Confidence
Coping with uncertainty for improved modelling and decision making in nuclear emergencies

EUROPEAN JOINT PROGRAMME FOR THE INTEGRATION OF RADIATION PROTECTION RESEARCH
CONCERT

Addressing the uncertainties in agricultural scenarios during the transition phase after a nuclear accident

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Training course

Use of uncertain information by decision makers at the various levels within the decision making process and its communication

VUJE, 13 - 15 May 2019. Trnava, Slovakia

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 662287

Outline

- Transition
- Agricultural Areas
- Main issues for recovery of the agricultural / food production systems
- Radiological situation of the scenario
  - Soil/plant system
  - Transfer pathways along food chain
  - Population Intake
  - Objectives and criteria to take actions during the transition phase
- Implementation of strategies
- Conclusion

Based on CONFIDENCE/CONCERT deliverable D9.21 “Addressing the uncertainties in agricultural scenarios”

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EDITORIAL: Reset needed so Fukushima can rebuild from nuclear disaster

March 11, 2019 at 14:30 JST

Rice is harvested in October in Okuma, Fukushima Prefecture, where an evacuation order is expected to be lifted as early as this spring, eight years after the accident at the Fukushima No. 1 nuclear power plant. (Asahi Shimbun file photo)

Eight years have passed since the Great East Japan Earthquake triggered a disaster at the Fukushima No. 1 nuclear power plant on March 11, 2011.

A shadow continues to be cast on the sentiment of the residents of Fukushima Prefecture by a negative public image due to radiation fears and fading public interest in the aftermath of the disaster.

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Transition phase

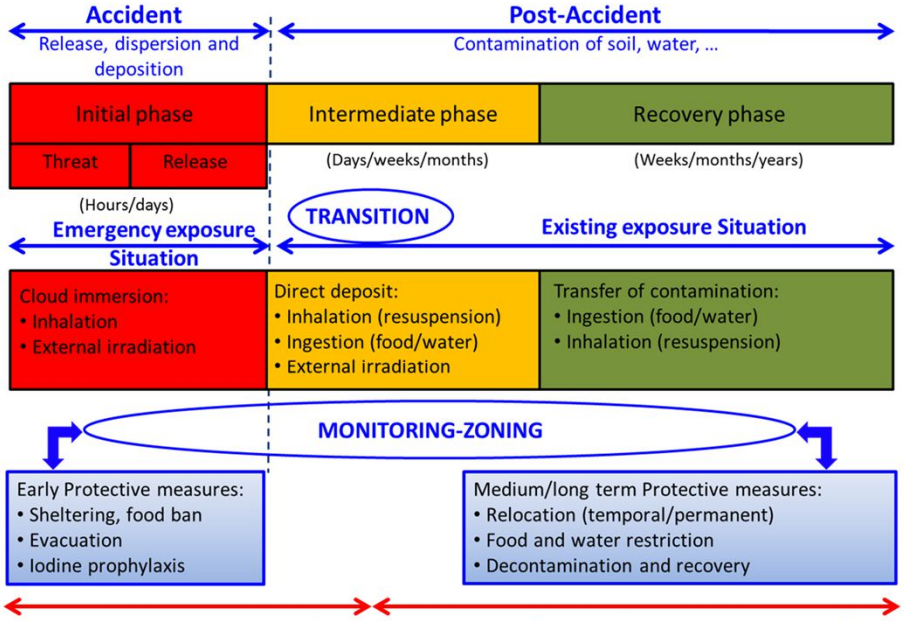
Following the course of a nuclear emergency, the transition phase is:

> *"The process and the time period during which there is a progression to* ***the point at which an emergency can be terminated****" and "****to facilitating the timely resumption of social and economic activity****"* (IAEA, 2018)

> *"… when* ***the source has been brought under control****, no further significant accidental releases or exposures resulting from the event are expected and the future development of the situation is well understood"* (IAEA, 2018)

The transition phase is not driven by urgency and allows,

- For the characterisation of the environmental contamination
- For the lifting of the emergency protective actions
- For adapting, justifying and optimising specific protection strategies, to prepare and begin the late phase recovery and
- For the engagement of the interested parties .



Urgent Phase.- Management plans are already organised: governmental stakeholders already involved

Recovery Phase.- The management plans are to be organised: governmental and non-governmental stakeholders, with different levels of involvement

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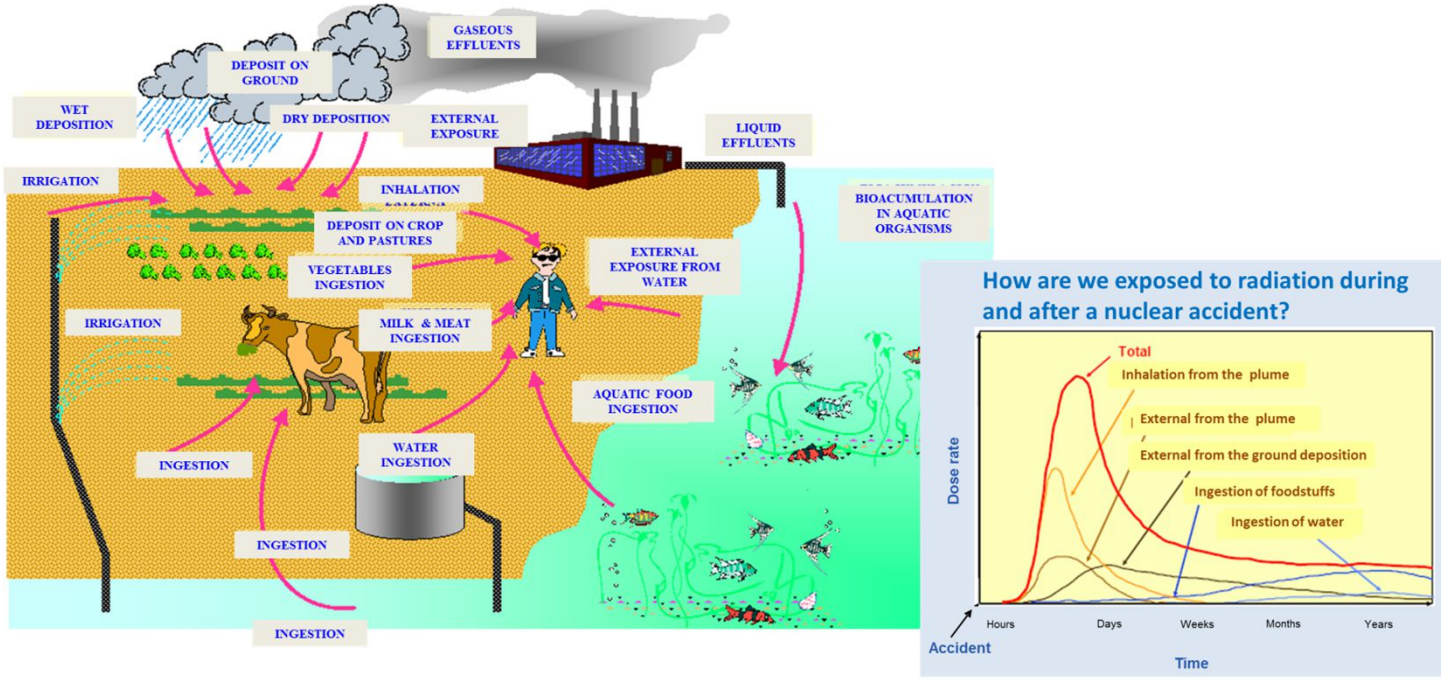
Contamination scenarios after a nuclear accident

- The accidental radioactive release can affect the environment and the human being through different routes of exposure.



