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# D 9.21 - Addressing the uncertainties in agricultural scenarios

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## **Abstract**

This document contains the deliverable D9.21 on “Addressing the uncertainties in agricultural scenarios” of the work package WP4 “Transition to long-term recovery, involving stakeholders in decision-making processes” of the CONFIDENCE Project (HORIZON 2020 EJP-CONCERT, EC GA 662287).

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

# Addressing the uncertainties in agricultural scenarios

**Final**

**Version 1.0**

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## Executive Summary

This document focuses on the first objective of the CONFIDENCE-WP4 task on “Establishment and optimisation of remediation strategies in generic scenarios”, discussing the uncertainties under which stakeholders and decision-makers operate during and beyond the transition phase of a nuclear accident when developing strategies and plans to recovery in agricultural areas.

In this document, 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.

This document is not intended to present a comprehensive review of all the sources of uncertainties when developing plans and strategies to recover the contaminated areas. Here, these sources and the concerns of experts and other interested parties are identified, as well as the different tools or methods available to reduce them or, where appropriate, consider them both in the planning for the recover and in decision-making.

Chapter 1 defines the transition phase and the challenges facing decision makers, defines the steps of a generic decision-making process, sets out the main issues for recovery in the agricultural environments and defines different types of uncertainties that come into play.

Chapter 2 discusses the uncertainties which underlie when defining the radiological situation, from the soil as source of the radioactive contamination to people through the pathways of transfer along the food chain, identify the parameters influencing on the behaviour of radionuclides and on the modelling estimations, and presents a methodology to develop risk maps regarding the radiological vulnerability. The information on this methodology is extended in the Appendix 2.

Chapter 3 shows a summary of the literature review on the radiological criteria of the radiological criteria applicable in emergency situation with the objective of investigate how uncertainties associated with decisions taken in this phase could influence the transition and long-term phases The extended information could be consulted in the Appendix 1.

Chapter 4 considers the implementation of recovery strategies and factors affecting the optimisation. A short list of the most common management options in the agricultural/food chain systems are included.

Chapter 5 gives a brief summary of the activities carried on in the framework of the WP4 to study the influence of societal factors, the preferences and the attitude of the stakeholders when planning and implement a strategy of recovery.





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## 1 Introduction

In the framework of the European project CONFIDENCE<sup>2</sup>, the work package WP4 (*Transition to long-term recovery, involving stakeholders in decision-making processes*) is devoted to improve the preparedness and response during the transition phase after a nuclear accident, identifying and trying to reduce the uncertainties in the subsequent management of the long-term exposure situation, reflecting the requirements of the new European Basic Safety Standards (BSS) [EURATOM, 2013].

For that purpose, a framework of structured collaboration involving the technical experts (partners) and stakeholders in a sequential process has been established. Three tasks have been distinguished to accomplish the work [Montero & Trueba, 2017]:

1. Establishment and optimisation of remediation strategies in generic scenarios. (**Recovery scenarios planning**)
2. Involvement of stakeholders in decisions to recover acceptable living conditions (**Scenario-based stakeholder engagement**).
3. Elaboration of guidelines and recommendations to address the planning and decision making during the transition phase. (**Guidelines and recommendations**)

In agreement with the general work plan of the WP4, the first task has been carried out during the first half of the project with the following objectives:

- to identify and assess the criteria and factors (including the spatial and temporal influence in the establishment of the reference levels and the evaluation of the uncertainties in the optimisation process), that improve/affect the selection, efficiency and ending of remediation strategies, in both urban/inhabited and agricultural areas through modelling and literature review.
- to agree on scenarios and identify remediation strategies as well as the questions and issues to be addressed by national stakeholder panels through a structured brainstorming process, concluding with a dedicated workshop.

This document focuses on the first objective, discussing the uncertainties under which stakeholders and decision-makers operate during and beyond the transition phase of a nuclear accident when developing strategies and plans to recovery in agricultural areas. A similar document has been elaborated to address this same objective in urban/inhabited areas [Charnock & Andersson, 2018]

In this document, 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.

This document is not intended to present a comprehensive review of all the sources of uncertainties when developing plans and strategies to recover the contaminated areas. Here, these sources and the concerns of experts and other interested parties are identified, as well as the different tools or methods available to reduce them or, where appropriate, consider them both in the planning for the recover and in decision-making.

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<sup>2</sup> CONFIDENCE: COping with uNcertainties For Improved modelling and DEcision making in Nuclear emergenCIes. HORIZON 2020 EJP-CONCERT, EC GA 662287. <https://portal.iket.kit.edu/CONFIDENCE/index.php>

This chapter defines the transition phase and the challenges facing decision makers, defines the steps of a generic decision-making process, sets out the main issues for recovery in the agricultural environments and defines different types of uncertainties that come into play.

Chapter 2 discusses the uncertainties which underlie when defining the radiological situation, from the soil as source of the radioactive contamination to people through the pathways of transfer along the food chain, identify the parameters influencing on the behaviour of radionuclides and on the modelling estimations, and presents a methodology to develop risk maps regarding the radiological vulnerability. The information on this methodology is extended in the Appendix 2.

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Chapter 4 considers the implementation of recovery strategies and factors affecting the optimisation. A short list of the most common management options in the agricultural/food chain systems are included.

Chapter 5 gives a brief summary of the activities carried on in the framework of the WP4 to study the influence of societal factors, the preferences and the attitude of the stakeholders when planning and implement a strategy of recovery.

## 1.1 Transition phase from emergency to recovery following a nuclear emergency

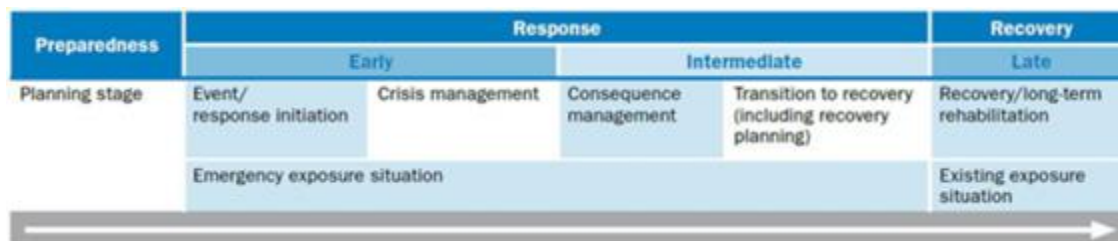
When an emergency involves a significant release of radioactive material to the environment (e.g. nuclear power plant accidents as in Chernobyl or Fukushima-Daiichi), we are faced, in accordance to the situation-based approach introduced by ICRP in their 2007 recommendations [ICRP, 2007], with an emergency exposure situation (EmES). The presence of residual radioactive material in the long-term results in an existing exposure situation (ExES). (see in Appendix 1, for more detailed information on terminology and definitions used in this report).

Therefore, following the course of the nuclear emergency, the “transition” from EmES to ExES requires efforts to cease the emergency response and establish specific plans to begin the recovery and/ or long term rehabilitation of the affected areas. The main objective is to facilitate the timely resumption of social and economic activities, as far as possible [IAEA, 2015].

The IAEA explains the concept of “transition phase” as:

*“The process and the time period during which there is a progression to the point at which an emergency can be terminated” [IAEA, 2018].*

This means that there is no clear-cut boundary, neither temporal nor geographical, between both situations and the difference come from the way they are managed. This report considers the overall emergency management timeline proposed by NEA, 2010 with three phases to identify the progression of the situation (see Figure 1) where a range of various stages and types of actions can be identified (elements in the middle of the scheme). The early and intermediate phases comprise the emergency response and the late phase is associated with long-term recovery, in concordance with the proposals of ICRP [Michiaki, 2016, Nisbet, 2017].



**Figure 1.** View of the emergency management timeline and emergency phases (Source [[NEA, 2010](#)]).

If it is assumed that the transition phase commences once the situation is stable,

*“... 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](#)],

Therefore, the term “transition phase” used by IAEA is equivalent to the whole “intermediate phase” as used by other organisations as ICRP and NEA/OCDE. This phase is divided between a stage of “consequence management” and a specific “transition to recovery” differentiating the various activities to address in each one.

[NEA 2010](#) identifies the “consequence management” as the first period in this transition/intermediate phase when the response efforts will focus on mitigating 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. During this time, characterisation of the contamination, review or lifting of initial countermeasures and consideration of new actions are ongoing. Urban and/or agricultural countermeasures, dietary aspects, stakeholder involvement mechanisms and international coordination become increasingly important, and activities addressing the transition to recovery will begin. The last period of the intermediate phase is defined by [NEA 2010](#) as the “transition to recovery”, when the emergency should be nearby to be terminated and the efforts will be directed to prepare plans and strategies to deal the management of following ExES and recovery of the contaminated areas.

## 1.2 Decision making process

During the intermediate/transition phase, the actions are not driven by urgency and allow, as emergency evolves:

- For the planning and implementation of activities to enable the emergency to be declared terminated in order to prepare the long-term recovery.
- For adapting, justifying and optimizing specific protection strategies, to prepare and begin the late phase recovery and
- For the engagement of the interested parties in decisions regarding the long-term recovery.

These plans need to be developed through a process of national dialogue with stakeholders, taking into account the inherent uncertainties on:

- the knowledge of the real consequences of an accident,
- the strategies to be implemented, and
- the potential socioeconomic impact on the affected population.

Management efforts are therefore complex because of the multiple objectives, actions, metrics, participants and so on and because the implementation takes place in a constrained world (location, money, time, resources, knowledge). The management of these complexities is the main challenge to deal with.

The success of the recovery plan will be measured by the ability of the recovery actions to be implemented in a timely manner, meeting the stakeholders' main concerns and the objectives pursued. It depends on the following:

- How is the problem addressed?
- Who (stakeholders) are involved in the recovery plan?
- What concerns are considered: health, environmental, social, economic, ...?
- What are the objectives pursued in the recovery plan?
- What are the evaluation criteria?
- What are the possible options?

The challenge lies precisely in being able to take the correct decisions, considering these issues. According to [SDM 2013](#) an organized and Structured Decision-Making (SDM) can help to address to identify and evaluate alternatives that focuses on engaging stakeholders, experts and decision makers in productive decision-oriented scenario-analysis as an iterative process as much as the evolution of the radiological situation requires. Figure 2 shows an scheme of the different key steps to follow:



**Figure 2** The key steps of a typical Structure Decision Making (SDM) process. (Source: [[SDM, 2013](#)]).

1. **Define the Problem / Clarify the Decision Context:** Define what question or problem is being addressed and why, identify who needs to be involved and how, establish scopes and bounds for the decision (constraints, goals or targets), and clarify the roles and responsibilities of the decision team.
2. **Define Objectives and Evaluation Criteria:** Together they define “what matters” about the decision (issues), drives the search for creative alternatives (preferred direction), and becomes the framework for comparing alternatives and making trade-offs between alternatives.
3. **Develop Alternatives:** A range of creative policy or management alternatives designed to address the objectives is developed. Alternatives should reflect substantially different approaches to the problem or different priorities across objectives, and should present decision makers with real options and choices. A “strategy” or “portfolio” is a logical combination of actions designed to be implemented as a package.

4. **Estimate Consequences:** Analytical exercise in which the performance of each alternative is estimated in terms of the evaluation criteria developed in Step 2 using available knowledge and predictive tools. Care must be taken to determine the focal areas of uncertainty and to ensure that these are represented properly in the analysis.
5. **Evaluate Trade-Offs and Select:** The next step involves evaluating the trade-offs and making value-based choices (Social, Technological, Environmental, Economic and/or Ethical values). Who is consulted and who participates in making choices may vary by the decision. Explicit choices about which alternative is preferred, could be made directly. Alternatively, structured methods for more explicitly weighting the evaluation criteria, making trade-offs, and scoring and ranking the alternatives may be used.
6. **Implement and Monitor:** The last step in the decision process then is to identify mechanisms for on-going monitoring to ensure accountability with respect to on-ground results, research to improve the information base for future decisions, and a review mechanism so that new information can be incorporated into future decisions. A key challenge will be to both reduce critical uncertainties and build in institutional flexibility to respond to new information without overextending management and political resources.

### 1.3 Main issues for recovery of the agricultural / food production systems

The definition of the problem, that is, how to approach the transition phase may be addressed knowing the objectives to achieve, the topics to be addressed and the criteria for decision to be used and allowing to identify and to evaluate, different alternatives involving stakeholders, experts and decision makers, dealing proactively with complexity and judgment in decision-making. However, the degree of involvement of stakeholders varies according precisely to the objectives, topics, criteria and type of participant that varies from those directly affected to those can contribute to solutions or those that are unaffected but interested.

All these issues can be identified in a decision-oriented scenario-analysis. The scenarios used in this process should be narrative descriptions of potential futures that focus the attention on relationships between events and decisions that need to be taken. Following this premise, the main aspects in the construction process of agricultural scenarios are:

- Characterize, in agricultural areas, the different elements or elemental units as function of the parameters or attributes that influence the behavior and transfer of radionuclides, that is:
  - Primary component: soil -plant/crop,
  - Secondary components: transfer pathway along food chain (Crop - animal - product)
  - Final component: Affected Population (inhabitants and consumers)
- Define and characterize the alternatives of actuation in each one of these components.
- Models and methods to estimate and measure the consequences (spatial-temporal evolution of the without and with countermeasures)
- Identify other factors that could influence on the practicability and optimization of the strategies (Social, economic, political, environmental and ethical values)

Scenario construction process in the transition phase follows a number of steps. The first one of them is the characterization of the radiological situation, allowing the zoning of the contaminated area. For this purpose, the best practice should design an appropriate monitoring program in order to know the real level of deposition on the affected area. In case this cannot be achieved or not fully completed,

the zoning should be based on other parameters such as dose criteria, EURATOM food intervention levels or radiological impact assessments in the long-term.

Equally necessary is the environmental characterization of the affected area in basic or elemental units in terms of parameters and attributes that affect and influence the behavior of the deposited radionuclides. This structuring facilitates not only the analysis of the fate of the radionuclides on the different surfaces by means of assessment models, also the response of the basic units to the different applicable recovery actions in terms of reducing external, inhalation or ingestion doses, activity concentrations or crop uptake. The final aim is to be able to identify the different exposure pathways with their corresponding elemental units, allowing the comparison of the evolution of the radiological situation along them, without and with the application of recovery actions, and taking into consideration that the latter can be applied on one or several elemental units.

As said previously, the evaluation models are necessary to assess the space-time evolution of the scenario with and without recovery actions, helping to define the objectives and quantify criteria for decision-making. Regarding the recovery actions, and depending on the contaminated scenario and the objectives to achieve, they can be applied individually on a determined elemental unit or several of them integrated in a joint action, not necessarily applied over the same elemental unit or in the same period of time. The decision-making process with the involvement of the stakeholders will develop, in each case, the best protection strategy designed to address the objectives defined previously.

#### 1.4 Uncertainties in the transition phase

As stated in [French et al., 2018], uncertainty is interpreted differently by different people and disciplines. It can include stochastic, epistemological, endpoint, judgemental, computational and modelling uncertainties, but there are also those related to ambiguities and partially formed value judgements as well as social and ethical uncertainties.

This generic interpretation of uncertainty can be specifically adapted to the transition phase, identifying those uncertainties related to the different challenges to face in the recovery process. There are therefore, uncertainties associated:

1. To the radiological situation of the scenario, contributing to the overall uncertainty associated with the estimated impact. They are referred specifically to:
  - Space-time evolution of the contamination and the prediction of the radiological situation in the long term
  - Results of the monitoring
  - Possible changes in the future use of the scenario
2. To the goals and criteria used in the design of the protection strategy:
  - Objectives pursued
  - Radiological criteria: reference levels
  - Indicator Units (time to carry out the implementation of the strategy, area affected, n° of persons affected.....)



### 3. To the protection strategy regarding:

- Effectiveness
- Side-effects
- Generated wastes and their disposal
- Costs
- Flexibility and adaptation of the strategy in order to take into account the evolution of the radiological situation?

### 4. To the social pressure regarding:

- Trust and confidence: Will the protection strategy really allow the resumption of social and economic activities; stigmatization of the affected area
- Acceptability of the recovery actions
- Conflicting interests among the affected population and/or affected economic activities of the affected area

However, the involvement of stakeholders in decision-making, another important challenge to be faced in the transition phase is also subject to uncertainties, in particular, on *“how to learn from the stakeholders and the public their preferences on clean-up and recovery strategies and integrate them into decision-making, recognising that they may be unclear on their valuation of these”* [French et al., 2018]. This implies the need to help them discuss, think about and, indeed, form their values and preferences. Many of the approaches to stakeholder engagement and public participation in decision making use multi-criteria decision analysis (MCDA) to articulate such exploratory discussions [Gregory et al., 2012; Papamichail & French, 2013].

## 2 Radiological situation of the scenario

Certain components of the scenario, in particular soils, may accumulate large amounts of radionuclides; such accumulations vary with radionuclide and type of soil. For some radionuclides (especially Cs, Sr and I isotopes), there is now a good understanding of the underlying environmental processes that can lead to exposure.

Once deposited, the behaviour of the radionuclides in the soil is mainly governed by physico-chemical processes that determine the fixation, mobility and bioavailability of radionuclides, being the processes involved: *i)* the infiltration, defined by the infiltration capacity of the soil, *ii)* the vertical migration, defined by the water holding capacity of the soil, *iii)* the sorption/desorption processes, defined by the physico-chemical retention capacity, and *iv)* the root uptake related to the fraction of radionuclide available in the soil solution and its potential transfer to plants, which can be quantified by the potassium and calcium status in soils [Trueba et al, 2015]. Therefore, a complete characterisation of the soils, in terms of their pedological properties, will allow a qualitative prediction of the behaviour of radionuclides in them. Table 1 shows the soil processes, parameters and properties associated to the behaviour of radionuclides in soils.

**Table 1** Soil processes, parameters and properties associated to the behaviour of radionuclides in soils.

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

The infiltration capacity is the rate of water entering the soil at any given instant (mm h<sup>-1</sup>). If no direct measure is available, an estimation of it can be made from other soil data such as texture, structure, clay content, organic matter content and cation exchange capacity. The water holding capacity is a soil property which estimates the maximum storage capacity of water in the soil pore space (mm cm<sup>-1</sup>), depending on the soil texture, the bulk density, the organic matter content and the permeability and taking into account the slope.

The soil parameters that determine the physico-chemical retention capacity vary depending on the type of radionuclide considered. Although radiocaesium takes part in exchangeable reactions, it can be fixed in soils in an irreversible way when adsorbed to the very selective, and small in number, frayed edge sites of micaceous clays (illite), so the clay content and its cation exchange capacity, determines its retention in soils. Radiostrontium is not fixed in soils taking part in exchangeable reactions and being the soil pH the parameter that conditions its solubility.

The bioavailability of <sup>137</sup>Cs for plant uptake will depend on the available fraction and the potassium status in the soil solution, while its retention in soils will depend on the content and type of clay minerals. The processes that affect the <sup>90</sup>Sr root uptake will depend on the calcium status and the pH.

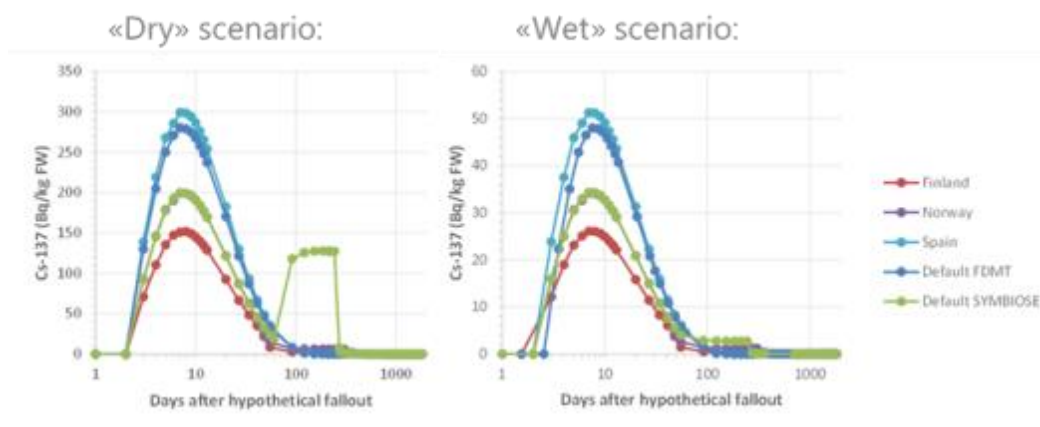
However, these factors can vary both spatially and temporally, giving raise to uncertainties that can be important in determining individual doses. The variation is due to changes of the activity concentrations of radionuclides over time, but also due to changes in the fluxes of radionuclides through the food-chain over time and space (surface affected, contamination zoning based on deposited activity, and how they change over time).

Furthermore, 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.

It is important to highlight that the uncertainties may be enhanced as a function of the assessment models used to determine the activity concentrations and doses, for instance the Terrestrial Food Chain and Dose Module (FDMT) [Müller et al, 2003] included in the JRODOS an ARGOS Decision Support Systems and SYMBIOSE. And not only because of the calculation models included in them also the parameters used for calculations.

