself reduces the activity, followed by its storage in its processed form, which further reduces the activity. However, storage of a food in a processed form, where the processing does not change the activity in the food, is modelled in LCMTF as a single countermeasure. The distinction for countermeasure combinations is that each countermeasure reduces the activity in a given food by acting on different parts of the food chain, eg. reducing the animal's contaminated feed and processing the milk produced.

Within LCMTF, countermeasure combinations are considered only on individual foods. The summing of endpoints across foods can be carried out within the evaluation subsystem, ESY. The countermeasure combinations are modelled in a multiplicative way, where the effectiveness of each countermeasure acts on the food activity concentrations by multiplying them by suitable reduction factors incorporating both radionuclide and time dependency.

Thirteen individual agricultural countermeasures are considered. The number of possible combinations of two countermeasures could therefore be as large as 78. Countermeasure combinations of three or more countermeasures are excluded, on the basis that the combination would probably be too complex to achieve in practice. Additionally, it is likely that the additional benefits of introducing a third or fourth countermeasure are small compared to those from a single or double combination. Many of the theoretical combinations of two countermeasures can be excluded as they are not compatible for a particular food and those combinations that are clearly impracticable have also not been considered in LCMTF. This reduces the total possible number of options to a manageable number which can be evaluated in ESY and interpreted by the decision maker. It is then the separate function of ESY to use further evaluation techniques to reduce the number of options to a few that are practicable.

Countermeasure combinations are not available in automatic mode. In the interactive mode, combinations can be chosen by the user via the input windows in both the exploratory and the decision mode. For most foods there are fewer than seven possible combinations. For milk, there are a possible 35, and for beef, pork and lamb, there are a possible 26. The possible combinations are listed in Appendix B. The list gives a total 40 countermeasure options.

In the exploratory mode, the endpoints calculated are the same as those for the individual countermeasure options. In the decision mode, the emphasis is on calculating selected endpoints to enable evaluation of the different countermeasure strategies. An additional set of endpoints are calculated for ESY and these are described in detail in Section 4.4.3.

4.2.2 Relative timings of combined options

For most options, the user chooses the starting times, where necessary, and the duration of the individual countermeasures within the specified combination. However, for some combinations of countermeasures there are certain other constraints on the timings to ensure that they are carried out in a particular order. For the timings of combinations where there is no need to force one option to occur before the other, it is assumed that they start at the same time. If a combination requires durations to be set in the Input Windows for both countermeasures, the user is only allowed to select the same durations for both countermeasures.

4.3 Re-contamination of area due to long range dispersion

If a location receives additional contamination due to the return of the plume, ie there are several deposition events at a location, the activity concentrations in foods arising from each event are calculated and summed to give a total temporal profile of the activity concentrations in each food.

4.4 Input to LCMTF

LCMTF receives information from within LCMT and from other modules of RODOS. Specific details of the interfaces with other RODOS modules are given in reference 2. The data specifying the default parameter values on the effectiveness of each countermeasure can be found in a number of text input files. These files may be edited by the user. A description of the data files is given in Appendix C.

LCMTF also requires information from the user via input-windows while running the RODOS system. These include selected criteria for the imposition of food bans, information on foods and agricultural countermeasures to be considered and the selection of options such as whether the impact of relocation is to be considered. Default values have been given for all input information that can be selected by the user; the user is free to overwrite any of this information. The choice of default values is described in detail in reference 4. A summary of the information available for selection via the Input Windows is given in Tables 5 and 6. The default timings for each of the agricultural countermeasure options that can be chosen by the user via the Input Windows are given in Table 7.

Input Windows	Available options to user
Foods	Choice of up to 5 foods (interactive exploratory mode) Choice of 1 food (interactive decision mode)
Selection of criteria	Activity concentration criterion for each food group for up to 5 radionuclide groups[a]
Selection of agricultural countermeasures	Choice of ‘No Action’ or up to 12 options for each food
Selection of timings and other information for each countermeasure option	See text for description of options available to the user for each countermeasure
Selection of organs for dose calculations	Effective dose always calculated; choice of 1 other organ from list
Selection of ages for dose calculations	Adults (default), 15 year old, 10 year old, 5 year old or 1 year old.

Note:

(a) It is not envisaged that the user will normally want to change the foods that are in the 5 food groups or the radionuclides associated with each radionuclide group. These can be changed by the user via the underlying data files but not via the Input Windows.

Table 5: Summary of Input Window Information for LCMTF

Radionuclide	Intervention Levels (Bq kg^{-1})		
	Food Group 1 – dairy produce ie milk and cream	**Food Group 2 - all major food items other than dairy produce**	**Food Group 3 – liquid foods, eg beer**
Isotopes of strontium, notably ^{90}Sr	125	750	125
Isotopes of iodine, notably ^{131}I	500	2000	500
Alpha-emitting isotopes of plutonium and transplutonium elements	20	80	20
All other radionuclides of half-life greater than 10 days, notably ^{134}Cs and ^{137}Cs [a]	1000	1250	1000

Notes:

(a) This category does not include ^{14}C, ^{3}H and ^{40}K.

Table 6: Default criteria for implementing food bans

Countermeasure	Quantity	Default value
Disposal or stopping production	Time when production stops	365 days
Food processing	None	-
Storing food	Maximum storage time for fresh food	180 days
	Maximum storage time for processed food	730 days
Removing animals from contaminated feed (t=0)	Durations of feeding – three required	7 days, 30 days, 90 days
Removing animals from contaminated feed (t>0)	Start time of feeding	2 days
	Durations of feeding – three required	7 days, 30 days, 90 days
Reducing animals' contaminated feed (t=0)	Durations of feeding – three required	7 days, 30 days, 90 days
	Fraction of diet replaced	0.25
Reducing animals' contaminated feed (t>0)	Start time of feeding	2 days
	Durations of feeding – three required	7 days, 30 days, 90 days
	Fraction of diet replaced	0.25
Adding sorbents to animal diet	Start time	2 days
	Duration	7 days
Substituting animal feeds in diet	Start time	7 days
Land amelioration	Start time when amelioration effective (>365 days)	365 days
	Durations of effectiveness (5 applications)	1095 days, 0,0,0,0
Change of crop	Earliest time when crop change occurs (>365 days)	365 days
	Time when activity concentration compared to criteria for crop variety change	730 days
	Time when activity concentration compared to criteria for crop species change	3650 days (10 years)
Change in land use	Time when activity concentration compared to criteria	25550 days (70 years)
Decontamination of agricultural land	Time decontamination occurs	90 days
	Length of time food production lost following decontamination	30 days crops 730 days pasture grass

Table 7: Summary of default agricultural countermeasure timings

4.5 Endpoints available directly to the user

A number of endpoints are displayed graphically to the user; these are described below for the automatic and interactive modes. A summary of the endpoints for the interactive mode is given in Table 8. The terms underlined are defined in the glossary in Section 4.5.5.

The time grid used by LCMT assumes that food activity concentrations and doses are calculated at discrete times on the time grid. For a countermeasure starting at a given time, the effect of the countermeasure, although implemented at that time, is not reflected in the activity concentration and dose endpoints until the next time on the grid. For the calculation of the duration between two times, it is assumed that the duration at a given time on the grid is the difference in time between that time and the previous one.

4.5.1 Interactive Exploratory Mode – NO ACTION

Potential food ban area and duration, days

The potential ban area and ban duration for each spatial grid point is displayed to the user on a map. This is calculated for the 'NO ACTION' case and is the duration that a food ban would be required in the absence of any other agricultural countermeasure. It is assumed that a ban would remain in place from the first time activity concentrations in the food exceeded the ban criteria until the last time the criteria are exceeded.

Potential collective dose received, man Sv

The potential collective ingestion dose received is the dose received in the maximum potential ban area integrated to 1, 2, 5 and 50 years. It is assumed that all food above the ban criteria is disposed of and replaced by uncontaminated food but that food contaminated at activity concentrations below the ban criteria is consumed somewhere, by someone. It is calculated for each food, one age (default is adult), for effective dose and dose in one other organ chosen by the user and is summed over all radionuclides considered in the ingestion pathway.

The collective dose is calculated assuming that all the food produced for human consumption is consumed somewhere by someone.

The endpoint is displayed to the user as text.

4.5.2 Interactive Exploratory Mode – All other countermeasure options

All the following endpoints are calculated within the potential ban area (see above).

Remaining ban duration, days

The ban duration remaining following implementation of the countermeasure as a function of spatial location. It is assumed that a ban would remain in place from the first time activity concentrations in the food exceeded the ban criteria until the last time the criteria are exceeded.

If the countermeasure option, ‘change in land use’ is evoked, an upper limit of 1 year after the accident is placed on the remaining ban duration for the original food being grown.

This endpoint is displayed to the user as a map.

Food Banned

This is a measure of the status of the amount of food banned as a function of time, and generally decreases with time as the extent of the ban area decreases. If the countermeasure leads to the production of a food ceasing for a period, the food lost during this period is not included in this endpoint.

For crops, this endpoint is expressed as the land area growing the specific crop of concern as a function of time [km^2]. For animals, the endpoint is expressed as the total number of animals whose product is banned as a function of time [heads]. For other foods, it is defined as the total amount of food banned per day, as a function of time. [kg/d].

For those foods banned on the basis of activity concentrations in the food as grown, e.g. milk, the amount banned is that leaving the farm. For those foods banned on the basis of activity concentrations in the food as eaten, e.g. butter, flour, it is the amount that is available for consumption.

The endpoint is displayed to the user as a graph.

Food Production Lost, kg

This is the integrated amount of a food that is lost from production as a function of time and includes food that is banned and food lost from stopping of its production. It is, therefore, a measure of the amount of food which would have to be found from another source to maintain normal availability to the public.

For those foods banned on the basis of activity concentrations in the food as grown, e.g. milk, the food lost is the amount leaving the farm. For those foods banned on the basis of activity concentrations in the food as eaten, e.g. butter, flour, it is the amount that is available for consumption.

If the countermeasure option, ‘change in land use’ is evoked, it is assumed that the original food being grown is not produced and all production of that food is lost.

The endpoint is displayed to the user as a graph.

Food Requiring Disposal

This is the total amount of food requiring disposal, i.e. the total amount of food banned. The disposal period covers when the food is banned and is still being produced.

For animals, this endpoint is expressed as the total number of animals requiring disposal due to their milk and meat being contaminated [heads]. For other foods, it is expressed as the total production requiring disposal [kg].

For those foods banned on the basis of activity concentrations in the food as grown, e.g. milk, the food requiring disposal is the amount leaving the farm. For those foods banned on the basis of activity concentrations in the food as eaten, e.g. butter, flour, it is the amount that is available for consumption.

The endpoint is displayed to the user as text.

Collective ingestion dose received

The collective ingestion dose received is the dose received within the potential ban area with the countermeasure implemented, integrated to 1, 2, 5 and 50 years. It is calculated for each food, one age (default is adult), for effective dose and dose in one other organ chosen by the user and is summed over all radionuclides considered in the ingestion pathway.

The collective dose is calculated assuming that all the food produced for human consumption is consumed somewhere by someone.