- The presence of residual radioactive material in the long-term results in an existing exposure situation.
- As time progresses, the exposure by ingestion of contaminated food and water is more important than other exposure pathways for the total calculation of the dose received by the population.

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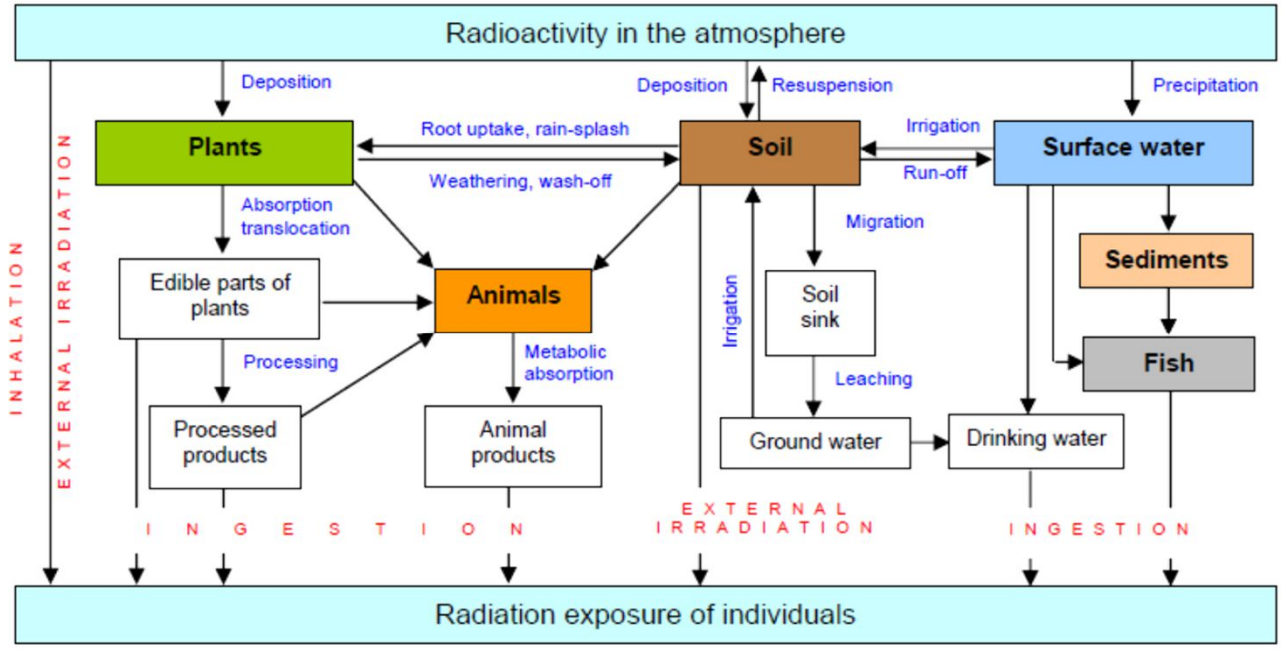
Agricultural environment

- The term “agricultural” is used very broadly to mean any area used with purposes of farming production, including grazing, where the products and the consumers are connected through the **food-chain**.



Major pathways involved in the transfer of radionuclides through the foodchain, following a release of radioactivity in the atmosphere

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Agricultural environment

- Agricultural systems affected by a radioactive deposit due to a release from a radiological or nuclear accident are **complex** and **not homogeneous environments.**
- Even within a particular region or area, there are multiple variables to be considered, which are inherently related to the affected systems, such as: **climate**, **soil type** and its properties, **type of crops**, seasonality, **agricultural practices**, etc.
- The **spatial** and **temporal variation** of some of these properties, give raise to **uncertainties** that can be important for the **evaluation of the radiological impact** and **response and consequences of the recovery actions**.
- **Radioecological models** describing fluxes of radioactivity through soil, plant, animals and consumption products, and **dose models** evaluating radiological impact to population from external and ingestion exposure are used. Models and parameters also can be sources of uncertainties.

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Main issues for recovery of the agricultural / food production systems

- In agricultural scenarios, the main aspects to consider:
  - Characterise the different elements or elemental units in the agricultural environments, as function of the parameters or attributes that influence the behaviour and transfer of radionuclides:
    - Primary component: soil -plant/crop,
    - Secondary components: transfer pathways along food chain (crop - animal - product)
    - Final component: the exposed individuals
  - Define and characterise the action alternatives in each one of these components.
  - Methods and models to estimate and measure the consequences (spatial-temporal evolution of the radionuclides without and with countermeasures)
  - Identify other factors that could influence the practicability and optimisation of the strategies (social, economic, political, environmental and ethical)

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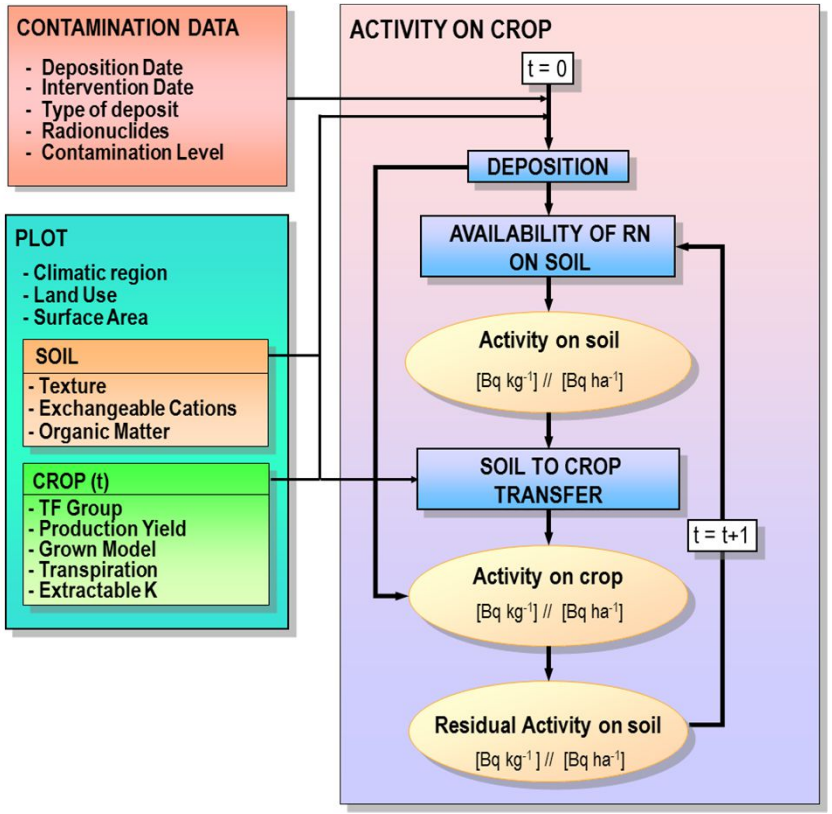
Primary component: Modelling the soil/crop system



