D9.71 – Guidance* for management/Post-Accident Recommendations based on output of the TERRITORIES project

Authors: TERRITORIES partners **

Reviewer(s): CONCERT coordination team

<table>
<thead>
<tr>
<th>Work package / Task</th>
<th>WP 9</th>
<th>T9.3</th>
<th>SST 9.3.3.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deliverable nature:</td>
<td>Report</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dissemination level: (Confidentiality)</td>
<td>Public</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contractual delivery date:</td>
<td>M55 extended to M56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual delivery date:</td>
<td>M57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Version:</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number of pages:</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keywords:</td>
<td>Nuclear Accidents; Off-site long term radiological consequences; Consideration of uncertainties; Decision-Making Processes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approved by the coordinator:</td>
<td>M57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Submitted to EC by the coordinator:</td>
<td>M57</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The word Guidance has to be understood as a set of general recommendations. The present document is not a guide aiming to replace any international guidance.
**TERRITORIES partners:**

<table>
<thead>
<tr>
<th>Country</th>
<th>Organisation</th>
<th>Staff involved in TERRITORIES project</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>IRSN</td>
<td>Jérôme GUILLEVIC, Gilles ALCADE, Karine BEAUGELIN-SEILLER, Jean-Marc BERTHO, Philippe CALMON, Charlotte CAZALA, Sylvie CHARRON, Olivier DIEZ, Laureline FEVRIER, Rodolphe GILBIN, Marc-André GONZE, Mathieu LE COZ, Gwenaelle LORIOT, Arnaud MANGERET, Pedram MASOUDI (post-doc), Didier MESTRALETTI, Christophe MOURLON, Marie SIMON-CORNU, Alain THOMASSIN, Mathilde ZEBRACKI.</td>
</tr>
<tr>
<td>Germany</td>
<td>BfS</td>
<td>Alexander DIENER, Florian GERING, Thomas HAMBURGER, Martin STEINER, Laura URSO, Christine WILLRODT.</td>
</tr>
<tr>
<td>France</td>
<td>CEPN</td>
<td>Pascal CROUAIL, Mélanie MAÎTRE, Thierry SCHNEIDER.</td>
</tr>
<tr>
<td>Spain</td>
<td>CIEMAT</td>
<td>Alla DVORZHAK, Sergi LÓPEZ-ASENSIO (PhD student), Juan Carlos MORA-CANADAS, Christian OLTRA-ALGADO, Danyl PÉREZ-SÁNCHEZ, Almudena REAL-GALLEGOS, Roser SALA-ESCARRABILL.</td>
</tr>
<tr>
<td>Norway</td>
<td>NMBU</td>
<td>Ole Christian LIND, Ståle NAVRUD, Deborah OUGHTON, Brit SALBU, Lindis SKIPPERUD.</td>
</tr>
<tr>
<td>Norway</td>
<td>DSA</td>
<td>Justin BROWN, Mark DOWDALL, Jan Erik DYVE, Ali HOSSEINI, Astrid LILAND, Jelena POPIC, Lavrans SKUTERUD.</td>
</tr>
<tr>
<td>UK</td>
<td>PHE</td>
<td>Iain BROWN, Tiberio CABIACNA, Kelly JONES, Alison JONES, Wayne OATWAY, Justin SMITH.</td>
</tr>
<tr>
<td>Belgium</td>
<td>SCK.CEN</td>
<td>Bieke ABELSHAUSEN, Talal ALMAHAINI, Chloé DIERCKX (student), Ferdiana HOTI (PhD student), Tanja PERKO, Lieve SWEECK, Catrinel TURCANU, Michiel VAN OUDHEUSDEN, Nathalie VANHOUDT, Axel VAN GOMPEL, Leen VERHEYEN, Jordi VIVES I BATLLE</td>
</tr>
<tr>
<td>Finland</td>
<td>STUK</td>
<td>Anti Kallio, Maarit MUIKKU, Pia VESTERBACKA</td>
</tr>
<tr>
<td>Estonia</td>
<td>University of TARTU</td>
<td>Andrei GORONOFSKI (PhD student), Cagatay IPBUKER (PhD student), Marko KAASIK, Rein KOCH, Dolores MAEKVI (student), Koit MAURING, Kata Maria METSAR-SALURI (student), Hanno OHVRIL, Stanislav SOCHYNSKYI (student), Keiu TELVE (PhD student), Alan Henry TKACZYK, Toomas VALJA, Martin VILBASTE.</td>
</tr>
<tr>
<td>France</td>
<td>MUTADIS</td>
<td>Stéphane BAUDE, Julien DEWOGHELAËRE, Gilles HERIARD DUBREUIL.</td>
</tr>
</tbody>
</table>

Disclaimer:

The information and views set out in this report are those of the author(s). The European Commission may not be held responsible for the use that may be made of the information contained therein.
Abstract

The TERRITORIES project, funded under the H2020 CONCERT, aims To Enhance unceRtainties Reduction and stakeholders Involvement TOwards integrated and graded Risk management of humans and wildlife In long-lasting radiological Exposure Situations.

Details of the research performed in TERRITORIES can be found on https://territories.eu, and is summarised in the appendices of this document.

Two documents present recommendations targeted to stakeholders concerned by management of existing exposure situations. Both were discussed at the TERRITORIES final workshop, 12-14 November 2019, and the present versions take account of the feedback from invited stakeholders.

The present document applies to post-accidental situations whereas the companion document, D9.72, applies to NORM situations.
# Table of contents

Preamble: NORM and post-accident as existing exposure situations ........................................ 5

I. Introduction.......................................................................................................................................................... 6

II. Governance of the post-accident situation ................................................................................................. 10

III. Rehabilitation of living conditions ............................................................................................................. 13

IV. Reliable co-constructed monitoring ........................................................................................................... 18

V. Technical tools serving post-accident governance ....................................................................................... 22

VI. Conclusion....................................................................................................................................................... 26

VII. References...................................................................................................................................................... 28

VIII. Extended abstracts of CONCERT-TERRITORIES deliverables quoted in this report ..................... 29
Preamble: NORM and post-accident as existing exposure situations

Radiation protection of human populations and the environment has recently evolved with the publication of International and European Basic Safety Standards (IAEA, 2011; EC, 2014), and the lessons learned from recent international experience, mainly after the Fukushima-Daiichi nuclear accident in 2011.

In the current system of radiological protection, radiological exposure situations in the long term after a nuclear accident, or a contamination by Naturally Occurring Radioactive Materials (NORMs) are generally identified as “existing exposure situations” and should be treated accordingly. The current way of managing radiological exposure associated with post-accident (Publication 111 (ICRP 2009)) and NORM exposure situations (Para. 284 of Publication 103 (ICRP, 2007); Publication 142 (ICRP, 2019)) is based on the same conceptual framework and follows the same principles, the most important of them being that any undue exposure has to be reduced as low as reasonably achievable below a tolerable level of individual dose (or reference level), economic and societal factors being taken into account (optimisation principle).

The scope of the TERRITORIES project covers existing exposure situations related to certain exposures due to naturally occurring radioactive materials, and post-accident situations. The work undertaken in this project involved a review of European legislation relevant to existing exposure situations and the international recommendations and standards underpinning the legislation. It involved gathering information and developing insights into existing exposure situations that have arisen from major nuclear accidents and from the legacies of mining and minerals processing activities. Based on this first analysis, uncertainties associated with the management of such situations have been identified and discussed with stakeholders in order to collect their views and see how to improve the consideration of such uncertainties in the management and recovery of impacted territories.

Recommendations have been compiled in two separate documents for each of these situations. One reason for this separation is that, even if these situations are considered as similar in the radiological protection system, they nevertheless present some differences. It is of interest to analyse them in order to determine in which way these differences could influence the impact of the related uncertainties in decision-making processes.

Among these differences, the largest one is probably the exceptional nature and the sudden occurrence of a large nuclear accident. Indeed, such a “violent” event deeply and durably affects the daily life of the population and impacts the socio-economic activities (Lochard et al., 2019).

Because of natural origin of the contamination of legacy sites, the impacts on the population and the society as well as on the environment are probably perceived lower, although radiological consequences could be similar or higher for specific groups of populations.

In both situations, even if recovery strategies mainly focus on radiological protection considerations, other dimensions (e.g. economic, social, governance, etc.) are at stake and bring uncertainties at all steps of the decision-making processes.
I. Introduction

I.1. Scope of D.9.71

A key aim of the TERRITORIES project is to propose recommendations for assessing and managing long-term exposure situations, both after a nuclear accident or in cases of enhanced natural radioactivity (NORM). More specifically, these recommendations concern, firstly, the treatment of the uncertainties associated with the evaluation of doses to human populations and wild species, and secondly their consideration in decision-making processes by the various concerned stakeholders (e.g. institutional structures, experts, associations, inhabitants, etc.).

The present deliverable 9.71 is dedicated to the presentation of recommendations aiming to improve the consideration of uncertainties in the decision-making process after nuclear accidents with off-site long term radiological consequences.

It must be pointed out that the recommendations suggested hereafter are based on feedback experiences which mainly come from ‘worst cases’ (Chernobyl and Fukushima major accidents were ranked level 7 on INES). An accident of this magnitude is a highly disruptive event that undermines institutions and profoundly and deeply disrupts the society and the life of people in all their dimensions (e.g., employment, access to public services, family life, social life, etc.). Less serious events (rated level 4 or higher on the IAEA INES scale) have been also discussed with stakeholders, in order to challenge with them the way to cope with uncertainties and to identify the resilience factors of their territory.

For the long-term, the main challenge of a post-accidental recovery policy is to (re)establish dignified living conditions for the impacted communities. It should be stressed here that the remediation and rehabilitation strategies implemented should not aim at – as they will not succeed to – a return to the previous (“ante”) situation. From this perspective, it will be particularly important to focus on conditions that can foster the resilience of the population. In that sense, the management process and the available technical tools need to be adapted to best respond to the revitalization challenges (e.g. social & economic activities, access to health care, development of public infrastructures, cultural identity, etc.) of the impacted territory.

I.2. Methodological approach : How to capture the uncertainties?