The endpoint is displayed to the user as text.

Resources

The resources calculated depend on the countermeasure being implemented. The resources for each countermeasure option considered in LCMTF are listed in Table 9. The total resources required integrated to a selection of times are displayed to the user as a graph. If a combination of 2 countermeasures has been implemented, the resources for both options are displayed as separate values.

Action Disallowed

If a countermeasure option chosen by the user is disallowed, a message is displayed to the user informing him that no endpoints have been calculated.

A countermeasure action may be disallowed within LCMT for one of two reasons. If the countermeasure only works in the middle of the potential ban period at any given location, most likely as a result of the user choosing unsuitable start and stop times for the countermeasure that do not reflect the time dependency of the activity concentrations in the food, the starting and finishing times for the food ban remain unchanged. The other case is if the user has specified a start time for the countermeasure that is later than the time when the potential ban would finish or has specified a finishing time for the countermeasure that is earlier than the time at which the potential ban would start.

If either of these conditions are met, the countermeasure is not implemented at the location and no endpoints are calculated for this countermeasure for this location. If the strategy is disallowed at all locations in the potential ban area, no endpoints are calculated for this countermeasure and the message ‘Action disallowed’ is displayed to the user.

4.5.3 Interactive Decision Mode

For the decision mode, endpoints have been chosen that can be directly compared between countermeasure options. Details of the interface between LCMTF and ESY, which includes arrays allowing descriptive text for each endpoint to be reproduced in ESY, are described in a separate document[2]. These endpoints are not displayed to the user directly.

The earliest start time of the ban, days

This is the earliest time that a food ban is required having implemented a countermeasure option anywhere within the potential ban area.

The maximum duration of the ban, days

This is the difference between the latest time when the food ban is lifted anywhere in the potential ban area and the earliest time a ban is in effect anywhere in the potential ban area. It is calculated taking into account any time period in which a food ban is required following implementation of each countermeasure. It should be noted that the locations where these two times are recorded are not necessarily be the same.

The total amount of food requiring disposal

See Section 4.5.2.

The total amount of lost food production

See Section 4.5.2.

The total amount of resources required

See Section 4.5.2.

Maximum potential individual dose received, Sv

This is the maximum individual dose received with ‘NO ACTION’ within the potential ban area for each food, summed over radionuclide for the age group and organ selected by the user. The doses are integrated to 1, 2, 5 and 50 years.

Potential collective dose received, man Sv

See Section 4.5.1.

The maximum individual dose saved, Sv

This is the maximum individual dose saved from implementing a countermeasure for the food of concern, summed over radionuclide for the age group and organ selected by the user. The doses are integrated to 1, 2, 5 and 50 years.

The collective dose saved, Sv

This is the collective dose saved from implementing a countermeasure for the food of concern, summed over radionuclide for the age group and organ selected by the user. The doses are integrated to 1, 2, 5 and 50 years.

4.5.4 Automatic Mode

In the automatic mode, the endpoints for NO ACTION are calculated, as described in Section 4.5.1 and the endpoints given in Section 4.5.2 for the interactive exploratory mode are calculated for the countermeasure option 'disposal of food' only.

4.5.5 Glossary of Terms for LCMTF endpoints

Food Ban Area

A food ban is considered necessary where the activity concentrations in a given food are above the food ban criteria in the absence of any other countermeasure. In LCMTF, the need for a food ban in the absence of any other action is required before any other countermeasures are considered. A food ban area is the maximum area where a food ban would be required considering all times after the accident.

Potential

Within LCMTF, the term 'potential' is used to refer to an endpoint which has been calculated assuming no countermeasure option has been applied. This is referred to in the RODOS graphics as the 'NO ACTION' case. For example, a potential ban area is the area identified as requiring a food ban at some time if no countermeasure actions were to be implemented. It should not be confused with the term 'initial ban area', which is the food ban area at the time of the accident. If a countermeasure is applied however far in the future, the endpoint is no longer the potential case.

Food as grown

This term is used to describe the status of a food and the associated activity concentrations in it at a time when it is first available for marketing, i.e. as it leaves the farm. Within the foodchain module of RODOS, FDMT, these foods are described as 'raw'. No processing factors or delays are included in the activity concentrations in these foods.

Food as eaten

This term is used to describe the status of a food and the associated activity concentrations in it at a time when it is first available for consumption. The effects of normal food preparation, delays due to distribution and any apportioning of the food into its derivatives, eg milk into butter, have been taken into account in the activity concentrations. Within the foodchain module of RODOS, FDMT, these foods are described as ‘processed’.

4.6 Endpoints for other modules of RODOS

Endpoints are calculated for the HEALTH and ECONOMICS modules of RODOS. Details of the interfaces with these modules are given elsewhere[2]. A summary of the endpoints calculated is given in Table 8.

Module				
Graphical display	ECONOMICS	HEALTH (SIMPLE)	HEALTH (COMPLEX)[a]	ESY
Potential ban area and duration, days (NO ACTION)	Total food requiring disposal	Lifetime adult individual effective dose saved as function of location, Sv (summed over food)	Individual dose saved (4 ages, 4 selected organs) integrated to a number of times as function of location, Sv (summed over food)	Earliest start time of the food ban, days
Potential collective dose received, manSv (NO ACTION)	Total food production lost			Maximum duration of the food ban, days
Remaining ban duration, days	Resources required			Total amount of food requiring disposal, kg
Food production lost as function of time				Total amount of lost food production, kg
				Total amount of resources required
Food banned as function of time				Maximum potential individual dose received, Sv
Total food disposed				Potential collective dose received, man Sv
Resources required (see Table 9)				Maximum individual dose saved, Sv
Collective dose received, man Sv				Collective dose saved, man Sv

Note:

(a) Only generated if required information on organs passed from FDMT.

Table 8: Summary of endpoints for FOOD OPTION

Countermeasure Option	Description of resource endpoint
Disposal of food	None[a]
Food processing	Total amount of food requiring processing, kg
Food storage	Maximum amount of food stored at any time and location, kg
Removal of animals from contaminated feed	Total uncontaminated feed required, kg
Addition of sorbents to animal diets	Total sorbents required, kg
Substitution of different feeds in animal diets	Total replacement feed required, kg
Amelioration of agricultural land	Total ameliorants required, kg
Change in crop variety or species grown	Total land area requiring reseeding, km^2
Change in agricultural land use	Total land area requiring change of use, km^2
Decontamination of agricultural land	Total land area requiring decontamination, km^2

Note:

(a) Total food requiring disposal is calculated as a separate endpoint (see Table 8). No additional resources are calcuated.

Table 9: Resource endpoints calculated for FOOD

5 Decontamination sub-module, LCMTD

The primary purpose of the decontamination sub-module, LCMTD is to assess the impact of decontamination implemented following an accident on the exposure to the population from external irradiation from deposited material and inhalation of resuspended radionuclides and its effect on the imposition of relocation. In this context, decontamination of buildings or land in inhabited areas is considered. Decontamination of agricultural land is considered in LCMTF and is discussed in Section 4.1.4.

LCMTD can be used to investigate the implications of carrying out a range of clean-up options which can be implemented in the short and longer term following deposition. A robust approach has been adopted which enables the user to scope possible decontamination techniques that might be feasible and to explore the impact that user-selected decontamination factors for specific urban surfaces and implementation times may have on doses received and the need for imposition of relocation.

5.1 METHODOLOGY

Several terms are used to describe the effectiveness of a decontamination technique in reducing contamination on a surface and radiation exposure. The term decontamination factor (DF) is used to describe the efficiency of a decontamination technique in removing radioactivity from the surface under treatment. A DF makes no reference to possible reductions in radiation exposure. The term dose reduction (DR) is used to describe the overall reduction in external or resuspension dose to a person living in a particular environment from the decontamination of a particular surface or range of surfaces. The efficiency of a decontamination technique can also be described as the ratio of the dose rate above the surface before and after decontamination. The reduction in dose rate above a surface is called the dose rate reduction factor (DRF).

The reduction in individual dose from external irradiation and resuspension achieved by decontamination depends upon a number of factors including the following: the decontamination technique employed; the type of deposition, ie wet or dry; the type of area in which decontamination takes place; the time when decontamination is implemented; the time following deposition and individual habits such as indoor/outdoor occupancy.

Account has been taken of these factors in the approach adopted in LCMTD by the use of a comprehensive data library containing information on the effectiveness of decontamination for both exposure pathways considered.

5.1.1 Exposure from external gamma irradiation from deposited material

The effectiveness of decontamination in reducing exposure from external irradiation from deposited material is modelled using dose reduction factors.

The dose reduction factor for a given decontamination technique is the fraction of the dose received without decontamination that remains after decontamination.

Dose reduction factors are calculated for outdoor and normal living doses using an urban dose model, EXPURT[4]. This approach requires that certain assumptions are made concerning the types of surface, buildings and the level of urbanisation within a chosen urban environment. Parameters which reflect a typical urban environment have been used[5]. Implicit in this assumption is that dose reduction factors are the same for all individuals in all areas decontaminated.

In the calculation of dose reductions, account is taken of the radionuclides that have been deposited, the time-dependence of the effectiveness of decontamination in reducing doses and whether deposition occurred under predominantly wet or dry conditions. The radionuclides contributing to the external doses are assigned to a radionuclide category depending on radioactive half-life and, to a limited extent, behaviour on urban surfaces. These categories are: half-lives less than 50 days, half-lives between 50 days and 3 years; half-lives greater than 3 years and short lived isotopes of iodine. The appropriate dose reduction is applied to the dose from each radionuclide and the total dose reduction is then calculated as a function of time. The total wet and dry deposition for a particular run of RODOS is passed to LCMTD from the atmospheric dispersion module; the deposition type contributing most to the total deposition is used to determine which data are chosen from the data library.

5.1.2 Exposure from inhalation of resuspended material

For inhalation of resuspended material the effectiveness of decontamination is modelled in a robust way using surface activity reduction factors for the surface undergoing decontamination. For impermeable surfaces, such as walls and roads, this factor is the same as the DF. For permeable surfaces, such as soil, it is taken as the reduction in activity in the top 1 cm layer of the soil. The surface activity reduction factor is dependent on the radionuclides that have been deposited, the effectiveness of decontamination in reducing the surface activity and whether deposition occurred under predominantly wet or dry conditions. Following decontamination, the activity on the surface being decontaminated is reduced by the surface activity reduction factor and the reduction in the total surface activity in the environment contributing to both outdoor and normal living doses is calculated taking into account the surface activities on the other urban surfaces at the time of decontamination. The surface activity reduction factor is assumed to apply to the surface for all times following decontamination. However, the impact of the reduction in surface activity on the decontaminated surface as a function of time will depend on how important the surface is in contributing to the total surface activity. The assumption is made that resuspension from all surfaces within the urban environment is the same and the reduction in surface activity represents the reduction in the inhalation dose from resuspended material. Due to the sparsity of data, a robust approach is needed to model the effect that decontamination has on future resuspension from a surface. In the absence of better data, two assumptions could be made: either that, following decontamination, all resuspendable material is removed and no further resuspension dose will be received, or that any radionuclides remaining on the surface will continue to be resuspended to the same extent as if no decontamination had taken place. In LCMTD the latter assumption has been adopted, although for some techniques, which are known to fix the activity to the surface, it is assumed that no further resuspension will take place. Details of the assumptions made for the decontamination techniques considered are given below.

