Evaluation and Network of EC – Decision Support Systems in the field of Terrestrial Radioecological Research – EVANET

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ABSTRACT : The importance and need of a coherent, harmonised and sensitive response to emergencies has been particularly obvious since the Chernobyl accident. Within the 4th framework programme of the EC, a major objective of a variety of projects was to derive holistic approaches to reliably predict radionuclide activity transfer in aquatic and terrestrial ecosystems. These projects were constructed as DSS making use of new tools such as GIS and geostatistics and improved understanding on behaviour of radioactive material in the environment, to identify cost-effective countermeasures to be implemented and their potential environmental side-effects and waste production. This was undertaken to improve the modelling description of the behaviour of radionuclides in the environment and also to develop a sound policy and practice in managing the impact of radiation (natural and artificial) on man and environment. Therefore, some projects additionally addressed the social-psychological-ethical aspects of remediation strategies, decision making and post accidental management policy. There is now an urgent need 1) to inform DSS developers and potential end users about the existing systems, of their capabilities, advantages, disadvantages, and 2) to interlink and compare the results of these projects with the RODOS system. This will allow the identification of overlaps, weaknesses and strengths within these projects and simultaneously allow the integration of the best features of existing systems into one common product which will be widely applicable in Europe. In this project, which addresses the environmental transfer of radioactive material in ***terrestrial ecosystems*** it is foreseen to produce a comprehensive synthesis report of existing systems, existing mechanistic models, impact assessment and environmental management systems, addressing natural/semi-natural, agricultural and urban environments

1 INTRODUCTION

Accidental releases do not respect any borders, as was also experienced after the Chernobyl accident and long-lived radionuclides can be dispersed over many countries. Therefore, contamination of agricultural land and production areas and consequently of food products is not only a concern of an individual country or nationality but requires a joint effort of the countries affected. For this purpose, Decision Support Systems (DSS) which take into account national but also international and generic needs, and which are based on the understanding of the nature and the processes involved, are inevitably required to support a good management system when confronted with such situations.

Especially within the 4th framework programme of the EC, several projects were supported which derived environmentally-based DSS to more reliably predict the transfer of radionuclides (mainly radiocaesium) in ecosystems to derive management systems provided for potential decision makers and stakeholders in case of accidental releases or natural of artificial radioactive substances. The European DSS RODOS represents one of the most ambitious and challenging projects since it tries to cover all important radionuclides, all important processes involved into the dispersion and transfer mechanisms and appropriate countermeasure strategies for different phases after an accident. In addition to RODOS, however, a variety of other projects have been undertaken which covered particular topics in much greater depth, having the potential to improving the existing Europe-wide applicable RODOS system. Each of those have advantages and disadvantages, have been developed for special ecosystems, or cover one aspect such as the soil-plant transfer of radiocaesium or potential side effects of countermeasures in much more detail. Especially the application of countermeasures to reducing the radiological consequences after accidental releases may cause non-desired effects of ecological, economic and social nature. Such an assessment requires appropriate models to predict the radionuclide behaviour in the environment; but also techniques for assessing economic, socio-psychological and ecological impacts. These aspects need to be accounted for when assessing the global impact of the above effects.
Though the individual systems themselves had different objectives and addressed different tasks, there exists some overlap in the parameters used: A careful re-evaluation and comparison between the individual DSS is urgently needed. The objectives of this project therefore is:

1) to provide a summary and a synthesis of the existing DSSs;
2) to identify weaknesses and strengths of the different approaches;
3) to verify and provide compatibility of the DSSs;
4) to integrate the DSSs for their holistic use for complete ecosystems and economic systems;
5) to inform the user community about the existence and their potential for improving the assessment and management;
6) to identify the potential to realise a holistic common approach for a wider application in Europe;
7) to explore the user market beyond the strict use for radioecology and radiation protection;
8) to provide information about further needed research in the field of radioecology and radiation protection which might find its implementation in the 6th framework programme.

   A critical evaluation of projects which have developed DSS systems within the 4th framework programme has not yet been undertaken . This network will:

   - Inform the scientific and user community and other interested parties on the existing DSS on terrestrial transfer of radioactive material;
   - Explore additional potential applications of DSS;
   - Compare the different DSS to identify its overlaps, its weaknesses and strengths;
   - Provide a synthesis of these different DSS;
   - Identify lack of knowledge in the present state-of-the-art in terrestrial radioecological science;
   - Provide a product capable of being incorporated into a European-wide useable DSS.

In addition, this network will help to continue existing scientific collaboration between institutions and will represent a forum for discussion of future research needs. The outcome of the project may directly be of value for the implementation of the 6th framework programme of the EC. The primary output of the project will considerably contribute to a framework aiding the selection of robust and practicable strategies to enable the long-term sustainable management of areas contaminated by nuclear accidents.