I.2.1. Definition

Both the TERRITORIES project and many previous studies of the Chernobyl and Fukushima accidents have shown that public policies struggle to respond to the complexity of the situation and to human issues. To account for all this complexity, and to identify the conditions for maintaining resilience, the TERRITORIES project (D9.65\(^1\)) introduced a wide definition of **uncertainty**, to refer to *any situation for which a fact, data or phenomenon and their causes or consequences are not known with certainty by a specific actor in her/his decision context.*

Uncertainties can be defined according to two main dimensions:

---

\(^1\) References denoted D\(x\).\(yy\) refer to CONCERT deliverables, available on [http://concert-h2020.eu/en/Publications](http://concert-h2020.eu/en/Publications). Among them, TERRITORIES deliverables (D9.59 to D9.79) are also shown on: [https://territories.eu/publications](https://territories.eu/publications). Extended abstracts of cited deliverables are presented in section VII.
• their “nature” by which is related to the essence of the uncertainties i.e. why it is uncertain? (e.g. imprecision in measurements are of different nature from absence or incompleteness of scientific knowledge about a phenomenon);
• their “object”, i.e. what uncertainty is about (e.g. contamination of the environment, health effects, economic consequences, cost of countermeasures, choices of the population as regard to stay/return in a contaminated territory or rebuilding a new life elsewhere...). Such characterisation by nature and object is helpful to clarify the meaning of uncertainty in such complex situations such post-accident and to define group of uncertainties that will be taken into account.

I.2.2. How to capture the uncertainties?

To better characterise the uncertainties at stake in post-accident situations and to improve the decision-making processes related to the management of such situations, one part of the TERRITORIES WP3 work aimed to better analyse the whole process of the recovery management. To that end, a systemic description of the uncertainties at stake in the recovery processes has been done, by notably considering technical, organisational, socio-economic and human dimensions associated with personal and community resilience. These dimensions have been considered along the process assessment of the situation that can be described as follow : identification of the possible recovery options, selection of recovery options and implementation.

More particularly, the work has been carried out in two steps:

The first step was to identify the main decision factors and criteria used in the management of post-accident situations that could impact the life of affected people and/or the environment. The work undertaken involved a review of European legislation relevant to the management of post-accident situations and the international recommendations and standards. It also involved gathering information and developing insights into existing situations that have arisen from major nuclear accidents in the past. This first step led to identify seven main domains where uncertainties are at stake (D9.65):

• Radiological characterisation and impact assessment,
• Zoning the affected areas,
• Feasibility and effectiveness of the remediation options,
• Short and long-term health consequences,
• Socio-economic and financial aspects,
• Quality of future life in the territory,
• Social trust.

It should be pointed out that these different domains of uncertainties may be of different importance depending on the targeted stakeholder(s) (e.g. local elected people, environmental NGOs, socio-economic actors, radiological protection experts, lay inhabitants, etc.) or on the modalities of governance; moreover, they may evolve over time. These transversal dimensions, which encompass inherent variability can also generate additional uncertainties in the decision-making processes.

Based on this first characterisation, these uncertainties have been sorted into two main categories, according to the key elements of decision making process for the management of post-accident situation:
- **Technical uncertainties** that can be reduced (with more data, better precision, or increased knowledge): related to the radiological characterisation and impact assessment; feasibility and effectiveness of the remediation options; Zoning the affected areas; technological and technical decisions and uncertainties.

- **Decisional uncertainty**, referring to indeterminacies in the decision-making process.
  - **Organisational uncertainties**, referring to modalities of organisation and governance arrangements, the variety of stakeholders and their different roles and responsibilities;
  - **Human life uncertainties**, taking into account the quality of future life in the territory, the social trust dimension, the uncertainties related to short and long-term health consequences, the evolution of the situation over time, risk perception, communication and stakeholder engagement;
  - **Economic uncertainties** associated with socio-economic and financial aspects of the recovery process but also with the future economy of the affected territory.

It is important to stress out that all of these types of uncertainties occur throughout the recovery process, and must be better considered in the decision-making to improve the management of post-accident situations.

The second step, after this preliminary screening was to deepen the analysis by identifying in which decision areas and for which potential decision factors and criteria, uncertainties should be the most questioned by stakeholders, as well as how they could impact their daily life and as a result, their decisions. This has been done through discussions and table-top exercises taking place in interactive experts/stakeholders panels and reflection groups. The panels and table-top exercises, based on scenarios of hypothetical accident, have specifically addressed uncertainties related to various issues at stake in post-accident situations: exposure scenarios (e.g. movement of people from affected areas), lifestyle changes, food restrictions, establishment and changes of reference levels, monitoring of the radiological situation, quality of life, local economic evolution, etc. In addition, an innovative methodology of pluralistic assessment of remediation pathways (CONCERT sub-subtask 9.3.3.3.4) has also been developed in this perspective. This new approach entitled *Pathway Evaluation Process in post-accident context* (PEP-PA), as a serious game, is structuring pluralistic and fair exchanges (notably between technical experts and civil society representatives) regarding elaboration and implementation of post-accident strategies and supporting the development of recommendations regarding the management of uncertainties identified in D9.65.

These interactions with stakeholders have resulted in the identification of 12 key recommendations that could enhance people’s resilience and reduce the related uncertainties in the decision making process for the management of post-accident situations. These recommendations have been divided into four main areas, corresponding to the resources (means of action, elements available to improve a difficult situation) to be dealt with in the assessment and management of such situations:

- **Governance of the post-accident situation**: recommendations 1 and 2 aim at reducing uncertainties related to challenges of governance and coordination, particularly arising from centralized decision and lack of knowledge of people’s concerns and views, and propose tools that improve decision processes in a post-accident context.
- **Rehabilitation of living conditions**: recommendations 3 to 6 respond to the uncertainties related to the necessary conditions to enhance the recovery process. They cover many dimensions such as the notion of “impacted community” and financial mechanisms to revitalize the impacted areas, the need to enlighten decisions...
and choices of population. A focus on waste management issues is particularly develop.

- **Reliable co-constructed monitoring**: recommendations 7 to 9 propose means to maintain citizen awareness and radiological protection culture, enhance transparency and sharing informations through joint database platform, and co-expertise for interpretation and analysis of data.

- **Technical tools serving post-accident governance**: recommendations 10 to 12 provide advice and recommendations for technical tools such as measurements and/or radioecological assessments that can better address the complexity in assessing radiological exposures to non-human biota and the need of early dialogue to discuss model uncertainties with stakeholders.

The following sections include introductions to these four areas that clarify the concepts and illustrate the base of the literature and feedback experience, as well as in which way and which area the associated recommendations could reduce uncertainty and foster the recovery process. A list of TERRITORIES deliverables together with the extended abstract of each deliverable is provided in annex.

It should be pointed out that these recommendations have been drawn up to be implemented since the preparedness phase, in order to improve the future decision-making processes and recovery management. These 12 recommendations have to be considered not individually but complementary and linked to each other through the iterative process of recovery. The different views, values, concerns and roles of the stakeholders have also been taken in consideration and mentioned in the recommendations.

Each recommendation is organized into three sub-sections:

- **Why**:
  - Reason: Rationale behind the recommendation,
  - Impact: Way in which the different actors involved in the assessment or management process may be impacted by the recommendation,
  - Connections: Link between this recommendation and the other aspects,
  - Consequences: Possible consequences if the recommendation is not considered.

- **How**: implementation of the recommendation, with references to TERRITORIES deliverables

- **By whom**: actors expected to apply the recommendation
II. Governance of the post-accident situation

The feedback experience from post-Chernobyl and post-Fukushima accident management clearly emphasized the influence and importance of the governance arrangements that could enhance the capacity of stakeholders to cope with uncertainties in the decision-making processes. These rely on a good understanding and knowledge of the worries and concerns of people whose life has been overwhelmed by the consequences of the accident. The notion of “governance” generally refers to a more encompassing phenomenon than government. It embraces governmental institutions, but it also subsumes informal, non-governmental mechanisms whereby those persons and organisations within its purview move ahead, satisfy their needs, and fulfill their wants (Rosenau 1992). Gerry Stoker (Stoker 1998) identifies five aspects of governance:

1. Governance concerns a range of organisations and actors, not all of which belong to the government sphere
2. It modifies the respective roles and responsibilities of public and private actors as established in traditional paradigms of policy making
3. It involves interdependence between organisations and actors engaged into collective action in contexts in which none of them has the necessary resources and knowledge to tackle the issue alone
4. It involves autonomous networks of actors
5. A key principle is that actions can be pursued without necessarily having the power or the authority of the State.

In this section, the term governance particularly refers to the participatory interactions between public authorities, experts and citizens, with an objective of a better effectiveness of the remediation process, considering the quality of life in the affected territory. This section tackles the roles and responsibilities of decision-makers, the subsidiarity principle in decision-making, and the possible coordination between the various stakeholders (e.g. local and national authorities, socio-economic actors, citizens, experts, etc.).
TERRITORIES recommends to

1. Develop tools and criteria to foster human resilience in governance

Why?
Experience from both the Chernobyl and Fukushima post-accident situations emphasized the need to place the populations of the affected territories at the centre of the public decision-making process. In order to create conditions for resilience, it should be recognised that the affected inhabitants are the main drivers of the recovery processes, of their living conditions in the short, medium and long term perspectives. Considering the fact that resilience of population is a key factor of the recovery processes; the issue is then to identify, in the preparedness phase, the extent to which post-accident management policies could contribute to foster or to impede human resilience. Identifying the levers of the resilience in the preparedness phase of post-accident governance enables the various designers of public policies to diagnose and better understand the needs of affected populations as well as their expectations regarding the recovery and governance strategies proposed by decision-makers or, conversely, to identify the extent to which remediation policies can improve the recovery of the conditions of a life worth living.

How?
Described as “the dignified condition of life” (cf D.9 69), seven criteria have been defined that encapsulate the several anthropological dimensions entailed by a process of recovery. It places humans in a dynamic perspective, at the centre of the fulfilment of their priorities while emphasizing the need for an enabling environment supporting their action. Post-accident policies are expected to foster human resilience by creating such enabling environment supporting local action and initiatives. As a support to preparedness, a dynamic multi-actors interaction process involving post-accident stakeholders (commonly called Post-Accident Pathways Evaluation Process) as a SERIOUS GAME, using these criteria has been developed and tested in the framework of TERRITORIES (see D.9.69). The use of such tool and criteria creates the conditions of a structured, fair and constructive dialogue between actors having different views and concerns such as potentially affected inhabitants, local governments, national public decision-makers, professionals, industry, NGOs, experts, media, etc.. The approach and the criteria can be tested and further developed according to various contexts and needs (during crisis exercises addressing post-accident phase, or in the affected territories after an accident to foster the building of rehabilitation projects). This could also be considered as an example of a first analytical step to map the issues and concerns of population that could be challenged and follow throughout the recovery process with other types of approaches (panels, dialogue, surveys, etc.).