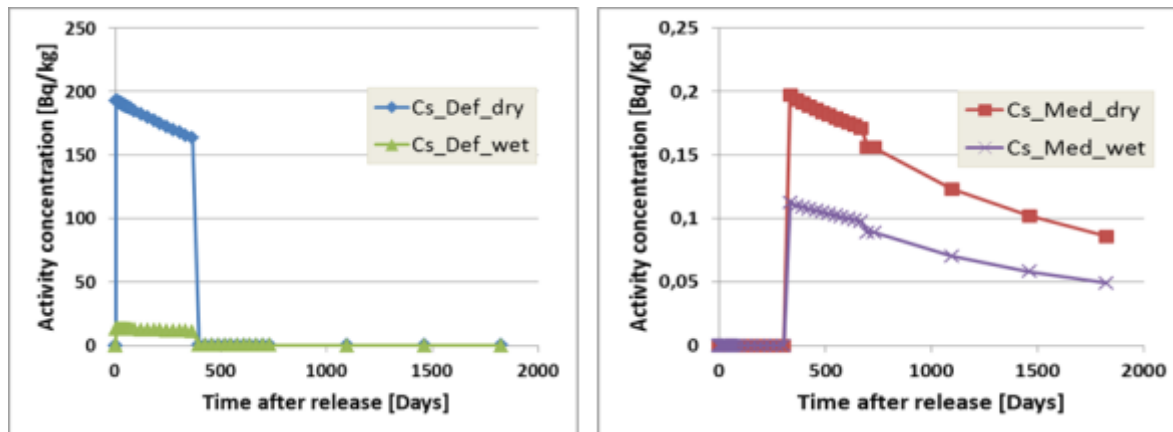
Models usually have default parameters, specific for a certain climatic region that may not be appropriate for other climatic regions in Europe. An exercise to analyse this differences was carried out within COMET Project [Thørring et al., 2016], in which the aim was to derive updated human food chain parameter values appropriate for Nordic and Mediterranean terrestrial ecosystems in order to do an exercise, in two scenarios (a dry one and a wet one) with the same deposition values and meteorological data, to compare results.

Figure 3 shows the results over time of <sup>137</sup>Cs activity concentrations in cow milk obtained, respectively, in the dry and wet scenario using the default parameters for FDMT and SYMBIOSE and the specific Nordic and Mediterranean parameters. Although the results follow very similar patterns (except in the case default SYMBIOSE in the dry scenario), the activity concentrations show significant differences.



**Figure 3** <sup>137</sup>Cs isotopes activity concentration over time in cow milk. Comparison between the results using default values and specific parameters used in Finland, Norway and Spain on dry scenario (left) and wet scenario (right) (Source: [Thørring et al., 2016]).

Furthermore, Figure 4 shows the comparison between the <sup>137</sup>Cs activity concentrations in winter wheat for the scenarios “Default” (left) and “Mediterranean” (right). The results obtained show clearly that the highest values occur in dry scenarios, both Default and Mediterranean, rather than in wet scenarios. The magnitude and temporal development of the activity concentrations in these foodstuffs, are clearly season dependant. During the selected deposition date, the winter cereals in the Mediterranean areas are already harvested, so the activity concentrations of winter wheat and flour wheat, in the following years, come from the root absorption of the radionuclides deposited on the bare soil and are several orders of magnitude lower [Trueba et al, 2017].



**Figure 4** Activity concentration over time of <sup>137</sup>Cs isotopes in Winter Wheat for the scenarios “Default” (left) and “Mediterranean” (right) (Source: [Trueba et al, 2017]).

The results of monitoring are also subject to uncertainties, related both to the monitoring plan itself and to the measurements and analytical determinations. In the affected area the monitoring plan should be carried out thoroughly, with the demonstration of compliance during the survey following scoping and characterization with the adequate number of samples.

The assessment of the behaviour and fate of the deposited radionuclides along the food chain can derive, with the help of Geographical Information Systems, in the elaboration of “radiological vulnerability maps”. These, are useful to define the potential foodstuff and feedstuff restriction areas but also to determine and plan remediation strategies in advance in order to minimise and mitigate the potential radiological effects, not only in health population, but also in the environment and in the socioeconomic structure of the affected area. Thus, radiological risk maps are a tool to be incorporated in the emergency preparedness plans.

The [Appendix 2](#) shows a summary of the methodology developed in a doctoral thesis carried out at CIEMAT titled: “Geographic Information Technologies Applied to Research the Radiological Vulnerability of the Agricultural Systems in the Iberian Peninsula”. It is also part of the research performed in the frame of ANURE Project: “Assessment of the Nuclear Risk in Europe - A Case Study in the Almaraz Nuclear Power Plant (Spain)”, developed between JRC Ispra and CIEMAT.

### 3 Objectives and criteria

A literature review of the radiological criteria applicable in emergency situation has been accomplished with the objective of investigate how uncertainties associated with decisions to be made in this phase could influence the transition and long-term phases. A summary of the work is presented following. The extended information could be consulted in the [Appendix 1](#).

#### 3.1 Scope

A protection strategy, adequate to the type of emergency exposure situations and estimated consequences shall be established in preparedness by national government. Different protective measures can be activated, depending on the scenarios of the accident and the circumstances:

1. Evacuation, temporary relocation and resettlement;
2. Food, water and commodities restriction

- at domestic level;
  - and for international trade;
3. Other protective measures:
- Sheltering;
  - Iodine thyroid blocking (ITB);
  - Medical triage and treatment.

Because the decision to implement the protective actions (or other response actions) needs to be made quickly in order to be the most effective, and especially during the most threatening phases of the accident, the international guidance and standards recommend the use of **pre-determined criteria** to help decide whether and when implement a protective measure (or a combination of protective measures). The criteria are set-up in the preparedness stage and embedded in the overall national protection strategy.

A literature review has been performed to identify and collect the criteria recommended by international organizations. The scope is the following:

- Only the urgent and intermediate phases have been considered;
- The criteria have been collected irrespective of the initiator of the emergency (referred as “a facility”);
- And irrespective of the distance to the facility and type of area (it can be urban, inhabited and agricultural lands).

Most of the identified criteria come from International Commission for Radiological Protection (ICRP) and International Atomic Energy Agency (IAEA) documentation, but other international organizations may recommend specific criteria related to their field of expertise (e.g. ITB for World Health Organization, WHO).

### 3.2 A specific framework for different types of criteria

**Different types of criteria, embedded in a specific framework** are recommended:

- **The reference level, which is the level of dose** above which it is inappropriate to allow exposures to occur. It is recommended to select it between 20 and 100 mSv for the population and to include dose contributions from all exposure pathways. Consideration to sensitive group (pregnant women, children etc.) and dose distribution should be made. This concept and the range of values associated reach consensus between ICRP, IAEA and the EU-BSS.
- **Dosimetric criteria to assist decision** on whether and when to implement protective measures from the protection strategy and ensure that doses are kept and optimized below the reference level. Globally, these criteria are to be used as triggers for protective actions – individually or in combination – to be implemented.
- However, the generic criteria are not measurable quantities, so **operational criteria** expressed in terms of parameters and measurable quantities should be derived from the generic criteria that act as a surrogate for the dosimetric criteria for implementing the protective measure. It could be noted that some operational criteria can be based on observable at the facility (e.g. level of water in circuit) and which can induce off-site the implementation of protective measures (evacuation).

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Figure 5 illustrates this global framework and Table 2 provides some general characteristics about these criteria.

From Table 2, it appears there are some elements of diversity between the dosimetric criteria for introduction of protective measures. But this diversity enables to give consideration to the potential range of situations in emergency (different scenarios) and to define specific goals in the protection strategy. Especially, by using different dosimetric concepts, quantities and pathways, these dosimetric criteria can be focused on specific individuals/groups, organs and also specific risks (*e.g.* releases dominated by radioiodine). They can also be used to ensure that specific organ-absorbed-dose are kept below appropriate level (*e.g.* thyroid, foetus) and, in addition, by using different period of time – day, week etc. – considerations can be given to the timing to implement the protective measures (measure that suffer no delay vs. early measure) and the development and evolution of the accident.

The operational criteria are to be derived from the dosimetric criteria to act as surrogate and to assist in decision. There is no limitation to the unit in which operational criteria can be expressed; typically they are expressed in terms of dose rates or activity of radioactive material released, time integrated air concentrations, ground or surface contamination, or activity concentration of radionuclides in the environment, in food, in water etc. No operational criterion derived from dosimetric criteria to avoid/minimize tissue reactions has been found in the literature review.

**Table 2: Main characteristics of the criteria associated with protective measures that can be used in emergency exposure situation**

| Type of criteria  | Number of values identified | Dosimetric quantities   | Dose concepts   | Pathways  | Time frames   | Link with protective measures   |
|---|-----------------------------|---|---|---|---|---|
| <b>Reference Level</b>  | 1 band                      | E (mSv)   | Residual dose   | Contribution from all pathways  | <ul style="list-style-type: none"> <li>Acute</li> <li>Or year</li> </ul>  | Link with the overall protection strategy   |
| <b>Dosimetric criteria to avoid/minimize tissue reactions</b>       | 9 criteria                  | AD <sub>T</sub> (Gy)  | <ul style="list-style-type: none"> <li>Projected (4)<sup>A</sup></li> <li>Received (5)</li> </ul>             | <ul style="list-style-type: none"> <li>External (4)</li> <li>Internal (5)</li> </ul>                                      | <ul style="list-style-type: none"> <li>Acute (4)</li> <li>30 days (5)</li> </ul>  | Combination of protective measures  |
| <b>Dosimetric criteria for introduction of protective measures</b>  | 21 criteria                 | <ul style="list-style-type: none"> <li>E (mSv) (9)</li> <li>H<sub>T</sub> (mSv) (8)</li> <li>AD<sub>T</sub> (Gy) (4)</li> </ul>   | <ul style="list-style-type: none"> <li>Projected (11)</li> <li>Received (2)</li> <li>Avertable (8)</li> </ul> | <ul style="list-style-type: none"> <li>Contribution from all relevant pathways (15)</li> <li>Internal only (6)</li> </ul> | <ul style="list-style-type: none"> <li>2 days (1)</li> <li>Week (3)</li> <li>Month (1)</li> <li>Full period of intra-utero development (5)</li> <li>Year (4)</li> <li>Life (1)</li> </ul> | <ul style="list-style-type: none"> <li>Combination of protective measures</li> <li>Specific to one protective measures</li> </ul> |
| <b>Operational criteria for introduction of protective measures</b> | 13 criteria                 | Based on observable quantities: <ul style="list-style-type: none"> <li>μSv/h,</li> <li>α/β/γ count/s,</li> <li>Bq/kg</li> <li>Bq/cm<sup>2</sup></li> <li>[<sup>131</sup>I], [<sup>137</sup>Cs]</li> </ul> |   | The complete set of operational criteria in a protection strategy should consider all the pathways.                       | N/A   | <ul style="list-style-type: none"> <li>Combination of protective measures</li> <li>Specific to one protective measures</li> </ul> |

<sup>A</sup> The number in bracket is the number of criteria with this characteristics. Example: 4 (of the 9) dosimetric criteria to avoid/minimize tissue reactions are based on a projected dose concept.

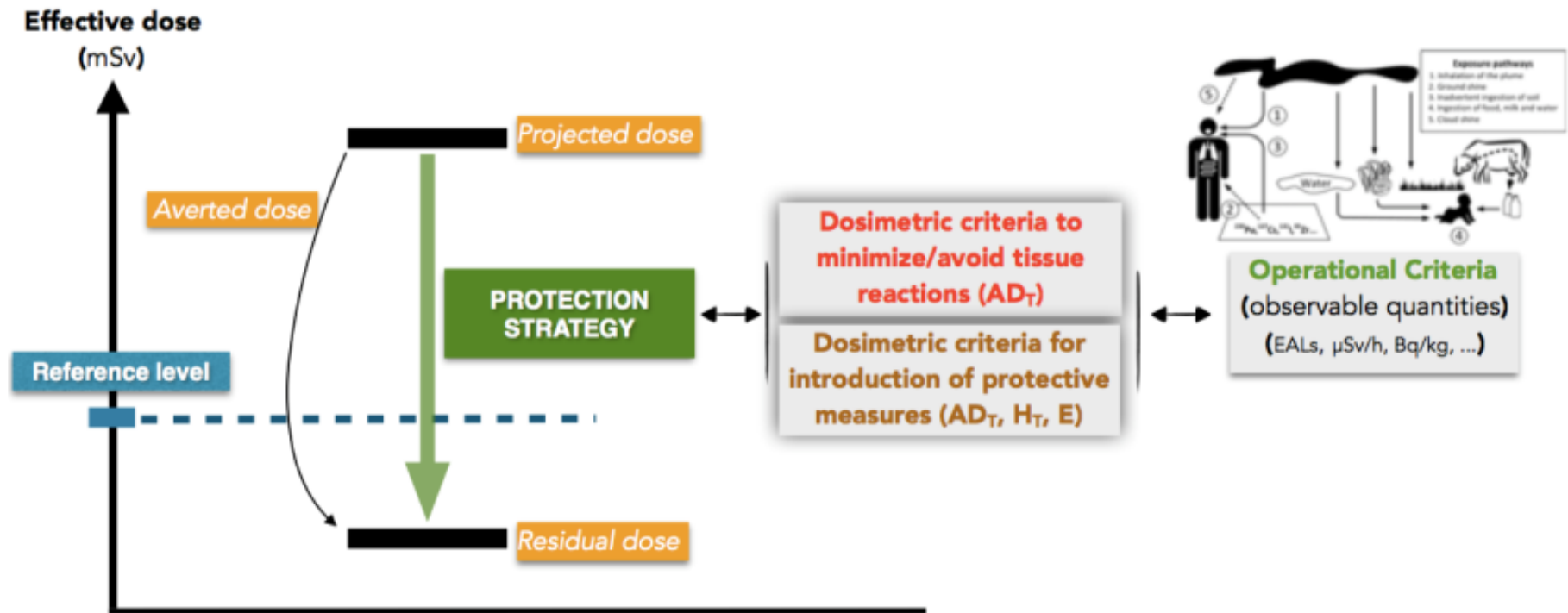


Figure 5. The framework and the different criteria that can be used in emergency exposure situations.



### 3.3 Link between the criteria and the protective measures

For each protective measure listed in *infra* § 6.1, all the dosimetric and the operational criteria that have been identified in the literature review have been listed. This is summarized in the Table 3 down below and all the figures and tables can be consulted in [Appendix 1](#).

For **evacuation and temporary relocation**, the dosimetric criteria are generally based on a projected effective dose and a 100 mSv value. An integrated time of 7 days is often used to decide for evacuation and a longer period of time (year or even lifetime) for relocation. Operational criteria based on living conditions – namely ground dose rate and activity concentration in food – are recommended. It should be noted that there are some little differences in the IAEA's operational criteria depending on the publication (one publication applies to light water reactor accident, the other publication is generic).

For **food, water and other commodities restriction**, a distinction can be made between criteria which apply at local scale and criteria that apply for international trade.

At local scale, recommendations are to ban or to restrict consumption and distribution of local products and to prevent contaminated food for both human and animal from entering the general distribution system.

- In addition, several criteria expressed in ground contamination and activity concentration in food are proposed and again, the stringency of the protective measures is graded according to the measured value.
- Finally, the IAEA also introduces dosimetric criteria for restriction of use of vehicles, equipment and “other items”.

Different organizations (namely ICRP, IAEA, WHO, European Commission) are recommending criteria with regard to the international trade of food and commodities coming from an area affected by a nuclear accident. The criteria are expressed as activity concentration in food, feed and generally derived from a 1 mSv/y criterion. But significant differences lie in the definitions of the type of food (*e.g.* infant food, non-essential food) and consumers groups, the radionuclides under consideration, the numerical values, etc. and these makes the comparison of the collected criteria not straightforward.

Few criteria with regard to **sheltering** have been collected. The criteria are based on a dosimetric concept in general (but different values are used between ICRP and IAEA) and operational criteria in ground dose rate are proposed.

By contrast, criteria collected for **iodine thyroid blocking intake** are quite numerous: the dosimetric criterion is based on a dose to the thyroid (absorbed or equivalent) but there are differences between the organizations (ICRP, IAEA, WHO) when it comes to the definition of the groups individuals (which are age-based), the numerical values and the period of time. Operational criteria based on ground contamination and ambient equivalent rate in front of the thyroid are proposed.

**Medical considerations** can take very different shape: medical treatment, decontamination, actions to limit the spread of contamination and actions to limit ingestion etc. and up to 14 different criteria are offered by IAEA on this theme. Globally the same dosimetric criterion is used but the medical considerations are graded according to the period of time (the longer the period of time is, the less urgent/stringent the medical consideration can be). Different

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operational criteria are proposed and are expressed in ground dose rate and skin dose rate. They are some little differences in the operational criteria depending on the IAEA publication.

For example, a key element from the French strategy is that, besides the regulation, a doctrine has been elaborated from a pluralistic committee and is explicitly intended for the preparation and the implementation of the steps necessary to deal with the emergency phase and the recovery.

### 3.4 Conclusions

This literature review clearly shows that various criteria have been defined in order to prepare and establish a framework to react quickly in the event of a nuclear accident.

Therefore, each country can propose its own emergency, preparedness and response plan by selecting the various recommended criteria accordingly with the pursued objectives (protecting public, protecting environment, protecting agricultural economy, etc.). Then during the event of a nuclear accident, the implementation of an emergency, preparedness and response plan will certainly raise various uncertainties directly linked to the use of criteria:

- Implementation and comprehension of criteria,
- Modelling for the calculation and the implementation of criteria,
- Measures,
- Effectiveness of the protective strategies associated with criteria
- Etc.

Therefore, these criteria are the basis of the decision-making process in the emergency situation. However, it is important to have in mind that, the implementation of these criteria will have consequences on the transition and long-term phases, and these consequences are very difficult to predict and so represent sources of uncertainties themselves. For instance, food restriction or evacuation can have heavy consequences on the agricultural economy and the long-term dynamics of a territory (e.g. feedback experiences of Chernobyl and Fukushima situations). The proper implementation of criteria in the emergency phase, which can subsequently adapt to the transition and long-term phases, is therefore a major challenge today. Also, it should be noted that, nowadays, few countries have defined a framework to be implemented in the transition and long-term phases (France, the United State for example).

Within the CONFIDENCE project, it is proposed to investigate with the French panel these elements, notably how the decisions taken in emergency situation are impacting the evolution of the transition phase and how far these decisions are influenced by the degree and type of uncertainties of the evaluation of these radiological criteria.

**Table 3** Protective measures and associated criteria proposed by international organizations: a synthetic table

| International organization   | ICRP                |                      |                    |                     |                      |               | IAEA   |               |             |   |                     |               | WHO                              |               |             |                                 |             |                                  | EC                               |                                  |                      |                  |             |                    |
|--|---------------------|----------------------|--------------------|---------------------|----------------------|---------------|--|---------------|-------------|---|---------------------|---------------|----------------------------------|---------------|-------------|---------------------------------|-------------|----------------------------------|----------------------------------|----------------------------------|----------------------|------------------|-------------|--------------------|
|  | Dosimetric criteria |                      |                    | Dosimetric criteria |                      |               | Operational criteria (IAEA, 2013, IAEA 2017) |               |             | Operational criteria (IAEA, 2011)               |                     |               | Operational criteria (IAEA 2005) |               |             | Dosimetric/operational criteria |             |                                  | Operational criteria             |                                  | Dosimetric criteria  |                  |             |                    |
| Type of the criteria   | Effective dose      | H <sub>thyroid</sub> | Effective dose     | H <sub>foetus</sub> | H <sub>thyroid</sub> | OIL1          | OIL2   | OIL3          | OIL4        | OIL7  | OIL8                | OIL1          | OIL2                             | OIL3          | OIL4        | OIL5                            | OIL6        | OIL1                             | OIL2                             | OIL3                             | H <sub>thyroid</sub> | Guideline Levels | MPLS        | Effective dose     |
| Criteria (unit)  | mSv/Δ <sup>A</sup>  | mSv/Δ <sup>A</sup>   | mSv/Δ <sup>A</sup> | mSv/Δ <sup>A</sup>  | mSv/Δ <sup>A</sup>   | μSv/h; ground | μSv/h; ground                                | μSv/h; ground | μSv/h; skin | Bq/kg <sup>131</sup> I, <sup>137</sup> Cs; food | μSv/h; skin/thyroid | α/β/y; ground | α/β/y; ground                    | α/β/y; ground | μSv/h; skin | Bq/kg; food                     | Bq/kg; food | Bq/cm <sup>2</sup> , mSv/h; skin | Bq/cm <sup>2</sup> , mSv/h; skin | Bq/cm <sup>2</sup> , mSv/h; skin | mGy, thyroid         | Bq/kg; food      | Bq/kg; food | mSv/Δ <sup>A</sup> |
| Protective measures  |                     |                      |                    |                     |                      |               |  |               |             |   |                     |               |                                  |               |             |                                 |             |                                  |                                  |                                  |                      |                  |             |                    |
| Evacuation   | X                   |                      | X                  | X                   |                      | X             |  |               |             |   |                     | X             |                                  |               |             |                                 |             |                                  |                                  |                                  |                      |                  |             | X                  |
| Relocation   | XX                  |                      | X                  | X                   |                      |               | X  |               |             | X   |                     |               | X                                |               |             | X                               | X           |                                  |                                  |                                  |                      |                  |             | XX                 |
| Food, water and other commodities restriction: at local scale      |                     |                      | XXX<br>X           | XXX<br>X            |                      | X             | X  | X             |             | X   |                     | X             |                                  | X             |             | X                               | X           |                                  |                                  |                                  |                      |                  |             |                    |
| Food, water and other commodities restriction: international trade |                     |                      | X                  | X                   |                      |               |  |               |             |   |                     |               |                                  |               |             |                                 |             |                                  |                                  |                                  |                      | X                | X           |                    |
| Sheltering   | X                   |                      | X                  | X                   |                      |               |  |               |             |   |                     | X             |                                  |               |             |                                 |             |                                  |                                  |                                  |                      |                  |             | X                  |
| Iodine Thyroid Blocking  |                     | X                    |                    |                     | XX                   | X             |  |               | X           |   | X                   |               |                                  | X             |             | X                               | X           |                                  |                                  |                                  | XXX                  |                  |             |                    |
| Medical consideration  |                     |                      | XXX                | XXX                 |                      | X             |  |               | X           |   | X                   |               |                                  |               | X           |                                 |             | X                                | X                                | X                                |                      |                  |             |                    |

'X': one criterion is recommended, 'XX': two criteria are recommended, etc. <sup>A</sup> Different dose values and/or different time frames (Δ) are recommended..