5.2 Decontamination Options

Two options are available to the user for consideration of decontamination. Selected techniques and implementation times can be chosen from a provided list; this is called the 'decontamination technique' option. The alternative is that a selection of DF values, urban surfaces and implementation times can be chosen; this is called the 'decontamination factor' option. The 'decontamination technique' option is available for users who want to evaluate the effectiveness of decontamination techniques for which data are available on the likely DFs that could be achieved. This option allows estimates of resources and waste generated to be made taking into account the area requiring decontamination. The 'decontamination factor' option enables the user to explore what level of decontamination is required to obtain the desired dose reductions. In addition, it enables the user to look at the dose reductions that could be achieved if data are available to the user on the effectiveness of specific decontamination techniques which are not held in the 'decontamination technique' option data library. The choice of either the 'decontamination technique' option or the 'decontamination factor' option is made by the user in the Input Windows as described in Section 5.5.

5.2.1 'Decontamination Technique' Option

A list of the decontamination techniques considered in the data library is given in Table 10. The user is limited to selecting from the given implementation times which have been chosen to scope the time period over which these techniques are likely to be considered. Decontamination factors have been chosen for the techniques and

Technique	Implementation times

Skim and burial ploughing	90 days and 2 years
Standard ploughing	30 days and 1 year
Plant and shrub removal	7 days and 90 days
Grass cutting	7 days and 14 days
Soil removal	90 days and 2 years
Double digging gardens	30 days and 1 year
Rotovating / digging gardens	30 days and 1 year
Tree / bush removal	30 days and 1 year
Road planing	90 days and 1 year
Fire hosing roads	7 days and 14 days
Vacuum sweeping roads	7 days and 14 days
Sand blasting external walls	14 days and 1 year
Roof brushing	30 days and 1 year
Vacuuming indoors	7 days and 14 days

Table 10: User choices for 'Decontamination techniques' option

implementation times considered and these are implicitly included in the dose reductions calculated. Details of the assumptions made are given in reference 3. Dose reductions as a function of time are included in the data library for outdoor doses and normal living doses, for deposition occurring under wet and dry conditions and for the radionuclide groups described above. The four groups are represented within the data library by barium-140, ruthenium-106, caesium-137 and iodine-131, respectively.

Surface activity reduction factors are also included in the data library for each technique and implementation time. Availability of any remaining activity on the surface to resuspend following decontamination for each technique has been assumed. The default values are given in reference 3.

For each of the techniques, default data are provided for the work rate (man h m^{-2}) and the amount of waste generated. Default values are provided in the Input Windows and can be changed by the user, allowing the flexibility to change the work rate if, within a particular region or country, it is very different to the default value. This flexibility is provided to ensure that the labour costs are estimated as realistically as possible as these tend to dominate the overall costs of decontamination. The work rate achieved is also dependent on the conditions under which decontamination is carried out: work rates in radioactive areas are likely to be reduced. In the Input windows, the user can also provide a factor to adjust the work rate from normal working conditions to working in a radioactive controlled area.

The equipment resources for each technique are fixed within LCMT and are used for the purpose of estimating the overall costs of decontamination. The types of equipment used for each technique and the working rate of each piece of equipment has been determined so that a realistic estimate of the equipment costs can be made within the ECONOMICS module. The equipment costs per m^2 decontaminated are calculated from the cost per hour to run the equipment and the working rate of the equipment. This is based on an optimum number of men operating the equipment. If the user changes the work rate, it is implicitly assumed that the optimum work rate is maintained.

Due to the large amount of data held in the decontamination data library, it is not possible to present all the default data used within LCMTD. Some illustrative data are presented here to provide the reader with information on the relative effectiveness of each technique. In Table 11 reductions in external dose for caesium-137 following implementation of each technique considered in the data library, the work rates involved and the waste material generated are presented. These dose reductions are not part of the data library but are the integrated dose reductions implied from the values in the data library. Table 12 gives an example of the data held in the data library for grass cutting implemented at 7 days.

5.2.1.1 Limitations

The data library of dose reductions for the 'decontamination technique' option only includes single techniques. The purpose of the module is to scope the possible consequences of implementing a range of techniques to enable decisions to be made on those which may be feasible. This is likely to be carried out before a detailed picture of the contamination pattern within an area is known. The information from LCMT can form part of any decision on decontaminating an area in the short term. In this period, it is likely that the user will wish to consider single techniques in order to assess feasibility. The impact of decontaminating several surfaces within an environment can be studied by considering them separately. However, it should be noted that if several techniques that impact on the same surface are considered, the effectiveness of the two techniques cannot necessarily be simply combined. In the longer term, the implementation of any decontamination strategy should be based on measured deposition levels on the surfaces of concern and the effectiveness of a technique (DF) for the actual situation of concern. The impact of such measured decontamination factors can be studied, assuming a generic urban environment as described above, using the 'decontamination factor' option in LCMTD. The results from the RODOS system should, however, be used to support measurements made in the actual area of concern and not in isolation.

5.2.2 'Decontamination Factor' Option

The decontamination options available to the user are listed in Table 13. Decontamination of roofs, walls and indoor surfaces of buildings, impermeable surfaces, ie roads and paved areas, permeable surfaces, ie soil and grass areas and trees can be considered. A wide selection of DFs and implementation times are made available to the user. These have been chosen to scope the range of decontamination effectiveness that could be achieved and the time periods over which decontamination is likely to be considered. Dose reductions as a function of time are included in the data library for outdoor doses and normal living doses, for deposition occurring under wet and dry conditions and for the radionuclide groups described above. The four groups are represented within the data library by barium-140, ruthenium-106, caesium-137 and iodine-131, respectively.

Surface activity reduction factors are also included in the data library for each DF, surface and implementation time. In the absence of any knowledge on the technique underlying the choice of DF by the user, it is assumed that any remaining activity on the surface continues to resuspend following decontamination.

5.2.2.1 Limitations

Given the exploratory nature of this option, endpoints concerning the work rates and waste generated cannot be calculated. These quantities are implicitly linked to a decontamination technique and default values can not be specified for a user-selected DF which could be obtained using many different decontamination techniques.

Decontamination Factor (DF)	1.2, 1.5, 2, 3, 5, 10, 50, 100
Urban surface	Walls, roofs, internal surfaces, paved, soil/grass, trees
Implementation times, d	1, 7, 14, 30, 90, 365, 730, 3650

Table13: User choices for 'decontamination factor' option

5.3 Decontamination and relocation

Decontamination can be considered in conjunction with relocation via the LCMTR module as described in Section 3. If the option to consider decontamination is chosen, the user has the same choice of decontamination options via the input windows as is described here. LCMTD calculates the expected doses with decontamination implemented at all the spatial grid points at which relocation is initially indicated or in the whole contaminated area. LCMTD uses the dose reduction and surface contamination reduction factors selected by the user to calculate the expected effective doses, summed over the resuspension and external exposure pathways, for those time periods appropriate for the criterion for imposition of relocation. The expected effective doses are passed to LCMTR and are used to determine the revised pattern of relocation and any remaining need and duration of relocation at each spatial grid point. The required endpoints are then calculated as described in Section 3.

5.4 Re-contamination of area due to long range dispersion

If a location receives additional contamination due to the return of the plume, ie there are several deposition events at a location, any dose reduction obtained from implementing a technique will be applied to doses arising from all deposition events that occur before the implementation time. It is assumed that doses arising from deposits occurring during or after implementation will not be affected by decontamination. The weather conditions during the first deposition event are used to determine which dose reduction data library is used based on the assumption that the first deposition event at a location is likely to be the largest.

Technique	Implementation time, days	Percentage reductions in external dose [a,b]		Work rate, man hours m^{-2} [c]	Waste generated, kg m^{-2}
		Initial deposition wet	Initial deposition dry		
Skim and burial ploughing	90, 730	30, 60	50	$3.3\ 10^{-4}$	0
Standard ploughing	30, 365	30, 50	60, 60	$1.6\ 10^{-4}$	0
Plant and shrub removal	7, 90	10, 10	20, 15	$2.0\ 10^{-3}$	2.0
Grass cutting	7, 14	10, 10	45, 45	$1.0\ 10^{-4}$	$1.3\ 10^{-1}$
Soil removal	90, 730	25, 50	45, 55	$4.5\ 10^{-3}$	$5.6\ 10^{1}$
Double digging gardens	30, 365	35, 50	60, 60	$1.0\ 10^{-1}$	0
Rotovating / digging gardens	30, 365	25, 30	45, 35	$1.0\ 10^{-2}$	0
Tree / bush removal	30, 365	0, 0	20, 0	$4.0\ 10^{-2}$	$1.0\ 10^{1}$
Road planing	90, 365	40, 20	15, 5	$4.5\ 10^{-3}$	$1.2\ 10^{2}$
Fire hosing roads	7, 14	30, 15	15, 15	$2.9\ 10^{-3}$	2.0
Vacuum sweeping roads	7, 14	30, 30	10, 10	$5.0\ 10^{-4}$	$2.0\ 10^{2}$
Sand blasting external walls	14, 365	0, 0	4, 8	$8.3\ 10^{-2}$	4.8
Roof brushing	30, 365	3, 2	3, 2	$3.6\ 10^{-1}$	$6.0\ 10^{-1}$
Vacuuming indoors	7, 14	0, 0	1, 1	$1.7\ 10^{-2}$	$5.0\ 10^{-3}$

Notes:

(a) External doses integrated to 1 year for implementation times < 1 year and integrated to 50 years for implementation times > or = 1 year.

(b) These dose reductions are not held in the data library but are the integrated doses implied from the doses held in the data library.

(c) These work rates are for normal working conditions. Adjustment for working in a contaminated area can be made. The default factor in LCMT is 0.31, ie the work rates in the table are divided by 0.31.