By whom?
This approach is to be proposed as a way to increase awareness and help to favour the interaction between stakeholders having different views and concerns along preparedness, to train and prepare them to face such disruptive situation beyond the radiological aspects. It is complementary to other approaches such as panel discussions. It can be usefully operated for different stakeholders:

- experts involved in post-accident management (cf. recommendation no. 12) as well as students, young experts (training)
- decision-makers and more specifically, those in charge of governmental and local level decisions (cf. recommendation no. 2);
- as a support public dialogue in the framework of institutional processes (SEA, EIA) associated with post-accident preparedness planning at national or local levels.
TERRITORIES recommends to

2. Design post-accident governance patterns to foster human resilience, clarify the actors role and responsibilities and enhance coordination

Why?
The experience of the Fukushima and Chernobyl accidents illustrates the difficulty of the governmental decision-making system to meet the needs and expectations of the people, as well as the multiplicity and complexity of the challenges and issues (health, socio-economic, etc...) posed by such situations. In both cases, questions about the roles and responsibilities of the different stakeholders emphasize the issues of coordination between actors at all levels of the many decision-making processes involved by post-accident recovery (authorities, ministries, and elected people from national to local, inhabitants, professionals, and in all areas affected (economy, agriculture ...). In Japan, “governance” modalities have been adapted to facilitate the management of the decontamination actions: creation of the cabinet office (as transversal structure of decisions), coordination with municipalities, state, and experts. D9.65 and D9.69 highlight the need for specific governance patterns to support post-accident engagement of public and private stakeholders involved in the territorial activities, to create an enabling environment for them to achieve recovery projects with the supports of experts and authorities (see for instance the specific governance patterns of the CORE2 recovery programme in Belarus after Chernobyl).

How?
This question has to be addressed at the highest level of Government in order to increase awareness of the interest and the importance of this aspect to enhance the recovery. In this perspective, general principles of post-accident governance, acknowledging affected inhabitants are main drivers of the recovery processes, should be settled as international guidelines (IAEA, EU) and then translated in the national contexts according to their legal, political and historical specificities. With the objective to study the necessary relevance and flexibility of governance arrangements (coordination, roles and responsibilities of the various stakeholders), at different levels (national to local), it is recommended:

- To deepen the feedback analysis from Chernobyl and Fukushima accident and other industrial or natural events by analyzing more in depth the roles and responsibilities of actors to improve the decision-making process as well as to enhance the resilience capacity of population (see above recommendation no. 1) and the recovery process;
- To discuss and analyze concrete case studies with experts, researchers of social and political sciences, decision-makers (mayor, prefect, etc.) in order to wider their views on roles and responsibilities in post-accident situations beyond the radiological aspect;
- To conduct national exercises (post accident phase) to challenge PA and emergency management plans and policies and the way roles and responsibilities of actors should be improved.

By whom?
This recommendation focuses on experts/decision makers and should be supported by national and international institutions and organisations, as well to relevant research communities (see above)

---

2 COoperation for the REhabilitation of living conditions in the contaminated territories of Belarus after Chernobyl (https://www.osce.org/minsk/32088?download=true)
III. Rehabilitation of living conditions

Many projects related to post-accident recovery following Chernobyl and Fukushima accidents have recognised that the rehabilitation of living conditions depends not only on radiological protection issues, but also needs to provide opportunities for improving living conditions that embraces all their dimensions (e.g. economy, employment, social and cultural aspects, etc.) and empowers locals to make informed decisions about their future in the territory.³

Reflection about rehabilitation of living conditions, notably in the preparedness phase, should rely on dialogue with local stakeholders to identify the possible levers of resilience, the resources available in this perspective and the key owners (institutional or others) of such resources. This dialogue would also help to design in advance appropriate protection strategies in accordance with the identified vulnerabilities of the concerned territory and the needs of the interested parties. Development of decision support tools is necessary and can give useful information to populations and public authorities that can enlighten decisions and choices about remediation strategies and options. As a final step, financial mechanisms have to be identified in order to enhance affected territory revitalization.

³ A non-exhaustive list would include the Chernobyl Forum (EUEP, 2003); EU projects: ETHOS (Heriard-Dubreuil et al, 2002), FARMING (Nisbet et al., 2004), STRATEGY (Howard et al., 2004), EURADOS (Nisbet et al., 2008), NERIS-TP (Raskob et al., 2013), PREPARE (Duranova, Raskob and Schneider, 2016) and SHAMISEN (Oughton et al., 2017); as well as ICRP Publication 111 (ICRP, 2009) and the IAEA Fukushima Report (IAEA Volume 5, 2015).
TERRITORIES recommends to

3. Engage dialogue with local stakeholders to better address the notion of “affected community” and anticipate post-accident provisions

Why?

According to emergency and recovery preparedness plans, authorities generally put in place a zoning, mainly based on radiological protection criteria, with a view to simplifying post-accident management. However, such a zoning often stigmatizes the impacted territory by differentiating and excluding it from its cultural, social and economic historical spaces. In case of an accident, over the long-term, the consequences could be disruptive for communities of inhabitants and the local economy (D9.65, D9.66 and D9.69). Indeed, zoning redraws urban and rural living spaces, and creates artificially and immediately a so-called “affected territory” which obviously never corresponds to socio-economic borders (“Bassin de vie”5, community of municipalities, industrial or agricultural production area, etc.), nor geographical and social spaces (country, “terroir”4, natural regions, human networks, ethnic or cultural communities, etc.). Facing these issues, it is preferable to extend the reflection to the human and environmental dimensions by better addressing the notion of “affected community”.

How?

To better cope with the complexity of post-accident situations, and reduce uncertainties related to the “zoning of affected areas”, during the preparedness phase, actors have to cooperate in the realization and coordination of collective actions with a shared vision on understanding the present and thinking the future of the ‘territorial capital’. Such a vision should contribute to the quality of life of the inhabitants, and could include consideration of, for example, local products which are iconic for the region, the most sensitive economic sectors and main employment areas, historical patrimony, natural and cultural resources, activities and traditional behaviours that underpin the consistency, coherence and attractiveness of the territory. It must be recognized that the ‘territorial capital’ often transcends the boundaries of the zoning (e.g., because of possible transborder consequences, impacts on common areas like rivers, lakes, seas, natural parks, loss of reputation affecting an entire economic sector as tourism or wine industry, etc.). Concrete actions include:

- Map the local-national stakeholders (e.g., elected people, farmers, industry representatives, environmental NGOs, etc.) who should be involved in the preparedness of recovery management and initiate a national-local multi-actor dialogue to identify the socio-economic issues, vulnerabilities, strengths and possible levers for resilience which contribute to the territorial capital of the potentially impacted regions;
- look upon dialogue initiatives based on multi-risk approaches (e.g. natural disaster, chemical, industrial accidents, food safety crisis, etc.) to gather a broader panel of actors who can contribute to the definition of the ‘territorial capital’;
- once the most sensitive socio-economic issues have been identified together with local actors, foresee initiatives and structures to support the dialogue on specific issues (e.g. dialogue with farmers and agricultural chambers on how to adapt countermeasures to the characteristics of the territory);
- on connection with recommendations no. 1 and no. 2 develop appropriate tools to initiate and foster dialogues between local and national stakeholders (e.g. serious games, panels, etc.);
- identify potential resources to support recovery projects of local actors and communities, anticipate policies establishing fair and equitable provisions (post-accident recovery package for local communities) to be offered to communities engaged in the process of rehabilitating their living conditions.

By whom?

Public authorities, experts, population, NGOs, socio-economic actors, neighbour countries.

---

4 In France, a “Bassin de vie” is a territorial entity on which inhabitants have access to the same current offers and services (water and food suppliers, health care, economic infrastructures, labor pool, etc.).

5 “Terroir is a set of environmental factors that affect crop’s phenotype, including unique environment contexts, farming practices and a crop’s specific growth habitat. As such, terroir is the basis of the French wine appellation d’origine controlee (AOC) system.” (Source: Wikipedia.fr).
TERRITORIES recommends to

4. Better understand the financial mechanisms that can help the affected community

Why?

Local actors often have difficulties picturing the possible economic consequences of an accident on their territory. In addition, they are not often aware of the existing financial mechanisms that could be dedicated to the recovery of economic activities, including compensation of economic losses (D9.66). Feedback experience from Fukushima clearly highlighted that financial strategies based on a geographical post-accident zoning are largely developed for compensation, but seem to be insufficiently developed to resume the socio-economic activities. However, although these financial strategies were necessary, they were sources of real or perceived iniquities. In this context, in the preparedness phase, it seems important to better understand the existing financial mechanisms as well as their rationales and identify those which could help the affected community.

How?

During the preparedness phase, existing national compensation systems and other provisions that could be suitable for covering financial consequences of nuclear accident, have to be examined in the light of each national political and cultural context. More particularly, the balance between financial supports allocated to compensation and revitalisation should be further investigated. This calls for a review of existing local, national or transborder mechanisms of financial support of and solidarity with the affected territories. The specific issues related to financial mechanisms that can help in revitalization of the territory should be discussed in close relation with local actors who have a clear vision of its levers of resilience. Actions would include:

- Review existing financial support mechanisms allocated to compensation and revitalisation;
- Analyse, together with the socio-economic actors, the relevance of these financial mechanisms and their possible accordance with the challenges related to the revitalization of the affected territory;
- In line with recommendation no. 3, search for other strategies of financial support not relying on geographical approach (zoning) but for instance on a sector-based approach;
- Further investigate the possible drawbacks of such financial mechanisms and try to find ways to provide flexible financial support that foster the social cohesion and the economic resilience.

By whom?

National/local public authorities, OECD, EC, socio-economic actors (e.g. producers, retailers, Chambers of Commerce, Chambers of Agriculture, Trade Unions and cooperatives, etc.)
TERRITORIES recommends to

5. Develop decision support tools to enlighten decision and choices of remediation strategies and options

Why?
As shown in D9.65, different remediation strategies have been implemented following past nuclear accidents. For the agricultural sector for instance, the decontamination strategy following the Fukushima accident was mainly based on a systematic removal of the top-soil, whereas in Chernobyl decontamination was rather driven by a cost-effectiveness-based approach for selecting agrotechnical and agrochemical countermeasures. The STRATEGY, FARMING, EURANOS and PREPARE research projects (see footnote 2) all highlighted that the implementation of countermeasures needs to be aligned with the specificities of the affected territory and cannot be implemented in a generic way at the risk of being ineffective. More generally, D9.66 and D9.69 highlight the importance of adapting remediation strategies to the needs of the people living in the affected territory and to give more flexibility to these strategies by allowing locals to select the most appropriate ones. In addition, feedback from Chernobyl and Fukushima accidents have also shown that radiological criteria (e.g. MPLs, derived reference levels of exposure, etc.) can be challenged and questioned by various stakeholders notably because of their economic and social consequences (e.g. food consumption and trade, waste management strategy, etc.). Remediation actions have also to be managed for a long period of time during which social and economic situation may drastically evolve (decrease in financial resources, saturation of contaminated wastes storage or disposal endpoints, cf. recommendation 6). D9.69 suggests that it would be interesting to use the notion of dynamic zoning over time to prioritize the actions to be taken (here we do it now, there we will do it later) rather than static zoning stigmatizing static differences (here we do something, there we do nothing) and open up for more perspectives and opportunities for people to project themselves into the future.