2 THE SOIL-PLANT TRANSFER MODULE IN THE DSS IN NATURAL/SEMI-NATURAL AND AGRICULTURAL ENVIRONMENTS AND APPROPRIATE COUNTERMEASURES

2.1. Introduction

An important aspect of any radioecological assessment model is the estimation of the transfer of radionuclides from the soil to plant and further to the food chain. This is important because the presence of radionuclides in the food products is a potential hazard for human health. The migration of radionuclide through the food chain takes place in two phases: firstly the absorption from soil by plant roots and secondly the ingestion of those plants directly by the human being or by animals, which will generate contaminated food product such as meat, milk, milk products.
Traditionally the flux between the soil and the plant compartment is quantified using transfer parameters: Transfer Factors (TFs) and Aggregated Transfer Factors (T_{agg}s).
TFs for soil to plants are defined as the ratio between the activity concentration in plants (Bq/kg dry weight) and the activity concentration in the soil (Bq/kg dry weight).

$$TF = \frac{\text{Plant activity concentration (Bq/kg dry weight)}}{\text{Soil activity concentration (Bq/kg dry weight)}} \qquad (1)$$

T_{agg}s is defined as the ratio of the activity concentration in plants (Bq/kg dry weight) and the Total deposition on the soil (Bq/m^2)

$$T_{agg} = \frac{\text{Activity concentration in plants (Bq/kg dry weight)}}{\text{Total deposition on the soil (Bq/m}^2\text{)}} \qquad (2)$$

The calculation of these parameters is extremely straightforward; this is due to the simplicity of the equation and even to the empirical data required. However, the main limitation of these parameters is in their variability.
The literature reports several set of transfer parameters and their variability can even be of two orders of magnitude. It is obvious that they are site and species specific. This variation is due to several factors, which can be divided into two categories: the first one is the experimental design. For a long time, any standard or experimental protocol for the estimation of the TFs or T_{agg}s was not present.
The activity concentration in plant was estimated considering only the edible or the inedible part of the plant or in some case the whole plant. Yet, the measurement of the weight had different approaches, dry or fresh weight. In some cases, the transfer parameters was considered in terms of unwashed plant, consequently soil particles present on the leafs surface was included in the measure, or in some other studies the plant was washed, thus the soil particles was removed.
Regarding the soil, the uncertainty on its measurements is mainly due on the consideration of air-dry weight or oven-dry weight. Concerning the experimental approach, it is important to mention another factor that might introduce a variation in the transfer parameters estimation. The plants considered were grown in different environmental conditions, which made the data not comparable. Plants that had been grown in controlled conditions, as in greenhouses, have different morphology to plants that had been grown in a natural ecosystem outdoor. This strongly influences their nutrients uptake and their development. These lack of standards prompted the International Union of Radioecology (IUR) to set

measurements protocol. The IUR compiled a data set with all the transfer parameters estimated using such standards. This data set is updated every time new measurements are available.
The second category of factors influencing the transfer factors variability regards the physiological requirements of the plants and the physico-chemical factors that govern the distribution of the radionuclides between the soil solid phase and the soil solution. Roots uptake is regulated by several factors, first of all by the deficient, sufficient and excess levels of nutrients or radionuclides present in the soil solution. Secondly by the plant requirements and finally by the soil conditions which make such element available, absorbed or fixed to the soil system.
Consequently, it is very difficult to generalise: different species react differently to similar environmental conditions. In addition, plants belonging to the same species have different absorption rate since the soil characteristics and the nutrients (and radionuclides) availability might not be the same. Obviously the uptake of radionuclides which have not any recognised physiological role as Pu and other actinides, is not governed by the previous assumption.
Transfer factors can be considered as a good tool for a first approximation of the fluxes within the ecosystem considered.The use of transfer factors is not the only approach that has been used to estimate the absorption of radionuclides by plant roots. A second method regards models where the soil-plant transfer has been predicted on the basis of the soil characteristics.
The Absalom model, which has been developed in conjunction with the SAVE and RESTORE project describes the roots uptake in function of the soil clay content, organic matter, pH and exchangeable K.
In the FORESTLAND project, a similar model has been developed. The soil system is described by several compartments which estimate the portion of radiocaesium available and unavailable. Obviously these models could still improved, for instance in the Absalom model quantitative information on soil clay mineralogy might mechanically improve the model perforce. However, the use of such models is more likely to reduce the variation, and thus the uncertainty on the fluxes between the soil and the plants that transfer parameters could introduce.
In the VI and V Framework programme, ten projects had produced Decision Support Systems (DSS) for terrestrial environments: CESER, FORIA, LANDSCAPE, RECLAIM, RESTORE, SAVE, SAVE-EC, RIFE2, STRESS, TEMAS. (EC, 2002) (see glossary). These systems have different objectives and address different tasks. As a result, some of them could be considered unique and thus their comparison could present some difficulties.
On the other hand, they consider similar environment as it is shown in the fig 1. For instance models such as TEMAS, SAVE and RESTORE can be applied for a rural scenario and a semi-natural ecosystem. On the opposite, systems as RIFE2, LANDSCAPE have been designed to give prediction only in semi natural ecosystem.
In the projects FORECO remediation strategies for forests were critically evaluated and a decision tree provided to find the best strategy for forest ecosystems after contamination on the example of the Chernobyl accident and provides a classification of restoration options considering dose reduction but also long-term ecological quality and economy. This aspect is also covered in CESER which addresses the long-term ecological consequences of restoration options in agricultural and semi-natural ecosystems. A ranking methodology is provided which helps the user to find the best strategy with the highest activity reduction effects and the less economic and ecological impact for a given landscape. Restoration strategies for different ecosystems were also suggested within RESTORE which especially took into account social – psychological aspects on self-help strategies and which was closely related to the inco-Copernicus project RECLAIM where the objectives were set to further provide detailed information for the radioactive contaminated sites in Russia, Ukraine, Belarus and Kazakhstan.