Table 11: External dose reductions for ^{137}Cs for default decontamination techniques

Dry weather at time of deposition

Time period (days)	0 - 1	1 – 7	7 – 14	14 - 30	30 – 90	90 - 365	365 - 730	730 - 3650	3650 - 18250
Ru-106									
Outdoor	1.00	1.00	1.99	1.99	2.00	2.06	2.16	2.32	2.57
Normal living	1.00	1.00	1.66	1.70	1.78	1.84	1.89	1.95	1.91
I-131									
Outdoor	1.00	1.00	1.99	2.00	2.00	2.03	1.00	1.00	1.00
Normal living	1.00	1.00	1.67	1.70	1.76	1.82	1.00	1.00	1.00
Cs-137									
Outdoor	1.00	1.00	1.99	1.99	2.00	2.06	2.16	2.42	2.58
Normal living	1.00	1.00	1.66	1.70	1.77	1.84	1.90	1.96	1.74
Ba-140									
Outdoor	1.00	1.00	1.98	1.99	1.99	2.02	1.00	1.00	1.00
Normal living	1.00	1.00	1.64	1.68	1.74	1.80	1.00	1.00	1.00

Wet weather at time of deposition

Time period (days)	0 - 1	1 – 7	7 - 14	14 - 30	30 - 90	90 - 365	365 - 730	730 - 3650	3650 - 18250
Ru-106									
Outdoor	1.00	1.00	1.10	1.10	1.10	1.11	1.13	1.16	1.23
Normal living	1.00	1.00	1.09	1.09	1.10	1.10	1.12	1.15	1.21
I-131									
Outdoor	1.00	1.00	1.10	1.10	1.10	1.10	1.00	1.00	1.00
Normal living	1.00	1.00	1.09	1.09	1.10	1.10	1.00	1.00	1.00
Cs-137									
Outdoor	1.00	1.00	1.10	1.10	1.10	1.11	1.13	1.19	1.23
Normal living	1.00	1.00	1.09	1.09	1.10	1.10	1.12	1.17	1.23
Ba-140									
Outdoor	1.00	1.00	1.10	1.10	1.10	1.10	1.00	1.00	1.00
Normal living	1.00	1.00	1.09	1.09	1.09	1.10	1.00	1.00	1.00

Table 12: Dose reductions in LCMTD data library for grass cutting implemented 7 days following deposition

5.5 Input to LCMTD

LCMTD receives information from within LCMT and from other modules of RODOS. Specific details of the interfaces with other RODOS modules are given in reference 1.

LCMTD also requires information from the user via input-windows while running the RODOS system. This is primarily information on decontamination option selection. Default values have been given for all input information that can be selected by the user; the user is free to overwrite any of this information. The choice of default values is described in detail in reference 2. A summary of the information available for selection or for changing by the user for running LCMTD is given in Table 14.

Selection of Input:	
Decontamination strategy options	Decontamination techniques Decontamination factor
Selection of decontamination techniques	Techniques and implementation times (up to 5 combinations) For each: work rates; active area work efficiency; waste
Selection of decontamination factors	DF, surface and implementation time (up to 5 combinations)
Selection of other organs for dose calculations	Organs selected from list in Input Window

Table 14: Summary of Input Window Information for LCMTD

5.6 Endpoints available directly to the user

If decontamination is considered in conjunction with relocation in LCMTR the endpoints relating to decontamination effectiveness are included in the LCMTR endpoints, as listed in Table 3. The endpoints described below are those available to the user if LCMT option 4 is selected, ie decontamination is considered on its own.

5.6.1 Automatic Mode

No decontamination related endpoints are calculated in the Automatic Mode.

5.6.2 Interactive Mode

Lifetime individual effective doses received

The individual doses are summed over all time periods to age 70 and over radionuclide and deposition event to get the expected individual lifetime dose received. The doses from both external irradiation and inhalation from resuspension are produced as well as the sum over exposure pathway. No reduction in dose is assumed until the decontamiantion implementation time which is defined by the user. The individual dose received at each spatial grid point are displayed to the user on a map.

Collective effective dose saved

The collective dose saved is calculated from the sum of the individual lifetime doses saved by decontamination at each location multiplied by the number of people at each location and then summing over all spatial grid points. The doses from resuspension, external irradiation and the sum over exposure pathways are provided. This endpoint is displayed to the user as text.

Map showing if decontamination has been implemented at each spatial grid point.

Total resources required for decontamination option chosen

The total resources required are calculated by multiplying the total area decontaminated by the resource requirements per unit area. The area of the surface decontaminated is used which is a fraction of the total area of land. The total man hours of effort (man hours) and total waste produced (kg) are displayed as text.

5.7 Endpoints to other modules of RODOS

Endpoints are calculated for the HEALTH and ECONOMICS modules of RODOS. Details of the interfaces with these modules are given elsewhere[2]. A summary of the endpoints calculated is given in Table 15.

Graphical display	ECONOMICS MODULE	HEALTH MODULE (SIMPLE)	HEALTH MODULE(COMPLEX)
Lifetime individual dose received as function of location, Sv (resuspension, external and total)	Area decontaminated, km^2	Lifetime adult individual effective dose saved as function of location, Sv	Individual dose saved (4 ages, 4 selected organs) integrated to a number of times as function of location
Total lifetime collective dose saved, manSv (resuspension, external and total)	Time at which decontamination is completed, days		
Where decontamination implemented as function of location	Work rate required for decontamination, man h m^{-2} [a]		
Total resources required for decontamination, effort (man h) and waste (kg)[1]	Waste generated from decontamination, kg m^{-2} [a]		
	Active area work efficiency factor [a]		
	Type of decontamination implemented		

Note:

(a) Decontamination technique option only

Table 15: Summary of endpoints for DECONTAMINATION ONLY OPTION

6 Control sub-module, LCMTC

The purpose of LCMTC is to control the calling of the relevant subroutines which perform the calculations of the endpoints requested by the user from the relevant sub-modules of LCMT. These sub-modules are LCMTR for relocation, LCMTF for food countermeasures and LCMTD for decontamination. It calls routines which calculate interface endpoints required by subsequent modules of RODOS and routines which output endpoints to the user via the RODOS graphics.

6.1 METHODOLOGY

LCMT accesses data which is held in shared memory by the RODOS operating subsystem (OSY). These data for LCMT are arranged in a number of common blocks, some of which are used by all sub-modules of LCMT, others which are specific to particular sub-modules. Options chosen by the user are passed from OSY in these common blocks and LCMTC calls the relevant sub-modules and subroutines necessary to achieve the task requested by the user.

If the debug option is on, LCMTC opens two text files for writing messages, one relating to progress through LCMT and the other for intermediate results. LCMTC then checks that the user's chosen options are allowable for a successful run of LCMT.

LCMTC calls the relevant sub-modules determined by the user's choice of calculations. It is not possible for the user to change which sub-modules are called once LCMT is running. However, during run time, the system may identify certain options chosen by the user that are not allowed or are not required. LCMTC will prevent these calculations being made. For example, the user may have chosen to consider food bans. If LCMTF determines that none are required, then the relevant subroutines are not called.

Finally, LCMTC calls the relevant subroutines to write results or to generate interface endpoints for the appropriate mode of operation.

6.2 Input

The input to LCMTC enabling LCMT to run comprises: input determining mode of operation and which sub-modules to call; input defining the user's choice of results endpoints; input defining the system's requirements for interface endpoints.

The combination of these inputs defines which subroutines will be called during program flow (see Appendix B). Details of setting up a run of LCMT within RODOS is given in the accompanying user guide[3].

6.3 Output

There are no specific results endpoints calculated by LCMTC. The sub-module serves to control which endpoints are calculated and which tasks are performed by the relevant sub-modules.

7 References

1. Mansfield, P M and Brown, J, Modelling approach in the aquatic late countermeasures module, LCMA and associated data within RODOS v4.0. RODOS(WG3)-TN(00)-??, NRPB-M*** (to be published).
2. Mansfield, P and Brown, J, Interfaces between the Terrestrial Late Countermeasures Module (LCMT) and other modules of RODOS: v4.0, RODOS(WG3)-TN(99)-?? (to be published)
3. Brown, J *et al*, Data for the effectiveness of decontamination and their applicability within Europe for use with decision support systems for nuclear emergency response, specifically the RODOS system. RODOS(WG3)-TN(00)-??, NRPB-R*** (to be published).
4. Brown, J, Data for the effectiveness of agricultural countermeasures and their applicability within Europe for use with decision support systems for nuclear emergency response, specifically the RODOS system. RODOS(WG3)-TN(00)-??, NRPB-R*** (to be published).
5. Brown, J, Cooper, J R *et al*, Review of decontamination and clean-up techniques for use in the UK following accidental releases of radioactivity to the environment, NRPB-R288, London HMSO, 1996.

APPENDIX A
PROGRAM FLOW AND LOGIC

This Appendix describes the interaction of LCMTC with the other sub-modules of LCMT in terms of program flow and calling logic in the Automatic and Interactive modes of operation.

Figures A1 – A4 show illustratively the program flow through the sub-modules, starting with LCMTC, for the main options.

Options available in the Automatic mode include :

- relocation

and/or

- food bans in the absence of countermeasures for milk and green vegetables

Options available in the Interactive mode include :

- relocation with or without decontamination of spatial grid points either affected by relocation or in all contaminated locations

and/or

- food bans in the absence of countermeasures and a selection of user chosen agricultural countermeasures or agricultural decontamination

or

- decontamination only to reduce external and resuspension doses.

In the Interactive mode, for both relocation and food, the logical arguments are as follows :

1. *Is there a problem ?*

This question is answered by comparing levels, either doses or activity concentrations in food, at each spatial grid point against the 'action' criteria. If there is no problem, program flow returns from LCMTD, LCMTR or LCMTF to LCMTC. In the event of a problem, the next question is,

2. *What is the extent of the problem ?*

The relevant sub-modules then assess the extent of the problem in terms of areas, people and food affected by the interdiction of relocation or food bans, the duration of interdiction and potential doses received. The next question is,

3. *What can be done to reduce the extent of the problem ?*

For relocation, there is the option to decontaminate a spatial grid point prior to or after relocation. For food, there is the option to impose different agricultural countermeasures or to decontaminate the land affected. The relevant parts of LCMTD are called for LCMTR and LCMTF as required.

Program flow and the calling of the sub-modules is determined by the main option selected by the user and is in the following order :

Option 4: LCMTC calls LCMTD. This is only possible in the Interactive mode and excludes all other program flow options.

Option 2: LCMTC calls LCMTR. If the user specified to consider decontamination for relocation, LCMTR calls LCMTD.

Option 3: LCMTC calls LCMTF.

Option 1: The calling of the sub-modules is the same as for Option 2 followed by Option 3.

LCMTR

If the user has requested that relocation should take place then LCMTC calls LCMTR. LCMTR will not be called if the user has requested option 4. If the option to consider food, LCMTF, has been requested then this will be called after LCMTR. If LCMTR is called then the program flow is as follows:

1. The required expected effective doses for resuspension and external exposure pathways are calculated. All spatial grid points and the time periods covered by the criterion for imposition of relocation are considered.
2. Doses are modified to take account of evacuation that has occurred at each spatial grid point, if requested.
3. The expected effective doses are compared with the imposition criterion for relocation to determine all those spatial grid points where relocation is necessary.
4. If relocation is not necessary then decontamination will not take place and program flow returns to LCMTC.
5. If relocation is necessary but decontamination is not requested then endpoints will be calculated for relocation only and program flow returns to LCMTC.
6. If relocation is necessary and decontamination is requested by the user at all contaminated grid points, the expected effective doses are modified and compared with the relocation criteria to determine if relocation is still necessary. OR If relocation is necessary and decontamination is requested by the user within the relocation area, the

expected effective doses are modified and compared with the relocation criteria to determine if relocation is still necessary.

7. If relocation is necessary at a spatial grid point and with the chosen decontamination strategy in place, the duration of relocation required and hence type of relocation (temporary or permanent) is calculated by comparison of the individual effective dose with the user specified criterion. If relocation is necessary at a spatial grid point the individual doses are set to zero for the duration that relocation is in force.