Two phases for the transfer to the crop:

- Dominated by **direct deposition**, if there are crops growing at the time of deposition
- Via **root uptake** if the deposition is prior to the sowing of any crop

- **Soil Compartment**. The attributes defining the compartment are related to the physical and chemical characteristics of the concerned soil stratum that have influence on the behaviour of radionuclides.
- **Vegetal Compartment**. It represents the cropping pattern since the deposition date. They are defined by the characteristics from both the own species and cultivation management.

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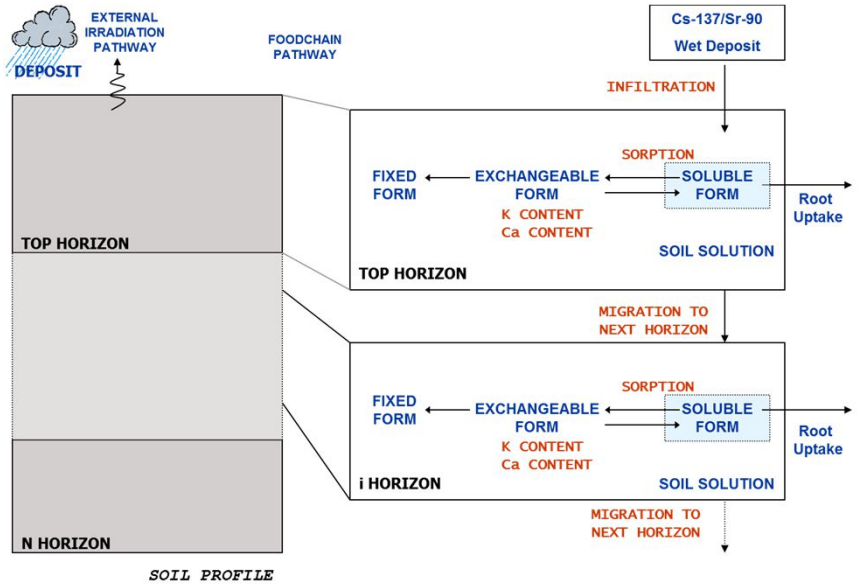
Availability of radionuclides in soil



Physical and chemical processes affecting the behaviour of radionuclides in a soil profile

- Once deposited, the behaviour of the radionuclides in the soil is mainly governed by physicochemical processes that determine the fixation, mobility and bioavailability of radionuclides.

Soil processes, parameters and properties associated to the behaviour of radionuclides in soils.

Soil processes parameters and properties	Food ingestion exposure pathway
INFILTRATION PROCESS	Infiltration capacity
Texture Structure Clay content, organic matter content Cation exchange capacity	
VERTICAL MIGRATION PROCESS	Water holding capacity
Texture Bulk density Organic matter content Permeability	
SORPTION/DESORPTION PROCESS	Physico-hemical retention capacity
Clay content, organic matter content	^{137}Cs
Cation exchange capacity	^{137}Cs
pH content	^{90}Sr
ROOT UPTAKE PROCESS	
Exchangeable potassium content	^{137}Cs transfer capacity
Exchangeable calcium content	^{90}Sr transfer capacity

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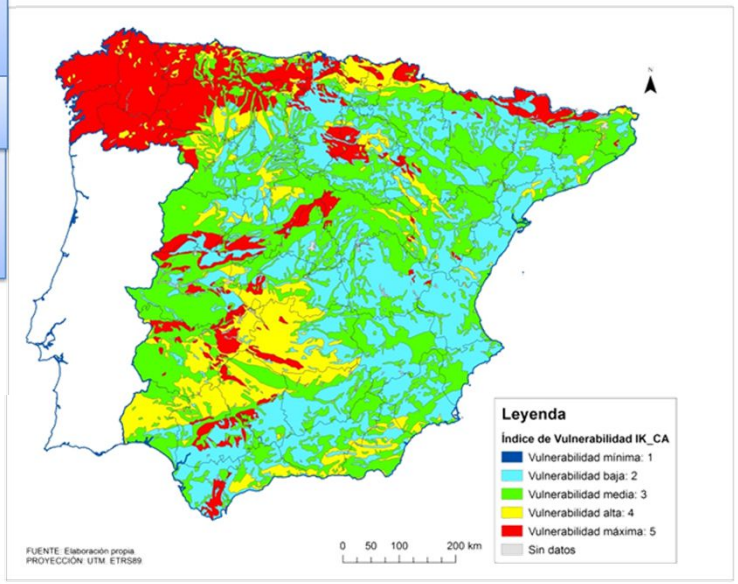
Dealing with the uncertainties associated to soil

Evaluation of vulnerability of soil to transfer Cs-137 or Sr-90 to food-chain

Vulnerability Indexes for food-chain	IF_FC	IH_FC	IFQ_{Cs}_FC	IFQ_{Sr}_FC	IK_FC	ICa_FC
Soil processes	Infiltration rate	Water retention	Cs:Physico-chemical retention	Sr:Physico-chemical retention	K status	Ca status
Soil properties	Texture, Structure, Dominant clay type	Texture, Structure, Porosity, Water capacity	Texture, CEC clay	pH	Exch. K content	Exch. Ca content
Reference parameter 60 cm depth	F (mm/h) (top layer)	R (mm/cm)	CEC (cmol/kg)	pH	K (cmol/kg)	Ca (cmol/kg)
Minimum	F≤1,0	R≤2,0	Clay2:1 non exp	pH>7,5	K>1,00	Ca>10,0
Low	1,0<F≤5,0	2,0<R≤3,0	Clay 2:1 exp	6,5<pH≤7,5	0,50<K ≤1,00	5,0<Ca≤10,0
Medium	5,0<F≤20,0	3,0<R≤4,0	Clay 1:1	5,5<pH≤6,5	0,25<K ≤0,50	2,0<Ca≤5,0
High	20,0<F≤50,0	4,0<R≤5,0	Peat	4,5<pH≤5,5	0,10<K≤0,25	1,0<Ca≤2,0
Maximum	F>50,0	R>5,0	Sand	pH≤4,5	K≤0,1	Ca≤1,0

Maximum vulnerability: at higher infiltration rates and higher water retention, Cs: sandy soils (no fixation) and minimum K status / Sr: low pH and minimum Ca status



Radiological Vulnerability Indices regarding the K status in soils contaminated with Cs-137, identify those areas were rehabilitation is a priority.