SAVE and SAVE-EC provides a detailed method on the dependence of radiocaesium transfer on soil characteristics and consequently agricultural but also semi-natural products such as sheep milk and meat and its spatial and temporal variation throughout Europe and Eastern Europe, whereas SEMINAT provides models and parameters on the long-term dynamics of radionuclides in semi-natural environments such as meadows and forests.

In LANDSCAPE model predictions for three different forest models on radiocaesium transfer scenarios for different endpoints in boreal forests were tested against measurements in experimental sites. The project covered major processes which influence radiocaesium concentration in vegetation and fungi, the quantification of radiocaesium intake of key herbivores such as moose and the quantification of forest management on radiocaesium dynamics. The RODOS contribution will provide the information how the natural and semi-natural environment is covered in this system and how more detailed findings can be integrated.

The usage of GIS techniques is especially dealt in STRESS, SAVE, SAVE-EC, and RESTORE which give indications on the spatial-temporal variation of activity concentrations within landscapes and food products. The dependence of the transfer of radiostrontium on soil types has been developed within RESTORE but due to lack of data (available only for the 30 km Chernobyl exclusive zone) could not be verified. Further completely different ecosystems (as the Semipalatinsk test site) have been tested on the generic nature of the models developed within SAVE and RESTORE and have be applicable within certain limits of uncertainty. Side effects on ecology have been covered by CESER and it will be tested how this system can be considered to contribute to RODOS. TEMAS can select the optimum management strategy for complex agricultural scenarios on whichever place of the European Community territory with different levels of contamination, uses and dimensions. The evaluation model was developed identifying relevant parameters and equations as consequence of the study of different real and simulated cases. At present the decision is based on radiological and cost criteria. All delivered software have been tested and compared.

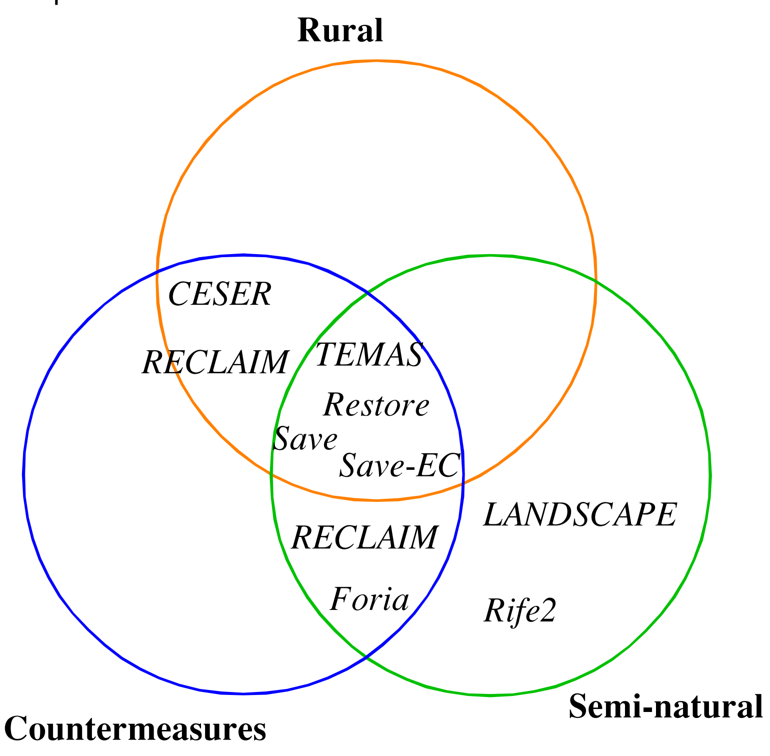

Figure 1. Environmental domain of the systems considered

2.2. Comparison of models

The first part of the EVANET-TERRA project had the aim of assessing the Decision Support System developed during the IV and the V Framework Programme. Such assessment had the objective to understand the capability of each system and to propose an adequate strategy plan for a cross comparison between them, in order to evaluate their response for a European scenario.
Three environments have been considered: rural, semi-natural and urban. The RESTORE project considers even freshwater ecosystems, but such environment is not going to be tested.
The following figures and tables summarise the systems domain, developments approaches and soil characteristics required. Using this representation the comparison between them is straightforward.