How?
Before discussing remediation strategies with local actors, it is important that experts review the different options that can be implemented in the different environmental compartments (soils, water, etc.), each option being characterised by the objective of protection (e.g. residual exposure), cost, feasibility, effectiveness and long-term robustness. Evaluation of remediation options through specific criteria and methods (e.g. multiple-criteria decision-making tools, life-cycle analysis methods) giving a holistic view of the situation (considering the different aspects of the remediation options out of the radiological one, including for example the side effects of remediation on the environment) should also be further investigated by experts to better accompany locals in their decisions. A participatory process is necessary to engage affected people and involve them in the decision process (cf. recommendations 1 and 2) to enhance the trust of people in the selected strategy and adapting the strategy to the worries of the different affected communities (recommendation 3). There is also a need to maintain this dialogue during the remediation process itself to take into consideration the possible evolution of the situation. This highlights the need to anticipate as far as possible the evolution of the contamination in time in order to help in selecting the remediation strategies. This can be one of the purposes to develop prospective radioecological models (cf. recommendation 10).

By whom?
Public authorities, experts develop the prospective tools, the alternatives with local communities and economic actors, give advises, explanations on the tools and discuss the different alternative and associated issues.
TERRITORIES recommends to

6. Anticipate waste management difficulties in building a strategy in relation with populations

Why?
Experience from both Fukushima and Chernobyl accident illustrated that the definition and application of a remediation and waste management strategy require a clear and operational organisation in order to be as effective as possible. This requires procedures, guidelines, and criteria in order to facilitate the remediation actions and the waste management in respect to the radiological protection rules. The technical feasibility, the effectiveness of the remediation actions and the human resources to implement these actions are key aspects of the remediation strategy. Even for countries having advanced nuclear technology, the existing disposal sites dedicated to radioactive wastes are not designed to accept the huge volume of wastes generated by such large accident like Chernobyl or Fukushima (D9.65). As an example, part of the Japanese strategy relies on the reduction of large volumes of combustible wastes and the possible reuse or recycle contaminated wastes in non-contaminated waste management streams. In addition, specific facilities (e.g. the so called Interim storage facility - ISF - and incineration centres) have been built to treat the most contaminated wastes to reduce their volumes and facilitate their management. However, waste management strategies require agreements on thresholds and criteria, which in turn depend on the nature, origin and ultimate use of the material (e.g., in roads, dams). Identification of appropriate streams, the availability of storage or disposal endpoints and the definition of threshold values guiding these alternatives are important source of uncertainties that can only be addressed with the involvement of the appropriate stakeholders. Indeed, feedback from Fukushima accident illustrates that Japanese government took the decision on the waste management strategy, without any consultation of the local population, which lead to rejections and fears about the presence of waste storages. In this context, reflection on waste management strategies needs to involve the affected populations.

How?
In order to anticipate a probable saturation of waste streams (treatment, storage, disposal), reflections should be conducted on a waste management strategy combining reduction of product volumes, adaptation of the standards defined for the management of the radiological waste, and orientation of contaminated waste towards conventional treatment channels. It will be necessary to check that conventional treatment facilities (incinerators, waste water treatment plants, etc.) and storage plants can manage very low-contaminated wastes in compliance with the radiation protection rules, and that the implementation of such a strategy is not detrimental to existing recycling systems. Such decisions, as well as how to organise the different steps (first storage at local levels, transport, temporary storage, recycle…), the monitoring and sharing of information on the management and radiological situation require the involvement of local stakeholders. In accordance with recommendations 1 and 3, such work needs to be carried out with the populations to ensure that their concerns and expectations, as well as economic issues, are taken into account. Waste management (particularly VLLW) is much less a question of health policy than of society’s choice regarding the use of financial resources to be devoted to it as well as a question related to the quality of the environment itself. The enlightenment of experts, authorities and industrials is necessary, but the decision on the management strategy to be taken cannot rely only on their own view. Civil society should be fully associated with it. Therefore, it is necessary to create the conditions for debating the issues linked to the proposed doctrinal developments and to build with civil society the avenues to explore (recommendation 1).

By whom?
Population, public authorities, experts.
IV. Reliable co-constructed monitoring

Sustainable management of a contaminated environment requires appropriate participatory processes to produce reliable assessment of the radiological situation and its potential evolution in the future. Although the importance of providing public access to monitoring equipment has been long recognised in post-accident management (e.g., STRATEGY, ETHOS), this was even more widely acknowledged following the Fukushima accident (e.g., PREPARE, SHAMISEN)\(^6\). To that extent, TERRITORIES strongly supports a co-constructed monitoring, involving experts and citizens, by notably developing appropriate tools, methods and structures dedicated to radiological measurements and their interpretation and analysis. The involvement of young generations to foster a long-lasting citizen vigilance is also addressed.

---

\(^6\) See references in footnote 2
TERRITORIES recommends to

7. Sustain long-term citizen awareness with the creation and intergenerational transmission of a radiological protection culture

Why?
The uncertainty and the variability of the radiological situation over the long term makes it necessary to establish means for maintaining the awareness of local communities over successive generations (D9.63). Feedback from Chernobyl and Fukushima accidents showed that it is important for residents of affected areas to keep the memory of what happened and how the situation is managed and evolves. The engagement of the population in surveillance of the radiological situation represents an essential component of a sustained vigilance within affected areas over the long term. The Fukushima accident also re-emphasized that engaging the concerned populations as agents of their own protection is a powerful tool in order to support the production of useful and reliable data for a shared and reliable characterisation of the radiological situation (see for example SHAMISEN recommendation no.28).

To initiate a sustainable culture of radiation protection at the community level that is adapted to the local situation (given the specificities of each territory), feedback experiences have highlighted the need to involve young generations in local monitoring projects. As a matter of fact, involving young generations seems to be a good way to develop practically and transmit within family, radiological protection skills, competences and knowledge (D9.65). Therefore, citizen science approaches and the use of technical devices (mobile apps, virtual reality, drones, social media, blogs, etc.) entice young generations to contribute to a sustainable and collective vigilance.

How?
It is expected that a close and open-minded cooperation between institutional and non-institutional experts, national and local authorities and the population living in contaminated areas is an effective approach for maintaining a long-term vigilance. During the preparedness phase, it seems important to provide opportunities for local actors to create the conditions for an intergenerational transmission of experience and knowledge and lay the foundations of citizen vigilance.

- Develop local projects co-constructed by authorities/citizens/experts that initiate the awareness of the radiological situation (e.g. by describing the reference status and initial radiological characterisation of the territory) maybe starting in priority in the vicinity of NPPs;
- Involve experts (institutional and non-institutional) in participating to citizen science ('on the field') projects and train them to disseminate a practical radiological protection culture among the population;
- Identify, train and involve local stakeholders (e.g. in the educational sector) in practical radiological protection as they could act as local ‘advisers’ in case of an accident;
- Develop monitoring tools and devices that entice population, and especially young generations, to participate to such local projects;
- Create networking structures to sustain exchanges between actors involved as of preparedness phase and investigate how this network can evolve in case of an accident (e.g. mistrust towards authorities, new actors willing to get involved, etc.).

By whom?
Public authorities, experts, local stakeholders, universities and schools, NGOs, manufacturers of monitoring tools and devices.
TERRITORIES recommends to

8. Encourage an integrated radiological monitoring system and the implementation of a joint database platform

Why?
Past research projects (e.g. PREPARE, SHAMISEN) emphasized the fact that trustworthy in-situ measurements help the local population to understand what is at stake in their own environment (D9.65) by helping them to make their everyday life easier “making the invisible visible”.

In post-accident situations, most decisions involve and impinge on a wide range of stakeholders (e.g. official institutions and national agencies, socio-economic actors, citizens, etc.). The environmental and health surveillance systems should be as comprehensive as possible: gathering data and information on the radiological situation from various providers, with different aims and desired accuracy (D9.66). In this context, measurements performed by the different stakeholders are complementary and can be grouped to constitute an integrated database reflecting the radiological situation at stake and its space and time variability.

Nowadays, the development of new mobile and connected devices, the acceleration of information sharing networks and the progress of the open data approach, call for the creation of an integrated and shared monitoring system (D9.66). Embracing these technologies can help to reduce uncertainties related to the ‘radiological characterisation’ and ‘social trust’.

How?
The implementation of an integrated system which gathers all measures produced by different actors (e.g. institutions, socio-economic actors, scientists, citizens) could provide a better characterisation of the environment and environment-related health issues. This would lead to a better response i.e. more effective countermeasures that could be undertaken in a climate of reciprocal trust between stakeholders. Key actions would include:

- Fund and develop an integrated platform for monitoring data which respects the data multiplicity by notably tracing and displaying their origin and acquisition techniques and conditions (e.g. devices used, sampling protocols (D9.60), measurement uncertainty, etc.);
- Scale the integrated platform to improve the completeness and accuracy of data produced by all actors (from local to national levels) and its evolution over time;
- Display monitoring results through open data portals (e.g. maps);
- Evaluate monitoring capabilities, financial and technical supports, types of structure (e.g. laboratories) and the associated operating modalities that would improve the production of monitoring data and information adapted to the needs of local residents. For instance, pay attention and give warnings to the users about the quality and limitations of measurement devices (e.g. smartphone apps);
- Define easy measurement protocols that will help population to produce quality data and that can be compared with the monitoring results of the institutional actors;
- Define the pluralistic governance of such an integrated platform as of the preparedness phase as well as in case of an accident;
- Investigate the ethical issues associated with the open access to data: georeferencing, confidentiality, potential economic impacts (competition, loss of values and image, etc.).

By whom?
Local and national authorities, experts, population, socio-economic actors, manufacturers of monitoring tools and devices.
TERRITORIES recommends to

9. Develop hubs of co-expertise for monitoring data interpretation and analysis

Why?

Post-Chernobyl and post-Fukushima accident management shows that the pluralism of organisations involved in the implementation of the radiation monitoring system is an important factor to favour confidence in the measurements (e.g. CORE programme, ICRP dialogue initiative in Fukushima)\(^7\).