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Assessment of the influence of regional factors in the transfer to food chain

Studying, ranking and mapping the influence of regional factors on the radiological risk due to food chain.

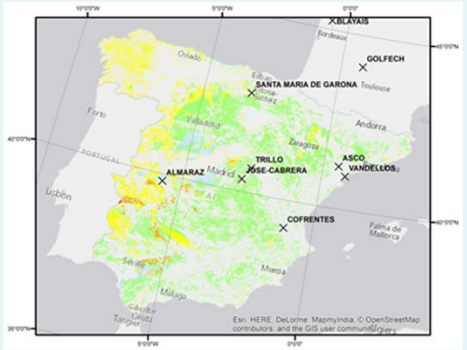
WEIGHTED DEPOSITION INDEX
Deposition Index weighted by the deposition frequency

VULNERABILITY INDEX
based on the Soil to Plant Transfer Factor

- ^{137}Cs to rainfed cereals
- TF adjusted considering:
  - K and clay topsoil content
  - Soil texture

(Poster presented at ICRER 2017)

Vulnerability Index (Cs137 Transfer Factor)
1: Min. Vuln. (<0,02)
2: Low Vuln. (0,02-0,12)
3: Med. Vuln. (0,12-0,5)
4: High Vuln. (0,5-0,6)
5: Max. Vuln. (>0,6)

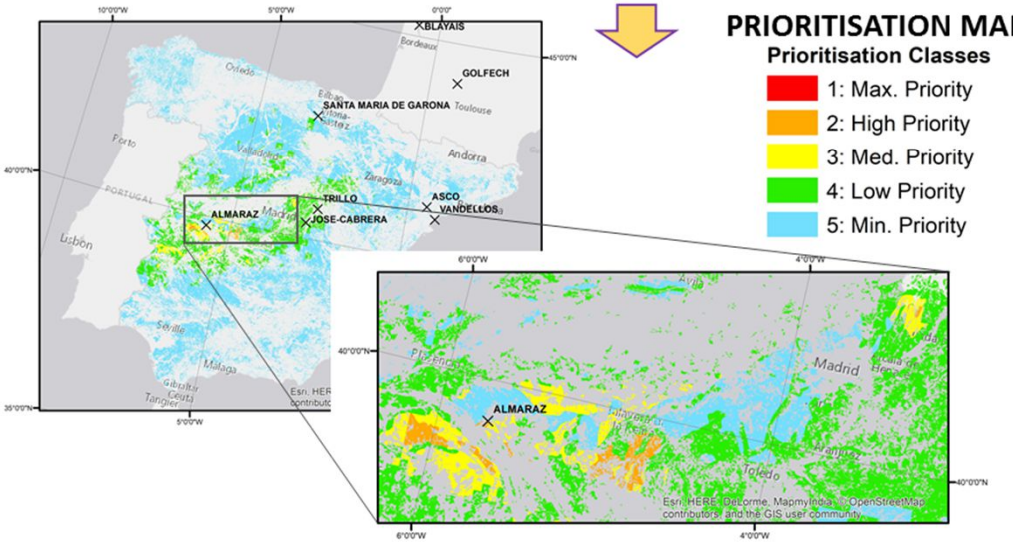


COMBINATION

Deposit Index Weighted \ Vulnerability Index	Min. Vuln.	Low Vuln.	Med. Vuln.	High Vuln.	Max. Vuln.
Min. Severity	5	5	5	5	5
Low Severity	5	5	4	4	4
Med. Severity	5	4	4	3	3
High Severity	5	4	3	2	2
Max. Severity	5	4	3	2	1

Possible combinations

PRIORITISATION MAP
Prioritisation Classes
1: Max. Priority
2: High Priority
3: Med. Priority
4: Low Priority
5: Min. Priority



PhD Thesis in CIEMAT

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Secondary component: Modelling the transfer pathways along food chain

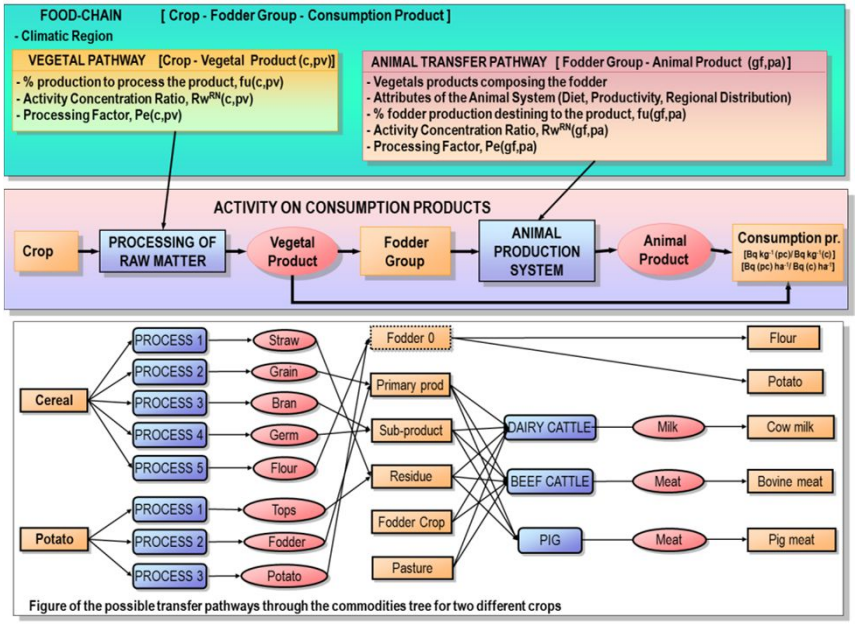

Figure of the possible transfer pathways through the commodities tree for two different crops

- The secondary component in the agricultural scenario includes the transfer pathways along the food-chain associated to a primary component.
- A transfer pathway represents the flow of radioactive contamination from a **primary commodity** (crop) to each **processed product** derived from it.
- The attributes characterising it are: a **processing factor**, a **transfer factor** and a **regional utilisation factor**.

- A distinction between **vegetal** and **animal transfer pathway** is made.
- The animal transfer pathway considers the processing of the feedstuffs through an intermediate compartment representing generic animal production systems in each European region to the final product for human consumption.