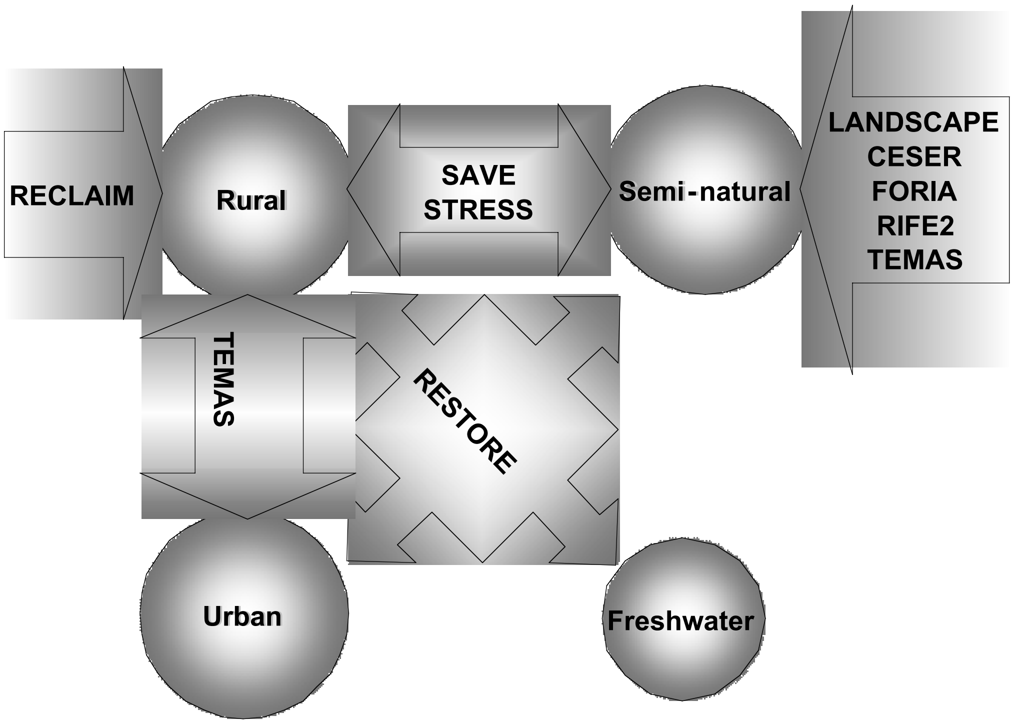

Fig. 2. Environments considered by the DSS

The approaches that had been adopted for the development of such systems are different from model to model (Fig.3). Systems as LANDSCAPE, SAVE and RESTORE adopted a dynamic semi-mechanistic model, which combines Transfer parameters with the use of a mechanistic model, which evaluate the radiocaesium available in the soil solution as a function of the soil characteristics (table1). The Absalom model, implemented in RESTORE and SAVE, has been developed for rural environment, soil to crops, while the LANDSCAPE model is for semi-natural environments. On the other hand the other systems adopt transfer parameters, consequently soil characteristics are not considered in the evaluation of plant contamination via roots uptake.
FORIA and CESER are two systems that differ the most. They evaluate the most suitable countermeasure plan for the scenario under consideration. The novel approach is the consideration of secondary effects of each countermeasure; consequently the best strategy

plant might not be the one with the highest reduction in the dose. However they have different environmental domain, rural for CESER and semi-natural for FORIA, as a consequence a cross comparison between them is not feasible, and the comparison with the other systems presents a few difficulties. SAVE, TEMAS and RESTORE/RECLAIM do not consider secondary effects, thus the countermeasures suggested are chosen only on the base of their reduction in dose or activity concentration in the environment.