Facing this observation, the recommendation no. 8 pleads for the creation of a joint database platform that gathers monitoring data produced by citizens and institutional actors. However, monitoring results *per se* are not meaningful for non-specialists. Indeed, experience also shows that multidisciplinary and pluralistic analyses of monitoring data are key levers of success to allow the population to better catch what is at stake in their own environment and to become actors of their own radiological protection (D9.65). This argues for a joint data analysis between all the monitoring actors to provide trustworthy interpretation.

How?

In this context, hubs of co-expertise should be created gathering all actors that could be involved in the characterisation of the environment in case of an accident (e.g. experts, authorities, citizens, NGOs, socio-economic actors) in order to implement joint interpretation and analysis of monitoring data. During the preparedness phase, concrete actions could lead to:

- Create ad-hoc structures, working groups, networks, etc. to engage in a joint data analysis process the various actors that could be involved in the environmental monitoring;
- Develop analytical tools that would facilitate the joint-analysis of data and that would help to deal with the management of data flux, the quality of measurements, geostatistical interpretation of measurement results, trend analyses, etc;
- Develop communication and information tools aiming at giving sense to the results;
- Rely on existing measurements networks (e.g. RNM\(^8\), SAFECAT\(^9\), Berkeley RADWATCH/DoseNet\(^10\), OpenRadiation\(^11\)) to practice co-expertise, challenge the analytical and communication tools and develop intercomparison exercises.

*By whom?*

Public authorities, population, socio-economic actors, experts.

---

\(^1\) Ibid footnote 1 and Lochard *et al.*, 2019
\(^2\) https://www.mesure-radioactivite.fr/
\(^3\) https://blog.safecast.org/
\(^4\) https://radwatch.berkeley.edu/dosenet/map
\(^5\) https://www.openradiation.org/
V. Technical tools serving post-accident governance

This section of the present report has been written in parallel with an equivalent section entitled “2. Technical resources in assessment of the situation” of the companion report D9.72. Recommendations 11, 12 and 13 introduced in this section are therefore similar to recommendations 1, 2 and 3 of D9.72, except for some specificities of application to NORM versus post-accidental situations.

The challenge here is to develop methods and tools for assessments that have the least possible uncertainty and thus maintain the confidence of the population in the relevance and quality of scientific expertise and the justification of public policies.

The aim of TERRITORIES has been to improve methods and tools to reduce uncertainty on impact assessments on people and the environment. An improvement of the knowledge of the uncertainties of these tools makes it possible to better control the domains of validity and the limits; identify the knowledge to be improved in order to reduce it, guide decision-makers on the relevance of management choices to radiological issues and, where appropriate, explain to the populations the limits that scientific tools face in the knowledge of evaluation impact.

This section addresses the use of models and/or measurement data, and their data analysis, to characterise contamination (recommendation 10), the complexity of evaluating impacts on the biota (recommendation 11), and the quantification of uncertainties in dose assessment (recommendation 12).
TERRITORIES recommends to

10. Use measurement and modelling appropriately to characterise the contamination

Why?

As described in D9.61 and D9.65, decisions made during the emergency and (early) transition phases are largely based on calculations and assumptions, whereas decisions made in the long term usually rely on field data. To characterise the contamination, using real site data should always be the preferred option. The choice of the measurement approach has to depend on the requirements of the assessment (i.e. on the purpose). In some cases, notably if citizen measurements are numerous, such datasets might be huge and tools adapted to deal with such big data are expected.

A short-coming of environmental measurement data is that they only give a snapshot of the environmental situation at a given time. For prospective assessments (see also recommendation 5), a radioecological model (i.e. providing output quantities such as activity concentrations and dose rates in units of Bq kg\(^{-1}\), Bq L\(^{-1}\), Gy h\(^{-1}\)), ideally one that has been calibrated and validated specifically for that situation, must be used to predict how the contamination patterns evolve into the future.

In all cases, cooperation of actors (i.e. those measuring environmental radioactivity, those modelling if any, and those assessing radiological impact), at all stages of the assessment (i.e. as early as the sampling campaign is designed), is the recommended way to ensure the selection of the most suitable characterisation of the environment.

How?

Regarding field data, D9.60 develops specific recommendations about radiological monitoring/sampling to ensure representative sampling during sampling campaigns, giving different examples of how to perform representative sampling. To make decisions, non-measurable quantities such as effective dose for humans are used. Those quantities are calculated by using real measured values of physical quantities, which should be properly quantified. Activity concentrations in soils or vegetables, or ambient dose rates are examples of those measurable quantities. How to properly determine correct values for those measurable quantities is one of the main concerns for assessors.

Through the example of datasets acquired by aircrafts flying above Fukushima prefecture, D9.60, D9.62 and D9.74 have also explored geostatistical tools to analyse spatial variability and to quantify it uncertainty. Beyond the scope of what was achieved within TERRITORIES, it could be useful to develop further such tools to analyse big data of ambient dose rates including citizen measurements (cf. recommendation 8), possibly in poles of co-expertise (cf. recommendation 9).

Regarding prospective models, D9.61 develops specific recommendations about fit-for-purpose radioecological modelling. Depending on whether the project is (a) to understand and predict the fate and transport of radionuclides in the environment, or (b) to perform a dose assessment, a suitable, fit for purpose model can then be used. Such models include either process-based modelling, which is recommended for fate and transport purposes, or dose assessment tools. The cooperation of modellers and experimentalists at all stages of the study (from conceptual model and sampling campaign design to assessment) is the recommended approach to ensure minimisation of uncertainties and the selection of the most suitable experimental and modelling approaches and the measurements necessary for them.

By whom?

This recommendation addresses institutional actors: academics, authorities and their TSOs (Technical Support Organizations), and more specifically those who measure and/or model environmental radioactivity and those who assess doses and treat these data.
TERRITORIES recommends to

11. Consider the complexity in assessing radiological exposures to non-human biota

Why?
Recent efforts have been made by international organisations (such as IAEA, ICRP and UNSCEAR) to include protection of non-human biota from ionising radiation in their guidance. This has resulted in an increased international practice of including protection of biota to environmental impact assessments. Although protection of biota is of growing interest to the international radiation protection community and is increasingly recognised as a necessity, the level of its implementation is so far not harmonised across different countries. Therefore one should take into consideration the local legislative context as well as the practical requirements set out by regulators in this regard. The system for the assessment of dose to non-human biota is simplified compared to the assessment system for humans. Organisms are represented by simple ellipsoidal geometries, the dose rates and effects are assessed for the whole body (no individual organs are considered), the dose conversion coefficients are for simplified exposure scenes, radiation weighting factors are not established. The transfer from environment to biota is determined by transfer factors rather than using biokinetic models. The protection target is at the level of the population (no individuals are considered per se), and dose rate benchmarks are determined on the basis of individual species sensitivity information, whereupon an ecosystem protection approach is assumed. These simplifications are necessary given the large variability of species, habitats and occupancies, and radiation sensitivity. D9.63 discusses the complexity of estimating the dose rate to wildlife due to the wide biodiversity and variability between modes of life. Controversies about the level at which significant effects may be observed, result partly from uncertainties in field dosimetry. An example is the use of inadequate proxy values, such as the ambient dose rate as a proxy for absorbed dose rate, leading to potentially misleading associations between dose and effects, especially in mobile species covering an inhomogeneously contaminated site.

How?
D9.63 identifies the important parameters in assessing doses to wildlife and highlights some of the difficulties to quantify them. Therefore it is recommended:

- To quantify both external and internal doses. Even when dose is estimated with animal-borne detectors a significant contribution to the measured dose may come from internal contamination.
- To take special precautions when estimating the dose received by the biota by measurement, i.e. to understand the uncertainties and pitfalls of field dosimetry. Ambient dose should not be used as a surrogate for dose to biota.
- To use a consistent dispersion and transfer modelling approach, for both the human and non-human biota, as first step in the dose assessment.

By whom?
This recommendation addresses institutional actors, including academics, authorities and their TSOs.
TERRITORIES recommends to

12. Establish a dialogue about uncertainties and their impact on assessment

**Why?**

Uncertainties are inherent to scientific outputs and how they will be identified or quantified needs to be discussed at an early stage of risk assessment with the authorities or actors involved in the decision-making process since this will have an impact the decision and/or remediation actions. The aim is to support more realistic evaluation of the predicted exposure to humans and non-human biota to support decision making. Such technical uncertainties may also influence the way the public view the outcomes of risk assessment and the decisions taken, as the trust in the decisions and methodologies used can increase or decrease as a function of communication of uncertainties.

**How?**

**Before any model is run,** the methods with which the uncertainties on the output will be tackled (i.e. either identified, in a list or in a text, or quantified, e.g. with a probability distribution) by modellers and assessors need to be discussed with decision-makers. Different types of uncertainties to be tackled include parameter/input uncertainty, uncertainty of the model structure, scenario uncertainty and monitoring uncertainty. They need to be considered and prioritised to the extent to which they impact the overall uncertainty of a model output (e.g. dose rate, or dose). The choice of the methods to identify or quantify uncertainties will depend strongly upon the purpose of the assessment, the feasibility of the model for this purpose and the data availability. An uncertainty analysis with quantification of different types of uncertainties, for example with a probabilistic output i.e. a probability distribution of outputs as concentrations, dose or dose rates instead of a single point estimate, is encouraged as the test cases in D9.62 demonstrate. Such probabilistic approaches can take good account of expert judgment and information from available data and will use the most up-to-date approaches within the scientific community. Nevertheless, a drawback is that results are obtained in the form of probability distributions (a set of different possible values), instead of a deterministic answer, and these outputs will need to be clarified to the end-user (decision-maker or public) and might lead to more difficult decision-making.

**After a model has been run,** and whatever the format of the output (distribution or single value), it is important to explain modelling results with expert judgement to support the decision or inform the population. This expert judgement can be fed by uncertainty analysis (are the highest predicted value beyond the reference value?) and by sensitivity analysis (which uncertainty contribution most impacts the output’s uncertainty and might impact the decision-making?).

**By whom?**

This recommendation addresses institutional actors: academics, authorities and their TSOs (Technical Support Organizations), and more specifically those who measure and/or model environmental radioactivity, those who assess doses, and those who take decisions on the basis of these outputs. Cooperation between them is important to ensure a consistent approach, particularly when it comes to communication to the public.
VI. Conclusion

This guidance document constitutes the final report of TERRITORIES project and builds on the collection and cross analysis of work provided by the different WPs. Its main objective has been to elaborate recommendations on how to deal with uncertainties in risk assessment and decision-making processes taking into account the preferences of stakeholders, especially those who are directly impacted by the adverse effects of long-lasting exposure situations. The present document also takes into account the comments provided by a wide range of experts and a broad audience of all stakeholder categories, on draft documents that were submitted for discussion at the final TERRITORIES event.