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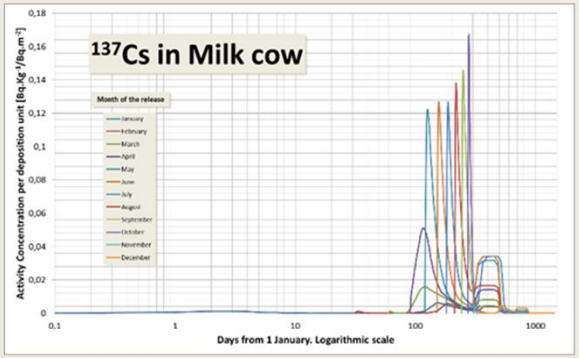
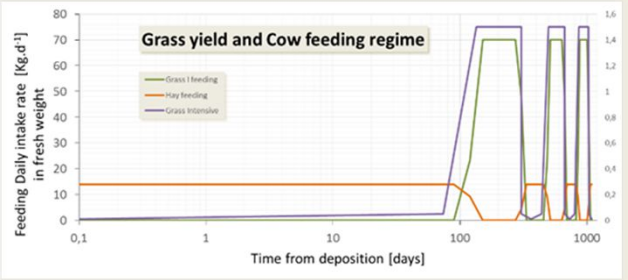
Seasonal variability on the concentration of activity in consumption products





Factors affecting the seasonal variability

- This variability is due, mainly to the regional farming practices:
  - dates of sowing and harvesting of crops and growth cycle and forage cut of grass and other feedstuffs
  - cow feeding regime
- In the case of the cow's products, there is a correlation between the maximum activity and the peaks of grass growth, matching also with the grazing period. When the feeding is changed to the hay from the grass cutting, during the maximum yield, there is an increase in the activity concentration in the product, due to the concentration of the contamination in the forage.

Seasonality influence in the elaboration of risk maps associated to the transfer of radioactivity through the food chain (ANURE project)

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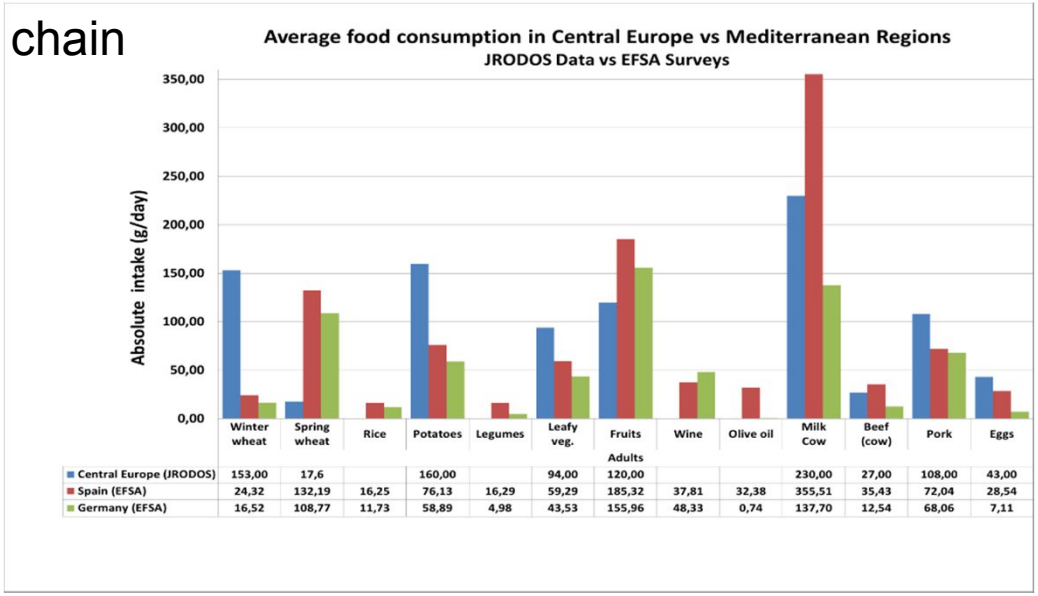
Final component: the exposed individuals

- The final component is the population.
- Dose model by ingestion, using parameters age-dependent as **committed effective dose equivalent per unit intake**, **consumption rates** and the **relative distribution** of each product.
- Aspects that influence the incorporation of activity by humans:
  - Storage of raw materials and / or products
  - Processing through the food chain
  - Dietary habits



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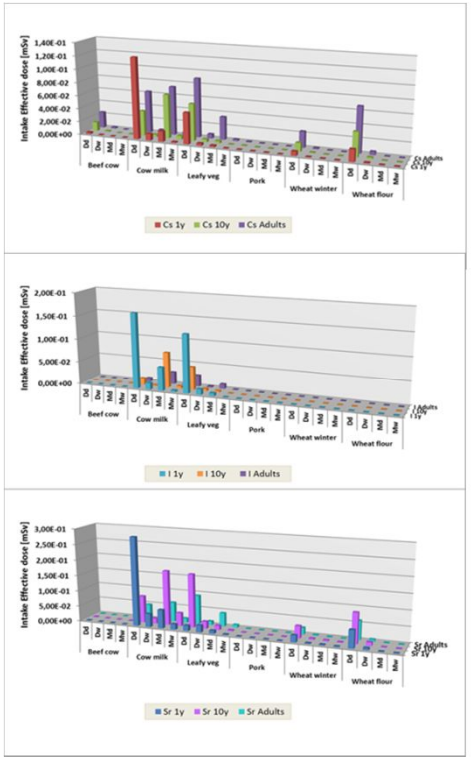
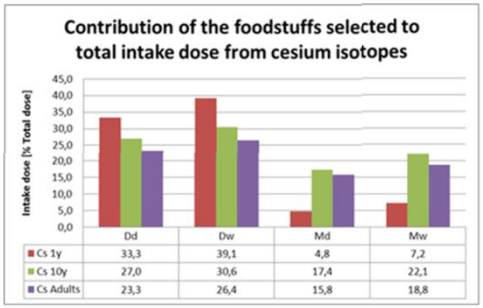
Effect of regional parameters on the food chain



Contribution of the selected foodstuffs to the intake dose, five years after the release, for the different age groups, shows:

- The values of the intake doses from the Mediterranean scenarios are lower than the values from the default scenarios, for the three radionuclides studied
- The intake of cow milk, for the age group 1y, gives the highest contribution to the effective dose for the three radionuclides.

Exercise to study the effect of regional parameters (Nordic and Mediterranean) on the food chain modelling. (COMET project)



The contribution of the total foodstuffs intake to the effective dose for ^{137}Cs, shows:

- 1y age group are the most sensible to the intake, using default parameters,
- 10y age group are the most sensible using Mediterranean parameters.