## 4 Implementation of strategies

Once a site has been characterized, the decision makers are faced with their first fundamental choice for the intended remedial action. They must decide whether they will:

- Leave the site undisturbed, while probably establishing a monitoring scheme for determining the evolution of the site. This option relies on natural processes to prevent significant exposure, and the monitoring scheme will identify if alternative actions are required.
- Contain or restrict the mobility of the radioactive contaminants: this involves immobilizing the contaminants inside the area in which they already exist, reducing the potential for further migration or entry into active pathways of exposure.
- Remove the radioactive contaminants from the site, using an appropriate treatment scheme: this involves extracting, concentrating and then safely disposing of the contaminants at another location.

The objective of any technique used in a remediation strategy is either to remove or reduce the source term or to block the exposure pathways.

In the case of dispersed contamination, a rigorous assessment of the actual and potential pathways is required to determine the optimal action.

The three generic options that represent the fundamental technical choices for remediation can be summarized as monitored non-intervention, containment and removal.

In this framework, and according to ICRP-103 [ICRP, 2007], protection can be achieved by taking action at the source (eg. the building source, the soil), or at points in the exposure pathways (the foodstuffs, feedstuffs, or modifications in the livestock husbandry), and occasionally by modifying the location or characteristics of the exposed individuals (eg., modifying the exposure times or the dietary habits of the exposed individuals).

This means, that the recovery actions are designed to target particular media and contamination pathways. The management options are not only aimed at addressing health concerns but also a wide range of other issues at stake, such as the local economy, societal concerns, and disposal of wastes. While many options are of a technical nature involving some form of physical or chemical intervention to reduce the transfer of radionuclides along the food chain, there are a few options that simply provide advice, reassurance monitoring and information, and support to the public for self-help actions.

Several tools are proposed to be used, such as:

- EURANOS Handbook for Management of Contaminated Food Production Systems [EURANOS, 2009].
- HARMONE Guidance Handbook for Recovery after a Radiological incident [Nisbet et al., 2017].
- AgriCP module in JRODOS [Gering et al., 2010]

Examples of the main management options that can be used both in agricultural areas are shown in **Table 4**, including decision criteria.

The implementation of a protection strategy has to be justified and the protection optimised. Reference levels of effective dose, as referred to previously, are used to constrain the optimisation process by either assisting in the planning of recovery strategies so that individual doses fall below the reference level or acting as a benchmark for judging the effectiveness of strategies after implementation [EURANOS, 2009].

The protection strategy can comprise one or a number of combined action options. It is important to highlight that the justification of a protection strategy goes far beyond the scope of radiological protection as its implementation is also associated to other types of impacts such as environmental, side-effects, economic and social. What is important is that the overall recovery strategy is justified in as much as it brings sufficient individual or societal benefit to offset any associated detriments. For example, a range of individually justified action options may be available but not provide a net benefit when considered as an overall strategy because collectively, they may bring too much disruption or may be too complex to manage. [Robinson, 2017, EAN, 2018].

The principle of optimisation is applied to situations where the implementation of a recovery strategy is already justified. Optimisation should ensure selection of the best strategy and its process, during recovery, can be implemented step by step. The best strategy is not necessarily the one that results in the lowest dose for individuals, as this depends on incident specific and location specific factors.

When carrying out optimisation of recovery strategies there are a number of factors that need to be taken into account, these are mainly:

1. **Effectiveness:** understood as the reduction in activity concentration in the target (soil, crop, animal product), after implementing the action option. It may be influenced by technical factors such as the availability of equipment, utilities, infrastructure, transport, consumables, operators and duration of treatment and application rates.
2. **Wastes:** is referred to the nature and volume of the wastes generated by the implementation of the action options. It is necessary to know if the wastes are contaminated and the type of applicable treatment: in situ or in an off-site facility; the latter case requires taking into account their transport and storage in the final disposal.
3. **Doses:** are referred to the incremental doses that may receive the workers in charge of the implementation of the option but also members of public.
4. **Costs:** are referred to the direct costs derived from implementing the option such as: equipment, utilities, infrastructure, transport, consumables, operator's wages, waste treatment. The costs will depend on the size and accessibility of the target, seasonality, availability of equipment and consumables within the contaminated area.
5. **Side-effects:** there are different types of them that may be incurred in following the implementation of the action option. They are mainly referred to:
  - **Environmental impact:** the implementation of options may affect the physical characteristics of the affected area and therefore components of the environment such as freshwater resources, freshwater quality, forest resources, wildlife reserves, biodiversity
  - **Agricultural impact:** such as reduction in soil fertility, overproduction, changes in land use
  - **Animal welfare:** on issues related to health, feeding and housing

**Table 4** Management options – agricultural scenarios (source [EURANOS, 2009])

| OBJECTIVES  | EFFECTIVENESS   | FEASIBILITY  | WASTE   | SIDE-EFFECTS  | COSTS | SOCIAL FACTORS  |
|---|---|--|---|---|-------|---|
| <b>Application of potassium fertilizers to arable soils and grasslands</b>  |   |  |   |   |       |   |
| Reduce plant uptake of Cs-137 by addition of K fertilizers  | Reduction factor up to 5 (80%) when the exchangeable K status < 0.5meq/100g soil  | Requires ordinary fertilizing equipment, ancillary, utilities, consumables                   | None  | Environmental (mobility of nutrients-water quality), impact                               |       | Farmer/food industry/consumers resistance                 |
| <b>Application of lime to arable soils and grassland</b>  |   |  |   |   |       |   |
| Reduce plant uptake of some RN by addition of lime to the soil  | Liming from pH 5 to 7, may decrease plant uptake of Sr-90 by: 50% (factor of 2)-sandy soils 67% (factor of 3)-loamy soils 75% (factor of 4)-clay soils 83% (factor of 6)-organic Liming in excess pH7/6 has no effect | Requires ordinary fertilizing equipment, ancillary, utilities, consumables                   | None  | Environmental (mobility of nutrients-water quality), agricultural (soil fertility) impact |       | Public/farmer resistance                                  |
| <b>Deep ploughing</b>   |   |  |   |   |       |   |
| Reduce RN uptake by crops, including pasture  | Uptake reduced by up to 90% (factor of 10) External dose reduced by 50-95% (factors of 2-20=)   | Requires plough, tractor, consumables  | None  | Environmental, agricultural impact  |       | Public confidence due to contamination at depth           |
| <b>Top soil removal</b>   |   |  |   |   |       |   |
| Reduce RN uptake by crops, including pasture  | 90-97% of the activity is removed   | Requires bobcat, bulldozer, vehicle to transport waste, consumables                          | Yes. Needs to be disposed                                     | Environmental (soil erosion), agricultural (soil fertility) impact                        |       | Farmer resistance (disruption of farming and waste)       |
| <b>Selection of edible crop that can be processed</b>   |   |  |   |   |       |   |
| Select crops suitable for processing so that the final edible product has activity concentrations less than intervention levels | Varies regarding crop and RN; Food processing factor= total activity of RN in the processed food (Bq)/total activity of RN in the raw material (Bq)   | Sowing/harvesting equipment, consumables; processing equipment                               | Depends on crops selected; includes food processing residuals | Environmental (change ecosystem), agricultural (change crop type) impact                  |       | Public confidence and acceptance on these foods processed |
| <b>Administration of AFCF boli to ruminants</b>   |   |  |   |   |       |   |
| To reduce activity concentrations of Cs in meat or milk below the intervention levels   | Up to 80% in lamb and reindeer meat and goat milk; up to 70% reduction in cow milk  | Administer by hand (sheep, cows and goats); dosing guns used for other intra-ruminal devices | None  | Animal welfare; conventional farming practices can be maintained                          |       | Acceptability to farmers, food industry and consumers     |

| OBJECTIVES   | EFFECTIVENESS   | FEASIBILITY   | WASTE                                   | SIDE-EFFECTS   | COSTS | SOCIAL FACTORS   |
|--|---|---|---|--|-------|--|
| <b>Live monitoring</b>   |   |   |   |  |       |  |
| To determine whether activity concentration in animals are below the intervention limits | Highly effective (near 100%) at excluding meat above intervention level from foodchain  | Portable, preferably lead-shielded NaI detector linked to a single or multi-channel analyser with battery supply calibrated for animals | None                                    | No direct impact other than a disruption to normal practice      |       | Stigma associated to the affected area                             |
| <b>Processing of milk for subsequent human consumption</b>                               |   |   |   |  |       |  |
| Produce milk products with activity concentrations less than intervention levels         | Depends on the RN and the product. Milk products prepared by isolating the fat and/or protein from the aqueous fraction tend to be depleted in Cs and I compared with raw milk.     | Milk processing plant, milk tankers, waste treatment facilities, consumables  | Percentage by mass of waste by-products | Parts of the processing plant may become contaminated            |       | Public confidence  |
| <b>Dietary advice</b>  |   |   |   |  |       |  |
| Dose reduction by giving advice on how to reduce their RN intake                         | Washing removes 10-90% (vegetables & fruit)<br>Peeling 10-100% of U, AM; 80% Cs and 50-90% Sr (root vegetables)<br>Blanching or boiling 50%<br>Filleting and washing fish 80% of Ra | Normal cooking utensils   | Not addressed                           | Loss of traditional activities, potential loss of home produced. |       | Positive consequences if the population has trust in institutions; |

- **Heritage protection:** referred to artistic, cultural and urban heritage but also natural parks
- **Legal constrains:** referred to types of restrictions need to be considered before the implementation of an option, such as water, foodstuffs and feedstuffs regulations

Figure 6 shows schematically the factors that need to be taken into account in the optimization process.

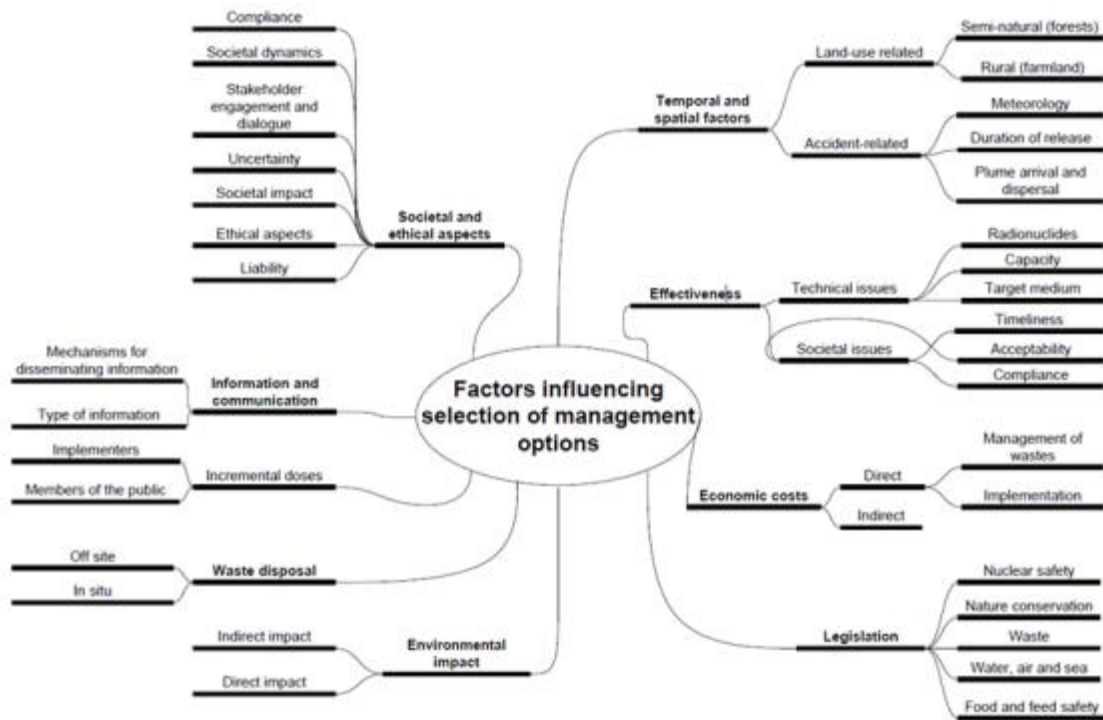


Figure 6 Factors influencing the selection of management options (Source [EURANOS, 2009])

## 5 Environmental and social aspects

There is another important source of uncertainty which need to be considered when implementing a protection strategy, the societal factors. These arise from people’s behaviours, attitudes and perceptions and are ultimately related to the society’s trust and confidence in their national institutions to facilitate the timely resumption of normal living conditions. Unlike technical factors, the impact of societal factors on the overall management of a protection strategy is difficult to quantify and can be contemplated from different points of view. For instance one may be the stigmatization of the food products coming from the affected area but also the confidence in whether the recovery strategy will really achieve its objectives.

Another source of uncertainty under this topic is the acceptability by the public of the recovery actions, not only on the “hypothetical” efficiency of the options per se, but also on issues related to the treatment of the wastes generated, the disruption of access to the affected area, the side-effects and the farmers, food industry and consumers resistance.



The implementation of the recovery strategy can give rise to conflicting interests among the affected population and/or affected economic activities of the area, regarding the primary objective of the protection strategy.

In the framework of WP4, by means of a questionnaire, we asked experts from the Confidence project and other relevant stakeholders from different countries to identify relevant topics regarding the emergency transition phase [Sala et al., 2018]. We carried out this first brainstorming exercise at the European level. We provided an initial transition phase scenario to put the respondents in situation (transition phase after a nuclear accident with external release of radioactivity to the environment). Then, we asked 15 questions about critical issues during this phase, objectives of the restoration plan, alternatives of action, and stakeholder engagement. The findings provided some relevant inputs about the main social uncertainties during the transition phase.

How to better inform people and how to involve stakeholders appeared as critical issues to be considered. In the same sense, frequent engagement with the affected population and risk communication were highlighted as priority actions.

When we asked about which should be the final objective of the restoration plan, some of the respondents raised the issue of building trust among the population, mainly to build confidence in the protection measures implemented to protect public health. Another objective that was pointed out was the minimization of the impacts on the population and their living conditions.

When we focused on stakeholder involvement, some challenges were highlighted such as communication difficulties (related with how to communicate uncertainties), loss of public trust, insufficient resources, lack of time, absence of public interest or real cooperation, existence of opposed goals and lack of legitimacy (balancing the need to consult and the need to make timely decisions).

This social uncertainties should be considered in transition phase planning, both in urban and rural contexts. More in depth results about social uncertainties would be provided by WP5.

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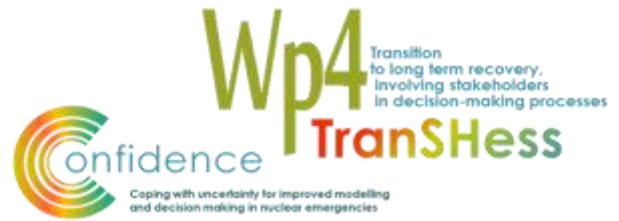
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## D 9.21 Appendix 1.

# A Literature Review of the International Recommendations on the Use of Criteria for Emergency Preparedness and Response

## Final

### Version 1.0

**CONFIDENCE-WP4.** Transition to long-term recovery, involving stakeholders in decision-making processes

**Document Number:** CONFIDENCE-WP4/T4.1.2-R01

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## APPENDIX 1. A LITERATURE REVIEW OF THE INTERNATIONAL RECOMMENDATIONS ON THE USE OF CRITERIA FOR EMERGENCY PREPAREDNESS AND RESPONSE

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## List of acronyms

|                 |  |
|-----------------|--|
| AD <sub>T</sub> | Absorbed Dose to a tissue or organ (in Gray)   |
| BSS             | Basic Safety Standards   |
| CFIL            | Council Food Intervention Level  |
| CODIRPA         | French Committee for the management of the post-accident situation following a nuclear emergency |
| E               | Effective dose (Sv)  |
| EAN             | European ALARA Network   |
| EC              | European Commission  |
| EmES            | Emergency exposure situation (under the ICRP definition)   |
| Euratom         | The European Atomic Energy Community   |
| ExES            | Existing exposure situation (under the ICRP definition)  |
| H <sub>T</sub>  | Equivalent dose to a tissue or organ (Sv)  |
| IAEA            | International Atomic Energy Agency   |
| ICRP            | International Commission for Radiological Protection   |
| MPL             | Maximum Permissible Level  |
| NERIS           | European Platform on preparedness for nuclear and radiological emergency response and recovery   |
| OIL             | Operational Intervention Level   |
| ITB             | Iodine Thyroid Blocking  |
| Sv              | Sievert  |
| WHO             | World Health Organization  |

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## 1 Introduction

### 1.1 Preamble

The occurrence of an “emergency exposure situation” in a nuclear facility has the potential to release radioactive substance in the environment, generally in the form of an atmospheric plume. In the most severe situation, this plume has the potential to cause elevated level of exposures within hours for those located close to the facility; workers and population. These injuries would be the result of inhalation and external exposure from the radioactive materials in the plume, from exposure to radiation emitted by radioactive material deposited on the ground or from the ingestion of contaminated foodstuffs. In order to be most effective, protective measures need to be taken preferably **before** arrival of the plume and not delayed from the use of analysis of environmental monitoring results. It is therefore important to be prepared and have a framework to react quickly in the event of a nuclear emergency.

The dynamics and the magnitude of the releases are difficult to predict, as well as the deposition pattern at short and long distance. However, the decision to act needs to be made quickly in order to avoid unnecessary exposure: experience from past accidents and emergency exercises show the importance of radiological criteria in the decision-making process but also the difficulties for decision-makers to select among them. It also pointed out the strong link between the criteria used in emergency situation with those adopted for the longer-term management of the post-accidental situation. Therefore, current international recommendations state the use of **pre-determined criteria**, linked with specific protective measures. Criteria are set-up in the preparedness stage and embedded in the overall (national) protection strategy for the management of an emergency exposure situation.

### 1.2 Objectives of the task

The objectives of CONFIDENCE task 4.1 are:

*“The modelling and literature review for urban/inhabited and agricultural areas will be carried out to identify and assess the criteria and factors (including the spatial and temporal influence in the establishment of reference levels and the evaluation of uncertainties in the process) that improve/affect the selection, efficiency and ending of remediation strategies. Based on the results, and taking advantage of the lessons learned from Fukushima and Chernobyl, a brainstorming process, using a structural communication technique and concluding with a dedicated workshop, will be conducted to agree on scenarios and identify remediation strategies as well as the questions and issues to be addressed in the stakeholder panels.”*

This document focuses on the first objective of the task (underlined) for radiological criteria applicable in emergency situation with the objective to further investigate how uncertainties associated with decisions to be made in this phase could influence the transition and long-term phases. To achieve it, the following approach is proposed:

1. Present the **conceptual framework attached with recommendations** in an emergency exposure situations.

This framework is lay down by the recommendations coming from the International Commission for Radiological Protection (ICRP) and the standards and documentation from the International Atomic Energy Agency (IAEA).

2. Then perform a **literature review to identify and collect criteria**.

Most of the identified criteria also come from ICRP and IAEA documentation, but other international organizations recommend specific criteria as far as it falls in their field of expertise (e.g. iodine intake and food restrictions for World Health Organization, WHO).

The focus of the document is *a priori* limited to criteria recommended at international level. However an insight on a national protection strategy for the management of an emergency exposure situation and the associated criteria is also provided (for France).

### 1.3 Structure of the document

The Chapter 2 provides definitions and some technical elements.

Chapter 3 presents the conceptual framework of the different types of criteria proposed by the ICRP and the IAEA and develops their specificities.

In Chapter 4, a systematic analysis of the collected criteria is performed: for each protective measure, the associated criteria are listed and their values shortly described.

Chapter 5 provides an illustration of chapters 3 and 4 by presenting the French plan and doctrine for the management of an emergency exposure situation and post-accidental situation and the associated criteria.

## 2 Background

### 2.1 Definition of an "emergency exposure situation"

The International Commission on Radiological Protection (ICRP) provides in Publication 103 (ICRP, 2007) the current framework of the radiological protection system. Three exposure situations are defined:

*"Planned exposure situations, which are situations involving the planned introduction and operation of sources [not further considered in this document]."*

*Emergency exposure situations, which are unexpected situations such as those that may occur during the operation of a planned situation, or from a malicious act, or from any other unexpected situation, and requiring urgent attention in order to avoid or reduce undesirable consequences.*

*Existing exposure situations, which are exposure situations that already exist when a decision on control has to be taken, such as those caused by natural background radiation" [not further considered in this document]. (§ 176 *ibid.*)*

The ICRP provides examples of situations that fall into the scope of emergency exposure situations:

*"Nuclear and radiological emergencies originating from a nuclear power plant or a laboratory, following a natural event, a human error, a mechanical or other failure, or a 'nuclear security event' (criminal acts involving nuclear material)". (§ 177, *ibid.*)*

The ICRP definition reaches consensus and is used by other international organizations, in international (IAEA, 2015) and European basic safety standards (Euratom, 2013) as well as in national regulations. In this document, the emergency exposure situations will be abbreviated "EmES".

The fundamentals principles of radiological protection (namely: justification, optimisation and dose limitation) apply in the case of EmES and their application have been further detailed in ICRP

Publication 109 (ICRP, 2009). ICRP is currently in the process of updating Publication 109 in the light of the Fukushima accident and merging it with Publication 111 (which apply to post-accident rehabilitation situation).

## 2.2 Terminology

“**Protective measures**” are the actions intended to avoid or reduce projected dose during EmES. These actions are labelled differently depending on the organizations: “*countermeasures*”, “*management options*”, “*response action*”, “*mitigation measures*” etc. In this document, we used the wording “*protective measures*”.

The literature review enable to identify the following protective measures:

1. Evacuation, temporary relocation and resettlement;
2. Food, water and commodities restriction
  - at local level;
  - and for international trade;
3. Sheltering;
4. Iodine thyroid blocking (ITB);
5. Medical considerations.