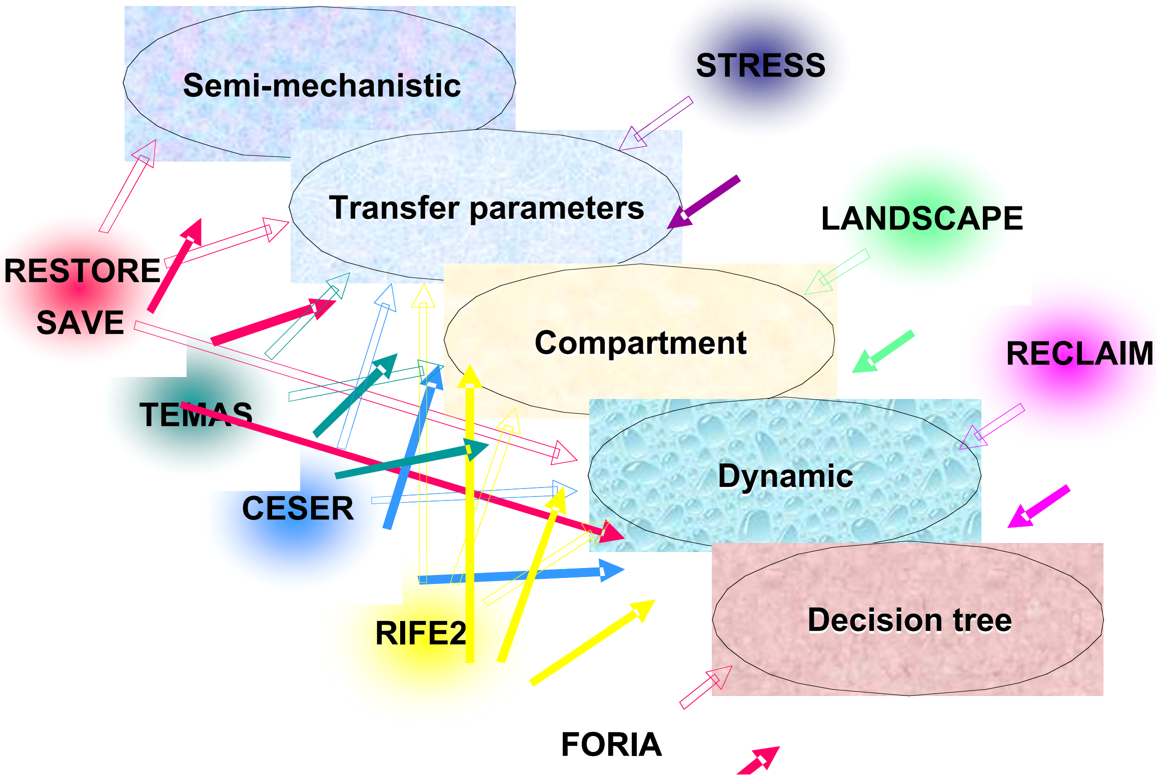

Fig. 3. The approaches adopted for different systems

The table 1 is reporting the characteristics that SAVE, TEMAS, RESTORE, RIFE2 and CESER required.

	Deposition		Transfer parameters		Spatial resolution	Soil characteristics	Countermeasures
	Chernobyl	Uniform	T_{agg}	TF			
RESTORE							
CESER							
LANDSCAPE							
SAVE							
TEMAS							
STRESS							
RECLAIM							
FORIA							
RIFE2							

Table 1. Characteristics of the DSSs

However it is important to point the fact that CESER is using these soil characteristics to assess the side effects of the countermeasures considered, while the other systems evaluate the activity concentration in the

3 THE PLANT - ANIMAL/PLANT - FOOD TRANSFER MODULE IN THE DSS IN NATURAL/SEMI-NATURAL AND AGRICULTURAL ENVIRONMENTS AND APPROPRIATE COUNTERMEASURES

3.1. Introduction

Irradiation for humans can occur via external and internal exposure by radionuclides. External exposure is due to irradiation by the passage of a cloud during an accident, irradiation from contaminated surfaces and, in medical investigations, due to X-ray or radionuclide therapies. Internal exposures occur from natural radionuclides and artificial radionuclides release into the environment either during normal operation of nuclear installations, accidental releases or as a consequence of nuclear weapons detonation. Radionuclides can enter the body either via wounds, through the skin, inhalation or ingestion of contaminated food and liquids. Due to the high contribution of contaminated foodstuff to the total dose in many circumstances, understanding, description and modelling of radionuclide transfer in food chains is one of the important topics in radiation protection and radioecology.
Animal products, especially milk and meat, are important components of the human diet and therefore play an important role in determining internal radiation doses. In the past, many experiments concerning the transfer of radionuclides to farm animals have been performed. Most of which have considered the radioisotopes of Cs, Sr, I and to a lesser extent H. Results from these studies is utilized in radioecological models.
Countermeasures to reduce especially radiocaesium, radioiodine and radiostrontium in animal products have been studied, tested and implemented, including those for animals living in semi-natural environments (Hove et al. 1990, Howard et al. 2001) However, to apply countermeasures most effectively the behaviour and transfer in animals needs to be understood and properly modelled.