These highest contributions could be due:

- The date of the accident (seasonality)
- The food consumption rates
- The Mediterranean diet is not complete in this exercise

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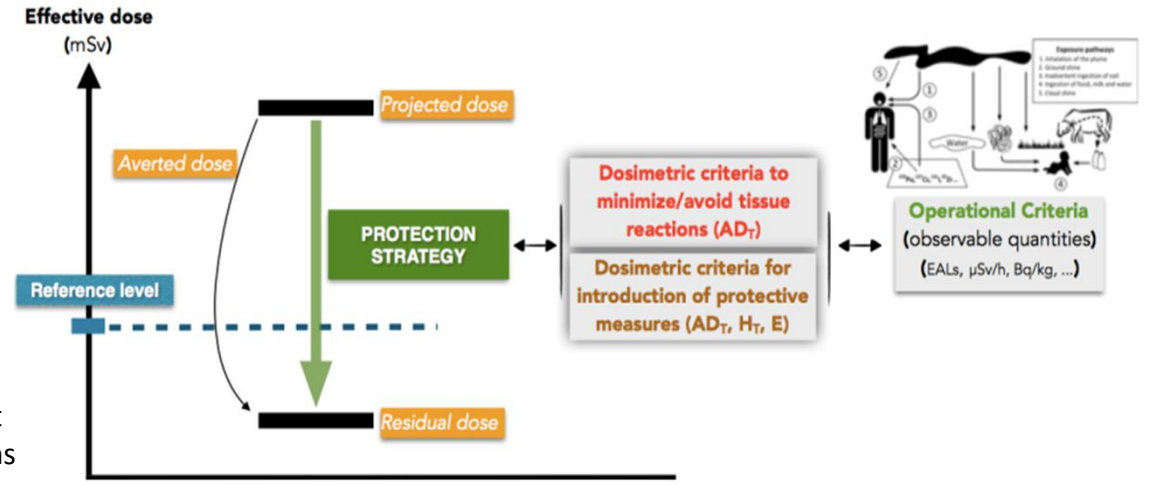
Objectives and criteria to take actions during the transition phase

- In the transition phase, the response efforts will focus on the **review** or **lifting of initial countermeasures,** to mitigate the consequences of the emergency on populations, infrastructures, environment and socio-economic structures through actions such as, **population protection measures**, **agricultural and food countermeasures**, **decontamination**, etc. and **planning** strategies for recovery.
- Actions must be **motivated** by the **radiological situation** – Radiological criteria
  - Reference level bands ICRP; Based in the Residual dose
  - Operational Intervention Levels (OILS): Deposition levels, Maximum permitted levels (MPL) in food / feed



The framework and the different criteria that can be used in emergency exposure situations

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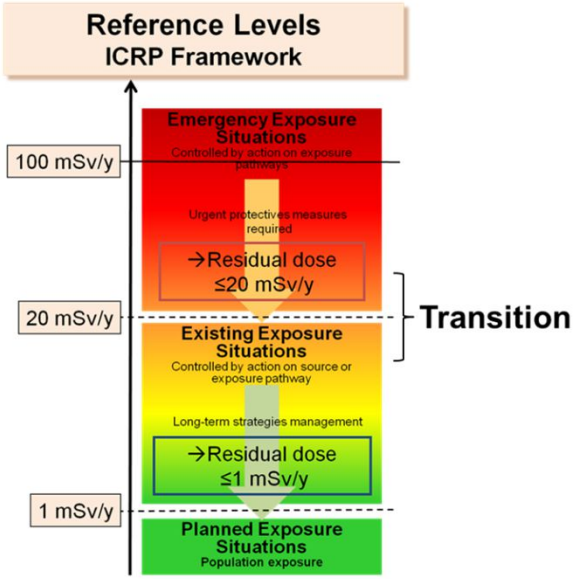
Generic Criteria and OILs to take actions



Framework categorising reference levels to use in existing and emergency exposure situations.

Protective action	Generic criteria				OILs	Consideration
	For taking the action		To adapt / lift the action		To adapt / lift the action	
	E	Hfetus	E	Hfetus (para 9 m)		
Evacuation	≥ 100 mSv (7d)	≥ 100 mSv (7d)	≥ 100 mSv (1y)	≥ 100 mSv	≥ OIL2	Substituting evacuation with relocation
			< 100 mSv (1y)	< 100 mSv	< OIL2	Lifting the evacuation. Take othe actions (decontamination)
			≤ 20 mSv (1y)	≤ 20 mSv	< OIL_T	Lifting the evacuation and terminate the emergency.
Realojo	≥ 100 mSv (1y)	≥ 100 mSv (9m)	< 100 mSv (1y)	< 100 mSv	< OIL2	Lifting the evacuation. Take othe actions (decontamination)
			≤ 20 mSv (1y)	≤ 20 mSv	< OIL_T	Lifting the evacuation and terminate the emergency.
Food, milk and drinking water restrictions in affected areas	≥ 10 mSv (1y)	≥ 10 mSv (9m)	< 10 mSv (1y)	< 10 mSv	< OIL6	Lifting after estimating the actual doses from the ingestion pathway and their contribution to the residual dose from all exposure pathways
Food, milk and drinking water restrictions for international trade	≥ 1 mSv (1y)	≥ 1 mSv (9m)	< 1 mSv (1y)	< 1 mSv	< MPL	Lifting of the restrictions on international trade of foods and feedstuffs
Local restrictions on non-food commodity	≥ 10 mSv (1y)	≥ 10 mSv (9m)	< 10 mSv (1y)	< 10 mSv	< OIL_C	Lifting after estimating the actual doses for the use and their contribution to the residual dose from all exposure pathways
Non-food commodity restrictions for international trade	≥ 1 mSv (1y)	≥ 1 mSv (9m)	< 1 mSv (1y)	< 1 mSv	< OIL_C	Lifting of the restrictions ontrading non-food commodities internationally

Contamination levels	Map key	External dose rate [µSv/h]	Total deposition Strong gamma and beta emitters together [kBq/m^2]	Total deposition Alpha emitters, [kBq/m^2]
Extremely contaminated		> 100	> 10.000	> 100
Heavily contaminated		10 - 100	1.000 - 10.000	10 - 100
Contaminated		1 - 10	100 - 1.000	1 - 10
Slightly contaminated		< 1	10 - 100	0,1 - 1
Non-contaminated		fondo	< 10	< 0,1

Maximum permitted levels (MPL) of radioactive contamination of food and feed following a nuclear accident or any other case of radiological emergency (Commission Regulation (Euratom) 2016/52, 15 January 2016)

Maximum permitted level of radioactive contamination [Bq.Kg^{-1}]							
	Food Group				Feedstuffs, according the animal consuming it		
Isotope group	Infant food	Dairy produce	Other food for general consumption	Liquid food	Pig farming	Poultry, lambs, calves	Other
All other nuclides ($T_{1/2}$ < 10 d), notably Cs-134 and Cs-137	400	1000	1250	1000	1250	2500	5000
Isotopes of iodine, notably I-131	150	500	2000	500			
Isotopes of strontium, notably Sr-90	75	125	750	125			
Alpha-amitting isotopes, notably Pu-239 and Am-241	1	20	80	20			

The levels for food derive from a dose level (CR) of 1 mSv / year and assuming that 10% of the diet, during the year following the emergency, is contaminated.
https://eur-lex.europa.eu/legal-content/ES/TXT/?qid=1531135147792&uri=CELEX:32016R0052