The criteria associated with the implementation of each of these protective measures, will be described in Chapter 4.

On the basis of the potential consequences of an EmeS, an overall “**protection strategy**” shall be developed. A protection strategy contains in particular<sup>4</sup> the timing and manner of implementing the selected protective measure, either individually and/or their combination. A protection strategy shall be “*optimized*”, driven by the use of several criteria: the reference level and also other specific criteria for taking a protective measure (or a combination) and other response actions (ICRP, 2009).

“**Timeline**”: The timescale for implementing the protective measures covers the period before the radioactive releases and extend over the days, weeks and even years after. There is no consensual terminology for the timeline, neither harmonized criteria that delimit the phases and to move from one phase to another (EAN, 2018)<sup>5</sup>. Still, a separation can be proposed between:

- An “*early phase*” with a time scale of hours to days, starting when the risk of release is identified (identification of threat and activation of the emergency response) and lasting for as long as the releases are in progress. This phase requires the urgent implementation of protective measures based on pre-determined criteria.
- An “*intermediate phase*” with time scale of days or weeks after the releases where the radiation level is no longer increasing: the radiological situation is being monitored and characterized to a certain extent to identify the need to stop, reinforce or add protective measure.

The “*late phase*” or recovery starts several months or years after the releases: the situation is stable and radioactive releases are characterized through extensive measurements. The aim of the characterisation is to adjust the protective measures to the prevailing situation and improve the long-term rehabilitation of the living conditions in the affected territories<sup>6</sup>.

<sup>4</sup> Further details on protection strategy are provided in §7 of ICRP, 2009.

<sup>6</sup> Even when the emergency situation is over, environmental contamination may persist for a long period of time. Management of this long-term exposure is considered an “existing exposure situation” (ExES). The transition from EmES to ExES will be made by the relevant authorities

In this document, only the **early and intermediate phases** are considered.

**“Facility” and “zone”.** – The scope of the documentation available is sometimes restricted to certain type (or class) of emergency, specific to nuclear power plant or following a radiological attack. Still, all these situations fall under the ICRP’s definition of EmES.

Similarly, some protective measures may be restricted *a priori* to certain zones around the facility. These zones are to be defined in the preparedness stage to commensurate the protective measure to hazard and can be referred as “*urgent protective actions zone*”, “*public protection zone*” “*precautionary action zone*” (IAEA wording), etc. These zones can equally include urban, inhabited and cultural areas.

Considering that,

1. The objective of the task is not geographically limited and encompass a priori urban, inhabited and agricultural land;
2. In the literature review, the classification of the zones, their size, the rationale for delimitation etc. is different;
3. The zoning lay out in the preparedness phase may be modified entirely according to the circumstances and the evolution of the accident;
4. And notably the different zones can evolve separately and, on the opposite, merge together at one time.

Collected criteria and analysis in this document **apply irrespective of the initiator of the emergency** (referred here as “a facility”) **and also irrespectively of the distance to the facility and type of area** (urban, inhabited, rural etc.).

## 2.3 References

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and based on the situation, but there is no pre-determined temporal or geographical sets of criteria to delineate this transition. At this stage, the difference between emergency and existing situations come from the way they are managed; there is no clear-cut boundary between the level of exposures themselves

### 3 The conceptual framework of the criteria associated with the implementation of protective measure during emergency exposure situations

The definition of dosimetric quantities, reference levels and commonly used dose concepts are presented in Appendix 1.

#### 3.1 Dosimetric criteria for introduction of protective measures

ICRP and IAEA recommend developing dosimetric criteria that will assist decision on whether and when to implement protective measures (and other response actions) from the protection strategy and ensure that doses are kept and optimized below the reference level..

Globally, these criteria are to be used as triggers, specific protective actions – individually or in combination – shall be implemented. The ICRP labelled these (formerly) as “*intervention level*” (§7.1.6 ICRP 2009) and the IAEA uses “*generic criteria to reduce the risk of stochastic effects*” (4.28, IAEA 2015).

The use of different dosimetric criteria enables to give consideration to the potential range of situations that can prevail in EmES and help to define specific goals in the protection strategy. Criteria can be focused on specific individuals, organs and specific risks (e.g. releases dominated by iodine). They can be used to assure that specific organ-absorbed-dose are kept below appropriate level (e.g. thyroid, foetus) and in addition, by using different time frames – day, week etc. – considerations can be given to the timing to implement the protective measures and to the development of the accident.

The IAEA has proposed a set of dosimetric criteria in IAEA, 2011<sup>7</sup> and later in IAEA, 2015<sup>8</sup> and these generic criteria are identical in both documents. The criteria are presented in Table 5 **Fehler! Verweisquelle konnte nicht gefunden werden..**

**Table 5: Generic dosimetric criteria for introduction of protection measures proposed by IAEA.**

| Generic Criteria  | Numerical value  | Example of protective measures  |
|---|--|---|
| <b>Projected dose that exceeds the following generic criteria: take urgent protective measures</b>                |  |   |
| $H_{\text{thyroid A}}$  | 50 mSv in the first week                               | Iodine thyroid blocking   |
| Effective dose: E   | 100 mSv in the first 7 days                            | Sheltering; evacuation; prevention of inadvertent ingestion; restrictions on food, milk and drinking water and restrictions on the food chain and water supply; restrictions on commodities other than food; contamination control; decontamination; registration; reassurance of the public            |
| Equivalent dose to the foetus: $H_{\text{foetus B}}$  | 100 mSv in the first 7 days                            |   |
| <b>Projected dose that exceeds the following generic criteria: take protective measures early in the response</b> |  |   |
| Effective dose: E   | 100 mSv in the first year                              | Temporary relocation; prevention of inadvertent ingestion; restrictions on food, milk and drinking water <sup>c</sup> and restrictions on the food chain and water supply; restrictions on commodities other than food; contamination control; decontamination; registration; reassurance of the public |
| Equivalent dose to the foetus: $H_{\text{foetus}}$  | 100 mSv for the full period of intra-utero development |   |
| Effective dose: E <sup>c</sup>  | 10 mSv in the first year                               | Restrict consumption, distribution and sale of  |

<sup>7</sup> Table 3 of IAEA 2011.

<sup>8</sup> Table II.2 – Table II-4 of IAEA 2015.

|   |  |  |
|---|--|--|
| Equivalent dose to the foetus: $H_{\text{foetus}}$  | 10 mSv for the full period of intra-utero development  | non-essential food <sup>9</sup> , milk and drinking water and restrict the use and distribution of other commodities. Replace essential food, milk and drinking water as soon as possible or relocate the people affected if replacements are not available. Estimate the doses of those who might have consumed food, milk and drinking water or used other commodities to determine whether this may have resulted in doses warranting medical attention |
| Effective dose: $E^D$   | 10 mSv in the first year                               | Restrict non-essential use. Use essential vehicles, equipment and other items from an affected area until replacements   |
| Equivalent dose to the foetus: $H_{\text{foetus}}$  | 10 mSv for the full period of intra-utero development  |  |
| Effective dose: $E^E$   | 1 mSv in the first year                                | Restrict non-essential international trade. Trade essential food and other commodities until replacements are available  |
| Equivalent dose to the foetus: $H_{\text{foetus}}$  | 1 mSv for the full period of intra-utero development   |  |
| <b><u>Dose that has been received</u> and that exceeds the following generic criteria: take longer term medical actions</b> |  |  |
| Effective dose: $E$   | 100 mSv in a month                                     | Health screening based on equivalent doses to specific radiosensitive organs (as a basis for longer term medical follow-up), registration, counselling   |
| Equivalent dose to the foetus: $H_{\text{foetus}}$  | 100 mSv for the full period of intra-utero development | Counselling to allow informed decisions to be made in individual circumstances   |

<sup>A</sup> Dose due to exposure to radioiodine.

<sup>B</sup> In the table,  $H_{\text{foetus}}$  is the equivalent dose to the foetus, derived as the sum of the dose from external exposure and the maximum committed equivalent dose to any organ of the embryo or foetus from intake to the embryo or foetus for different chemical compounds and different times relative to conception.

<sup>C</sup> Dose from ingestion of food, milk and drinking water and from the use of other commodities.

<sup>D</sup> Dose from the use of vehicles, equipment or other items from an affected area.

<sup>E</sup> Dose from food and other commodities traded internationally.

In general, generic criteria recommended by IAEA cover a combination of protective measures and sometimes only one protective measure (ITB). By using different time frame (e.g. week vs. month vs. year) the criteria enables making a distinction between protective measures that suffer no delay and protective measures that need to be taken early.

### 3.2 Operational criteria for introduction of protective measure

The abovementioned criteria in infra § 3.6 are expressed as projected or received dose and these are not measurable quantities in the field. Since most protective measures shall be taken without delay to be effective, the ICRP and the IAEA also introduced the concept of **operational criteria**; that is to say values of measurable or observable quantities (by an instrument or laboratory analysis) that act as a surrogate for the dosimetric criteria for introduction of protective measure. The ICRP uses the global term of “triggers” (§7.2.5, ICRP, 2009) and the IAEA make a distinction between “emergency action levels” (EALs) and “operational intervention levels” (OILs) (IAEA, 2015).

#### 3.2.1 Criteria based on facility’s condition (EALs)

The ICRP recommends to set up triggers based on plant condition and the IAEA introduced the specific terminology of Emergency Actions Levels (EALs) (IAEA, 2015), but the two concepts are identical. These

<sup>9</sup> The definition of “Non essential food” is not provided in IAEA document.



are criteria observed at the facility and used to detect, classify and declare the situation, its severity and the potential development. These are based on instrument reading (e.g. amount of water in reactor vessel, injection rate below a certain level etc.) and any other observable (e.g. failure of emergency power supply).

These criteria are to be used by emergency responders to decide the relevant technical protection measures (Appendix III, 2 [IAEA, 2015](#)).

### 3.2.2 Operational criteria

These operational criteria are considered from the radiation protection point of view, unlike the EALs for which criteria are equally operational but focussed on the facility. Operational criteria (trigger in ICRP terminology or OILs for the IAEA) are so observable in the field derived from a dosimetric criterion to avoid or minimize tissue reactions (e.g. **Fehler! Verweisquelle konnte nicht gefunden werden.**) or dosimetric criterion for introduction of protective measure to manage stochastic effects (e.g. **Fehler! Verweisquelle konnte nicht gefunden werden.**). Once the occurrence of an operational criterion has been identified in EmES, decision makers can be advised that the associated protective measures should be implemented.

There is no limitation to the unit in which operational criteria can be expressed; typically they are expressed in terms of dose rates or activity of radioactive material released, time integrated air concentrations, ground or surface contamination, or activity concentration of radionuclides in the environment, in food, in water etc.

The IAEA has recommended OILs from the dosimetric criteria for introduction of protective measures in 2011 (cf. pp. 35-49, Table 8 – Table 11, [IAEA, 2011](#)) and later in 2013 specifically for light water reactor accident (cf. Table 7 to Table 9, [IAEA, 2013](#)). The detailed calculation, hypotheses and models from IAEA's OILs in [IAEA, 2013](#) are described in [IAEA, 2017](#).

WHO and EC have also proposed some values. The ICRP does not explicitly recommend numerical value (and besides [ICRP, 2009](#) provides here reference to IAEA publications). All the operational criteria will be described in infra §4.

No trigger or OIL derived from dosimetric criteria to avoid/minimize tissue reactions has been found in the literature review.

## 3.3 Guidance values for emergency workers

Both the ICRP and the IAEA recommend guidance values in term of exposure for emergency workers acting at the concerned facility or its vicinity. These values are listed in Annexe 2. An observation here is that the numerical values are quite different with regard to the type of emergency action that has to be achieved by the emergency workers: the higher the potential benefits of the action is the higher the allowed exposure can be.

## 3.4 Elements of synthesis

The conceptual framework of criteria to be used in EmES proposed by international organizations is the following:

- **The reference level** is the level of dose above which it is inappropriate to plan to allow exposures to occur. It should be selected between 20 and 100 mSv and includes dose contributions from all exposure pathways and give consideration to sensitive groups and to the dose distribution. The concept of reference level and the band of value attached reach consensus.
- **Dosimetric criteria to assist decision** on whether/when to implement one or a combination of protective measure. Different dose concepts, dosimetric quantities and time frame can

be used to give consideration to the specific circumstances of the accident, individuals and organs etc.

- The abovementioned criteria are not measurable quantities. So **operational criteria** expressed in terms of parameters and measurable quantities should be derived by calculation and used as surrogate of the dosimetric criteria.

The infra § 4 presents, for each protective measure listed in infra § 2.2, the list of dosimetric and operational criteria that are recommended by international organizations (mostly ICRP and IAEA, but also other international organizations).

### 3.5 References

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- EAN, 2018. Conclusions and recommendations from the 17th EAN Workshop 'ALARA in Emergency Exposure Situations', Journal of Radiological Protection **38**, pp. 434-439, 2018.
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## 4 Focus on the operational criteria associated with specific protective measure

For each protective measure, all the dosimetric and operational criteria that have been identified from the literature review are listed and their values briefly described.

### 4.1 Evacuation and temporary relocation

#### 4.1.1 Criteria for evacuation

##### 4.1.1.1 Description and rationale

Evacuation is the rapid removal of people from an area to avoid or reduce short-term radiation exposure. Conducted as much as possible before a release occurs, evacuation can prevent exposure from all pathways and it is potentially the most efficient protective measure.

From the radiological point of view, it is generally preferred over sheltering (IAEA, 2015), repeated ITB intake (ICRP, 2009) and can be conducted even during release given its benefits (IAEA, 2015). It is recommended to combine systematically evacuation with ITB (if it can be done without delaying the evacuation) (IAEA, 2015).

##### 4.1.1.2 Criteria

The proposed criteria with regard to evacuation are presented in Table 6.

**Table 6: Criteria for evacuation**

| Criteria   | Numerical value   | Characteristics  |
|--|---|--|
| Effective dose (ICRP, 2005).   | 50 mSv in the first week.   | <ul style="list-style-type: none"> <li>• Avertable dose</li> <li>• Temporary evacuation</li> </ul> |
| Generic criteria: effective dose: E (IAEA, 2011; IAEA, 2015).                                  | 100 mSv in the first 7 days.  | Projected dose.  |
| Generic criteria: equivalent dose to the foetus: $H_{\text{foetus}}$ (IAEA, 2011; IAEA, 2015). | 100 mSv in the first 7 days   | Projected dose.  |
| OIL1: dose rate at 1 m above ground (IAEA, 2013).  | > 1000 $\mu\text{Sv/h}$ .   | Safely evacuate  |
| OIL1: ground dose rate <sup>A</sup> (IAEA, 2011).  | <ul style="list-style-type: none"> <li>• Gamma dose rate at 1 m from surface &gt; 1000 <math>\mu\text{Sv/h}</math>.</li> <li>• Direct beta surface contamination &gt; 2000 counts/s.</li> <li>• Direct alpha surface contamination &gt; 50 counts/s.</li> </ul> | Immediately evacuate   |

<sup>A</sup> Measuring ground dose rate in an elevated background is not trivial and IAEA also proposed a criterion about the assessment of the contamination monitoring instruments in II.20 et seq. IAEA 2011.

Only few criteria have been collected when it comes to evacuation. The dosimetric criteria are generally based on a projected effective dose; however ICRP and IAEA proposed different values: 50 mSv / first week vs. 100 mSv / first week. Operational criteria based on ground dose rate measurement are also proposed: OIL1 from IAEA 2013 specifically apply for accident from a light water reactor and OIL1 from IAEA, 2011 is generic. These two OILs are slightly different, because OIL1 from IAEA, 2011 gives more details to the different types of radionuclides.

It could be noted that evacuation is clearly linked with other protective measures such as ITB. There is the potential for interaction between the protective measures and their respective effect on the exposure. This kind of interaction between the protective measures does not appear explicitly in the collected criteria but will be considered in the overall protection strategy.

## 4.1.2 Temporary relocation

### 4.1.2.1 Description and rationale

The radioactive releases from the facility may involve levels of contamination that may impeach inhabitation as previously. This means that the population need to be relocated for a certain period of time. Evacuation and relocation both involve the displacement of population but they differ in their condition and timing: evacuation if an urgent removal to avoid significant exposure from a release when relocation aims to limit exposure on a longer term, generally from deposited radioactivity. Evacuated population can be directed to specific shelter and premises such as school, arena etc. when relocated population are to be directed to accommodation/dwellings suitable for a longer-term stay.

### 4.1.2.2 Criteria

The proposed criteria with regard to relocation are presented in Table 7.

**Table 7: Criteria for relocation**

| Criteria  | Numerical value   | Characteristics   |
|---|---|---|
| Effective dose (ICRP, 2005; ICRP, 2009).  | <ul style="list-style-type: none"> <li>• 1 Sv (total life a priori).</li> <li>• or 100 mSv in the first year.</li> </ul>  | <ul style="list-style-type: none"> <li>• Avertable dose.</li> <li>• Permanent relocation.</li> </ul>  |
| Generic criteria: effective dose: E (IAEA, 2011; IAEA, 2015)                                  | 100 mSv in the first year.  | <ul style="list-style-type: none"> <li>• Projected dose.</li> <li>• Temporary relocation</li> </ul>   |
| Generic criteria: equivalent dose to the foetus: $H_{\text{foetus}}$ (IAEA, 2011; IAEA, 2015) | 100 mSv for the full period of in-utero development   | <ul style="list-style-type: none"> <li>• Projected dose.</li> <li>• Temporary relocation.</li> </ul>  |
| OIL2: dose rate at 1 m above ground (IAEA, 2013).   | <ul style="list-style-type: none"> <li>• <math>\leq 10</math> days after shutdown: <math>&gt; 100 \mu\text{Sv/h}</math>.</li> <li>• <math>&gt; 10</math> days after shutdown: <math>&gt; 25 \mu\text{Sv/h}</math>.</li> </ul>   | <ul style="list-style-type: none"> <li>• Instruct the public to prepare to relocate.</li> <li>• Relocate within in a week (for values <math>&gt; 2</math> times OIL1, cf. Table 4).</li> <li>• Or within a month (for values <math>&gt; \text{OIL2}</math>).</li> </ul> |
| OIL7: radionuclides concentration in food, milk and drinking water (IAEA, 2013)               | <ul style="list-style-type: none"> <li>• <math>&gt; 1000 \text{ Bq/kg}</math> of <math>^{131}\text{I}</math>,</li> <li>• or <math>&gt; 200 \text{ Bq/kg}</math> of <math>^{137}\text{Cs}</math></li> </ul>  | <ul style="list-style-type: none"> <li>• Relocation if values are exceeded and if replacement of food, milk and drinking water is not possible</li> </ul>   |
| OIL2: ground dose rate (IAEA, 2011).  | <ul style="list-style-type: none"> <li>• Gamma dose rate at 1 m from surface <math>&gt; 100 \mu\text{Sv/h}</math>.</li> <li>• Direct beta surface contamination <math>&gt; 200 \text{ counts/s}</math>.</li> <li>• Direct alpha surface contamination <math>&gt; 10 \text{ counts/s}</math>.</li> </ul> | Temporary relocation.   |
| OIL5: concentration in food, milk and drinking water from laboratory analysis (IAEA, 2011)    | <ul style="list-style-type: none"> <li>• <math>100 \text{ Bq/kg}</math> gross beta,</li> <li>• or <math>5 \text{ Bq/kg}</math> gross alpha.</li> </ul>  | If $> \text{OIL5}$ : assess using OIL6  |
| OIL6: concentration in food, milk and drinking water from laboratory analysis (IAEA, 2011)    | Calculate $\sum_i C_{f,i}/\text{OIL6}_i$ where $C_{f,i}$ is the measured concentration of the radionuclides and $\text{OIL6}_i$ the values in Table 10 of IAEA 2011.  | Relocation if $> 1$ and if replacement of food, milk and drinking water is not possible.  |

## 4.2 Food, water and other commodities restriction

### 4.2.1 Food, water and other commodities restriction: criteria for local use<sup>10</sup>

The past nuclear accident showed that consumption of vegetables grown in the open (especially leafy ones), local products, including wild products (such as mushroom, berries, fish, game etc.), milk from animals eating on contaminated grass, and rainwater consumption can be larger contributors to exposure. Control of milk is very important because it is a significant part of the diet of children in many countries, as well as concentrating important radionuclides (radioiodine).

At a local scale (Table 8), international guidance has been found only in IAEA recommendations and is aiming to:

- Ban or to restrict consumption and distribution of local products, wild-grown products, milk, rainwater and animal feed (until comprehensive sampling and monitoring).
- To prevent contaminated food for both human and animal from entering the general distribution system.