8. The LCMTR endpoints are calculated.

9. Return to LCMTC

The program flow for LCMTR is shown in Figures A1 and A2.

LCMTF

LCMTC calls LCMTF if requested by the user. LCMTF cannot be called if option 4 is called. LCMTF is called after LCMTR if relocation is requested, regardless of whether relocation was required. If relocation is required, the pattern of relocation is used by LCMTF. Due to the complexity of actions which may occur at each spatial grid point, LCMTF operates on a spatial grid point by spatial grid point, and food by food, basis, calculating every endpoint requested at each spatial and temporal grid point in turn before moving on to the next food or next spatial grid point. The loop structure of foods selected by the user is inside the loop over spatial grid point. Endpoints are summed over foods and over spatial grid points where appropriate.

1. LCMTF determines if food bans are required in the absence of countermeasures by comparing with user chosen criteria. If a ban is required, the extent and duration of the bans for each food affected are calculated. If activity concentrations do not exceed the criteria, program flow returns to LCMTC.
2. If the user has selected to consider the effects of relocation on agricultural production, LCMTF checks if any relocation has been implemented and, if it has, the food production in the relocation area is modified.
3. If activity concentrations exceed the criteria, LCMTF calls the food countermeasure options allowable and/or requested. The effect of each countermeasure or countermeasure combination is considered separately.
4. The activity concentrations in each chosen food are modified for the agricultural countermeasure imposed.

5. The modified activity concentrations in the food are compared with the ban criteria. The extent and duration of any remaining food ban is calculated.

6. LCMTF endpoints are calculated.

7. Return to LCMTC

The program flow in LCMTF is shown in Figures A1 and A3.

LCMTD

LCMTD may be called directly from LCMTC if the user has specified the 'decontamination only' option. In this case the decontamination of agricultural land is not considered. LCMTD carries out decontamination in all contaminated areas.

1. The expected doses for resuspension and external exposure pathways for all time periods and all contaminated spatial grid points are calculated.

2. External dose reduction factors and surface activity reduction factors for the decontamination techniques chosen are applied to all the contaminated spatial grid points.

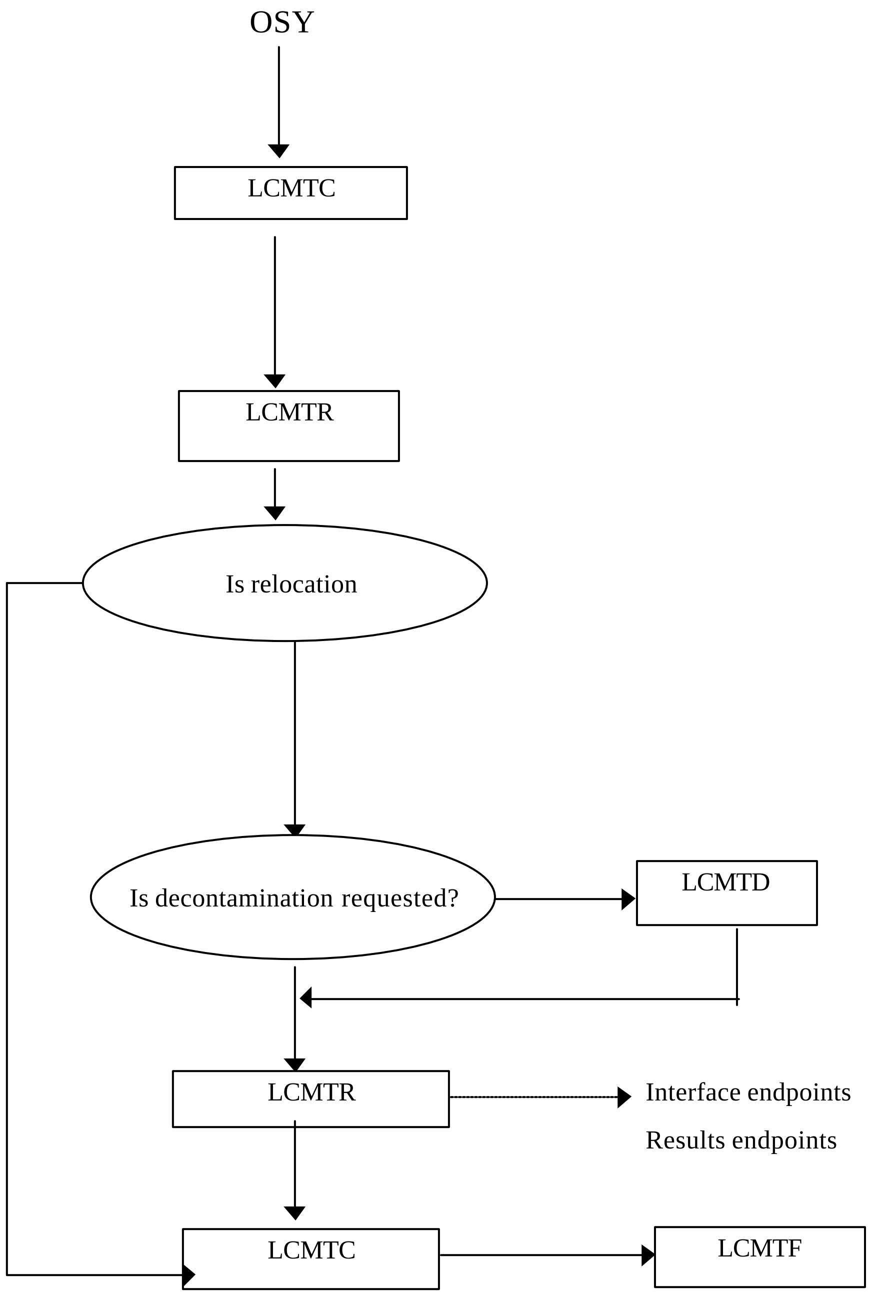
3. LCMTD endpoints are calculated.

4. Return to LCMTC.

The program flow for the 'decontamination only' option is shown in Figure A4.

Figure A1: Submodules of LCMT for option 1: relocation and food (default)

RELOCATION AND FOOD
a. RELOCATION



RELOCATION AND FOOD

b. FOOD

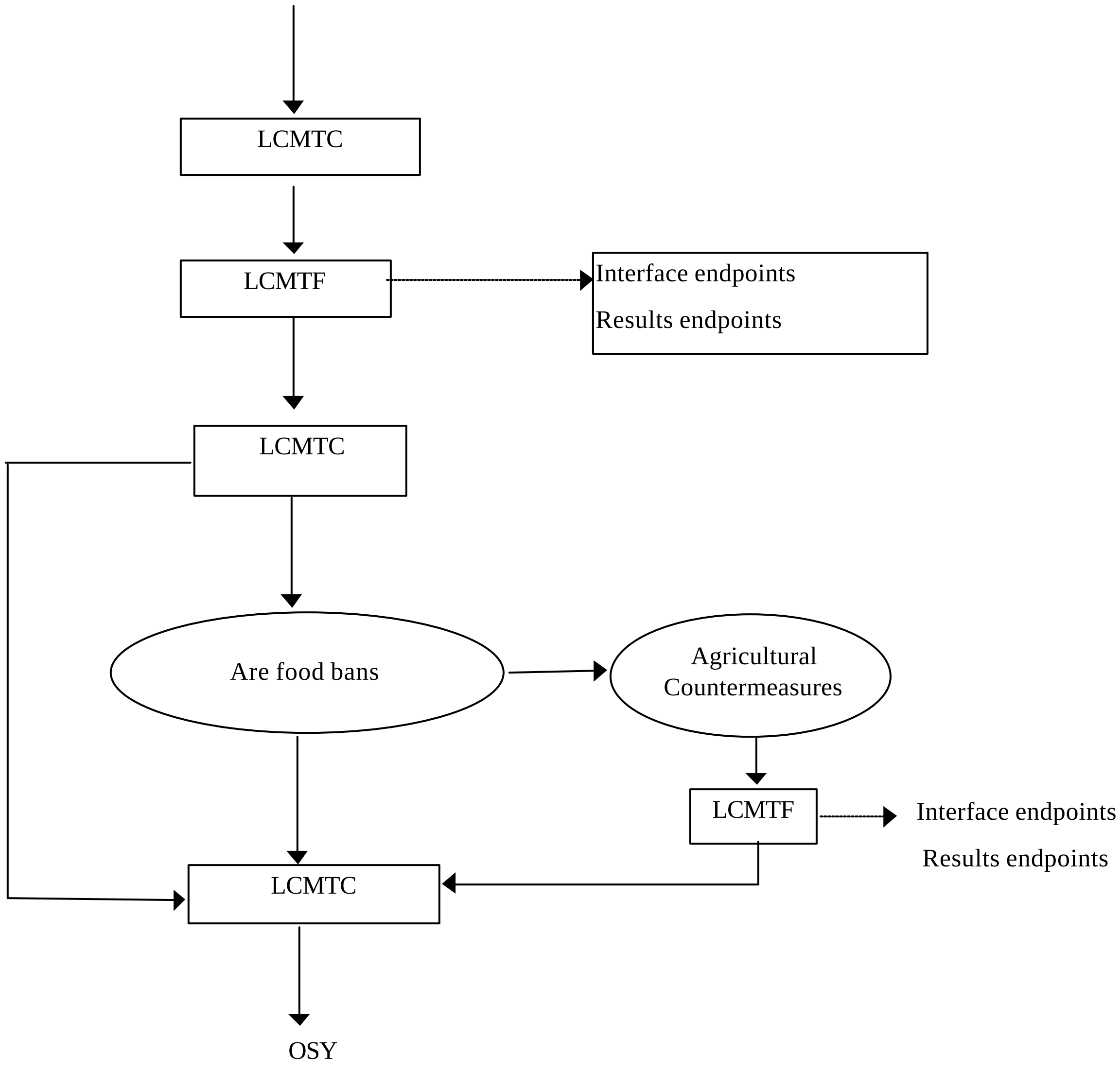


Figure A2. Sub-modules of LCMT for option 1: Relocation and food (default)