In the radiological protection system, radiological exposure situations in the long-term after a nuclear accident, or a contamination by Naturally Occurring Radioactive Materials (NORMs) are generally identified as “existing exposure situations”, and their management follow the same principles and are mainly driven by radiological protection considerations. Many international documents insist on the importance of taking into account other dimensions than the radiological impacts and recognised that the complexity of post-accident situations cannot be managed without addressing all dimensions of daily life (i.e. health, economic, social, environmental psychological, cultural, ethical, and other aspects), which bring a high degree of uncertainty in decision-making process and decision-taking.

This guidance document identifies key recommendations to enhance decision-making processes using an innovative approach. This has been done by taking a systemic view of the post-accident situation that attempts to embrace all the dimensions of such complex situations and that places population concerns and resilience at the center at each step of the process. This required an integrated approach made possible by collaborative work between multidisciplinary skills such as human and social sciences, nuclear metrology, radioecology, radiation protection, modelling, etc.

This work also relies on the development and use of multi-actors interaction processes that involved post-accident stakeholders in order to create the conditions of a structured, fair and constructive dialogue between actors having different views and concerns. This constitutes a first step to identify the main uncertainties of concern and to explore the difficulties that have emerged with the management of existing exposures that have arisen to date, with a view to developing improved mechanisms for use in the future. This analytical approach by causes and consequences of decision making embracing all the dimension of the recovery process constitute a mean to make a diagnosis of such situations that could help in reducing uncertainties to a level that can be considered fit-for-purpose considering the circumstances and constitute a way to deepen to give some concrete followings to how the “reasonably” could be traducted in concrete actions for the management of post-accident situations.

Next step are to:

- to test the relevance of this methodological approach to identify key sources of uncertainties that could impact decision-making process, and the ability and efficiency of the recommendations to enhance decision making process in considering the life of affected people and/or the state/quality of the environment and wildlife,
- to apply these recommendations as a support to preparedness in more concrete situations during crisis exercises addressing post-accident phase, or in affected territories to foster the building of rehabilitation projects; through dialogues in the territories, and with national and international authorities, development and improvement of technical tools....
• to investigate in research programs some aspects of the decision-making processes such as the roles and responsibilities of national and local actors and their potential coordination;

Any decision made at each phase after a nuclear accident (emergency, transition), will have consequences on what would happen afterwards during the post accident management phase, by decreasing or increasing the level of uncertainty underlying the forthcoming decisions. The way uncertainties are propagated in time during these different phases should be further investigated.
VII. References


In addition, references denoted Dx.yy refer to CONCERT deliverables, available on http://concert-h2020.eu/en/Publications. Among them, TERRITORIES deliverables (D9.59 to D9.79) are also shown on: https://territories.eu/publications. Extended abstracts of TERRITORIES deliverables cited in this document are presented in section VII.
VIII. Extended abstracts of CONCERT-TERRITORIES deliverables quoted in this report

D9.60: Guidance to reduce sampling uncertainty

Deliverable 9.60 addressed one of the aspects of the radiological characterisation of long-term contaminated territories. Such characterisation can be based on multiple monitoring resources and therefore will depend on the methods used, the spatial and temporal integration scales applied, the actors performing the measurements and the objectives of the monitoring campaign.

Levels of radioactivity concentration in the environment compartments (air, soils, food, water, etc) are not only variable with time, due to several processes, including radioactive disintegration, migration and dilution of radionuclides, but also in space, mainly because the initial radioactivity is not homogeneous in the contaminated areas, but also due to other aspects as the characteristics of the area. Moreover, the processes used can change with the time.

To make decisions, non-measurable quantities such as effective dose for humans are used, in present and future generations. Those quantities are calculated by using measured values of physical quantities, which should be properly quantified. Activity concentrations in soils or vegetables, or ambient dose equivalent are examples of measurable quantities. How to properly determine correct values to those measurable quantities is one of the main concerns for assessors and for decision makers. Moreover, for many applications the values are not measured, but estimated using available models. Obviously this determination possesses a degree of uncertainty, and the possible uncertainties and variabilities which can affect the final result should be also properly determined. One of the sources of uncertainty, well-known and treated in other fields, as in chemical laboratories but also in radioactivity measurements and often not quantified as a part of the measurement process in radioecology is the so called sampling uncertainty.

Many authors state that sampling uncertainty is often the most important contributor to the total uncertainty of the measurement process, especially in environmental sciences. Nevertheless, little attention has been paid to properly characterise it, neither when designing in-situ measurement campaigns nor when defining sampling criteria to reduce the associated uncertainty as much as possible, i.e. to properly characterise variability at different spatial scales. There are methods to quantify this uncertainty, like the empirical or top-down approach, repeating the sampling as often as needed, using different sampling instruments, protocols; or the modelling or bottom-up approach, using a predefined model from sampling theory.
To calculate sampling uncertainty many aspects should be considered: the temporal and spatial variations, but also the size of the sample, or the collection/acquisition time. The intention of this document was not to create new methods to address this specific problem, but to compile all available information to provide guidance to other scientists.

One of the problems is how to define optimum locations for monitoring and sampling, but also how to optimise the number of samples necessary to adequately characterise the variability of the contaminations in a given time and area. Some methods are based on expert judgements, which define a priori what should be measured, where the samples should be taken and what the size of the samples should be. Some other methods statistically define the optimum locations and the number of samples to be taken, based, among other parameters, on the level of contamination in a given location. None of those methods are perfect for every situation, and combinations of methods are often necessary. For instance, a purely random sampling can detect by chance every hot spot in a contaminated place, but it can also skip them. A systematic stratified method would provide a general idea of where the locations of the more contaminated zones are. But still there are specific problems, as for example those related only with hot-particles that require a further refinement.

The problem can be approached in a multi-stage process:

1. Broadly identify where the contamination is expected by using expert judgement. This is often based on previous experience or information, or on the outcome of dispersion models. This first stage can clarify whether hot particles are expected to be correlated with zones of high activity levels or not. This first stage can cause problems if the initial information is not sufficient.

2. Secondly use any of the methods mentioned in D9.60 (e.g. random, stratified or adaptive cluster sampling) to define the location of all the samples required, within the area previously defined. Also specify the number of samples and their size (e.g. in terms of mass, volume or time).

3. Refine the initial characterisation of the zone by using the quantities previously monitored. The use of quick ambient dose equivalent measurements (by foot, car or plane) to provide a general view is an example. In this stage as many refinements as necessary should be performed. For example, if higher activities are found in given locations, more exhaustive monitoring should be performed in those more contaminated zones, while less effort is required in the less contaminated zones.

4. Interpolate all the measurements performed in the previous stages and in laboratories, to provide quantitative results in the entire affected zone. Kriging methods, for instance, are used for a multi-dimension interpolation.

This process will provide an acceptable characterisation of the contamination in a zone. Several aspects should be considered in the characterisation of the sampling uncertainties:

Repeatability of monitoring process: A sample or in-situ measurement cannot be repeated under exactly the same conditions. For instance, if a sample of soil is taken to make laboratory measurements, a second sample of soil at the same location will be only approximately the same, but it cannot be identical. The same will happen with airborne measurements. In this case, a second survey after some years will be very difficult to be done at exactly the same points and the measurements will be different because of several processes (e.g. radioactive decay or migration due to rainfall). Some effects can be taken into account by mathematical corrections, as for example corrections for radioactive decay.

Fractal character of the contamination: When using higher and higher resolutions to characterise the radioactivity in a zone, a similar contamination pattern can be observed due to unavoidable variability. The contamination pattern is in principle smaller when the resolution is higher, but with a very similar
shape of the contamination pattern. This problem continues even in the scale of a laboratory analysing samples. For example, the measurement of several 1 kg soil samples, taken at the same location, will provide a distribution of the measured quantity, which will be characterised by the expected values of that quantity (usually average and variance). However, if one of those samples is used to take for instance 10 aliquots of 1 mg to perform alpha spectrometry, the same pattern will be expected. Moreover, the possibility of finding hot particles increases in those small samples.

This problem continues if additional dimensions are included. For instance, creating 2D maps of contamination in a given space doesn't imply that the contamination in depth (3D maps) will be known.

Movement of the radionuclides in the environment: A survey campaign by means of in-situ measurements (in-situ gamma spectrometry, or ambient dose equivalent), or by sampling material from the contaminated area, and interpolating the measurement results, will provide a view of the observed quantity at that given point in time. However, many processes will affect the concentrations of environmental media with time, more importantly when the interesting periods can be thousands of years. Time dependence is usually modelled and sometimes the validity of the models is checked by repeating the measurement campaign at different points in time. Some of the time-dependent effects are well known and can be easily corrected, as the radioactive decay. The uncertainties arising from sampling and monitoring should be included in the uncertainties propagation of the models.

In summary, this deliverable D9.60 describes and explains some of the methods proposed in the bibliography to address and discuss sampling uncertainty. Effort should be taken to explain and train laboratory staff in charge of performing sampling and monitoring campaigns in order to implement a method to quantify the sampling uncertainty.
D9.61: Guidance to select level of complexity on radioecological models

Models in radioecology, as in other fields, have several purposes, the most important being the prediction of the behaviour of radionuclides in different ecosystems and the understanding of the processes driving that behaviour. These models are often finally used for regulatory purposes by transforming the values to a limiting quantity, such as effective dose or absorbed dose to demonstrate the protection of humans or biota respectively. To account for the consideration that several processes are not perfectly known, a considerable overestimation of the predictions is normally included in the models. Moreover, the final estimations of doses are directly proportional to the estimations of activity concentrations in the environment. Obviously, for many applications, only models can be used for prognosis such as predicting future activity concentrations. For that reason, and to avoid undue restrictions caused by poor results of the models, improvement of models is desirable and a continuous effort in this direction is needed. In D9.61, a methodology which can be used to systematically improve the models is presented by providing a conceptual overview of the system through the use of Interaction Matrices and Features, Events and Processes.

For the developers and the end users of the models, objective indicators to show whether models are improved or not, are desirable. A methodology combining quantitative and qualitative indicators was elaborated.

In the report a comparison of widely used models (usually simpler) with more advanced models (usually more complex) has been carried out in those sites included in the Territories Library Database where a compilation of measured data was included. Specifically several models have been applied in the Norwegian Fen site (NORM), in the Belgian NORM site, in the Fukushima forests contaminated by the FDNPP 2011 accident and in the West Cumbrian beaches, contaminated by releases from the Sellafield reprocessing facility.