**Table 8: Criteria for food and water restrictions at local scale.**

| Criteria  | Numerical value   | Characteristics  |
|---|---|--|
| Generic criteria: effective dose: E<br>(IAEA, 2011; IAEA, 2015).                                  | 100 mSv in the first 7 days.                            | <ul style="list-style-type: none"> <li>• Projected dose.</li> <li>• Urgent actions.</li> <li>• Restriction on food, milk and drinking water.</li> <li>• Restriction on the food chain.</li> <li>• Restriction on commodities other than food.</li> </ul>   |
| Generic criteria: equivalent dose to the foetus: $H_{\text{foetus}}$<br>(IAEA, 2011; IAEA, 2015). | 100 mSv in the first 7 days                             | <ul style="list-style-type: none"> <li>• Projected dose.</li> <li>• Urgent actions.</li> <li>• Restriction on food, milk and drinking water.</li> <li>• Restriction on the food chain.</li> <li>• Restriction on commodities other than food.</li> </ul>   |
| Generic criteria: effective dose: E<br>(IAEA, 2011; IAEA, 2015).                                  | 100 mSv in the first year.                              | <ul style="list-style-type: none"> <li>• Projected dose.</li> <li>• Early actions.</li> <li>• Restriction on food, milk and drinking water.</li> <li>• Restriction on the food chain.</li> <li>• Restriction on commodities other than food.</li> </ul>  |
| Generic criteria: equivalent dose to the foetus: $H_{\text{foetus}}$<br>(IAEA, 2011; IAEA, 2015). | 100 mSv for the full period of intra utero development. | <ul style="list-style-type: none"> <li>• Projected dose.</li> <li>• Early action.</li> <li>• Restriction on food, milk and drinking water.</li> <li>• Restriction on the food chain.</li> <li>• Restriction on commodities other than food.</li> </ul>   |
| Generic criteria: effective dose: E<br>(IAEA, 2015).  | 10 mSv in the first year.                               | <ul style="list-style-type: none"> <li>• Projected dose from ingestion of food and water and “other commodities”.</li> <li>• Restriction on non-essential food, milk and drinking water.</li> <li>• Restriction on the food chain.</li> <li>• Restriction on commodities other than food.</li> </ul> |
| Generic criteria: equivalent dose to the foetus: $H_{\text{foetus}}$<br>(IAEA, 2015).             | 10 mSv for the full period of intra utero development.  | <ul style="list-style-type: none"> <li>• Projected dose from ingestion of food and water and “other commodities”.</li> <li>• Restriction on non-essential food, milk and drinking water.</li> <li>• Restriction on the food chain.</li> <li>• Restriction on commodities other than food.</li> </ul> |

<sup>10</sup> To be used by non-evacuated people or people that return in affected areas.

|  |   |  |
|--|---|--|
| OIL1: dose rate at 1 m above ground (IAEA, 2013).  | > 1000 $\mu\text{Sv/h}$ .   | <ul style="list-style-type: none"> <li>• Stop consumption and distribution of all local products.</li> <li>• Stop distribution of commodities (until assessment).</li> </ul>                                 |
| OIL2: dose rate at 1 m above ground (IAEA, 2013).  | <ul style="list-style-type: none"> <li>• <math>\leq 10</math> days after shutdown: &gt; 100 <math>\mu\text{Sv/h}</math></li> <li>• &gt; 10 days after shutdown: &gt; 25 <math>\mu\text{Sv/h}</math>.</li> </ul>   | Stop consumption and distribution of local products.   |
| OIL3: dose rate at 1 m above ground (IAEA, 2013).  | > 1 $\mu\text{Sv/h}$ .  | <ul style="list-style-type: none"> <li>• Stop consumption and distribution of non-essential local products (until assessment).</li> <li>• Stop distribution of commodities (until assessment).</li> </ul>    |
| OIL7: radionuclides concentration in food, milk and drinking water (IAEA, 2013)            | <ul style="list-style-type: none"> <li>• &gt; 1000 Bq/kg of <math>^{131}\text{I}</math>, or &gt; 200 Bq/kg of <math>^{137}\text{Cs}</math></li> </ul>   | • Stop consumption and distribution of non-essential local products  |
| OIL1: ground dose rate (IAEA, 2011).   | <ul style="list-style-type: none"> <li>• Gamma dose rate at 1 m from surface &gt; 1000 <math>\mu\text{Sv/h}</math>.</li> <li>• Direct beta surface contamination &gt; 2000 counts/s.</li> <li>• Direct alpha surface contamination &gt; 50 counts/s.</li> </ul> | • Stop consumption local products  |
| OIL3: ground dose rate (IAEA, 2011).   | <ul style="list-style-type: none"> <li>• Gamma dose rate at 1 m from surface &gt; 1 <math>\mu\text{Sv/h}</math>.</li> <li>• Direct beta surface contamination &gt; 20 counts/s.</li> <li>• Direct alpha surface contamination &gt; 2 counts/s.</li> </ul>       | <ul style="list-style-type: none"> <li>• Stop consumption of non-essential local products</li> <li>• Screen products in the area out to at least 10 times the distance to which OIL3 is exceeded.</li> </ul> |
| OIL5: concentration in food, milk and drinking water from laboratory analysis (IAEA, 2011) | <ul style="list-style-type: none"> <li>• 100 Bq/kg gross beta,</li> <li>• or 5 Bq/kg gross alpha.</li> </ul>  | • If > OIL5: assess using OIL6   |
| OIL6: concentration in food, milk and drinking water from laboratory analysis (IAEA, 2011) | <ul style="list-style-type: none"> <li>• Calculate <math>\sum_i C_{f,i}/\text{OIL6}_i</math> where <math>C_{f,i}</math> is the measured concentration of the radionuclides and <math>\text{OIL6}_i</math> the values in Table 10 of IAEA 2011.</li> </ul>       | • Relocation if > 1 and if replacement of food, milk and drinking water is not possible.   |

The number of proposed criteria is quiet elevated when it comes to food restrictions on food, water and other commodities: up to 14 criteria can be considered.

When a projected dose is used, it could be 100 mSv or 10 mSv but different time scale are also proposed (it can be week, month or year). The longer the time frame and the less stringent the protective measures: urgent restriction vs. early restriction vs. restriction of non-essential food (however, no definition of “non-essential food” is provided).

In addition to the projected dose, IAEA also proposed operational criteria expressed as ground dose rate and radioactive concentrations in the food and water. The stringency of the protective measure is graded with regard to the absolute values of ground dose rate. Again, different OILs are provided depending on the publication (IAEA 2011 vs. IAEA 2013) and it is not straightforward to compare them.

IAEA's OILs expressed as activity concentration in food are provided, with different values depending on the publication.

In addition to food restriction, IAEA (IAEA, 2015) also introduces dosimetric criteria for the restriction of use of vehicles, equipment and "other items" (Table 9). In this case, a projected dose of 10 mSv is proposed.

**Table 9: Criteria for other commodities restriction at local scale**

| Criteria  | Numerical value  | Characteristics  |
|---|--|--|
| Generic criteria: effective dose: E<br>(IAEA, 2015).                                  | 10 mSv in the first year.                              | <ul style="list-style-type: none"> <li>Projected dose from the use of vehicle, equipment and other item only.</li> <li>Restriction on non-essential use until replacements are available.</li> </ul> |
| Generic criteria: equivalent dose to the foetus: $H_{\text{foetus}}$<br>(IAEA, 2015). | 10 mSv for the full period of intra utero development. | <ul style="list-style-type: none"> <li>Projected dose from the use of vehicle, equipment and other item only.</li> <li>Restriction on non-essential use until replacements are available.</li> </ul> |

#### 4.2.2 Food, water and other commodities restriction: criteria for international trade

International standards linked with the presence of radionuclides in food and commodities intended for international trade coming from an area affected by a nuclear accident are set up by different organizations and have been found in the IAEA documentation (IAEA 2015), the joint FAO/WHO *Codex Alimentarius* (Codex, 2005) and in the European Community regulation (Maximum Permitted Levels, known as MPLs, EC, 2016).

##### 4.2.2.1 Criteria recommended by the IAEA

The IAEA proposes two generic criteria using a 1mSv projected dose criterion (Table 10). The IAEA does not provide here operational criteria and the previous distinction between foods and "non-essential foods" that was used at local scale is no longer used.

**Table 10: IAEA criteria for foods and commodities restrictions for international trade.**

| Criteria  | Numerical value                                       | Characteristics  |
|---|---|--|
| Generic criteria: effective dose: E<br>(IAEA, 2011; IAEA, 2015).                                  | 1 mSv per year.                                       | <ul style="list-style-type: none"> <li>Projected dose from food and other commodities.</li> <li>Restriction on non-essential international trade, until replacements are available.</li> </ul> |
| Generic criteria: equivalent dose to the foetus: $H_{\text{foetus}}$<br>(IAEA, 2011; IAEA, 2015). | 1 mSv for the full period of intra utero development. | <ul style="list-style-type: none"> <li>Projected dose from food and other commodities.</li> <li>Restriction on non-essential international trade, until replacements are available.</li> </ul> |

##### 4.2.2.2 The FAO/WHO's Codex Alimentarius

The Codex Alimentarius contains "guidelines level" for "radionuclides in foods destined for human consumption and traded internationally following a nuclear or radiological emergency". The first Codex was developed just after the Chernobyl accident in 1986 at a time when no guidance on international trade in food and feed containing radionuclides was established. The values in in Table 11 come from the last version of the Codex (Codex, 2006).

The Codex guidelines levels are based on a dose criterion of 1 mSv in a year and the assumption that 10% of the diet is of imported food, all of which has contamination at the guideline level during the whole year. 20 radionuclides important for uptake into the food chain are screened, and they are divided into 4 groups according to their radio-toxicity. Two categories of foods are considered: “infant foods” (*i.e.* food intended for such use) and “foods other than infant foods”, giving a total of eight values levels. For foods that are eaten in small quantities such as caviar and truffles, etc. the guideline levels can be increased by a factor of 10. Finally, within each group, the level applies to the sum of the activity of the radionuclides in the group.

**Table 11: Codex Alimentarius guideline levels for radionuclides in food following a nuclear or radiological emergency.**

| Product                       | Representative radionuclides   | Guideline level (Bq/kg) |
|-------------------------------|--|-------------------------|
| Infant food                   | $^{238}\text{Pu}$ , $^{239}\text{Pu}$ , $^{240}\text{Pu}$ , $^{241}\text{Am}$  | 1                       |
|                               | $^{90}\text{Sr}$ , $^{106}\text{Ru}$ , $^{129}\text{I}$ , $^{131}\text{I}$ , $^{235}\text{U}$  | 100                     |
|                               | $^{35}\text{S}^{\text{A}}$ , $^{60}\text{Co}$ , $^{89}\text{Sr}$ , $^{103}\text{Ru}$ , $^{134}\text{Cs}$ , $^{137}\text{Cs}$ , $^{144}\text{Ce}$ , $^{192}\text{Ir}$ | 1000                    |
|                               | $^3\text{H}^{\text{B}}$ , $^{14}\text{C}$ , $^{99}\text{Tc}$   | 1000                    |
| Foods other than infant foods | $^{238}\text{Pu}$ , $^{239}\text{Pu}$ , $^{240}\text{Pu}$ , $^{241}\text{Am}$  | 10                      |
|                               | $^{90}\text{Sr}$ , $^{106}\text{Ru}$ , $^{129}\text{I}$ , $^{131}\text{I}$ , $^{235}\text{U}$  | 100                     |
|                               | $^{35}\text{S}^{\text{A}}$ , $^{60}\text{Co}$ , $^{89}\text{Sr}$ , $^{103}\text{Ru}$ , $^{134}\text{Cs}$ , $^{137}\text{Cs}$ , $^{144}\text{Ce}$ , $^{192}\text{Ir}$ | 1000                    |
|                               | $^3\text{H}^{\text{B}}$ , $^{14}\text{C}$ , $^{99}\text{Tc}$   | 10 000                  |

<sup>A</sup> Represents the value for organically bound sulphur.

<sup>B</sup> Represents the value for organically bound tritium.

#### 4.2.2.3 The European Maximum Permitted Levels (MPLs)

Following the Chernobyl nuclear accident, the Council of the European Communities has issued a number of Regulations concerning contamination levels in food that may apply for radiological accidents (EU, 1989a; EU, 1989b; EU, 1990). Then, following Fukushima accident, a new Directive has been issued (EU, 2016), superseding the previous Directives. This Directive is intended to ensure uniformity of standards across the European Union and would become legally binding if a nuclear accident occurs in the EU or anywhere in the world. The ‘maximum permitted levels’ (MPLs) in marketed foods (also known as Council Food Intervention Levels, CFILs) are specified. Provision has been made within the Regulations for the MPLs to be revised if they prove to be inappropriate under the specific circumstances of an accident (cf. § 10, EU, 2016).

The MPLs can be described as follow:

- Twenty MPLs are provided for human foods and three are for animal feeds.
- The MPLs for foods are divided into four groups of radionuclides (strontium, iodine, alpha-emitting radionuclides, and other radionuclides with relatively long half-lives) and five food categories (baby foods, dairy foods, other major foods, minor foods and liquid foods).
- The MPLs for animal feeds apply to radioisotopes of caesium only, and are specified for feed intended for animal divided in three categories.
- It is advocated that using these groups, the MPLs are kept to a manageable number, while, at the same time, important differences in the behaviour of radionuclides and people’s dietary habits are taken into account.
- Within each group, the level applies to the sum of the activity of the radionuclides in the group. The MPLs are intended to be applied independently: if the combined activity concentration level for one radionuclide group in one food category is exceeded, then restrictions on food apply.



The EC states that the validity of the MPLs starts “immediately” after an accident and their enforcement period as short as possible (Article 3, [EU, 2016](#)) and not exceeds a period of 3 months. In addition, the EC shall provide new MPLs a month after the date of application of the first MPLs, confirming or modifying the value in line with the nature and location of the accident and the evolution of the level of radioactive contamination effectively measured.

**Table 12: European Maximum Permitted Levels (MPLs) for foods and animal feeds.**

| Radionuclide   | Baby foods                               | Dairy produce <sup>D</sup> | Minor foods | Other | Liquid food <sup>E</sup> |
|--|--|----------------------------|-------------|-------|--------------------------|
| Isotopes of strontium ( <sup>89</sup> Sr, <sup>90</sup> Sr)                    | 75                                       | 125                        | 7 500       | 750   | 125                      |
| Isotopes of iodine ( <sup>131</sup> I)   | 150                                      | 500                        | 20 000      | 2 000 | 500                      |
| Alpha-emitting isotopes of plutonium and trans-plutonium elements <sup>A</sup> | 1  | 20                         | 800         | 80    | 20                       |
| All other radionuclides of half-life greater than 10 days <sup>B</sup>         | 400                                      | 1 000                      | 12 500      | 1 250 | 1 000                    |
| Animal feed intended for ...   | Intervention levels <sup>C</sup> (Bq/kg) |                            |             |       |                          |
| Pigs   | 1 250                                    |                            |             |       |                          |
| Poultry, lambs and calves  | 2 500                                    |                            |             |       |                          |
| Other  | 5 000                                    |                            |             |       |                          |

<sup>A</sup> This category includes <sup>238</sup>Pu and <sup>241</sup>Am.

<sup>B</sup> This category includes <sup>60</sup>Co, <sup>75</sup>Se, <sup>95</sup>Nb, <sup>95</sup>Zr, <sup>103</sup>Ru, <sup>106</sup>Ru, <sup>110m</sup>Ag, <sup>125</sup>Sb, <sup>134</sup>Cs, <sup>137</sup>Cs, <sup>141</sup>Ce, <sup>144</sup>Ce, <sup>169</sup>Yb, <sup>192</sup>Ir, <sup>226</sup>Ra and <sup>235</sup>U. <sup>14</sup>C, <sup>3</sup>H and <sup>40</sup>K are not included in this group.

<sup>C</sup> Intervention levels are for <sup>134</sup>Cs and <sup>137</sup>Cs only.

<sup>D</sup> Milk and cream only.

<sup>E</sup> Member States can choose to decide to apply Council Directive 2013/51 Euratom that apply to mineral waters and water, §6.

### 4.2.3 An insight on agricultural management options

The Handbook for Food Production Systems ([EURANOS, 2009](#)) is a result of a series of European initiatives that started in the early 1990s and integrated in the EURANOS project. The aim of the project was to increase the coherence of emergency preparedness and management in Europe, following the releases of radionuclides to the environment. The handbook focuses on food production systems and propose 58 “management options” to reduce or avert radioactive contamination of food and agricultural and forestry products before they reach the consumers. Notably 38 countermeasures are potentially applicable in the urgent and early phases of an accident.

It should be noted that the EURANOS Handbook does not propose criteria based on numerical criteria but rather introduce a list of factors to be considered: “*the implementation of these management options is not trivial and that a number of complex factors need to be taken into account in the decision-making process itself*” (p. 24, *ibid.*). The EURANOS Handbook proposes 30 factors total that can be divided in 9 main categories. As a result, the implementation of the agricultural protective measures is based on a global approach, taking into consideration a large array of factors and (especially non-quantitative factors) such as the local economy, societal and ethical concerns and disposal of wastes etc.

### 4.3 Other protective actions

#### 4.3.1 Sheltering

##### 4.3.1.1 Description and rationale

Sheltering is “the use of the structure of a building to reduce exposure from an airborne plume and deposited materials”. Still, the effectiveness of sheltering depends on the construction of the building being used and its ability to provide effective protection (and also the capacity to stay). Sheltering is not recommended for long time and recommendation varies: 1 day (IAEA, 2013) or 2 days (ICRP, 2009). Sheltering is *per se* a protective measure that cannot last long.

Sheltering is easy and relatively quick to implement and can be used prior to an evacuation. However for severe EmES, sheltering in a typical dwelling may not be sufficient, especially close to the facility and sheltering by itself is not regarded adequate protection against a release and it is recommended to undertake it in conjunction with ITB if possible. Sheltering can also be used if evacuation is delayed or not possible (*e.g.* flooding, lack of transport etc.)

Sheltering for long period may be implemented, for special facilities that need to be staffed (*e.g.* telecommunications centres, industrial facilities and plants that cannot be evacuated or easily shutdown until certain actions have been taken) and also premises where evacuation cannot be performed rapidly (*e.g.* hospitals and prisons). In this case, specific plans should be prepared to take into consideration reduction of staff and suitability of the functioning.

##### 4.3.1.2 Criteria

Proposed criteria with regard to sheltering are presented in Table 13.

**Table 13: Criteria for sheltering**

| Criteria   | Numerical value  | Characteristics   |
|--|--|---|
| Effective dose (ICRP, 2005).   | 10 mSv in 2 days.  | Avertable dose (for which the protective measure is generally optimised). |
| Generic criteria: effective dose: E (IAEA, 2011; IAEA, 2015)                           | 100 mSv in the first 7 days.   | Projected dose.   |
| Generic criteria: equivalent dose to the foetus: $H_{foetus}$ (IAEA, 2011; IAEA, 2015) | 100 mSv in the first 7 days.   | Projected dose.   |
| OIL1: ground dose rate <sup>A</sup> (IAEA, 2011).                                      | <ul style="list-style-type: none"> <li>• Gamma dose rate at 1 m from surface &gt; 1000 <math>\mu</math>Sv/h.</li> <li>• Direct beta surface contamination &gt; 2000 counts/s.</li> <li>• Direct alpha surface contamination &gt; 50 counts/s.</li> </ul> | Provide substantial shelter.  |

A few criteria specifically related to sheltering have been collected. The criteria use a dosimetric concept (effective dose) in general. However there are differences when it comes to the rationale (averted vs. projected), the numerical values and the time scale (10 mSv in 2 days does not compare with 100 mSv/in 7 days). The IAEA also proposes OILs in term of ground dose rate.

Sheltering illustrates that the protective measure is not necessary go/no-go action but can be more or less graded (no-sheltering vs. simple sheltering vs. substantial sheltering) and the interaction of

different protective action: sheltering plus ITB, sheltering vs. evacuation etc. These interactions do not appear a priori in the criteria (e.g. from **Fehler! Verweisquelle konnte nicht gefunden werden.**) but shall be considered in the overall protection strategy.

### 4.3.2 Iodine thyroid blocking

#### 4.3.2.1 Description and rationale

Large amount of radioactive iodine can be released when the fuel in the reactor core overheats. Iodine thyroid blocking (ITB, or 'iodine prophylaxis') is a protective measure based on the administration of a compound of stable iodine (usually potassium iodine KI, but other compounds may be used;  $KIO_3$  etc.) to prevent or reduce dose to the thyroid gland in the case of inhalation of radioiodine.

Optimal timing of administration starts 24 hours before, and up to 2 hours after the expected exposure, so it is recommended that provisions for pre-distribution of ITB should be considered at the planning stage. ITB intake later than 24 hours following the exposure may finally carry more harms than benefit (by prolonging the biological half-life of radioactive iodine in the thyroid).

The World Health Organization (WHO) recently stated<sup>11</sup> that a single KI administration is sufficient and will provide protection for 24 hours and that repeated ITB may be considered in the case of prolonged (> 24 hours) or repeated exposure, unavoidable ingestion of contaminated food and when evacuation is not feasible, (WHO, 2017). WHO recommendations on this topic are still debated by different experts. Indeed an overview of European regulations shows that there are significant differences between countries in the strategy adopted with ITB (ENCO, 2014).

#### 4.3.2.2 Criteria

Proposed criteria with regard to ITB are provided by ICRP (ICRP, 2005), IAEA (IAEA, 2005; IAEA, 2011; IAEA 2013; IAEA 2015) and the World Health Organization (WHO, 1999, WHO, 2017) and these are presented in Table 14.