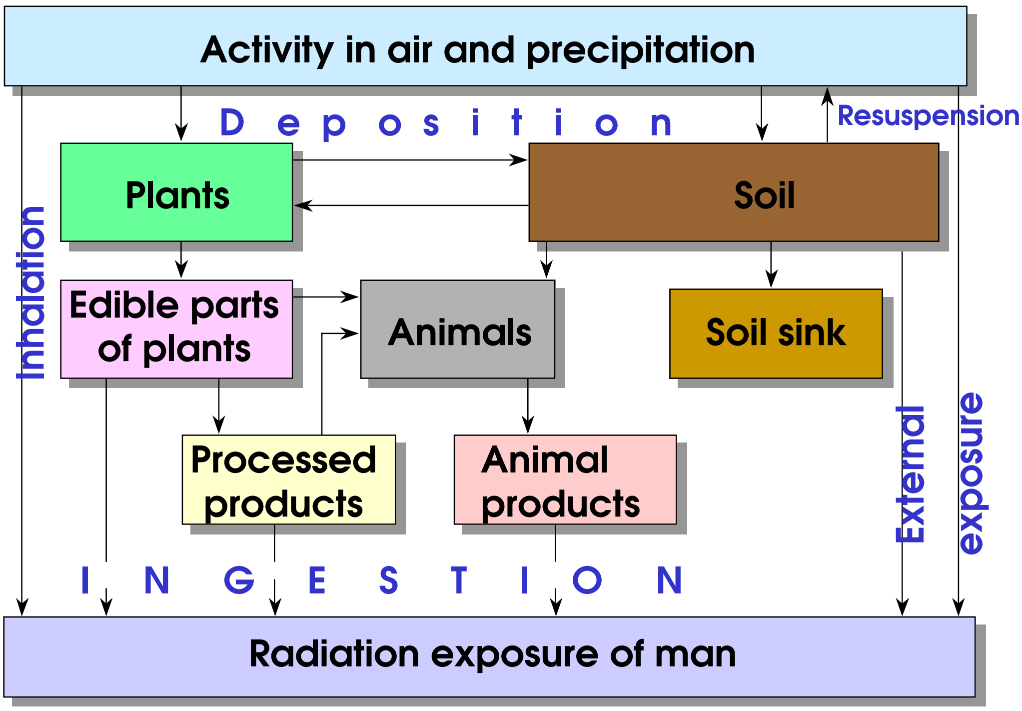

Fig. 4. Major pathways for human contaminationContamination of food products is a major contributor to internal exposure for human consumers, Fig.4. Contamination of food products from both intensively farmed, free ranging and wild animals can represent a major route of internal radiation exposure for human from both routine and accidental releases of radioactivity into the environment. Predictive models to estimate the transfer of a given radionuclide to animal food products make use of published data on radionuclide behaviour in the animal, such as distribution and retention in different organs or tissues and subsequent excretion routes. Depending on the availability of experimental data, compartment models comparable to the models used in ICRP documents for dose estimates to humans such as ICRP 60 have been developed to describe empirical transfer rates between different key compartments once the radionuclide has entered the body. In simpler (animal) models, activity concentrations in an animal product of concern, and consequently the activity intake by humans, can be calculated based on the known activity intake in time and the activity concentration with the product considered.

Animals can be contaminated by three different routes: through the skin or by wound, by inhalation, and, most importantly, by ingestion of contaminated feed. Uptake through the skin or wounds is usually not an important route of contamination, although skin lesions can provide a direct entry for radionuclides into an animals circulation system especially for those radionuclides for which gastrointestinal absorption is low. To describe the transfer of radiocaesium from feed to the milk (F_m) and meat (F_f) a transfer coefficient have been introduced by Ward, et al. (1965). The transfer coefficients were defined as the equilibrium ratio between the radionuclide activity concentration in milk (F_m), or in meat (F_f), and the daily intake of this radionuclide. Such transfer coefficients are applicable only for a constant long-term rate of activity intake by adult animals.

However, the suitability and validity of this parameter now often used in radioecological models was discussed later by the same authors (Ward & Johnson 1989). One of the major problems is the need for equilibrium conditions, which are rarely achieved, especially for long-lived radionuclides such as Co, Pu etc. due to the restricted lifetime of animals. Therefore, for a variety of radionuclides this might lead to an underestimate, especially of F_f values. A second problem is that the physical and chemical form, source and stable or analogue intake of the radionuclide will influence the transfer coefficient. Therefore those values determined in laboratory studies with ionic radionuclides often do not reflect reality.

Transfer coefficients are affected by many different factors. They vary with physics-chemical form of the radionuclide, stable element status, physiological status (lactating, non-lactating), growth rate and feeding level (Howard et al., 2001). Variations of the transfer coefficients therefore can be in the order of 2 to 3 orders of magnitude. The table 2 gives a summary of the F_f transfer values, for radiocaesium, regarding several animal species.