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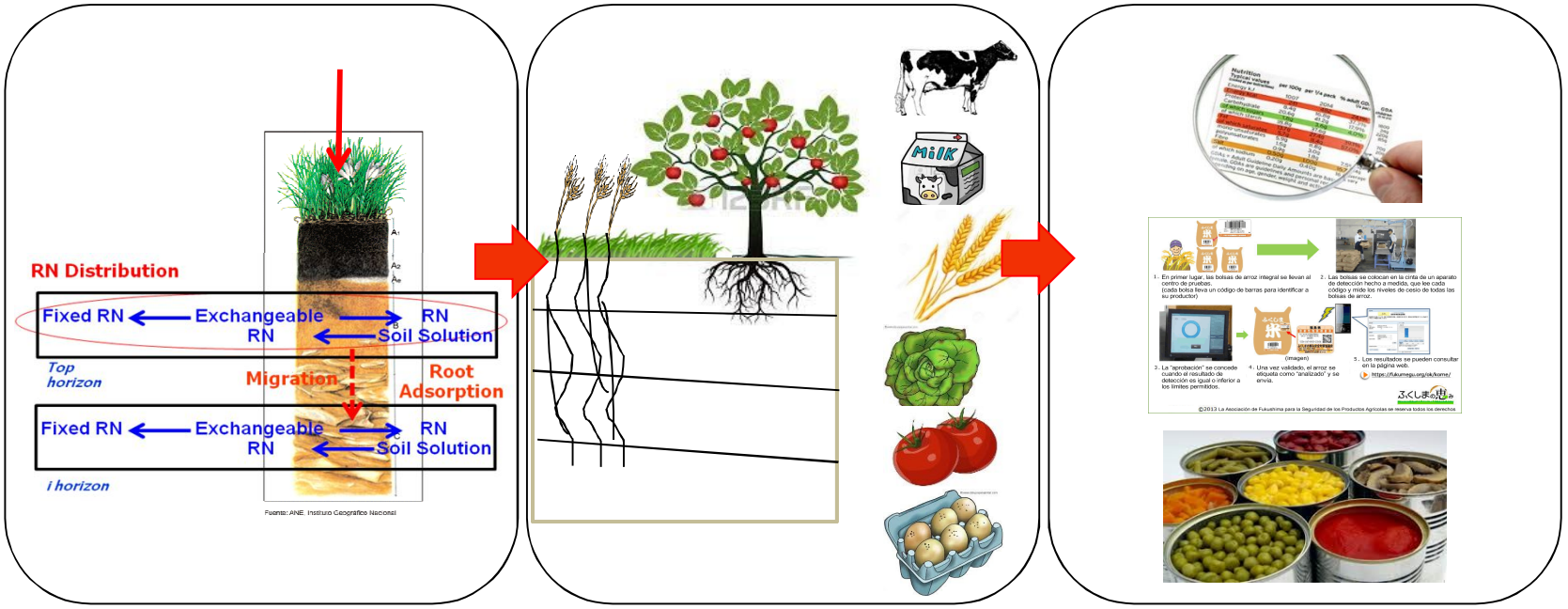
Recovery Strategy

Protection can be achieved by taking action at the source, or at points in the exposure pathways, and occasionally by modifying the location or characteristics of the exposed individuals (ICRP-103).

Soil is the source: reduce the transfer of RN to crops

Foodstuffs are the points in the ingestion exposure pathway: reduce activity concentrations

Modifying the dietary habits of the exposed individuals



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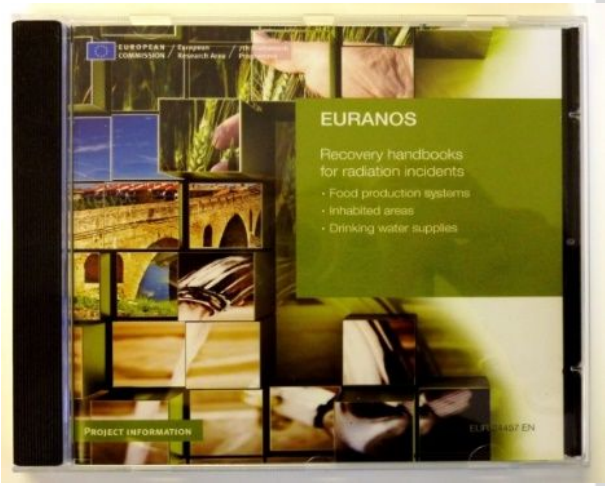
Factors for implementation

- The implementation of these actions requires taking into account a series of factors that facilitate the establishment and implementation of recovery actions. These include:

- Target (source, RN, media, exposure)
- Effectiveness: technical and societal factors
- Feasibility
- Incremental doses
- Waste disposal issues: generation of waste and its disposal
- Societal and ethical factors
- Side-effects including direct and indirect environmental impacts
- Costs
- Legislation
- Information and communication issues



EURANOS recovery handbooks for management of food production systems, inhabited areas and drinking water supplies

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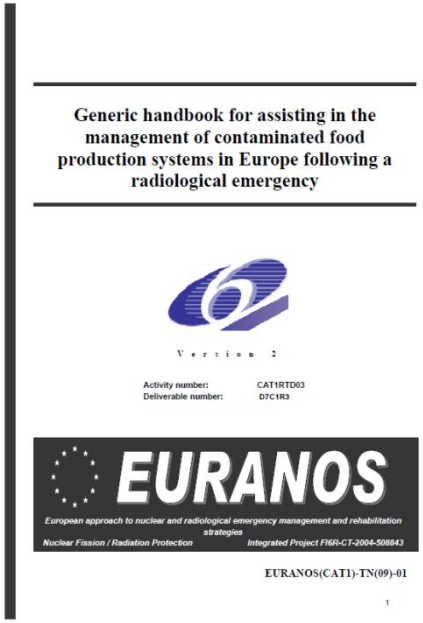
Management options to reduce the consequences of contamination of the foodchain



- Starting point: Handbook for food production systems
  - Outlines the many factors that influence the implementation of the these options
  - Provides guidance on planning for recovery in advance
  - Illustrates how to select and combine the different options and builds a recovery strategy

GENERAL APPLICABILITY
Dilution
Feeding of animals with crops/milk in excess of intervention levels
Leaching of horticultural peat
Prevention of fire in forests, shrubland, and other sensitive areas
Restriction on the entry of food into the foodchain (food ban)
Selection of alternative use

SOIL, CROPS, GRASSLAND
Application of lime to arable soils and grasslands
Application of potassium fertilizers to arable soils and grasslands
Deep ploughing
Shallow ploughing
Skim and burial ploughing
Topsoil removal
Early removal of crops
Land Improvement
Processing of crops for subsequent consumption
Selection of edible crop that can be processed
Pruning/defoliation of fruit trees and vines

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Management options to reduce the consequences of contamination of the foodchain

LIVESTOCK AND ANIMAL PRODUCTS
Addition of AFCF to concentrate ration
Addition of calcium to concentrate ration
Administration of AFCF boli to ruminants
Administration of clay minerals to feed
Distribution of saltlicks containing AFCF
Clean feeding
Selective grazing regime
Decontamination techniques for milk
Live monitoring
Manipulation of slaughter times
Slaughtering of dairy livestock
Suppression of lactation before slaughter
Processing of milk for subsequent human consumption
Salting of meat
Change of hunting session

SOCIETAL
Dietary advice
Food labelling
Local provision of monitoring equipment
Processing and/or storage prior to consumption
Raising of intervention limits
Restrictions on gathering wildfoods

- Application of the handbook, examples:
  - In the preparedness phase, under non-crisis conditions to engage stakeholders and to develop local/regional/national plans
  - In the post-accident phase by local and national stakeholders as part of the decision-aiding process.