**Table 14: Criteria for the iodine thyroid blocking intake**

| Criteria   | Numerical value   | Characteristics   |
|--|---|---|
| Equivalent dose to the thyroid (ICRP, 2005).   | 100 mSv.  | Avertable dose (if radioiodine is present).   |
| Generic criteria: equivalent dose to the thyroid: $H_{\text{thyroid}}$ (IAEA, 2011; IAEA, 2015). | 50 mSv in the first 7 days.   | Projected dose (only due to radioiodine).   |
| OIL1: ground dose rate at 1 m above ground (IAEA, 2013).   | > 1000 $\mu\text{Sv/h}$ .   | Instruct the public to take ITB.  |
| OIL4: dose rate at 10 cm from skin (IAEA, 2013).   | > 1 $\mu\text{Sv/h}$ .  | Instruct the public to take ITB if not already taken.   |
| OIL3: ground dose rate (IAEA, 2011).   | <ul style="list-style-type: none"> <li>• Gamma dose rate at 1 m from surface &gt; 1 <math>\mu\text{Sv/h}</math>.</li> <li>• Direct beta surface contamination &gt; 20 counts/s.</li> <li>• Direct alpha surface contamination &gt; 2 counts/s.</li> </ul> | Consider providing ITB for fresh fission products and for iodine contamination if replacement for essential local produce or milk is not immediately available. |

<sup>11</sup> Cf. [http://www.who.int/ionizing\\_radiation/pub\\_meet/tech\\_briefings/potassium\\_iodide/en](http://www.who.int/ionizing_radiation/pub_meet/tech_briefings/potassium_iodide/en)

|   |  |   |
|---|--|---|
| OIL5: concentration in food, milk and drinking water from laboratory analysis (IAEA, 2011).                                 | <ul style="list-style-type: none"> <li>• 100 Bq/kg gross beta,</li> <li>• or 5 Bq/kg gross alpha.</li> </ul>   | If value exceeded: assess using OIL6.   |
| OIL6: concentration in food, milk and drinking water from laboratory analysis (IAEA, 2011).                                 | <ul style="list-style-type: none"> <li>• Calculate <math>\sum_i C_{f,i}/OIL6_i</math>, where <math>C_{f,i}</math> is the measured concentration of the radionuclides and <math>OIL6_i</math> the values in Table 10 of IAEA, 2011.</li> </ul>              | Consider ITB if $> 1$ and if replacement of food, milk and drinking water is not possible.  |
| OIL8: Dose rate (above background) in contact with the skin in front of the thyroid 1 to 6 days after exposure (IAEA 2011). | <ul style="list-style-type: none"> <li>• for age <math>\leq 7</math> years: <math>&gt; 0.5 \mu\text{Sv/h}</math>.</li> <li>• for age <math>&gt; 7</math> years: <math>&gt; 2 \mu\text{Sv/h}</math>.</li> </ul>   | Instruct to take ITB if not already taken.  |
| Generic intervention level: equivalent dose to the thyroid $H_{\text{thyroid}}$ (IAEA, 2005).                               | 100 mGy.   | <ul style="list-style-type: none"> <li>• Avertable committed dose to the thyroid due to radioiodine.</li> <li>• The dose refers to the average (over suitably) chosen sample of the population (<math>\neq</math> most exposed).</li> <li>• For practical reason, one intervention level is recommended for all age group.</li> </ul> |
| Reference level for consideration in planning stable iodine prophylaxis (WHO, 1999, WHO, 2017).                             | <ul style="list-style-type: none"> <li>• Dose to neonates, infants, children, adolescents to 18 years and pregnant and lactating women (WHO, 1999): 10 mGy.</li> <li>• Dose to adults under 40: 50 mGy.</li> <li>• Adults over 40 years: 5 mGy.</li> </ul> | <ul style="list-style-type: none"> <li>• Avertable dose to the thyroid from inhalation (and ingestion of milk by infant if alternative supply cannot be made available).</li> <li>• Notes that the mass of intake vary with age.</li> </ul>   |

The criteria related to ITB are quite numerous: up to 12 different criteria have been identified. Generally, the dosimetric criterion is based on the dose to the thyroid (projected or averted) but there are differences between the organizations when it comes to the definition of the groups of individuals (which are age-based), the numerical values and the time frame. The literature review also identified a very specific operational criteria based on the dose rate in front of the thyroid in contact with the skin (hence after the radioactive intake), based on ground dose rate measurement and also activity concentration in food.

### 4.3.3 Medical consideration

#### 4.3.3.1 Description and rationale

Widespread contamination from releases may occur and lead to external exposure of the public from cloud or ground shine or to internal exposure from inhalation and ingestion. Triage centres are to be established rapidly outside the evacuated area to screen casualties and determine the level of medical consideration for those exposed.

Medical consideration can take very different shape:

- Immediate medical consultation, hospitalization and treatment (decorporation). These are recommended for the management of emergency workers;
- Decontamination, that is to say the removal of contamination by physical, chemical or biological process. Initial decontamination could be very simple: removing outer clothing and washing the bare skin (hands and face) has proven to be efficient;
- Limit the spread of contamination;
- Prevent inadvertent ingestion. Indeed, inadvertent ingestion of deposited material can be a significant source of exposure in the first days and recommendations to evacuees are to keep their hands away from their mouth, not to drink, eat and smoke until hands are washed, do not let children play on the ground and do not perform activity that could result in the creation

of dust etc. For example exceeding OIL4 (skin contamination, **Fehler! Verweisquelle konnte nicht gefunden werden.**) could indicate that the person has inhaled or inadvertently ingested enough radioactive material to warrant a medical consideration.

In addition to the medical treatment, medical advice and counselling to everyone who is examined (or request it), who has concerns about the impact of the emergency on their health etc. shall be provided. In the light of the Fukushima accident, registration for medical follow-up (targeting the overall well-being, not only the potential radiation effect) and epidemiological studies is also strongly recommended (SHAMISEN, 2017).

#### 4.3.3.2 Criteria

The collected criteria with regard to medical consideration are presented in Table 15.

**Table 15: Criteria for medical consideration**

| Criteria  | Numerical value                                      | Characteristics   |
|---|--|---|
| Generic criteria: effective dose: E<br>(IAEA, 2011; IAEA, 2015).                                  | 100 mSv in the first 7 days.                         | <ul style="list-style-type: none"> <li>● Projected dose.</li> <li>● Urgent actions:                             <ul style="list-style-type: none"> <li>○ Contamination control;</li> <li>○ Decontamination;</li> <li>○ Registration</li> </ul> </li> </ul>  |
| Generic criteria: equivalent dose to the foetus: $H_{\text{foetus}}$<br>(IAEA, 2011; IAEA, 2015). | 100 mSv in the first 7 days.                         | <ul style="list-style-type: none"> <li>● Projected dose.</li> <li>● Urgent actions:                             <ul style="list-style-type: none"> <li>○ Contamination control;</li> <li>○ Decontamination;</li> <li>○ Registration.</li> </ul> </li> </ul> |
| Generic criteria: effective dose: E<br>(IAEA, 2011; IAEA, 2015).                                  | 100 mSv in the first year.                           | <ul style="list-style-type: none"> <li>● Projected dose</li> <li>● Early actions:                             <ul style="list-style-type: none"> <li>○ Contamination control;</li> <li>○ Decontamination;</li> <li>○ Registration.</li> </ul> </li> </ul>   |
| Generic criteria: equivalent dose to the foetus: $H_{\text{foetus}}$<br>(IAEA, 2011; IAEA, 2015). | 100 mSv for the full period of in utero development  | <ul style="list-style-type: none"> <li>● Projected dose</li> <li>● Early actions:                             <ul style="list-style-type: none"> <li>○ Contamination control;</li> <li>○ Decontamination;</li> <li>○ Registration.</li> </ul> </li> </ul>   |
| Generic criteria: effective dose: E<br>(IAEA, 2011; IAEA, 2015).                                  | 100 mSv in a month.                                  | <ul style="list-style-type: none"> <li>● Dose received.</li> <li>○ Health screening/follow-up;</li> <li>○ Registration;</li> <li>○ Counselling.</li> </ul>  |
| Generic criteria: equivalent dose to the foetus: $H_{\text{foetus}}$<br>(IAEA, 2011; IAEA, 2015). | 100 mSv for the full period of in utero development. | <ul style="list-style-type: none"> <li>● Dose received.</li> <li>● Require:                             <ul style="list-style-type: none"> <li>○ Counselling.</li> </ul> </li> </ul>  |
| OIL1: dose rate at 1 m above ground (IAEA, 2013).   | > 1000 $\mu\text{Sv/h}$ .                            | <ul style="list-style-type: none"> <li>● Reduce inadvertent ingestion</li> <li>● Provide registration, monitoring, decontamination and medical screening</li> <li>● Consider follow-up.</li> </ul>  |

|   |  |   |
|---|--|---|
| OIL4: dose rate at 10 cm from skin (IAEA, 2013).  | 1 $\mu\text{Sv/h}$   | <ul style="list-style-type: none"> <li>• Reduce inadvertent ingestion (all case)</li> <li>• If OIL4 exceeded:                             <ul style="list-style-type: none"> <li>○ decontamination.</li> <li>○ medical screening/follow-up.</li> <li>○ medical counselling.</li> </ul> </li> </ul>                    |
| OIL8: Dose rate (above background) in contact with the skin in front of the thyroid 1 to 6 days after exposure (IAEA 2013). | <ul style="list-style-type: none"> <li>• for age <math>\leq 7</math> years: 0.5 <math>\mu\text{Sv/h}</math>.</li> <li>• for age <math>&gt; 7</math> years; 2 <math>\mu\text{Sv/h}</math>.</li> </ul>   | <ul style="list-style-type: none"> <li>• Prevent inadvertent ingestion (all case)</li> <li>• If OIL8 exceeded:                             <ul style="list-style-type: none"> <li>○ medical screening/follow-up.</li> </ul> </li> </ul>   |
| OIL1: ground dose rate (IAEA, 2011).  | <ul style="list-style-type: none"> <li>• Gamma dose rate at 1 m from surface <math>&gt; 1000 \mu\text{Sv/h}</math>.</li> <li>• Direct beta surface contamination <math>&gt; 2000 \text{ counts/s}</math>.</li> <li>• Direct alpha surface contamination <math>&gt; 50 \text{ counts/s}</math>.</li> </ul>  | <ul style="list-style-type: none"> <li>• Reduce inadvertent ingestion</li> <li>• Provide decontamination</li> <li>• Registration</li> <li>• Medical examination</li> </ul>  |
| OIL4: skin dose rate (IAEA, 2011).  | <ul style="list-style-type: none"> <li>• Gamma dose rate at 10 cm <math>&gt; 1 \mu\text{Sv/h}</math>.</li> <li>• Direct beta surface contamination <math>&gt; 1000 \text{ counts/s}</math>.</li> <li>• Direct alpha surface contamination <math>&gt; 50 \text{ counts/s}</math>.</li> </ul>  | <ul style="list-style-type: none"> <li>• Reduce inadvertent ingestion</li> <li>• Provide decontamination of the skin</li> <li>• Registration</li> <li>• Medical examination</li> </ul>  |
| OIL1: skin contamination (IAEA, 2005).  | <ul style="list-style-type: none"> <li>• Low toxicity beta/gamma contamination <math>&gt; 1.10^6 \text{ Bq/cm}^2</math>.</li> <li>• Beta/gamma contamination <math>&gt; 1.10^4 \text{ Bq/cm}^2</math>.</li> <li>• Beta/gamma dose rate <math>&gt; 2\text{-}3 \text{ Sv/h}</math>.</li> <li>• Alpha contamination <math>&gt; 1000 \text{ Bq/cm}^2</math>.</li> </ul>    | <ul style="list-style-type: none"> <li>• Require                             <ul style="list-style-type: none"> <li>○ Prevent inadvertent ingestion</li> <li>○ Limit spread of contamination</li> <li>○ Decontamination</li> <li>○ Medical screening/follow-up</li> <li>○ Medical counselling</li> </ul> </li> </ul>  |
| OIL2: skin contamination (IAEA, 2005).  | <ul style="list-style-type: none"> <li>• Low toxicity beta/gamma contamination <math>&gt; 1.10^5 \text{ Bq/cm}^2</math>.</li> <li>• Beta/gamma contamination <math>&gt; 1.10^3 \text{ Bq/cm}^2</math>.</li> <li>• Beta/gamma dose rate <math>&gt; 0.2\text{-}0.3 \text{ Sv/h}</math>.</li> <li>• Alpha contamination <math>&gt; 100 \text{ Bq/cm}^2</math>.</li> </ul> | <ul style="list-style-type: none"> <li>• Consider                             <ul style="list-style-type: none"> <li>○ Prevent inadvertent ingestion</li> <li>○ Limit spread of contamination</li> <li>○ Decontamination</li> <li>○ Medical screening/follow-up</li> <li>○ Medical counselling</li> </ul> </li> </ul> |
| OIL3: skin contamination (IAEA, 2005).  | <ul style="list-style-type: none"> <li>• Low toxicity beta/gamma contamination <math>&gt; 1.10^4 \text{ Bq/cm}^2</math>.</li> <li>• Beta/gamma contamination <math>&gt; 1.10^2 \text{ Bq/cm}^2</math>.</li> <li>• Beta/gamma dose rate <math>&lt; \text{detection level}</math>.</li> <li>• Alpha contamination <math>&gt; 10 \text{ Bq/cm}^2</math>.</li> </ul>       | <ul style="list-style-type: none"> <li>• Optional                             <ul style="list-style-type: none"> <li>○ Decontamination</li> <li>○ Medical counselling</li> </ul> </li> </ul>  |

Up to 14 different criteria that can relate with medical consideration have been identified in IAEA documentation. When it comes to the dosimetric criteria, a dose of 100 mSv (projected or received) is generally proposed as a criterion and different time scales are used (it could be week, month or year) to grade the level of medical consideration.

In addition, operation criteria have been derived and are expressed in measurable ground dose rate, skin dose rate and thyroid dose rate and are also recommended. However, different values can be found for skin contamination depending on the publication (OIL4, in IAEA 2013, OIL4 in IAEA 2011 and OIL1/2/3 in IAEA 2015) and their comparison is not straightforward.

## 4.4 References

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## 5 The French strategy for the protection of the population in a nuclear accident: regulation and elements of doctrine

### 5.1 The French protection strategy and associated criteria

For the sake of illustration of chapters 3 and 4, this chapter presents the criteria lay out in the French protection strategy for the management of an EmES. This information can be found in the National Response Plan (SGDSN, 2014), the French public health code (CSP, 2018, article R.1333-80) and official 'decision' from the safety nuclear authority (ASN, 2009).

France has been implementing stringent radiation protection and nuclear safety and security measures for many years. However, this does not mean that the country is exempt from having to be prepared to deal with an emergency. Changes in France, Europe and other parts of the globe have made it necessary for France to reconsider how it responds to nuclear and radiological emergencies. As the potential impact of a nuclear or radiological accident can affect a wide range of activities, the plan described herein is based on a cross-sector and interministerial approach to emergency response. This plan covers all nuclear or radiological emergencies, regardless of their cause, that may conceivably occur in mainland France and its overseas territories or abroad and which may severely disrupt the country's functioning (SGDSN, 2014).

The order to seek shelter may be given immediately in an emergency. Furthermore, the areas in which protective measures are to be implemented are defined using the response levels set out in ASN decision 2009-DC-0153, approved by the minister of health, for radiological emergencies. This decision calls for the prefect to be ready to order (SGDSN, 2014):

- an evacuation if public-exposure predictions exceed a whole-body effective dose of 50 mSv,
- shelter-in-place if public-exposure predictions exceed a wholebody effective dose of 10 mSv,
- stable-iodine prophylaxis if thyroid-exposure predictions exceed an equivalent dose to the thyroid of 50 mSv,
- food restrictions (consumption of local foodstuffs and trade) can be apply.

The decision to implement protective measures is taken based on an analysis of the risks and benefits for the population. This analysis is based on the natural hazards, local data (e.g. lay of the land, population density) and knowledge of the release, the weather conditions and the estimated doses for each factor. It may be conducted to compare the radiological risks of evacuating the public against those of having the public shelter in place.

This plan covers the emergency phase, its resolution and preparations for the post-accident phase.

### 5.2 Elements of policy for the management of the post-accident situation: the CODIRPA

In addition to the regulatory requirements, in 2005, a pluralistic steering committee gathering national and local administration and experts, representatives from the civil society, etc. was set up by the government to establish the framework, the preparation and the implementation of the steps necessary to deal with a post-accident situation and notably for *preparing the social and economic recovery of the affected area*" (§ C a., ASN, 2012). The Policy Elements for Post-Accident Management in the Event of Nuclear Accident doctrine (CODIRPA), published in 2012 by the French Nuclear Safety Authority (ASN, 2012) is the main output of the first phase of the CODIRPA.

**Discussions are on-going to be updated and revised by the CODIRPA with regard to the recent feedback from Fukushima accident and considering more severe scenarios. This presentation is based on the last published document (ASN, 2012).**



### 5.2.1 Different zones and different protective measures

Post-accident zoning is designed to provide a structuring framework within which actions to protect the population and manage contamination across the territories affected by the accident can be instituted.

The first post-accident zoning is established on the basis of a predictive model of future population exposure to the ambient radioactivity in the inhabited zones and contamination in the food chain, as a result of deposited radioactivity. This depends directly on the extent of the radioactive deposits, the persistence of which can vary substantially. The zoning is determined by the local authority. Once adopted, the first zoning is reported to the local agencies elected officials, through prefecture orders, in order to be applied administratively and operationally (ASN, 2012).

The public protection zone (ZPP) is defined as the area within which actions designed to reduce exposure to ambient radioactivity for residents of the said areas as low as reasonably achievable are warranted. This area is defined for the purpose of providing radiation protection for the population living in the most contaminated territories, based on dosimetric guidance values. The initial definition of the ZPP will be made on the basis of assessment of projected doses likely to be received during the month following the end of release, without taking into account the effectiveness of the contamination reduction actions implemented in the area. The ZPP is in other words delineated based on the most disadvantageous of the two following exposure indicators:

- the projected effective dose received during the first month following the end of release, regardless of pathways of exposure, including ingestion of contaminated local foodstuffs, the guidance value used being approximately 10 mSv over the first month;
- the projected thyroid equivalent dose received over the course of the first month following the end of release, regardless of pathways of exposure, in particular ingestion of contaminated local foodstuffs, the selected guidance value being approximately 50 mSv over the first month.

The dosimetric guidance values are not to be interpreted as thresholds or limits. The uncertainties as to dose estimates are such that other factors than dose should be considered. These other factors are connected with the conditions under which the actions envisioned are carried out in reality, and are best assessed at the local level. Contextual factors may also make it appropriate to use more restrictive or higher values, or even to refrain from implementing any protection actions at all. In the ZPP, movement is to remain free in principle, except in forests or other places where radioactive substances may have concentrated, in which case access restrictions may be declared.

In the ZPP, all foodstuffs produced or derived from fishing, hunting or gathering are banned from consumption and introduction on the market, regardless of their degree of contamination, for a period of at least one month. These foodstuffs are considered as waste as long as the ZPP is in effect. Where non-food products are concerned (commodities), the possibility for introducing them on the market should be considered on a case-by-case basis and combined with specific monitoring.

It may be that, across part of the ZPP, despite the ban on consumption of foodstuffs of local origin, exposure across the population may continue to be deemed too high, due to radioactivity deposited in the living environments. In this case, inhabitants must be displaced from the relevant part of the ZPP, probably for a longer duration, and a relocation perimeter (PE) must be established.

The relocation perimeter shall be delineated based on the results of an assessment showing the projected effective doses over the first month following release, not taking into account the contaminated foodstuffs of local origin ingested, comparing them to a guidance value on the order of 10 mSv over the first month.

For operational purposes, the CODIRPA states that indicators used to define the ZPP and the relocation perimeter can be set in a measurable quantities onsite, and propose for instance dose rate equivalent (mSv/h or µSv/h) or in surface activity (Bq/m<sup>2</sup>) looking at the radionuclides in the deposit (§ 2.1, *ibid.*).

The Territories Surveillance Zone (ZST) is defined as the “*zone encompassing all areas within which, in a given category of agricultural production likely to be grown and harvested within the month to follow, the European MPLs (§ 4.6, EU, 2016 see infra § 4.2) may be exceeded*” – even temporarily. These pre-established figures will apply in ‘reflex’ mode and will stay applicable for a duration that does not exceed 3 months<sup>12</sup>.

In the ZST, the protective measures are the immediate prohibition of trade and consumption of food (to be gradually lifted) and the implementation of clearance control strategy aiming at reducing progressively the size of the area.

The ZST is initially delineated on the basis of predictive assessments carried out via modelling, and, as early as possible, from radiological monitoring devices suited to each agricultural production sector that have to be installed to allow the re-introduction on the market of the products. So contrary to the ZPP where the ban shall be issued for a pre-set and renewable period, the implementation of controls is to be a priority in ZST. Moreover, unlike the ZPPs, aimed at protecting the populations,, the ZST is designed primarily to limit the consequences on trade activities, by guaranteeing that only compliant products enter the distribution channels.

### 5.2.2 Evolution of the zoning and protective measures

The CODIRPA provides numerical considerations to the evolution of the zoning and protective measures, justified by the increasing knowledge of the actual consequences of the accident (contamination measurement, monitoring etc.) and the evolution of the radiological situation (effect of the protective measures etc.). The criteria value are in fact the same as those described in infra § 5.2.1 but should be calculated for a year, not a month (hence for the 2<sup>nd</sup> to the 13<sup>th</sup> months after the accident).

### 5.3 Synthesis on the French Protection strategy and criteria

The criteria found in the French plan and CODIRPA are summarised in Table 16. The French public health code (CSP, 2018, article R.1333-80) has based its reference levels on those of the European basic safety standards (Euratom, 2013).

**Table 16: Criteria proposed by the French protection strategy**

| Type of criteria   | Number of criteria | Dosimetric quantities                           | Dose concepts | Pathways              | Time frame    | Protective measures                      |
|--|--------------------|---|---------------|-----------------------|---------------|--|
| Dosimetric criteria for introduction of protective measure | 1                  | • E = 50 mSv                                    | • Projected   | • External            |               | • Evacuation                             |
|  | 1                  | • E = 10 mSv                                    | • Projected   | • External            |               | • Sheltering                             |
|  | 1                  | • H <sub>thyroid</sub> = 50 mSv                 | • Projected   | • Internal            |               | • ITB                                    |
|  | 2                  | • E = 10 mSv<br>• H <sub>thyroid</sub> = 50 mSv | • Projected   | • External + internal | • First month | • ZPP’s protective measures <sup>A</sup> |

<sup>12</sup> Following radiological emergency, new regulations and numerical values have to be proposed by the European Commission within one month following the implementation of the initial ones, confirming or adapting the levels in accordance with the circumstances of the event.

|   |   |  |   |  |   |  |
|---|---|--|---|--|---|--|
| <b>Radiological criteria for introduction of protective measure</b> | 1   | <ul style="list-style-type: none"> <li>Level &gt; Euratom MPLs (EU, 2016)</li> </ul> | <ul style="list-style-type: none"> <li>Projected or measured</li> </ul> | <ul style="list-style-type: none"> <li>Contamination level in foodstuff</li> </ul> | <ul style="list-style-type: none"> <li>And 2<sup>nd</sup>-13<sup>th</sup> months</li> <li>For the next month</li> </ul> | <ul style="list-style-type: none"> <li>Relocation</li> <li>ZST's protective measures <sup>B</sup></li> </ul> |
|   | <ul style="list-style-type: none"> <li>"Indicators used to define the ZPP and the relocation perimeter can be stated in magnitudes that are measurable onsite"</li> </ul> |  |   |  |   |  |

<sup>A</sup> ZPP: food bans (trade and consumption), limitation of use of commodities, radiological measurements, health surveillance, decontamination actions and specific wastes management. Consider evacuation, relocation and ITB if the specific intervention level is met.