Transfer coefficients are adopted by several assessment models, for the estimation of the animal tissues contamination after an accidental or routine release. (e.g. Müller and Pröhl, 1993). Most of the approaches are based on a conventional equilibrium transfer factor. For dynamic models, transfer coefficients are combined with biological half-lives (i.e. the time taken for the radionuclide activity concentration in tissues, or milk, to be reduced by one half of its initial value) (Crout et al. 2002, in press). More complex compartment models (Galeriu, D et al. 2001) are used to describe the behaviour of radionuclides in animals, however they do not necessarily result in a higher reliability of more accurate prediction.

ANIMAL	TRANSFER COEFFICIENT, d/kg	REFERENCE
Chicken	3.5	Voigt et al.(1993)
Grouse	10	Moss and Horrill (1996)
Lactating sheep	0.18	Howard et al.(1995)
Lamb	0.046 – 0.35	IAEA (1994)
Goat	0.012 – 0.38	IAEA (1994)
Moose	0.03 – 0.07	Johanson (1994)
Red deer	0.49	Mayes et al. (1994)
Roe deer	0.35	Keszthelyi et al.(1990)
Beef cattle	0.01 – 0.06	IAEA (1994)
Reindeer	0.30	Jones et al(1989)
Pig	0.03 – 1.1	IAEA (1994)

Table 2. Transfer coefficients for radiocaesium to muscles (Howard et al., 2001).

One of the simpler methods to describe the transfer of radionuclides to animal products is the aggregated transfer factor Tag. This factor describes the activity concentration in the product related to the deposited activity ($Bq\ kg^{-1}$ / $Bq\ m^{-2}$). This measure has especially been introduced to allow a rapid prediction of the potentially expected activity concentration in a given animal (but also plant) product used for human consumption. It is quite obvious that this factor changes with time according to the effective ecological half-lives in different ecosystems. For radiocaesium the following steady state model based on experimental data in the Chernobyl affected areas has been proposed (Voigt & Semioshkina. 2000):

$$\mathbf{Tag_t = (A1*exp(-k1*t) + A2*exp(-k2*t)) * Tag_0}$$

- Tag_t = Aggregated transfer factor at time = t (m^2/kg)
- Tag_0 = Aggregated transfer factor at time = 0 (1986) (m^2/kg)
- A1 = Empirical parameter (fitted to 0.814)
- A2 = Empirical parameter (1 - A1 = 0.186)
- k1 = Empirical first order decay constant fast pool (0.6935 y^{-1})
- k2 = Empirical first order decay constant slow pool (0.06935 y^{-1})

The Tag concept is not extensively used in agricultural production systems (although it is in common usage in the FSU) and should not be used in the first few weeks after a deposition event when interception and surface contamination are important. However it is valuable in semi-natural environments where ecological half-lives can be very long and it is difficult to conduct detailed transfer studies/parameterise appropriate models. In Table 3 some Tag values for different animal products are given.

Animal Product	Soil type			
	Peat	Sand	Loam	Clay
Milk	0.6	0.2	0.1	0.05
Meat	0.444	0.15	0.075	0.035
Wild boar meat	6	2	1	0.5
Roe dear meat	18	6	3	1.5

Table 3. Examples of T_{agg} values for anomal products (m^2/kg) used in RESTORE EDSS (Voigt&Semioschkina,2000)

3.2. Models comparison

The DSS that are considered for EVANET-TERRA project use different approaches to estimate the transfer of radionuclides from the plants to the animals. Table 4 shows the approaches in available models for plant-animal or plant-food transfer of radionuclides in the EVANET-TERRA project. Practically every of considered models deals with long-term prediction, take into account the time dependence of transfer coefficients or have a dynamic interaction between the compartments.

Project	Approach			
	Equilibrium transfer coefficient	T_{agg} values	Compartment model	Countermeasure
RESTORE				
CESER				
LANDSCAPE				
SAVE				
TEMAS				
STRESS				
RECLAIM				
SEMINAT				