RELOCATION ONLY

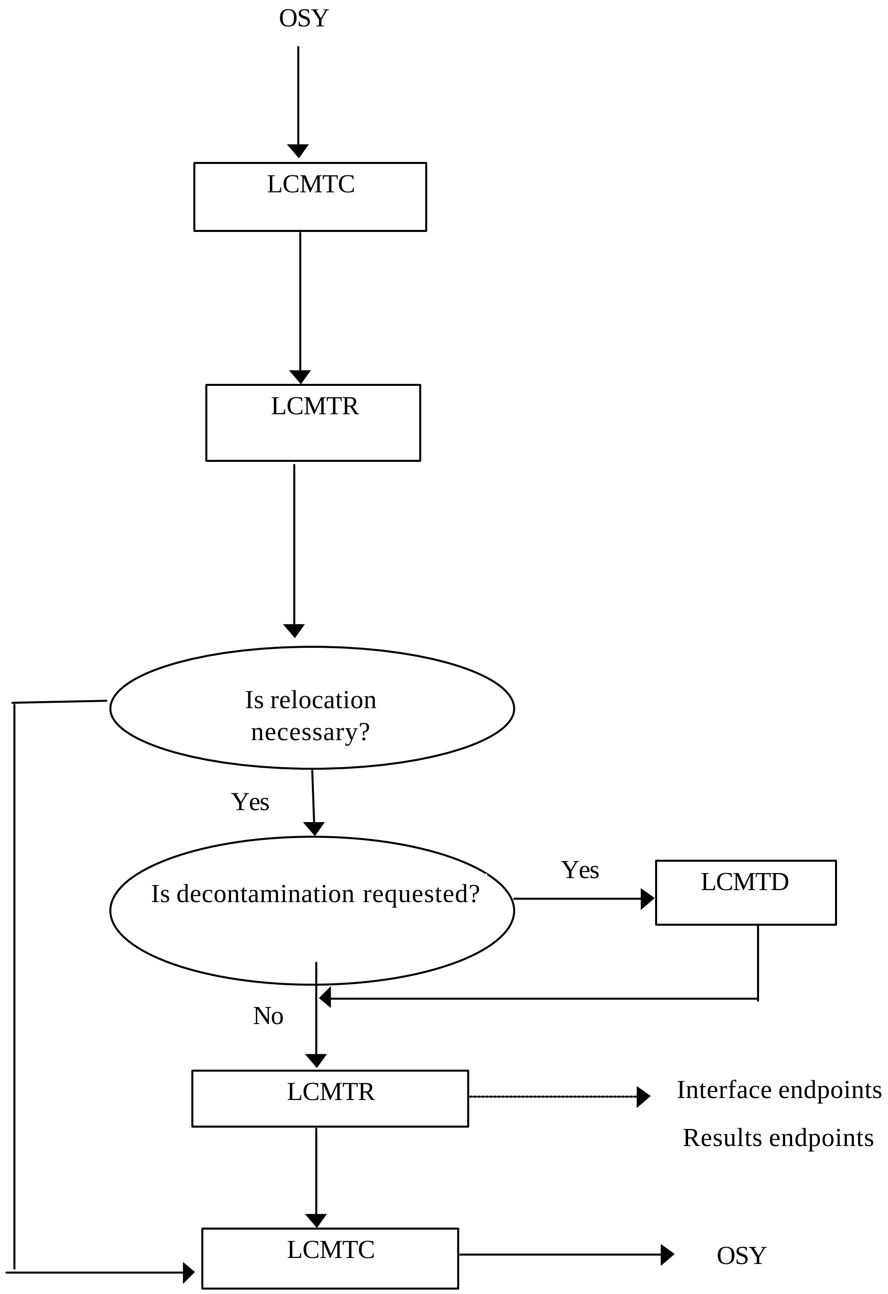


Figure A3. Submodules of LCMT for option 2: Relocation only

FOOD ONLY

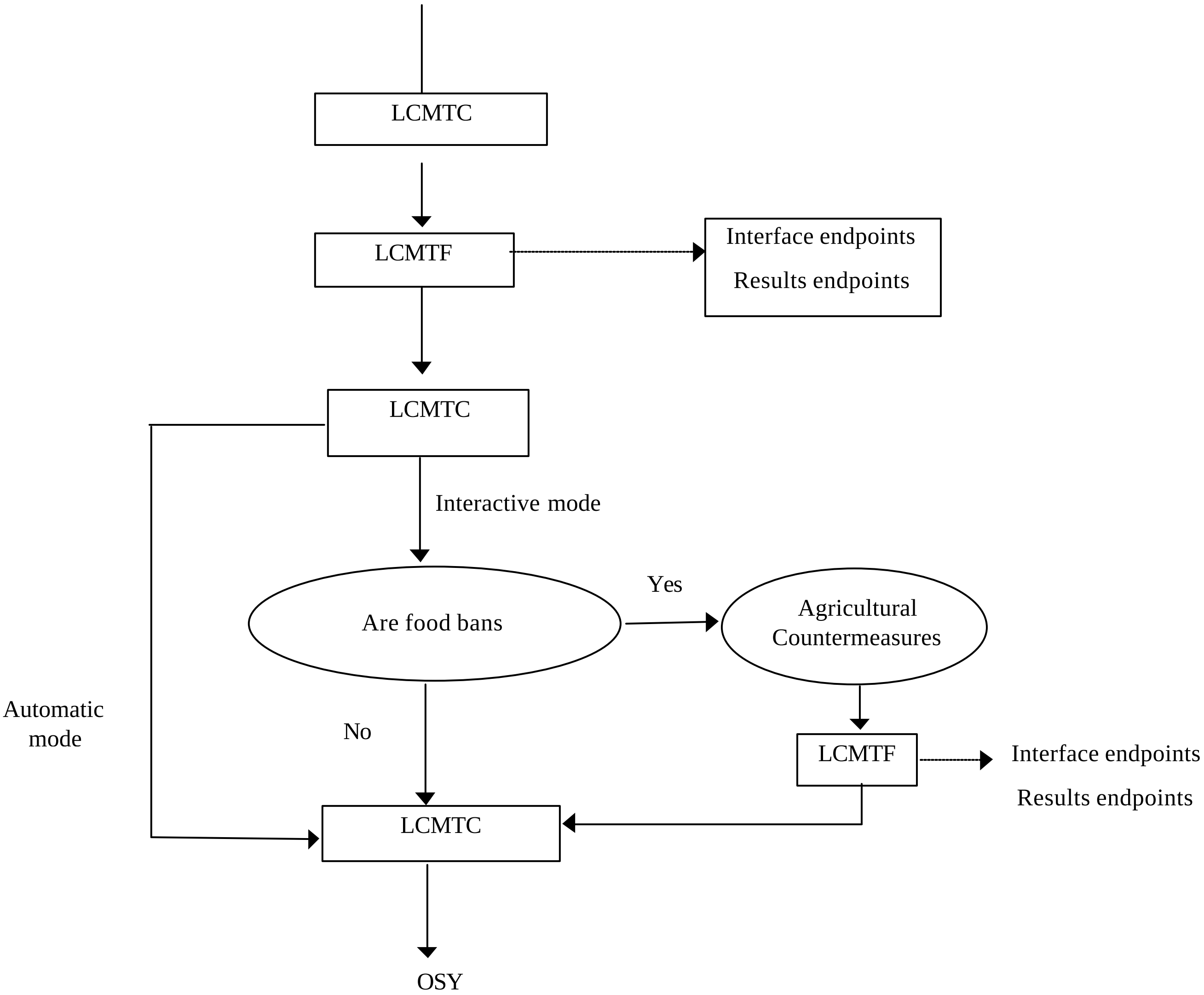


Figure A4. Sub-modules of LCMT for option 3: Food only

DECONTAMINATION ONLY

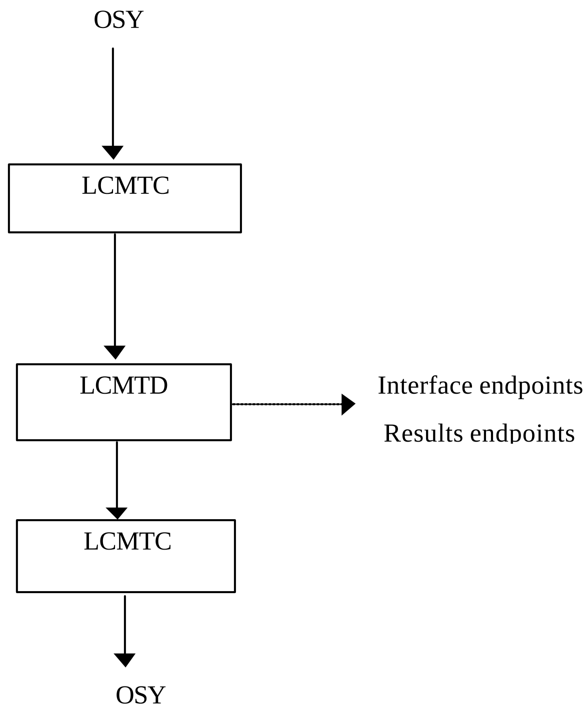


Figure A5. Sub-modules of LCMT for option 4: Decontamination only

Appendix B

Agricultural Countermeasure Combinations

This Appendix gives the list of agricultural countermeasure combinations that are available for each food considered in LCMTF. In addition the constraints placed on the timings of countermeasure combinations are given.

Countermeasure combinations

Milk (29 options)

Disposal or stopping production
Food processing
Storing food
Removing from contaminated feed at t=0
Removing from contaminated feed at t>0
Reducing contaminated feed at t=0
Reducing contaminated feed at t>0
Adding sorbents
Substituting feed
Change to forestry
Agricultural decontamination
Food processing and Storing food
Removing from contaminated feed at t=0 and Food processing
Removing from contaminated feed at t>0 and Food processing
Reducing contaminated feed at t=0 and Food processing
Reducing contaminated feed at t>0 and Food processing
Adding sorbents and Food processing
Substituting feed and Food processing
Removing from contaminated feed at t=0 and Storing food
Removing from contaminated feed at t>0 and Storing food
Reducing contaminated feed at t=0 and Storing food
Reducing contaminated feed at t>0 and Storing food
Adding sorbents and Storing food
Substituting feed and Storing food
Reducing contaminated feed at t=0 and Adding sorbents
Reducing contaminated feed at t>0 and Adding sorbents
Reducing contaminated feed at t=0 and Substituting feed

Reducing contaminated feed at t>0 and Substituting feed
Adding sorbents and Substituting feed

Beef-cow, Beef-bull, Pork, Lamb (21 options)

Disposal or stopping production
Storing food
Removing from contaminated feed at t=0
Removing from contaminated feed at t>0
Reducing contaminated feed at t=0
Reducing contaminated feed at t>0
Adding sorbents
Substituting feed
Change to forestry
Agricultural decontamination
Removing from contaminated feed at t=0 and Storing food
Removing from contaminated feed at t>0 and Storing food
Reducing contaminated feed at t=0 and Storing food
Reducing contaminated feed at t>0 and Storing food
Adding sorbents and Storing food
Substituting feed and Storing food
Reducing contaminated feed at t=0 and Adding sorbents
Reducing contaminated feed at t>0 and Adding sorbents
Reducing contaminated feed at t=0 and Substituting feed
Reducing contaminated feed at t>0 and Substituting feed
Adding sorbents and Substituting feed

Spring wheat (whole), Winter wheat (whole) (13 options)

Disposal or stopping production
Food processing
Storing food
Land amelioration
Change of crop
Change to forestry
Agricultural decontamination
Food processing and Storing food
Land amelioration and Food processing

Change of crop and Food processing

Agricultural decontamination and Food processing

Land amelioration and Change of crop

Agricultural decontamination and Change of crop

Sheep-milk, Goat-milk, Chicken, Eggs (16 options)