This deliverable can be regarded as a methodology to improve and show objectively the improvement of models applied to real case studies of long-term situations where contamination exists (often referred to as legacy sites). Applications in different situations can be seen as examples of implementing this process. Several recommendations were provided:

Developing a model

- Develop a model that is as simple as possible but able to predict over a wide range of possible conditions. Ideally, one might use the model to be applicable over a broad number of different compartments in the environment, yielding outputs/results that are adequately (or closely) correlated with empirical measurements. This should be achieved with the highest realism (or accuracy) that is practicable, without losing the characterisossibility of including a degree of conservatism in the case regulators need their use.

- Typical steps for model development: (1) Model Study Plan, (2) Data and conceptualization, (3) Model set-up, (4) Calibration and validation and (5) Simulation and evaluation.

- Formulate the problem and define the assessment context, considering the model might either be specific for one given assessment, or generic for a range of assessments.

- Efforts should be made to map and characterise uncertainties at all stages of the model development where practicable.

- Attempt to document whether all processes are captured. This might involve the development of a conceptual model or the consideration of existing models. One way to achieve this may be through the application of an Interaction Matrix (IM) together with Features-Event Processes (FEPs) analysis.
• Keep the number of independent model parameters as low as practicable. Adequately representing mathematically the processes to an adequate level of complexity is a very important challenge. In cases where various models are available for a given radioecological problem the model with the optimum structure should be selected.

• Transform the conceptual model into a mathematical representation and computer coding in a rigorous manner. That means not only determination of the different mathematical equations for every process, but also appropriate characterisation of every parameter included in every equation, in most cases site-dependent to obtain enhanced accuracy.

• Ensure adequate quality assurance. Obviously, an adequate quality assurance is needed in all the steps to establish whether a model is fit for purpose and that the correct level of complexity has been selected.

• Provide appropriate model calibration and validation. This might involve obtaining locally determined parameters and input data for the calibration, a comparison with measurements which is part of the validation of the model within the bounds of the applicability and uncertainties.

• Use appropriate model performance indicators. In order to test the goodness-of-fit of a given model in a given situation, several metrics exist, as the Root Mean Squared Logarithmic Error (RMSLE), BIAS and MG (RMSLE and MG are defined as unitless statistics for quantitative performance measurements of a given model. In addition to these metrics, qualitative indicators are necessary for the purpose of judging the quality of a model.

• Involve stakeholders. The development of a fit-for-purpose model is a procedure that should involve all the stakeholders, from the beginning and at all stages of the process, such as those involving (i) the establishment of the desired level of accuracy or conservatism, (ii) the validation of the model to show how accurate the model behaves under different situations and (iii) the demonstration (including quality assurance) that a robust system has been developed.

Selection of a model (prior to performing assessment)

• Select criteria that can be used to establish model adequacy. These criteria ideally should be specified in terms associated with measurable quantities, such as radionuclide activity concentrations or external exposure (equivalent or absorbed dose), although often non-measurable quantities are used for selecting the criteria (e.g. effective dose). Selecting a model that is adequate or fit-for-purpose for a given objective is an important step that needs to be performed in advance of any assessment. This process would be, among other considerations, dependent on the context of the assessment and that this should be informed by stakeholders. A central role in this process should be played by the end user, who will use the outputs of the model and who have all the information related with the application context and purpose of the modelling.

• Uncertainty which the end user is ready to accept in the assessment. If the final result does not have a satisfactory uncertainty outcome, the selection of a more refined model and/or another model may have to be considered.

• The ability of a model to reproduce measurable data in the range of application. A suitable methodology for comparing correspondence between modelled and empirical datasets has been developed in the present deliverable.

• Aim towards the simplest practicable model. In many applications in dose assessments for humans and biota, requiring prediction of radionuclide behaviour and fate, accuracy is often achieved
by including additional complexity within the models. Conversely, conservatism, in many situations, is sometimes achieved by simplifying the models.

- Be aware that models have different ranges of application. Many new models are developed for very specific situations, for instance, to model the dispersion and migration of radionuclides in a specific type of soil with given characteristics (pH, CEC, granulometry, humidity, porosity, chemical composition, microbiota, etc), and transfer to a specific type of vegetation (there are, for example, known important differences in the uptake and translocation of radionuclides in different plant species, e.g. pine, wheat, tomato). This specificity might (although with no guarantee) ensure high accuracy for the given situation, but a slight change in the conditions will give completely different results and may lead to a loss of accuracy. An example of such a case is the coupled tree and soil ‘compartments’, as used by forest models. The application of the same model, using the parameters determined from Chernobyl-contaminated environments, to a different nuclear accident, e.g. Fukushima accident, provides less than convincing predictions. For this reason, there is a requirement for local parameters to be determined and site-specific models to be developed. Moreover, there are important limitations in the use of more complex models with many chemical parameters, in a new situation, where this information is often not available.

Use of a model in an assessment

- Employment of tiered or graded approach. This is especially relevant, with regard to modelling applications within assessments associated with regulation, where the endpoint is to determine whether the risk associated with an exposure is acceptable. As widely used models tend to overestimate the consequences in every situation, the tendency is to develop new models that are able to obtain accurate predictions in particular situations, thereby avoiding an unneeded expense of resources to overprotect populations of humans or biota.

- Provide rigorous evaluation of the model. This evaluation is obtained by the use of the selected, calibrated and validated model and should address whether the model application meets the objectives of the assessment.

- Involve stakeholders. The implementation of a fit-for purpose model is a procedure that should involve all the stakeholders, from the beginning and at all stages of the process, such as those involving the demonstration (including quality assurance) to show that good results have been achieved.

- Decide whether the analysis needs to be deterministic or probabilistic and, if the latter is required, the model should be developed by using relevant mathematical techniques.

There is a general requirement in the field of radiological protection to ensure that the application of the system of protection is commensurate with the radiation risks associated with the exposure situation.
D9.62: Guidance on uncertainty analysis for RADIOECOLOGICAL MODELS

Radioecology is the discipline that deals with quantifying the transport of radionuclides in the environment and their transfer from one environmental compartment into another. The endpoints of radioecological models, i.e. activity concentrations and ambient doses rates, provide the basis for calculating the doses to humans and non-human biota, which in turn are the input for carrying out an environmental risk assessment and support decision-making for management activities at contaminated sites.

The activity levels of radionuclides in the environment can either be quantified via measurements or via radioecological models, if measurements are not possible or not feasible with reasonable effort. Radioecological models need to account for many physico-chemical and biological processes that occur in nature and their large variability.

Depending on the purpose of a risk assessment (e.g. realistic or conservative) and the extent to which environmental processes are understood in detail, radioecological models range from extremely simplified representations of reality (e.g. transfer factor model) to rather sophisticated and complex ones (e.g. process-based models for quantifying wet interception). Radioecological models are often implemented using simulation software that facilitates the development of compartment models by automatically generating the corresponding system of ordinary differential equations or written from scratch using programming tools and languages such as Python, C++ or R. In any case, radioecological models are a simplified representation of reality associated with an uncertainty budget, which in turn will affect the uncertainty of the risk assessment.

D9.62 report summarises the efforts of the CONCERT sub-subtask 9.3.1.3 (= TERRITORIES Task 1.3) participants towards quantitative analyses of uncertainties of radioecological models and structures them in form of a guidance document. In fact, a careful analysis of the uncertainty budget is the prerequisite to assess the quality and robustness of model predictions and/or forecasts. It also helps to critically evaluate the underlying scientific basis and increases confidence and acceptance when communicating scientific results to stakeholders and the public.

Uncertainty in the output of a radioecological model arises from many different contributions: uncertainty due to the choice and range of model parameters, uncertainty due to the inevitable simplification in model structure and conceptualisation (conceptual model uncertainty), uncertainty due to sampling and monitoring of input variables, uncertainty in the knowledge of the scenario to be modelled, uncertainty in the subjective interpretation of the assessment problem (modeller’s uncertainty) and uncertainty in the mathematical/numerical implementation of the model.

The prioritisation of the various types of uncertainty that contribute to the total uncertainty budget of a radioecological model depends on the model under consideration, the data available and the specific assessment situation. In this guidance document, propagated parameter/input uncertainty, conceptual model uncertainty, scenario uncertainty and monitoring uncertainty are treated in more detail and are prioritised with respect to other contributions to uncertainty. This is done on the one hand because these types of uncertainty certainly contribute largely to the total uncertainty budget of radioecological models applied to long-lasting exposure situations, which are the main focus of the TERRITORIES project. On the other hand, the analysis of these types of uncertainties requires a structured effort that would definitely benefit from a compilation of potential approaches and a guidance document, which has been so far missing in radioecology. Nevertheless, the authors acknowledge that mathematical/numerical uncertainty and modeller’s uncertainty are important. Readers of this guidance document and users of radioecological models should not neglect these two types of uncertainty.

The type of approach to carry out a quantitative uncertainty analysis, either probabilistic or Bayesian (seldom an analytical approach), needs to be chosen depending on the information and data available. Some approaches require a minimum quality of data and will not work properly otherwise. Effort
Deliverable D9.71

should also be spent on retrieving information about potential correlations of the model parameters. Sensitivity analyses provide insight into the impact of varying parameter values on the model output (parameter sensitivity analysis) as well as into the importance of a specific process for the model output (process sensitivity analysis). Sensitivity analyses are often the first step before proceeding with the detailed uncertainty analysis.

Detail is provided about the state of the art for coping with propagated parameter uncertainty and conceptual model uncertainty in the field of radioecology. In particular, available methodologies are explained and literature references from the field of radioecology are provided to the reader.

Test cases give examples of how the methodologies for dealing with the quantification of different types of uncertainty, including probabilistic and Bayesian approaches, can be applied to real situations and models in the field of radioecology. The test cases consider to a large extent NORM situations and post-accidental situations, for which data are available from the TERRITORIES Library Database (TLD).

The test case on contamination of wild boar meat following the Chernobyl accident underlines, what are the consequences of a too simplistic model structure and how this has implications in the decisions for which prognostic calculations are required. If conceptual (structural) uncertainty is not accounted for the predictions of a simple transfer factor model are misleading since long-term variability of contamination cannot be quantified with a reasonable level of uncertainty. In addition the test case shows that correlations can be accounted for in a convenient and straightforward way as long as processes involved are understood and considered with an adequate level of complexity. An over-estimation of the contamination can lead to restriction of hunting, restriction of boar meat consumption in an area where hunting is part of the local habits and traditions. In contrast, an under-estimation of the contamination can lead to an increase of dose to local population.