Table 4. Approach adopted for the systems considered

Following projects use in the calculation and prediction of food contamination the transfer coefficients approach:
CESER DSS addresses the long-term ecological consequences of restoration options in agricultural and semi-natural ecosystems. A ranking methodology is provided which helps the user to find the best strategy with the highest activity reduction effects and the less economic and ecological impact for a given landscape.
The RESTORE project had been closely related to the inco-Copernicus project RECLAIM, in which the objectives were set to provide further detailed information for the radioactive contaminated sites in Russia, Ukraine, Belarus and Kazakhstan.
SAVE and SAVE-EC provides a detailed method on the dependence of radiocaesium transfer with soil characteristics for rural environments. However it considers as well semi-natural products such as sheep/cow milk and meat. All food products are spatially and temporally described throughout Europe and Eastern Europe.
Aggregated transfer factors (T_{agg}) are used to calculate the transfer of radionuclides from the mineral and organic soil compartments to a specified semi-natural product in TEMAS.
The compartment model have been used to provide long-term dynamic for the semi-natural environment, such as SEMINAT (PEATLAND) and LANDSCAPE. In the LANDSCAPE system, three different compartment models are used to estimate the transfer of radiocaesium in a semi-natural environment, to several endpoints. The project covered major processes: radiocaesium transfer to vegetation and fungi, quantification of radiocaesium intake by key herbivores such as moose and finally quantification of forest management on radiocaesium dynamics.
The models consider a different animal species and animal product, for example, SAVE/SAVE-EC considers eight animal food products: lamb meat, goat meat, cow milk, sheep milk, goat milk, beef, pork, poultry and eggs. But most of models confined to a cow and ship and corresponding milk and meat. The models available for EVANET didn’t consider explicitly the processes of radionuclides absorption in gastro-intestinal tract of animals, metabolism and recycling between different organs.

5 REFERENCES

LANDSCAPE, Final Report, Oct. 1999
CESER, Final Report, 1998
TEMAS, Final Report, 1998
RESTORE, Final Report, 1999
SAVE, Final Report, 1998
FORIA, DSS, 1999
STRESS, Final Report, 1999
RECLAIM, Final Report, 1998
SEMINAT, Final Report, 1999
Crout N.M.J.(2002), in press

[1] Galeriu, D., Crout, N.M.J., Melintescu, A., Beresford, N.A., Peterson, S.R. & van Hees, M. (2001) A metabolic derivation of tritium transfer factors in animal products. Radiation & Environ. Biophys. 40, 325-334. products. Radiat Environ Biophy.

[2] Hove, K., Pedersen, Ø., Garmo, T.H., Hansen, H.S., Staaland, H. (1990) Fungi: A major source of radiocesium contamination of grazing ruminants in Norway. Hlth. Phys., 59, 189-192.

[3] Howard, B.J., Beresford, N. A., Voigt, G. (2001). Countermeasures for animal products: a review of effectiveness and potential usefulness after an accident. J Environ Radioactivity 56, 115-137.

[4] Howard, B.J. & Beresford, N.A (2001) Advances in animal radioecology. In: Radioactive pollutants: impact on the environment and humans. pp 187-207. Proc of Int Symp in Aix-en-Provence, France, 3 – 7 Sept 2001. EDP Science: Les Ulis.

[5] International Atomic Energy Agency (IAEA) (1994) Handbook of transfer parameter values for the prediction of radionuclide transfer in temperate environments. Technical Report Series No.

[6] Müller, H. & Pröhl, G. (1993) ECOSYS-87: A dynamic model for assessing radiological consequences of nuclear accidents. Health Phys, 64: 232-252.

[7] Voigt, G. (1993) Chemical methods to reduce the radioactive contamination of animals and their products in agricultural ecosystems. Science of the Total Environment 137, 205-255.

[8] Voigt G. & Semioshkina N. (2000) GSF Report 08/00, Restoration Strategies for Radioactive Contamibated Ecosystems.

[9] Ward, G.M., Johnson, J.E., Stewart H.F. (1965) Deposition of fallout ^{137}Cs of forage and its transfer to cow's milk. Procedures 2nd AEC Symposium on Fallout. Edited by Klement A.W. Jr. National Technical Information Center, Oak Ridge.

[10] Ward, G.M. and Johnson, J.E. (1989) Assessment of milk transfer coefficients for use in prediction models of radioactivity transport. Sci Total Environ, 85, 287-294.

GLOSSARY

CESER – Safeguarding the Human Food Chain through Countermeasures may have negative Impacts on the Environment, Economy and Humans
FORECO – Forest Ecosystems: Classification of Restoration Options Considering Dose Reduction, Long-term Ecological Quality & Economic Factors
LANDSCAPE - An integrated approach to radionuclide flow in semi-natural ecosystems underlying exposure pathways to man
RECLAIM – Time-depended Optimisation of Strategies for Countermeasures use to reduce population radiation dose and reclaim abandoned areas
RESTORE – Restoration Strategies for Radioactive Contaminated Ecosystems
RODOS - A Real-time On-line Decision Support System for off-site emergency management in Europe.
SAVE/SAVE-EC Spatial Analysis of Vulnerable Ecosystems in Europe
SEMINAT – Long Term Dynamics of Radionuclides in Semi-Natural Environments: Derivation of Parameters and Modelling
STRESS – Spatial and Temporal radioecological Survey Systems
STRATEGY – Sustainable Restoration and long-term Management of contaminated rural, urban and industrial Ecosystems
TEMAS – Techniques and Management Strategies for Environmental Restoration and their Ecological Consequences