Disposal or stopping production

Storing food

Removing from contaminated feed at t=0

Removing from contaminated feed at t>0

Reducing contaminated feed at t=0

Reducing contaminated feed at t>0

Adding sorbents

Change to forestry

Agricultural decontamination

Removing from contaminated feed at t=0 and Storing food

Removing from contaminated feed at t>0 and Storing food

Reducing contaminated feed at t=0 and Storing food

Reducing contaminated feed at t>0 and Storing food

Adding sorbents and Storing food

Reducing contaminated feed at t=0 and Adding sorbents

Reducing contaminated feed at t>0 and Adding sorbents

Spring wheat (flour), Spring wheat (bran), Winter wheat (flour), Winter wheat (bran), Rye (whole), Rye (flour), Rye (bran), Oats, Potatoes, Leafy vegetables, Root vegetables, Fruit vegetables (8 options)

Disposal or stopping production

Storing food

Land amelioration

Change of crop

Change to forestry

Agricultural decontamination

Land amelioration and Change of crop

Agricultural decontamination and Change of crop

Condensed milk, Cream, Butter, Cheese (rennet), Cheese (acid), Veal, Roe deer, Beer (4 options)

Disposal or stopping production

Storing food

Change to forestry

Agricultural decontamination

Constraints on timing of countermeasure combinations

Storage always follows *processing*

Processing always follows:

removal of animals from contaminated feed for T>0

reduction in contaminated diet of animals for T>0

sorbents to animals

substitution of animal diets from contaminated feed for T>0.

amelioration

decontamination of land

Storage always follows:

removal of animals from contaminated feed for T>0

reduction in contaminated feed for T>0

sorbents to animals

substitution of animal diets from contaminated feed

Appendix C

Data files and default values for agricultural countermeasures (LCMTF)

The text data files containing information relevant to the effectiveness of the agricultural countermeasures included in LCMT are listed below and contain the default parameter values. Further information on the default values can be found in reference 3.

```
 C * File: FCBANS4.DATA.  Read by READBANS.F  LCMTF
version 4
C*********************************************************
C * Food bans
C*********************************************************
C NUCNAM, IGROUP:  Nuclide names and groups (CFILs) to
which the
C elements belong (18 elements, 5 groups - allocation to
groups)
'ncr*' 4    ! chromium
'nmn*' 4    ! manganese
'nfe*' 4    ! iron
'nco*' 4    ! cobalt
'nzn*' 4    ! zinc
'nsr*' 1    ! strontium
'nzr*' 4    ! zirconium
'nnb*' 4    ! niobium
'nmo*' 4    ! molybdenum
'nru*' 4    ! ruthenium
'nag*' 4    ! silver
'nte*' 4    ! tellurium
'nii*' 2    ! iodine
'ncs*' 4    ! cesium
'nba*' 4    ! barium
'nce*' 4    ! cerium
'npu*' 3    ! plutonium
'ncm*' 3    ! curium
C FOONAM: Food names
C NGRPFO: CFIL group to which food belongs
```

```
C IRELFO: Categorisation of food production for
management of relocated
C       : areas :-  daily management required = 1
C               :-  occasional management required = 0
C (35 foods into 5 groups - allocation to groups)
C FOONAM, NGRPFO, IRELFO
'fmil' 1    1  ! cow's milk
'fcom' 2    1  ! condensed milk
'fcre' 1    1  ! cream
'fbut' 2    1  ! butter
'fchr' 2    1  ! cheese (rennet)
'fcha' 2    1  ! cheese (acid)
'fmis' 1    1  ! sheep's milk
'fmig' 1    1  ! goat's milk
'fbec' 2    1  ! beef (cow)
'fbeb' 2    1  ! beef (bull)
'fvea' 2    1  ! veal
'fpor' 2    1  ! pork
'flam' 2    0  ! lamb
'fchi' 2    1  ! chicken
'froe' 2    0  ! roe deer
'fegg' 2    1  ! eggs
'fvel' 2    0  ! leafy vegetables
'fver' 2    0  ! root vegetables
'fvef' 2    0  ! fruit vegetables
'ffru' 2    0  ! fruit
'fber' 2    0  ! berries
'fpot' 2    0  ! potatoes
'fsww' 2    0  ! spring wheat whole
'fswf' 2    0  ! spring wheat flour
'fswb' 2    0  ! spring wheat bran
'fwww' 2    0  ! winter wheat whole
'fwwf' 2    0  ! winter wheat flour
'fwwb' 2    0  ! winter wheat bran
'fryw' 2    0  ! rye whole
'fryf' 2    0  ! rye flour
'fryb' 2    0  ! rye bran
```

```
'foat' 2    0  ! oats
'fbee' 3    0  ! beer
'f**1' 5    0  ! User-defined food 1
'f**2' 5    0  ! User-defined food 2
```

C * **File: FCPROC4.DATA**. Read by READPROC.F LCMTF version 4

```
C*********************************************************
C * Food Processing
C*********************************************************
C FPFLAG (milk) = 0 decontaminate only; = 1 process only; = 2 decon + process
0
C Decontamination factors for milk (<= 1.0) for 5 element groups:
C FPFMILK (5 element groups) FPMILK()
'nsr*' 0.05    ! Strontium group
'ncs*' 0.05   ! Cesium group
'nii*' 0.05   ! Iodine group
'n***' 1.0    ! Element group 4
'n***' 1.0    ! Element group 5
```

C * **File: FCSTOR4.DATA**. Read by READSTOR.F LCMTF version 4

```
C*********************************************************
C * Food storage
C*********************************************************
C ISTOR: (35 foods) ISTOR=1 storage only, =2 process + store)
'fmil'  2  ! cow's milk (default: 180 and 730 d
'fcom'  1  ! condensed milk
'fcre'  1  ! cream
'fbut'  1  ! butter
'fchr'  1  ! cheese (rennet)
'fcha'  1  ! cheese (acid)
'fmig'  2  ! goat's milk
'fmis'  2  ! sheep's milk
'fbec'  2  ! beef (cow)
```

```
'fbeb'  2  ! beef (bull)
'fvea'  2  ! veal
'fpor'  2  ! pork
'flam'  2  ! lamb
'fchi'  2  ! chicken
'froe'  2  ! roe deer
'fegg'  2  ! eggs
'fvel'  2  ! leafy vegetables
'fver'  2  ! root vegetables
'fvef'  2  ! fruit vegetables
'ffru'  2  ! fruit
'fber'  2  ! berries
'fpot'  2  ! potatoes
'fsww'  1  ! spring wheat whole
'fswf'  1  ! spring wheat flour
'fswb'  1  ! spring wheat bran
'fwww'  1  ! winter wheat whole
'fwwf'  1  ! winter wheat flour
'fwwb'  1  ! winter wheat bran
'fryw'  1  ! rye whole
'fryf'  1  ! rye flour
'fryb'  1  ! rye bran
'foat'  1  ! oats
'fbee'  1  ! beer
'f###'  2  !
'f###'  2  !
```

C * **File: FCADDS4.DATA**. Read by READADDS.F LCMTF version 4

```
C*********************************************************
C * Addition of sorbents
C*********************************************************
C FCDBSORB: List of sorbent identifiers (up to 5 sorbents)
'sor1'    ! AFCF added to feed (for Cs)
'sor2'    ! Bentonite added to feed (for Cs)
'sor3'    ! AFCF in boli (for Cs)
```

```
'sor4'    ! Stable calcium (for Sr)

'sor5'    !

C FCDBFADDS, FCDBFSORB: Food and which sorbent to use for
each food considered (9 foods)

'fmil'       'sor1'    ! cow's milk
'fmig'       'sor1'    ! goat's milk
'fmis'       'sor1'    ! sheep's milk
'fbec'       'sor1'    ! beef (cow)
'fbeb'       'sor1'    ! beef (bull)
'fpor'       'sor1'    ! pork
'flam'       'sor1'    ! lamb
'fchi'       'sor1'    ! chicken
'fegg'       'sor1'    ! eggs


C FADNUC: Element groups for reduction factors

ncs*nsr*n***n***n***

C Activity concentration reduction factors

C sor1 : Reduction factors FADCRF(9 foods, 5 element
groups) and kg/animal/day FCDB3()

'fmil'   0.2  1.0 1.0 1.0 1.0    3.0E-3    ! cow's milk
'fmig'   0.2  1.0 1.0 1.0 1.0    1.5E-3    ! goat's milk
'fmis'   0.2  1.0 1.0 1.0 1.0    1.5E-3    ! sheep's milk
'fbec'   0.33 1.0 1.0 1.0 1.0    3.0E-3    ! beef (cow)
'fbeb'   0.33 1.0 1.0 1.0 1.0    3.0E-3    ! beef (bull)
'fpor'   0.33 1.0 1.0 1.0 1.0    1.5E-3    ! pork
'flam'   0.33 1.0 1.0 1.0 1.0    1.5E-3    ! lamb
'fchi'   0.15 1.0 1.0 1.0 1.0    1.0E-3    ! chicken
'fegg'   1.0  1.0 1.0 1.0 1.0    1.0E-3    ! eggs

C sor2 : Reduction factors FADCRF(9 foods, 5 element
groups) and kg/animal/day FCDB3()

'fmil'   0.2  1.0 1.0 1.0 1.0    1.0E+0    ! cow's milk
'fmig'   0.2  1.0 1.0 1.0 1.0    1.5E-1    ! goat's milk
'fmis'   0.2  1.0 1.0 1.0 1.0    0.1E+0    ! sheep's milk
'fbec'   0.33 1.0 1.0 1.0 1.0    1.0E+0    ! beef (cow)
'fbeb'   0.33 1.0 1.0 1.0 1.0    1.0E+0    ! beef (bull)
'fpor'   0.33 1.0 1.0 1.0 1.0    1.6E-1    ! pork
'flam'   0.33 1.0 1.0 1.0 1.0    0.1E+0    ! lamb
'fchi'   0.65 1.0 1.0 1.0 1.0    5.0E-3    ! chicken
```

```
'fegg'   0.65 1.0 1.0 1.0 1.0    5.0E-3    ! eggs
C sor3 : Reduction factors FADCRF(9 foods, 5 element
groups) and kg/animal/day FCDB3()
'fmil'   0.2  1.0 1.0 1.0 1.0    1.0E-3    ! cow's milk
'fmig'   0.2  1.0 1.0 1.0 1.0    5.0E-4    ! goat's milk
'fmis'   0.2  1.0 1.0 1.0 1.0    5.0E-4    ! sheep's milk
'fbec'   0.33 1.0 1.0 1.0 1.0    1.0E-3    ! beef (cow)
'fbeb'   0.33 1.0 1.0 1.0 1.0    1.0E-3    ! beef (bull)
'fpor'   0.33 1.0 1.0 1.0 1.0    5.0E-4    ! pork
'flam'   0.33 1.0 1.0 1.0 1.0    5.0E-4    ! lamb
'fchi'   0.15 1.0 1.0 1.0 1.0    3.0E-4    ! chicken
'fegg'   1.0  1.0 1.0 1.0 1.0    0.0E+0    ! eggs
C sor4 : Reduction factors FADCRF(9 foods, 5 element
groups) and kg/animal/day FCDB3()
'fmil'   1.0  0.5 1.0 1.0 1.0    0.1E+0    ! cow's milk
'fmig'   1.0  0.5 1.0 1.0 1.0    0.1E+0    ! goat's milk
'fmis'   1.0  0.5 1.0 1.0 1.0    0.1E+0    ! sheep's milk
'fbec'   1.0  0.5 1.0 1.0 1.0    0.1E+0    ! beef (cow)
'fbeb'   1.0  0.5 1.0 1.0 1.0    0.1E+0    ! beef (bull)
'fpor'   1.0  0.5 1.0 1.0 1.0    0.1E+0    ! pork
'flam'   1.0  0.5 1.0 1.0 1.0    0.1E+0    ! lamb
'fchi'   1.0  0.5 1.0 1.0 1.0    1.0E-1    ! chicken
'fegg'   1.0  1.0 1.0 1.0 1.0    0.0E+0    ! eggs
C sor5 : Reduction factors FADCRF(9 foods, 5 element
groups) and kg/animal/day FCDB3()
'fmil'   1.0  1.0 1.0 1.0 1.0    0.0E+0    ! cow's milk
'fmig'   1.0  1.0 1.0 1.0 1.0    0.0E+0    ! goat's milk
'fmis'   1.0  1.0 1.0 1.0 1.0    0.0E+0    ! sheep's milk
'fbec'   1.0  1.0 1.0 1.0 1.0    0.0E+0    ! beef (cow)
'fbeb'   1.0  1.0 1.0 1.0 1.0    0.0E+0    ! beef (bull)
'fpor'   1.0  1.0 1.0 1.0 1.0    0.0E+0    ! pork
'flam'   1.0  1.0 1.0 1.0 1.0    0.0E+0    ! lamb
'fchi'   1.0  1.0 1.0 1.0 1.0    0.0E+0    ! chicken
'fegg'   1.0  1.0 1.0 1.0 1.0    0.0E+0    ! eggs
'EOF'
```