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Criteria to consider when evaluating management options (1)

- EFFECTIVENESS: is the reduction in activity concentration in the target (soil, crop, animal product). May be influenced by technical and social factors (e.g. soil fertility, fat content, existence of markets for alternative produce, ….)
- FEASIBILITY: is referred to the equipment, utilities, infrastructure, skills and consumables which may be required to implement the option
- WASTE: is referred to the nature and volume; it is necessary to know if it is contaminated, its treatment (in situ/off site facility), transport and storage. May be influenced by social and legal factors (e.g. public acceptability, feasibility of treatment, ..)
- DOSES: are referred to the incremental doses that may receive individuals in charge of the implementation of the option (operators and members of public)
- COSTS: are referred to the direct costs derived from implementing the option such as: equipment, consumables, operators, waste treatment. May be influenced by size and accessibility of the target, seasonality, availability of equipment and consumables within the contaminated area

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Criteria to consider when evaluating management options (2)

- SIDE-EFFECTS: incurred following the implementation of the option. They may show different natures:
  - Environmental impact (e.g. wildlife reserves, pollution)
  - Agricultural impact (e.g. reduction in soil fertility, overproductions)
  - Social impact (e.g. society´s trust in their national institutions, public´s risk perception)
- CONSTRAINS: several types of restrictions need to be considered before the implementation of an option:
  - Legal: foodstuffs regulations, animal welfare , heritage protection
  - Social: acceptability of the option from the affected population
  - Environmental: physical characteristics of the affected area
- OTHERS: Communication needs/Ethical considerations

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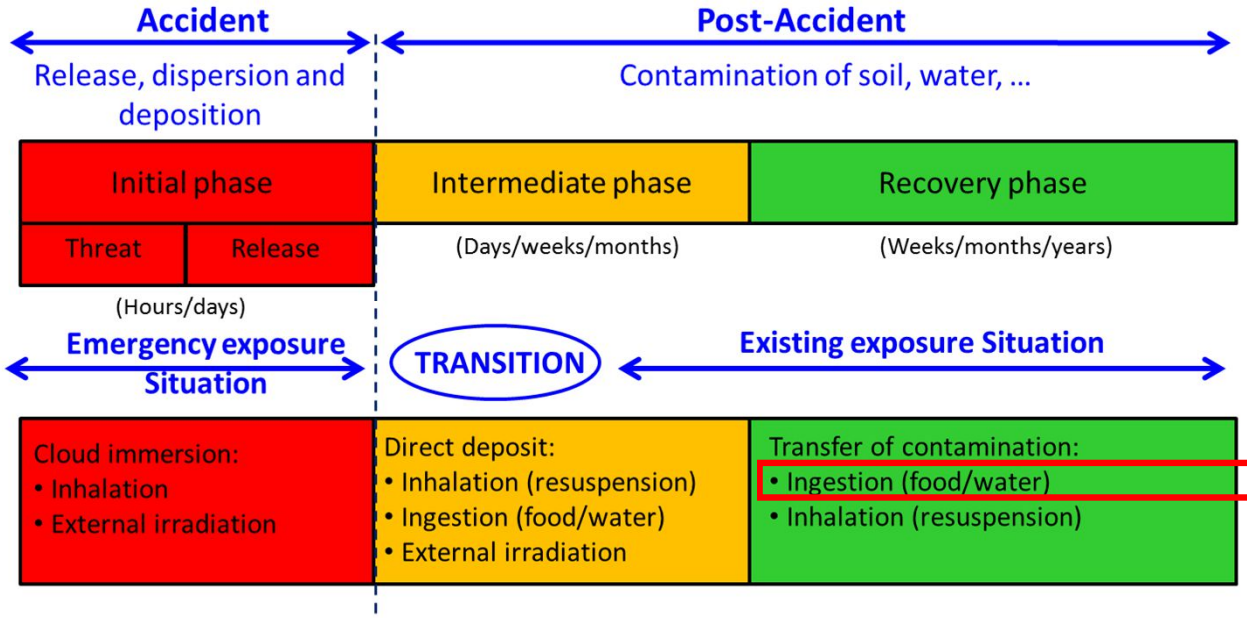
Some conclusions



The prediction of food contamination and doses to humans is a key element in the implementation and management of the long-term rehabilitation process.

Assessment relies on the:

- Ability of the modelling to predict the time dependence of the transfer process
- Availability of reliable parameters

Affect the reduction of the uncertainties of the estimated doses and the response of the potential recovery strategies to be applied

Region-specific parameters imply a more realistic assessment

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Uncertainties raised when planning the implementation of the recovery strategy in the transition phase

- Issues in the agricultural environments
  - Zoning? Constrains? Reference levels?
  - Identification of product systems / soils / pathways /products / population groups more vulnerable
  - Prognostic versus monitoring results? In which cases should these results be used? How to obtain a balanced use?
  - Selection and establishment of strategies. How to apply the optimisation principle?
  - Effects influencing the decision and future evolution of scenarios: Social, Technological, Economic, Environmental, Political and Ethical values. Criteria to measure them.
- How to translate this issues into goals and objectives suitable for the restoration of agricultural environments?

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Uncertainties raised when planning the implementation of the recovery strategy in the transition phase

- The cessation of production or restriction in consumption are actions in the emergency phase, but difficult to keep over time; economic compensation?
- Are there enough resources (material, human, economic, technical) to implement the different options?
- What will be the effects on the food distribution chain? Possible socio-economic impact.
- Need to establish a framework of recovery in advance that includes actions, strategies, criteria, compensatory regime, exchange networks, information, ...
- Roles of the national institutions to both coordinate the actions to be carried out and to encourage stakeholders to take part in their management.

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Training course

Use of uncertain information by decision makers at the various levels within the decision making process and its communication

VUJE, 13 - 15 May 2019. Trnava, Slovakia

Confidence
Coping with uncertainty for improved modelling and decision making in nuclear emergencies

EUROPEAN JOINT PROGRAMME FOR THE INTEGRATION OF RADIATION PROTECTION RESEARCH
CONCERT

Addressing the uncertainties in agricultural scenarios during the transition phase after a nuclear accident

Thank you for your attention!

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MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
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Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

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