<sup>B</sup> ZST: food restrictions (trade: waiting for measurement; consumption: not recommended) and clearance control strategy.

The framework found in the French protection strategy is in line with the framework recommended by international and described in infra § 1. The protective measures are associated with dosimetric criteria, expressed in mSv and in line with values recommended at international level. Measurable quantities (operational criteria) are also set up. Two protective measures are particularly at stake: evacuation and food ban and restriction.

A key element from the French Strategy is that, besides the regulation, a doctrine has been elaborated from a pluralistic committee and is explicitly intended for the preparation and the implementation of the steps necessary to deal with the post-accident situation and recovery.

## 5.4 References

ASN, 2009, Décision n° 2009-DC-0153 de l'Autorité de sûreté nucléaire du 18 août 2009 relative aux niveaux d'intervention en situation d'urgence radiologique, ASN, 2009.

ASN, 2012, Eléments de doctrine pour la gestion post accidentelle d'un accident nucléaire, a document established by the CODIRPA, final version, 5 October 2012.

CSP, 2018, Article R1333-80 du Code de la Santé Publique <https://www.legifrance.gouv.fr/affichCodeArticle.do?cidTexte=LEGITEXT000006072665&idArticle=LEGIARTI000006910215&dateTexte=&categorieLien=cid>

Euratom, 2013. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom

EU, 2016. Council Regulation (Euratom) No 2016/52 laying down maximum permitted levels of radioactive contamination of food and feed following a nuclear accident or any other case of radiological emergency and repealing Regulation (Euratom) No 3395/87 and Commission Regulation (Euratom) No 994/89 and (Euratom) No. 770/90 Off. J. Eur. Commun. L13/22, EU 2016.

SGDSN, 2014. Plan National de Réponse - Accident Nucléaire ou Radiologique majeur, 200/SGDSN/PSE/PSN, February 2014 edition.

## Annexe 1. Definitions of dosimetric quantities and dose concepts

## Dosimetric quantities

Specific dosimetric quantities are used for the assessment of doses in radiation protection: *absorbed dose* ( $AD_T$ , in Gray), *equivalent dose*<sup>13</sup> ( $H_T$ , in Sv) and *effective dose* ( $E$ , in Sv) (ICRP, 1991a). Absorbed dose is a physical quantity (J/kg), so to allow consideration to the radiological risk, the absorbed dose to a given organ or tissue  $T$  is first corrected with radiation weighting factors  $w_R$  (that express the biological effectiveness of radiations) to obtain the weighted average of the equivalent dose quantity  $H_T$  to the irradiated tissue. The result is further corrected for the tissues or organs being irradiated using tissue ratio  $w_T$  (that express the varying sensitivity of organs and tissues to ionising radiation) to calculate the effective dose quantity  $E$ . The sum of effective doses to all organs and tissues of the body represents the effective dose for the whole body.

$$E = \sum_T \sum_R w_T \cdot w_R \cdot AD_{R,T}$$

But because the equivalent dose and effective dose are not measurable quantities, operational quantities are used for the assessment of  $H_T$  and  $E$ : the ambient dose equivalent  $H^*(d)$  is the dose equivalent produced by the corresponding field of radiation in a standardized sphere at a depth  $d$  and the personal dose equivalent  $H_p(d)$  is the dose equivalent in tissue below a specified point on the body at an appropriate depth  $d$ . These quantities are measurable and used for the practical evaluation of dose.

The usual dosimetric quantities are listed in **Fehler! Verweisquelle konnte nicht gefunden werden..**

**Table 1. Dosimetric quantities used in radiation protection.**

| Dosimetric quantity                    | Symbol                | Purpose   |
|--|-----------------------|---|
| Weighted absorbed dose                 | $AD_T$ , Gy (in J/kg) | For evaluating deterministic effects induced as a result of exposure of an organ or tissue        |
| Equivalent dose                        | $H_T$ , Sv (in J/kg)  | For evaluating stochastic effects induced as a result of exposure of an organ or tissue           |
| Effective dose                         | $E$ , Sv              | For evaluating detriment related to the occurrence of stochastic effects in an exposed population |
| Personal dose <sup>14</sup> equivalent | $H_p(d)$              | For monitoring external exposure of an individual   |
| Ambient dose <sup>14</sup> equivalent  | $H^*(d)$              | For monitoring a radiation field at the site of an emergency                                      |

At high doses radiation exposures may cause deterministic effects (to be referred now as “tissue reactions”<sup>14</sup>). Such clinically observable damage occurs above doses threshold, specific to the organ and the tissue. The extent of damage depends upon the absorbed dose (and dose rate) as well as radiation quality and the sensitivity of the tissue. In this case, ICRP does not recommend using  $H_T$  or  $E$  but absorbed dose (ICRP, 2007).

<sup>13</sup> ICRP is currently proposing to abandon the concept of equivalent dose, except for specific exposure situations.

<sup>14</sup> ICRP Statement on Tissue Reaction, April 2011, <http://www.icrp.org/docs/2011%20Seoul.pdf> IAEA used and continue to use the wording of “deterministic effect”. To be in line with IAEA document that have been analysed, we keep the wording “deterministic effect”.

## Dose concepts in the case of emergency exposure situations

There is consensus in the literature review to distinguish:

- the *projected dose* as the overall exposure projected to occur as a result of an EmES (no protection strategy is applied);
- the *residual dose* as the dose that would result when a given protection strategy is implemented;
- and each protective measure will avert a certain exposure and this is referred to as *averted dose*.

Projected, residual and averted dose can be expressed as absorbed dose (Gy), equivalent dose (mSv) or effective dose (mSv)..

## Reference level

The concept of ‘reference level’ has been introduced by ICRP in Publication 103 (ICRP, 2007). It is defined as:

*“The level of dose or risk, above which it is judged to be inappropriate to plan to allow exposures to occur and for which therefore protective actions should be planned and optimised. The chosen value for a reference level will depend upon the prevailing circumstances of the exposure situation under consideration” (§ 234, ICRP, 2007).*

The current system of radiological protection recommends the use reference level in the case of EmES (and not dose limit). The broad idea is that exposures should be reduced below the selected reference level and reduced as low as reasonably achievable (ALARA) through the implementation of the protection strategy.

The ICRP recommends selecting a **reference level between 20 mSv and 100 mSv** effective dose for EmES (ICRP, 2007). The reference level can be “*incurred either acutely or in a year*” and shall consider all exposure pathways (§ b, ICRP, 2009). Consideration shall be given to the distribution of exposure and also to different population groups; illustrated by a representative person (§ 40 *et seq. ibid.*) and especially groups at greatest risk such as pregnant women, children/new-born etc. and a specific reference level can be selected for each of them.

The concept of reference level and the band of value attached (20-100 mSv) have been adopted by the IAEA (IAEA, 2015) and the European Basic Safety Standard (BSS) (Annexe 2, Euratom, 2013<sup>15</sup>). But despite this common conceptual framework, the implementation of the ICRP recommendations has proven to be challenging for national arrangements and current practices show large variability in the interpretation and the use of reference levels (NEA, 2013; EAN, 2018).

The ICRP is currently in the process of reviewing Publication 109 focused on EmES, merging it with Publication 111<sup>16</sup> and taking into account the experience from Fukushima accident (where the application of the different dose concept and notably reference level proved to be difficult in practice, ICRP, 2016).

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<sup>15</sup> Note that the EU-BSS does not go into further details and values with regard to EmES: it requires the Members States to elaborate their protection strategy and the associated criteria.

<sup>16</sup> Application of the Commission's Recommendations to the Protection of People Living in Long-term Contaminated Areas After a Nuclear Accident or a Radiation Emergency

## Why other criteria are needed to assist decisions?

Both the ICRP (ICRP, 1991a; ICRP, 2005; ICRP, 2009) and the IAEA (IAEA, 2011; IAEA, 2015) clearly state that **the use of solely reference level is not sufficient to develop an optimized protection strategy and that specific criteria to assist decision shall be set.**

From the literature review, three different types of criteria can be distinguished:

1. *Dosimetric criteria to avoid or minimize tissue reactions* and for which any protective measures and other responses actions are expected to be taken under any circumstances;
2. *Dosimetric criteria for introduction of protective measure* (or a combination of protective measures) within the protection strategy;
3. *Operational criteria for introduction of protective measures* (or a combination of protective measures) based on *measurable quantities*.

These criteria and their difference will be developed in the following paragraphs.

### Dosimetric criteria to avoid or minimize tissue reactions

In EmES, it is possible that some individuals may be exposed to elevated level of exposure so high that, without medical treatment, this will result in deterministic injuries. Both the ICRP (§ 7.1.2 ICRP, 2009) and the IAEA (§ 3.2 IAEA, 2015) recommend to set criteria for taking protective measures under any circumstances to avoid or minimize severe deterministic effects.

The criteria and associated protective measures recommended by IAEA are presented in **Fehler! Verweisquelle konnte nicht gefunden werden.** (IAEA, 2015). The ICRP does not explicitly recommend numerical values in this case.

**Table 2. Dosimetric criteria to avoid or minimize tissue reactions proposed by IAEA.**

| External acute exposure (< 10 hours)                                   |  | Example of protective measures  |
|--|--|---|
| AD <sub>red marrow</sub>   | 1 Gy   | If this dose is <b>projected</b> : <ul style="list-style-type: none"> <li>• Take precautionary urgent protective measure immediately (even under difficult conditions) to keep doses below the generic criteria</li> <li>• Provide public information and warnings</li> <li>• Carry out urgent decontamination</li> </ul>   |
| AD <sub>foetus</sub>   | 0.1 Gy   |   |
| AD <sub>tissue</sub> <sup>A</sup>                                      | 25 Gy at 0.5 cm  |   |
| AD <sub>skin</sub> <sup>B</sup>  | 10 Gy to 100 cm <sup>2</sup>   |   |
| Internal exposure from acute intake ( $\Delta = 30$ days) <sup>C</sup> |  |   |
| AD( $\Delta$ ) <sub>red marrow</sub>                                   | <ul style="list-style-type: none"> <li>• 2 Gy for radionuclides with <math>Z \leq 89</math><sup>D</sup></li> <li>• 0.2 Gy for radionuclides with <math>Z \geq 90</math><sup>D</sup></li> </ul> | If this dose <b>has been received</b> : <ul style="list-style-type: none"> <li>• Perform immediate medical examination, consultation and indicated medical treatment</li> <li>• Carry out contamination control</li> <li>• Carry out immediate de-corporation (if applicable)</li> <li>• Carry out registration for long term health monitoring (medical follow-up)</li> <li>• Provide comprehensive psychological counselling</li> </ul> |
| AD( $\Delta$ ) <sub>thyroid</sub>                                      | 2 Gy   |   |
| AD( $\Delta$ ) <sub>lung</sub> <sup>E</sup>                            | 30 Gy  |   |
| AD( $\Delta$ ) <sub>colon</sub>  | 20 Gy  |   |
| AD( $\Delta'$ ) <sub>foetus</sub> <sup>F</sup>                         | 0.1 Gy   |   |

<sup>A</sup> Dose delivered to 100 cm<sup>2</sup> at a depth of 0.5 cm under the body surface in tissue due to close contact with a radioactive source.

<sup>B</sup> Dose to the 100 cm<sup>2</sup> dermis.

<sup>C</sup> AD( $\Delta$ ) is the weighted absorbed dose delivered over the period of time  $\Delta$  by the intake that will result in a severe deterministic effect in 5% of exposed individuals.

<sup>D</sup> Different generic criteria are used to take into account the significant difference in weighted absorbed dose from exposure at the intake threshold for these two groups of radionuclides.

<sup>E</sup> For the purposes of these generic criteria, 'lung' means the alveolar-interstitial region of the respiratory tract.

<sup>F</sup> For this particular case,  $\Delta'$  means the period of in utero development.

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The numerical figures in **Fehler! Verweisquelle konnte nicht gefunden werden.** are expressed in relative biological effectiveness absorbed dose to organ (Gy) and established at “*levels of dose that are approaching the thresholds for [severe tissue reactions]*” (§ 3.1, [IAEA, 2015](#)). A distinction is made between external exposure and exposition from the intake of radioactive material. For internal exposure, the threshold depends on many factors, such as the activity of the intake, radionuclides and half-life, etc. and the values have been established by IAEA considering a 30 days committed weighted dose.





## D 9.21 Appendix 2.

# Behaviour of radionuclides in Spanish agricultural systems and response to recovery actions

## Final

### Version 1.0

**CONFIDENCE-WP4.** Transition to long-term recovery, involving stakeholders in decision-making processes

**Document Number: CONFIDENCE-WP4/T4.1.2-R02**

García-Puerta B.; Trueba, C.; Montero, M. (CIEMAT)

## Document Information

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## APPENDIX 2. BEHAVIOUR OF RADIONUCLIDES IN SPANISH AGRICULTURAL SYSTEMS AND RESPONSE TO RECOVERY ACTIONS

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## 1 Introduction

Agricultural systems affected by a radioactive deposit due to a release from a radiological or nuclear accident are complex and not homogeneous environments. Even inside of a particular region, there are multiple variables to be considered, which are inherently related to the affected farming ecosystem, such as: climate, soil type and its properties, kinds of crops, time of the year when the radionuclides are deposited, etc. Since the deposit occurs and during the transition phase the radionuclides can migrate to lower soil horizons, be transported due to runoff and erosion [1]; they also can be uptaken by the crop roots [1]. The quantity of the bioavailable fraction of the deposited radionuclides depends on the soil and its properties, which makes possible that bioavailability in soil itself, and then, from the soil to the plants in the root uptake process [1]. Eventually, due to this root uptake, the radionuclides enter in the food chain. Beside the public-health risk derived from the consumption of the cultivated products that are contaminated (via food-chain), undesirable effects are caused in the environment and in the socioeconomic structure of the affected area.

The assessment of the issues derived from a situation like that, in such a heterogeneous environment, where different physicochemical mechanisms are involved, requires having a global view and implies to take into account as much related factors as possible. In that sense, the more local and accurate the considered influencing parameter values are, the more precise the soil-to-plant transfer, and the better characterised the radiological vulnerability of the agricultural system will be [2]; therefore, more realistic the modelled scenario will be, and then, it will have less degree of uncertainties. With this information, radiological vulnerability maps can be elaborated. These maps represent the capability of the agricultural systems to transfer radionuclides to the food chain, in case of they are affected by a radioactive deposit [2].

Knowing the probability of a deposition occurrence, in combination with the radiological vulnerability, radiological risk maps can be built. These risk maps are useful to define remediation strategies beforehand. The potential foodstuff and feedstuff restriction areas can also be determined in advance. Thus, remediation and restriction measures can be planned to minimise and mitigate the potential radiological effects, not only in health population, but also in the environment and in the socioeconomic structure. Thus, radiological risk maps are a tool to be incorporated in the emergency preparedness plans [2] and [3].

The success of the implemented strategies (remediation and/or restriction ones) is in the information used by the decision-makers, thus, it is essential to improve the tools they work with. The aim of this work is to provide more resources for an effective decision-making process to minimize the consequences in the food-chain derived from a radioactive release.

The methodology presented here is part of a doctoral thesis carried out at CIEMAT titled: "Geographic Information Technologies Applied to Research the Radiological Vulnerability of the Agricultural Systems in the Iberian Peninsula". It is also part of the research performed in the frame of ANURE Project: "Assessment of the Nuclear Risk in Europe - A Case Study in the Almaraz Nuclear Power Plant (Spain)", developed between JRC Ispra and CIEMAT [4].

## 2 Evaluation of the considered parameters

The behaviour of the deposited radionuclides on soil depends, on one hand, on the sort of radionuclides released and, on the other hand, on the soil type where it is deposited, as well as its properties. In this case, the considered radionuclide is  $^{137}\text{Cs}$  and its entry in the food chain through the rainfed cereals.

### 2.1 Soil parameters

In this point the main factors that influence the  $^{137}\text{Cs}$  behaviour in soil are described. It must be pointed out that once the radionuclide is incorporated in soil, it is not considered the involvement of runoff processes or resuspension phenomena [1].

Soil infiltration capacity, referred to the water penetration speed in soil, affects the  $^{137}\text{Cs}$  availability in soils. Texture and soil structure are key in that process: in a coarse texture, as well as in a soil with a strong and stable structure, the infiltration capacity is higher than in a soil with a fine texture or in a soil without structure, because of the less active particle surface and its higher porosity. Thus, the coarser the texture, and/or the stronger and stable the structure, the higher the soil infiltration capacity, which encourages water that contains  $^{137}\text{Cs}$ , to penetrate more deeply, out of the root zone, resulting in less uptake of  $^{137}\text{Cs}$  by crops [1].

Water storage capacity indicates how easily soils can retain water in its pores (once gravitational water has migrated) and, beside porosity, it is related to field capacity and soil permeability. The soil parameters that control these factors are soil texture and structure, as well as the slope which controls the runoff. In contrast to soil infiltration capacity, the coarser the texture, and/or the stronger the structure, the lower the soil water storage capacity, and the more proportion of the  $^{137}\text{Cs}$  is available, which means that the more  $^{137}\text{Cs}$  could be uptake by plants [1].

Cation exchange capacity (CIC) also influences on the way that  $^{137}\text{Cs}$  is retained in soil and depends on clay and organic matter content. Regarding to clay, not only the quantity, but also the type of clay in soil is important to define this radionuclide's behaviour, since clay acts as a K reservoir, which is more notably regarding to non-expansive ones like illites. It is important to take into account that due to the physicochemical similarities between K and Cs, both are competitors at incorporating into the soil structure. Their entry in soil structure implies reducing these elements' bioavailability; thus, the higher the proportions of clay, the less  $^{137}\text{Cs}$  will be absorbed by crops. In respect of organic matter content, high proportions of it means lower CIC, therefore  $^{137}\text{Cs}$  will be more bioavailable to be absorbed by crops. In any case, sandy soils are the ones which have the less CIC values, thus there is more bioavailable  $^{137}\text{Cs}$  in this kind of soil than in any other [1].

K nutrient status. Due to the similarity in the physicochemical properties between radiocaesium and potassium previously mentioned, high concentrations of K reduces the  $^{137}\text{Cs}$  uptake by crops, because although both are competitors [5], plants tend to uptake the K molecule because of its smaller size in comparison with the Cs molecule.

#### 2.1.1 Identification of the soil properties in the Spanish Iberian Peninsula

Firstly, it is necessary to identify the geographical distribution for the different soil types along the Spanish Iberian Peninsula, which is the chosen area to apply the developed methodology. In order to identify the Spanish soil, the European soil map has been used [6]. These are the reasons why this map has been chosen:

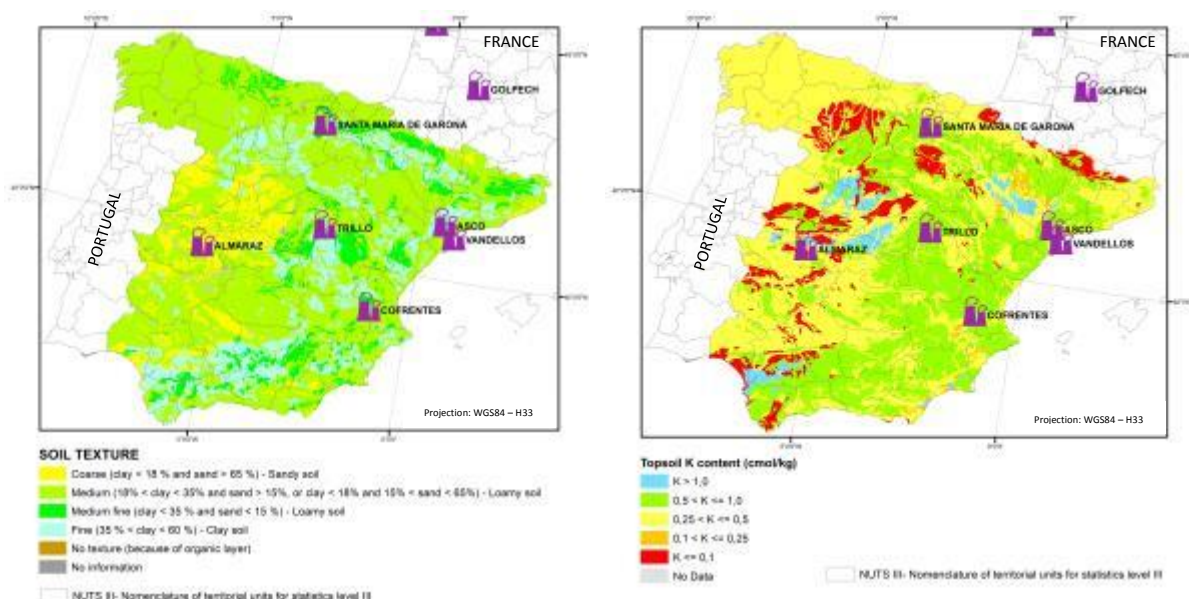
- The scale of the map (1:1000000) is an appropriate one to represent soils at the country level.
- The mapped soils are linked to a large database in which soil properties are given for each fraction of the represented territory.
- Different soil classifications are used: from the FAO 1974 (modified in 1985), to the WRB [6].
- It is a continuous map for whole Europe, in which soils from every European country is represented, so this map can be used to elaborate the radiological vulnerability map.