C * **File: FCSUBS4.DATA**. Read by READSUBS.F LCMTF version 4

```
C*******************************************************
C * Substitution of diet.  Default data based on FDMT
default diets
C*******************************************************
C * FSBREPFEED: Up to 8 replacement feeds; f*** = feed is
not replaced
C * FSBRATES  : kg/d fresh mass of replacement feed for
feeding regime
C * at time of substitution in each of 5 radioecological
regions
C * Animal
C * FSBREPFEED(region), FSBRATES(region)
 Region___1   Region___2   Region___3   Region___4   Region___5
'fmil'
 'fgri' 42.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 1, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 2, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 3, kg/d
 'fwba'  6.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 4, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 5, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 6, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 7, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 8, kg/d

'fbec'
 'fgri' 42.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 1, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 2, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 3, kg/d
 'fwba'  6.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 4, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 5, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 6, kg/d
```

```
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 7, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 8, kg/d


'fbeb'
 'fmai' 17.0  'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 1, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 2, kg/d
 'fwba' 2.5   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 3, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 4, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 5, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 6, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 7, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 8, kg/d


'fpor'
 'fwba'  1.5  'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 1, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 2, kg/d
 'fbrr'  6.5  'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 3, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 4, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 5, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 6, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 7, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 8, kg/d


'flam'
 'fgre'  3.0  'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 1, kg/d
```

```
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 2, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 3, kg/d
 'fwba'  0.4  'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 4, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 5, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 6, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 7, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 8, kg/d


'fmis'
 'fgre'  5.5  'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 1, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 2, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 3, kg/d
 'fwba'  0.8  'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 4, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 5, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 6, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 7, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 8, kg/d


'fmig'
 'fgre'  8.0  'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 1, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 2, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 3, kg/d
 'fwba'  1.0  'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 4, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 5, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 6, kg/d
```

```
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 7, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 8, kg/d


'fchi'
 'fwwh'  0.05 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 1, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 2, kg/d
 'fmab'  0.1  'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 3, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 4, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 5, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 6, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 7, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 8, kg/d


'fegg'
 'fwwh'  0.05 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 1, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 2, kg/d
 'fmab'  0.1 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.  !
Feed 3, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 4, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 5, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 6, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 7, kg/d
 'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.   'f***'  0.
! Feed 8, kg/d
 'EOF'
```

C * **File: FCAMEL4.DATA**. Read by READAMEL.F LCMTF version 4

```
C*****************************************************
C * Amelioration of land
```

```
C*********************************************************

C Element groups or elements considered for activity
concentration reduction factors

ncs*nsr*n***n***n*** (caesium, strontium, dummy, dummy,
dummy)

C 'food'; FAMQUAN(): kg of ameliorant per km2 (8 raw
foods)

C FAMCRF: activity concentration reduction factors for 5
applications and 5 element groups:

C (in Bq/kg following application / Bq/kg before
application)

'fswh' 5.0E+5    ! spring wheat,
'ncs*' 0.5  1.0  1.0  1.0  1.0    ! cesium group
'nsr*' 0.4  1.0  1.0  1.0  1.0    ! strontium group
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 3
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 4
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 5

'fwwh' 5.0E+5    ! winter wheat,
'ncs*' 0.5  1.0  1.0  1.0  1.0    ! cesium group
'nsr*' 0.4  1.0  1.0  1.0  1.0    ! strontium group
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 3
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 4
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 5

'frye' 5.0E+5    ! rye
'ncs*' 0.5  1.0  1.0  1.0  1.0    ! cesium group
'nsr*' 0.4  1.0  1.0  1.0  1.0    ! strontium group
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 3
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 4
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 5

'foat' 5.0E+5    ! oats
'ncs*' 0.5  1.0  1.0  1.0  1.0    ! cesium group
'nsr*' 0.4  1.0  1.0  1.0  1.0    ! strontium group
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 3
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 4
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 5
```

```
'fpot' 5.0E+5    ! potatoes
'ncs*' 0.5  1.0  1.0  1.0  1.0    ! cesium group
'nsr*' 0.4  1.0  1.0  1.0  1.0    ! strontium group
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 3
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 4
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 5

'fvel' 5.0E+5    ! leafy vegetables
'ncs*' 0.5  1.0  1.0  1.0  1.0    ! cesium group (default
= 0.5 1.0..)
'nsr*' 0.4  1.0  1.0  1.0  1.0    ! strontium group
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 3
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 4
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 5

'fver' 5.0E+5    ! root vegetables
'ncs*' 0.5  1.0  1.0  1.0  1.0    ! cesium group
'nsr*' 0.4  1.0  1.0  1.0  1.0    ! strontium group
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 3
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 4
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 5

'fvef' 5.0E+5    ! fruit vegetables
'ncs*' 0.5  1.0  1.0  1.0  1.0    ! cesium group
'nsr*' 0.4  1.0  1.0  1.0  1.0    ! strontium group
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 3
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 4
'n***' 1.0  1.0  1.0  1.0  1.0    ! group 5
```

C * **File: FCCROP4.DATA.** Read by READCROP.F LCMTF version 4

```
C
*********************************************************
C * Crop change
C********************************************************
! * 18 elements FCDBELE
'nag*' ! silver
```

```
'nba*' ! barium
'nce*' ! cerium
'ncm*' ! curium
'nco*' ! cobalt
'ncr*' ! chromium
'ncs*' ! cesium
'nfe*' ! iron
'nii*' ! iodine
'nmn*' ! manganese
'nmo*' ! molybdenum
'nnb*' ! niobium
'npu*' ! plutonium
'nru*' ! ruthenium
'nsr*' ! strontium
'nte*' ! tellurium
'nzn*' ! zinc
'nzr*' ! zirconium

C * Factors for change in crop variety for 18 elements for 8 crops
C * TF_RATIO: Highest reduction in root uptake factors for new crop variety
'fswh'    ! spring wheat
3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0
'fwwh'    ! winter wheat
3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0
'frye'    ! rye
3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0
'foat'    ! oats
3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0
'fpot'    ! potatoes
3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0
'fver'    ! root vegetable
```

```
3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0
3.0 3.0 3.0 3.0

'fvel'    ! leafy vegetables

3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0
3.0 3.0 3.0 3.0

'fvef'    ! fruit vegetables

3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0 3.0
3.0 3.0 3.0 3.0
```

C * **File: FCDECF4.DATA.** Read by READDECF.F LCMTF version 4

```
C*********************************************************

C * Agricultural decontamination

C*********************************************************

C FCDBFDECF: 8 crops and pasture

C FDCNUC   : Up to 5 element groups considered for decontamination

C          : factors

C FCDDCRF  : Activity concentration reduction factor for

C          : decontamination < 1.

C FCDBFDECF, FCDDCRF

         'ncs*' 'nsr*' 'n***' 'n***' 'n***'

'fwwh'    0.3    0.3    0.3    0.3    0.3

'fswh'    0.3    0.3    0.3    0.3    0.3

'frye'    0.3    0.3    0.3    0.3    0.3

'foat'    0.3    0.3    0.3    0.3    0.3

'fpot'    0.3    0.3    0.3    0.3    0.3

'fvel'    0.3    0.3    0.3    0.3    0.3

'fver'    0.3    0.3    0.3    0.3    0.3

'fvef'    0.3    0.3    0.3    0.3    0.3

'fpas'    0.1    0.1    0.1    0.1    0.1
```

C * **File: FCDBASE4.DATA.** Read by FCDBASE.F LCMTF version 3.2/4.0

```
C*********************************************************

C * Data base

C*********************************************************

C FCDBFPROD, FCDB10(): Conversion of production grid to animal numbers (9 foods)

'fmil'      5000            ! l of milk per cow / yr
```

```
'fmig'       1100              ! l of milk per goat /yr
'fmis'        750              ! l of milk per sheep /yr
'fbec'        150              ! kg of beef per cow
'fbeb'        150              ! kg of beef per bull
'fpor'         25              ! kg of pork per pig
'flam'         15              ! kg of lamb per lamb
'fchi'          0.7            ! kg of chicken meat per
chicken
'fegg'        300              ! number of eggs laid per
yr per chicken

C FCDBFEED, FCWETDRY(): Water content of feedstuffs -
fraction (22 feeds)
'fgri'  0.2
'fhyi'  1.0
'fgre'  0.2
'fhye'  1.0
'fmai'  0.2
'fmab'  0.35
'fpot'  0.2
'fbee'  0.2
'fbel'  0.2
'fwba'  0.9
'fsba'  0.9
'fwwh'  0.9
'fswh'  0.9
'frye'  0.9
'foat'  0.9
'fdir'  0.2
'fbrr'  0.2
'fsmm'  0.1
'fmis'  0.95
'fwhr'  0.05
'fwha'  0.05
'f###'  1.0

C * canim: List of foods which are deemed to be animals
'fbec' 'fbeb' 'fvea' 'fpor' 'flam' 'fchi' 'froe'
```

```
C * ccrop: List of foods which are deemed to be crops
'fsww' 'fswf' 'fswb' 'fwww' 'fwwf' 'fwwb' 'fryw' 'fryf'
'fryb' 'foat' 'fpot' 'fvel' 'fver' 'fvef' 'ffru' 'fber'
```

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