Thus, by using this map and its linked database, it is possible to obtain a geographical distribution of the different soil types and the soil properties.

Besides the European soils map, a Spanish soil profile database has been used in order to complete the soil properties [5]. In order to have a more local specificity for the soil representation, soil groups have been made considering the soil type from the European soil map and the bed rock [1]. This grouping has been done in the European soil map and the Spanish soil database, so both can be linked. This is intended to complete information of the map with the specific Spanish soil data and to mapping the soil types.

According to the previous considerations, the key parameters that control the  $^{137}\text{Cs}$  soil-to-plant transfer are K and clay content and soil texture [7]. Regarding to the K and clay content, the values taken into consideration are the ones which correspond to the mean topsoil value for each soil group [1]; those are taken from the Spanish soil database [5]. In this case, topsoil values are taken into account because is where the root zone is located. For the soil texture, the one indicated in the European soil map has been considered. It is important to say that, although organic matter is also a relevant parameter to be considered, Spanish soils are basically mineral soils that have, overall, low organic matter content.

Figure 1 (a) shows the texture soil map [6], where the organic soils are also mapped (located in the Northwest), and (b) the K content in the Spanish soils [5], for their topsoil.



**Figure 1. a)** Spanish topsoil texture and the location of the organic topsoils (Source: European soil map [6]).  
**b)** Mean topsoil K content (Source: Spanish soil profiles database [5]).

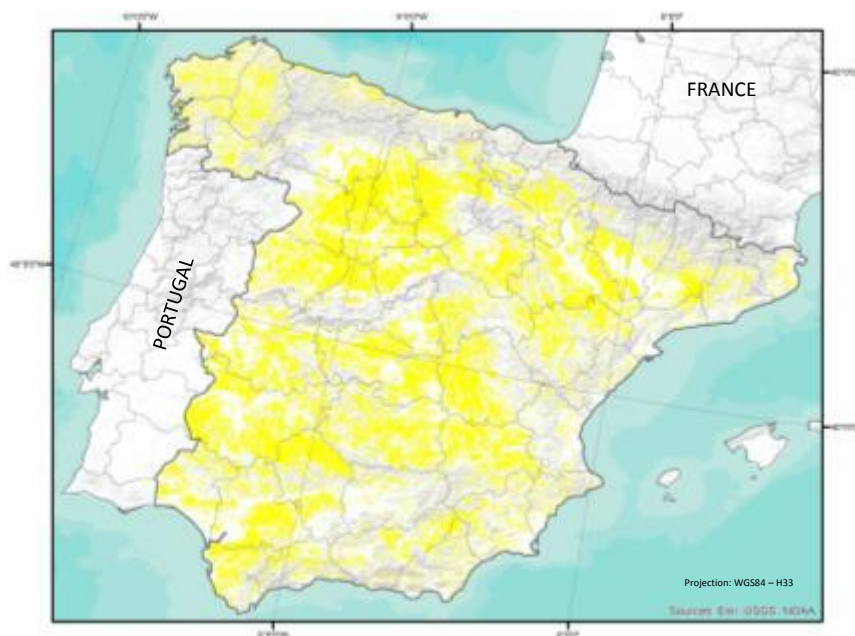
## 2.2 Identification of the cultivated crops in the Spanish Iberian Peninsula

To consider the exposure risk through the food-chain it is necessary to know the potentially affected crops distribution. This distribution could be considered as an uncertainty, since even if the location of every kind of crops is perfectly known in the studied area, crops distribution can vary from year to year, so the distribution might be updated.

Rainfed cereals have been chosen as representative crop to illustrate the developed methodology because these are one of the main cultivated products, not only in Spain, but also in the rest of Europe. The distribution for the rest of the harvested products in Spain have been also associated to their corresponding land uses to create a cultivated crop map.

To carry out that distribution, Corine Land Cover [8] map has been used as base map, in which five main land-use classes are represented according to their land cover properties, depending on the kind of crops and their associations when cultivated areas are inter-mixed in a patchwork system. One of these classes is the “Agricultural areas” class, which is made up of eleven subclasses. Taking into consideration those land cover properties, rainfed cereals has been associated to the following five agricultural subclasses: “Non-irrigated arable land” (which is the main land use where rainfed cereals are), “Annual crops associated with permanent crops”, “Complex cultivation patterns and Land principally occupied by agriculture, with significant areas of natural vegetation” and “Agro-forestry areas”. Although the rainfed cereals distribution has been performed applying general criteria, this is a first approach that has allowed to develop the design methodology. Thus, this crop is considered to grow only in the listed land uses; this distribution is shown in figure 2.

A methodology to obtain a more accurate crop map distribution is currently being done in the framework of the doctoral thesis.



**Figure 2.** In yellow are represented those areas where the land use corresponds with the one appropriated to cultivate rainfed cereals in the Spanish Iberian Peninsula.



## 2.3 Soil to plant radionuclide transfer

Transfer factor soil-to-plant is the parameter to be applied to quantify the amount of the bioavailable fraction of the radionuclides deposited on soil that would be uptaken by plants [9]. From this parameter the radiological vulnerability of the agricultural system is assessed [3]. In the selected case study, as it was said before, rainfed cereal crops have been considered to define the vulnerability of the agricultural system in case of an accidental radioactive release deposited in the Spanish Iberian Peninsula.

There is relatively little data available related to the transfer factors in Spain, thus, those have been derived from the general literature [9]. According to the bibliography, transfer factors are specific for each crop and for each soil texture.

The transfer factors indicated in table 1 are the result of the compilation of several experimental values obtained all around the world for the grain of cereals in temperate climates [9]. As it can be seen from the table 1, the order of magnitude of the transfer factor range values is so wide that it is suppose that the characteristic Mediterranean values are included on them. However, having the specific properties of the Spanish soils, it was decided to adjust those transfer factor values according to the K and clay content; this way, soil-to-plant transfer values have been obtained in order to get more locally oriented radiological vulnerability maps [7]. For that purpose, by using a Geographical Information System [10], topsoil properties map has been overlapped with the cultivated rainfed cereals map in Spain. Thus, adjusted transfer factors mean values have been assigned to the corresponding soil group through its texture.

| Texture                         | Number of samples | Mean                  | Standard deviation | Minimum               | Maximum               |
|---------------------------------|-------------------|-----------------------|--------------------|-----------------------|-----------------------|
| <b>Sandy</b>                    | 156               | $3,90 \times 10^{-2}$ | 3,3                | $2,00 \times 10^{-3}$ | $6,60 \times 10^{-1}$ |
| <b>Loamy</b>                    | 158               | $2,00 \times 10^{-2}$ | 4,1                | $8,00 \times 10^{-4}$ | $2,00 \times 10^{-1}$ |
| <b>Clay</b>                     | 110               | $1,10 \times 10^{-2}$ | 2,7                | $2,00 \times 10^{-4}$ | $9,00 \times 10^{-2}$ |
| <b>Organic<br/>(No texture)</b> | 28                | $4,30 \times 10^{-2}$ | 2,7                | $1,00 \times 10^{-2}$ | $7,30 \times 10^{-1}$ |

**Table 1.** Transfer factors values for grain cereals in temperate environments. The mean values for each mineral texture class and for the organic soils correspond to the geometric mean of the whole considered transfer factor values. [9].

To assign the adjusted transfer factor for each soil group, the following expression has been applied [7]:

$$TF_{CS_{Adjusted}} = \left( \frac{TF_{Max} - TF_M}{0,1 - K_{Final}} \right) \times (K - K_{Final}) + TF_M$$

where:

- $TF_{Max}$  is the maximum transfer factor value given in the bibliography.
- $TF_M$  is the mean transfer factor value given in the bibliography.
- $K$  is the topsoil's potassium mean content in each soil group (in cmol/kg) obtained from the Spanish soil profile database [5].
- $K_{Final}$  is the theoretical concentration of K that is been sought and depends on its percentage of clay [1]. This value represents the maximum K reservoir capacity of the soil, which depends

on the clay content on soil, and that influences the transfer. The considered values are the following (Table 2):

| Clay percentage | $K_{Final}$ [cmol/kg] |
|-----------------|-----------------------|
| 0 – 10 %        | 0,6                   |
| 10 – 20%        | 0,9                   |
| 20 – 30 %       | 1                     |
| > 30%           | 1,1                   |

**Table 2.**  $K_{Final}$  values (cmol/kg) to assess the adjusted soil-to-plant transfer factor for  $^{137}Cs$ . [1].

In table 3 the range and the mean of the adjusted  $^{137}Cs$  transfer factor values for rainfed cereals’ grain, for the different textural classes, can be seen. Values for K content (expressed in cmol/kg) are also given for each mineral texture class and for organic soils.

As it can be seen, the adjusted transfer factors for sandy and organic soils becomes lower than the one given in the biography in an order of magnitude, while for loamy and clay soils’ transfer factors are slightly higher.

| Texture                     | $TF_{A\_Min}$         | $TF_{A\_Max}$         | $T_{A\_FM}$           | $K_{Min}$             | $K_{Max}$             | $K_M$                 |
|-----------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| <b>Sandy</b>                | $1,42 \times 10^{-2}$ | $6,60 \times 10^{-1}$ | $3,30 \times 10^{-1}$ | $1,00 \times 10^{-1}$ | 1,14                  | $5,30 \times 10^{-1}$ |
| <b>Loamy</b>                | $1,28 \times 10^{-2}$ | $1,63 \times 10^{-1}$ | $8,93 \times 10^{-2}$ | $2,67 \times 10^{-1}$ | 1,14                  | $6,36 \times 10^{-1}$ |
| <b>Clay</b>                 | $1,10 \times 10^{-2}$ | $4,83 \times 10^{-2}$ | $3,47 \times 10^{-2}$ | $5,75 \times 10^{-1}$ | 1,40                  | $7,39 \times 10^{-1}$ |
| <b>Organic (No texture)</b> | $2,58 \times 10^{-1}$ | $2,58 \times 10^{-1}$ | $2,58 \times 10^{-1}$ | $6,50 \times 10^{-1}$ | $6,50 \times 10^{-1}$ | $6,50 \times 10^{-1}$ |

**Table 3.** Adjusted  $^{137}Cs$  soil-to-plant transfer factors values (minimum:  $TF_{A\_Min}$ , maximum:  $TF_{A\_Max}$  and mean:  $TF_{A\_M}$ ) and the grain’s cereals in temperate environments, according to the K and clay content in soil, for each soil texture considered and for organic soils, obtained for Spanish topsoils. For each texture class, K concentration ( $K_{Min}$ : Minimum K content;  $K_{Max}$ : maximum K content;  $K_M$ : mean K content) in the Spanish soil profiles considered (cmol/kg) is also included.

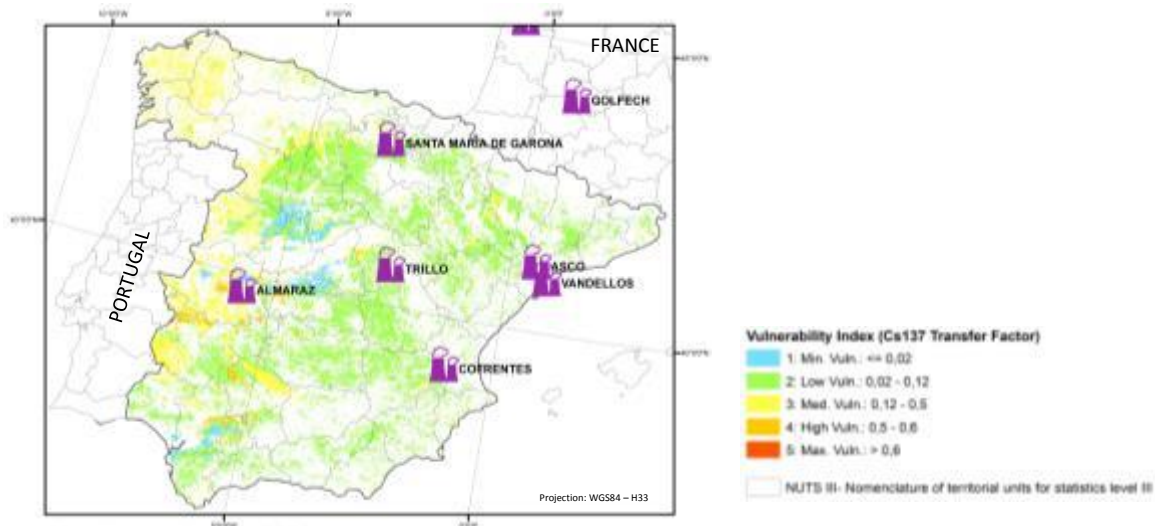
### 3 Radiological vulnerability of agricultural systems

From the resultant adjusted transfer factors of all the soil groups, five categories have been done (see table 4) which correspond to the radiological vulnerability index of the agricultural system [2], referred, in this case, to the potential transfer of  $^{137}Cs$  to the rainfed cereals grain in Spain. Mapping the radiological vulnerability index, potentially more vulnerable areas in case a release occurs are identify. In the figure 3 the vulnerability map is presented.

| Vulnerability Index | Vulnerability Category | Range of the $TF_{Adjusted}$              |
|---------------------|------------------------|---|
| <b>1</b>            | Minimum Vulnerability  | $< 2,0 \times 10^{-2}$                    |
| <b>2</b>            | Low Vulnerability      | $2,0 \times 10^{-2} - 1,2 \times 10^{-1}$ |
| <b>3</b>            | Medium Vulnerability   | $1,2 \times 10^{-1} - 5,0 \times 10^{-1}$ |
| <b>4</b>            | High Vulnerability     | $5,0 \times 10^{-1} - 6,0 \times 10^{-1}$ |
| <b>5</b>            | Maximum Vulnerability  | $> 6,0 \times 10^{-1}$                    |

**Table 4.** Radiological Vulnerability Index for the rainfed cereals in Spain, with regard to  $^{137}Cs$ . [2].

It must be pointed out that the categorisation, that has been done from the adjusted transfer factors shows some degree of uncertainty, as the categories can be established considering different approaches, for instance: adding or reducing the vulnerability classes or considering other thresholds between classes, among others.



**Figure 3.** Radiological Vulnerability map for the Spanish rainfed cereals regarding to the  $^{137}\text{Cs}$ . [2].

This radiological vulnerability map represents a categorization of the radiological consequences for the crop (in the presented case, rainfed cereals), and hence for the potential entrance of this radionuclide in human food chain.

Thus, taking into account this vulnerability map in a Spanish agricultural scenario where a  $^{137}\text{Cs}$  deposition would occur, strategies could be set for recovery or remediation measures; these measures could be focused on those affected areas where the radiological consequences would be more severe not only from a radiological point of view, but also from a socioeconomic perspective.

## 4 Recovery and restoration strategies

Usual practices in agricultural systems are applied with the aim to improve soil properties, and then, to increase the crops yield. These practices are also implemented to recover and restore damaged areas and consist of chemical techniques such as adding K (to avoid plants uptake Cs), or Ca (to avoid plants uptake Sr), mechanic techniques, including ploughing, or phytoremediation [11].

In the case study, recovery strategies are focused on increasing the topsoil K content in those areas where there is low K content in soil.

The proportion of clay influences on the possible maximum content of K in soil, because the more percentage of clay, the more capability the soil has for retaining K, or, in its absence, its competitor: Cs [7]. Therefore, the K storage ratio in soil depends on clay content (see table 6), meaning that the same quantity of K in a sandy soil corresponds to a very high storage ratio, while reflects a very low one in a clay soil.

| K storage ratio | K content according to the clay percentage [cmol/kg] |                       |                       |                       |
|-----------------|--|-----------------------|-----------------------|-----------------------|
|                 | 0 – 10 %   | 10 – 20%              | 20 – 30 %             | > 30%                 |
| Very low        | $K \leq 0,1$   | $K \leq 0,3$          | $K \leq 0,4$          | $K \leq 0,5$          |
| Low             | $0,1 \leq K \leq 0,2$                                | $0,3 \leq K \leq 0,5$ | $0,4 \leq K \leq 0,6$ | $0,5 \leq K \leq 0,7$ |
| Medium          | $0,2 \leq K \leq 0,4$                                | $0,5 \leq K \leq 0,6$ | $0,6 \leq K \leq 0,7$ | $0,7 \leq K \leq 0,9$ |
| High            | $0,4 \leq K \leq 0,5$                                | $0,6 \leq K \leq 0,8$ | $0,7 \leq K \leq 0,9$ | $0,9 \leq K \leq 1,0$ |
| Very high       | $K > 0,5$  | $K > 0,8$             | $K > 0,9$             | $K > 1,0$             |

**Table 6.** K storage ratio in soil (in cmol/kg) according to its clay percentage.

The desired final content of K in soil, obtained after the agricultural practice, can be the one that reduces the exposure to the smallest possible bioavailable  $^{137}\text{Cs}$  content as a countermeasure, or to a relatively low ratio, so the transfer is partially reduced [1]. In this case, as an example of the applied methodology, the second option is presented, which corresponds to the fertilization values.

Thus, depending on the K content and the percentage of clay in soil, a quantity of K must be incorporated in the soil to avoid the entrance of  $^{137}\text{Cs}$  in the crystal structure of the clay minerals, that become bioavailable for the crops to be uptaken. In table 7 the eventual K concentration to be achieved to get a medium K storage ratio is shown [1]; so, by reaching those final K values, the storage ratio of K in every soil group will be in “Medium”, according to table 6.

| Clay percentage | Eventual K content to achieve for a fertilization practice [cmol/kg] |
|-----------------|--|
| 0 – 10 %        | 0,4  |
| 10 – 20%        | 0,6  |
| 20 – 30 %       | 0,7  |
| > 30%           | 0,9  |

**Table 7.** Eventual K content (cmol/kg) in soil according to its clay percentage for a fertilization practice. [1].

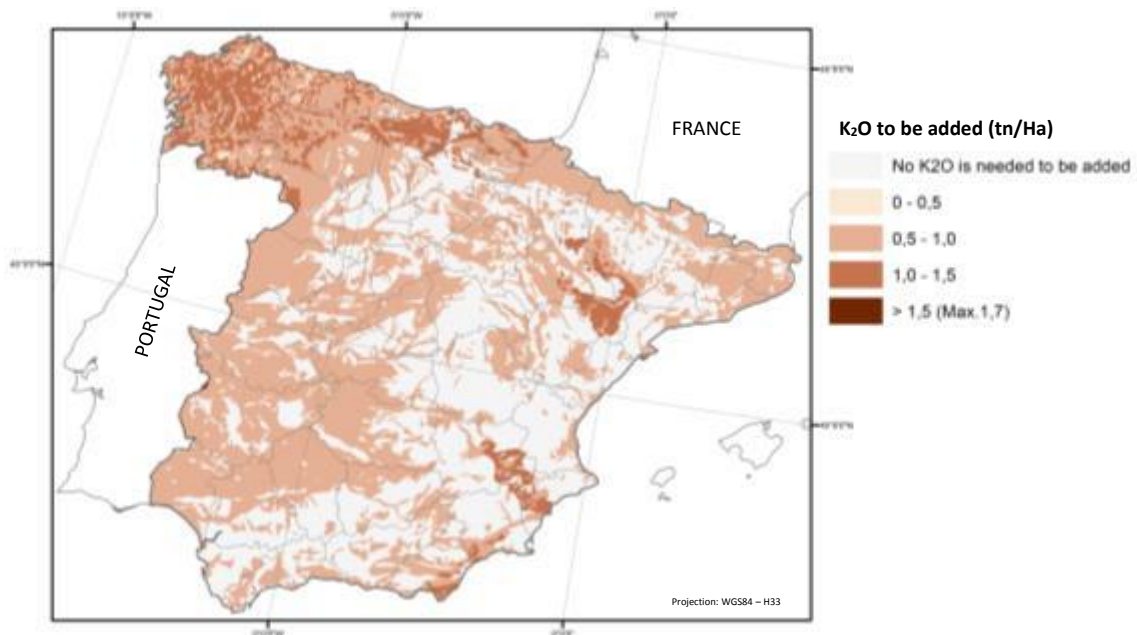
Taking into account the initial K concentration in soil and the eventual K content target, the amount of fertilizers to be added, in tones of  $\text{K}_2\text{O}$  per hectare, can be assess by applying the following formula [1]:

$$K_2O [t/ha] = \Delta K \times 39,10 \times 0,1 \times e_1 \times 0,01 \times d_1 \times 1,2$$

where:

- $e_1$  is the topsoil thickness, in metres.
- $d_1$  is the topsoil apparent density, in  $\text{t/m}^3$ .

In doing so, the  $K_2O$  needed to add is obtained. However, to assess that value for each soil group, firstly the formula has to be applied to each soil profile that is included in each group [1]; nevertheless, there are some profiles which have enough K content so that it is no necessary to add  $K_2O$ . Secondly,  $K_2O$  is assessed for each soil group by adding up the  $K_2O$  of every soil profile that corresponds to each soil group and then dividing it by the number of soil profiles which have K deficit in the group [1]. The tones per hectare obtained are the average of  $K_2O$  to be added in each group to get, in the presented case, a medium K storage ratio. The mapping of the  $K_2O$  to be added in the Spanish soils for fertilization can be seen in figure 8.



**Figure 8.** Map of the average of  $K_2O$  (in tn/ha) needed to add in the Spanish soils for fertilization, considering the properties of the differentiated soil groups.

As it can be seen, in much of the Spanish Peninsula it would not be necessary to add potassium, mainly in the Eastern half. On the other hand, there is only a spot where it is necessary to increase the quantity of potassium with more than 1,5 t/Ha, which is located in the Southwest of Spain, just in the Portuguese border.

Comparing this map with the prioritization one, it is clear that priority areas where more K in soil is needed are located where the amount of  $K_2O$  to be added is between 0,5 and 1 tones per hectare. Having this information beforehand could be very useful facing a recovery situation in the preparedness and response process.

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