A list of good practices is provided to support the reader in understanding and carrying out uncertainty analysis of radioecological models. For example, these good practices include to “distinguish and discuss the various contributions to the overall uncertainty budget and prioritise them for your specific model/available data”; “Identify and discuss if key processes or input variables are excluded from the model due to gaps in knowledge or ignored for simplicity.”; “Be aware of potential correlations between model parameters/factors/input variables and take them into account, at least by discussing them and trying to quantify them even in a simplified way”; “Identify available data sets or produce new relevant data to validate your new model.” etc. The guidance is written in a simple way, in order to bring along not only modellers and risk assessors but also decision makers and interested members of the public.
D9.63. Guidance about exposure scenario

When assessing radiological doses to humans and wildlife, the selection of exposure scenarios and consideration of the inherent variability in human and wildlife behaviour plays a critical role. This report discusses the potential impact of the variability in those behaviours and focuses on those likely to have the largest impact on doses.

Radiological assessments for humans have been undertaken for decades and there are many useful data sources describing the most relevant variability in human behaviour. This report focuses on the two pathways that are the most important to dose in contaminated areas: external exposure and consumption of local food. For external exposure, the variability in dose is mainly influenced by differences in occupancy in contaminated areas, times spent indoors and outdoors and housing type. For internal exposure, the greatest variability in dose is likely to be related to food consumption rates and the amount of the food consumed that is locally produced.

Estimating the dose to wildlife exposed to ionising radiation can be even more complex than for human populations, due to the wide biodiversity and variability between modes of life. This report investigates the different approaches to estimating the total dose that an organism will receive from different exposure routes, accounting for the variability of the relevant parameters. It has been concluded that for wildlife, large variabilities or uncertainties in behaviour do not necessarily translate into a large range in the overall dose received, because the impact of behavioural variabilities or uncertainties most significantly depends on the dominant exposure pathway, which in turn is dependent on the nature of the ionising radiation to which organisms are exposed. For wildlife, it is particularly important to be able to identify the different (animal and plant) species present in an area of interest and to identify potential confounding variables such as exposure to other stressors e.g. chemicals, physical stressors.
D9.65: Synthesis report about decision-making processes

This report dealt with decision making processes related to the control of radiation safety in situations that can arise from the aftermath of nuclear accidents. In the current system of radiological protection, radiological exposure situations in the long term after a nuclear accident, are generally identified as ‘existing exposure situations’ and should be treated accordingly. The current way of managing radiological exposure associated with post-accident exposure situations, is based on the same conceptual framework and follows the same principles. Criteria need to be in place as a basis for decision making and assessment needs to be undertaken of what the level of exposure will occur over time and how effective control measures will be to reduce exposures.

There are many associated uncertainties of scientific, economic, political and societal dimensions and these factors have led to considerable difficulty in managing existing exposure situations in the past. This report is a first screening to identify in which decision areas, and for which potential decision factors and criteria, uncertainties are the highest and the most questioned by the public, as well as how important the impact of these uncertainties could be.

In Part 1, the regulatory context for managing existing exposure situations, which is based on international recommendations and standards, is summarized. Part 2 aim at identifying to which uncertainties the different stakeholders are confronted with, as well as to which extent these uncertainties influence their decisions through the analysis of several feedback experiences after past accidents (post Chernobyl and the post Fukushima accidents).

The main conclusions are the following:

Regulatory context for managing existing exposure situations, which is based on international recommendations and standards, (Part 1)

- **Conclusion on International recommendation and standards and European legislation for the management of post-accident situations**

  Following the revision of the radiological protection system by ICRP in 2007, introducing the need to adapt the three principles of radiological protection (justification, optimization and limitation) to the three main types of exposure situation (planned exposure situation, emergency and existing exposure situations), all international and European bodies have modified their recommendation, standards and legislation according to this new approach.

ICRP Publication 111, detailing the Publication 103 principles for the case of existing exposure situations following a nuclear accident or a radiation emergency, clearly reveals the general approach to be adapted, namely: (i) justify the protective actions which must do more good than harm; (ii) set up a reference level between 1 and 20 mSv / year as a guide value to conduct the optimization actions and so, (iii) reduce as low as reasonably achievable exposures. This approach has been taken up by IAEA and the European Commission, which propose the same interval for establishing the dose criterion (1-20 mSv/year). Now, ICRP is updating its publication 111, which is likely to clarify the range of value for the selection of the reference level (from the lower part of the band 1-20 mSv/year in the current Pub. 111, to below 10 mSv/year in its update).

The management of the Fukushima accident has shown that implementing these international standards require the definition of strategies which are not necessarily straightforward, and that uncertainties about the real situation can induce difficulties in the decision-making process.

- **Overview of criteria proposed for the management of contaminated goods in post-accident situations**
International standards propose management criteria in terms of individual dose, but leave national authorities free to implement derived criteria to limit contamination through certain exposure pathways.

As regards to the management of contaminated goods, international standards agree to say that derived dose criteria—in terms of activity concentrations of specific radionuclides can be based on existing guidelines proposed by WHO or the Codex, with obviously, adaptation to the circumstances of the real situation. The guideline levels proposed by the Codex or the WHO guidelines have not been established in the same context and so, present different approaches, either concerning the value of the indicative dose (0.1 mSv/year for WHO Guidelines and 1 mSv/year for the Codex) or concerning the function of these derived criteria (guideline/guide value Vs restrictive value/limit value).

The European Commission, has also developed its own control system of foodstuff and feedstuff, after the Chernobyl accident and define MPLs that are not harmonized with the values proposed by Codex. In case of a future accident, this leaves room for uncertainties on how implementing these standards and how these will be understood and accepted by affected population.

- **Overview of criteria proposed by the French post-accident management doctrine**

A short description of the French emergency and recovery preparedness plan elaborated by a group of stakeholders, from several national and local authorities and representatives of the civil society is also given as an illustration of national guidelines and plans regarding the management of a potential future nuclear accident. The doctrine published in 2012 is structured around five priorities:

- The immediate delineation of a post-accident zoning of the contaminated area which is used in particular to prohibit the consumption and placing locally-produced foods on the market;
- The efficient organisation of medical and psychological care, human radiation monitoring, financial support and compensation for those affected by the consequences of the accident;
- The permanent radiological characterisation of the environment, foodstuffs and drinking water;
- The emergence of new forms of governance based on the vigilance and active participation of the population concerned, a key point for social and economic recovery within affected areas;
- A sustainable waste management in response of the rapid increase of diverse kinds of contaminated waste.

The recovery of the affected territory and the rehabilitation of the living conditions begin if three conditions are completed: - the first condition is that uncertainties about the actual radiological situation must have been drastically reduced before to allow the population to return home; - the second one is the rehabilitation of the living context thanks to the restoration and revitalization of the necessary infrastructures (electricity, water and gas supply, medical care, schools, transport, administrative and commercial facilities, etc.), and; - the third one is a clear transfer of the decision-making from the national to the local level, from authorities to inhabitants and local stakeholders.

- **1.4 Main lessons learned from past experiences with stakeholders (e.g. PREPARE project)**

The overall objective was to contribute to the development of strategies and guidance for the management of contaminated products (foodstuffs and/or other goods), based on the views of the stakeholder (producers, retailers, consumers, experts, associations, etc.) from 11 countries. Some of the key messages illustrate how criteria used in existing post-accident management frameworks would particularly impact the life of local populations and so, are questionable.
One of the main lessons learnt from this PREPARE project’s work package was that the participants acquire knowledge, and skills on post-accident management and offer to experts and scientists a new look at the feasibility and efficiency of their proposals. The panellists also point out that the criteria proposed in international standards and European legislation are often unclear and leave the room to uncertainties and misunderstandings—and have proposed to open a dialogue on the calculation assumptions and the consistency, understanding and usefulness of the radiological criteria proposed by experts and authorities in order to derive more robust and manageable options.

**Insights on past experiences of post-nuclear accident situations and analysis of related uncertainties (part 2)**

The strategies and associated decision criteria used for mitigating exposures during the management of the post Chernobyl and the post Fukushima accidents have been investigated (e.g. prolonged evacuation and food and other activity restrictions, specific agricultural countermeasures and strategies of remediation and their evolution as well as waste generation and management issues).

Based on this work, part 2 aim at identifying to which uncertainties the different stakeholders are confronted with, as well as to which extent these uncertainties influence their decisions.

- **Feedbacks from past experiences**

In post-accident situations, the existing exposure situation mainly concerns the recovery phase. Feedbacks from post Chernobyl (in ex USSR and Norway) and post-Fukushima situations will focus on the main lessons learnt that could be drawn from the so called ‘recovery phase’. Additionally, a case study on the Semipalatinsk nuclear weapon test site in Kazakhstan has been reviewed.

However, it is also important to consider the emergency phase, insofar as the strategies taken during this phase often determine the decisions to make later on. Thus, in the following, some paragraphs will explain the main decisions taken during the emergency phases after the Chernobyl and Fukushima accidents, and this aims only to better understand the decisions that have been made afterward.

More particularly, the analysis focus on: the long-term contaminated area zoning and its time-space evolution from early (evacuation of the population) to late phase of PA management (goals of recovery, radiological criteria and associated zoning); the food management criteria, factors that govern the implementation and lifting of agricultural (land, vegetal and animals products) and environmental countermeasures (forests ...); the decontamination and remediation actions, the waste management, the financial mechanisms and other factors that influence the decision of populations to stay or to leave the affected areas and the return or non-return home of evacuated/displaced populations; and the governance and organisational aspects of the management.

- **Manifestation of uncertainty in a post-nuclear accident context**

It must be pointed out that, the feedback experience and the manifestation of uncertainty that have been collected hereafter mainly come from ‘worst cases’ (Chernobyl and Fukushima major accidents were ranked level 7 on INES). For these severe accidents, numerous projects have already allowed to gather a series of local stakeholders concerns, priorities and trade-offs as well as decision dilemmas. The manifestation of uncertainties have been collected through interviews with, and testimonies of affected and concerned people - i.e. those who suffered from the aftermath and have to manage the consequences of the Chernobyl and Fukushima catastrophes - and a review of several European projects (ETHOS, FARMING, SAGE, EURANOS, ...).
Based on the previous research projects and from part 1 and 2, a preliminary analysis structured in six manifestations of uncertainties is proposed and detailed:

- Radiological characterisation and impact assessment
- Zoning of affected areas
- Feasibility and effectiveness of the remediation options
- Health consequences
- Socio-economic and financial aspects
- Quality of future life in the territory
- Social distrust
D9.66 stakeholder panel/FRANCE.

The deliverable D.9.66 documents part of the work undertaken in the TERRITORIES work package 3 that deals with stakeholder involvement in decision-making processes for long lasting exposure situations, and especially post-nuclear accident situations (subtask 3.3.1). In particular, it aims at identifying and understanding stakeholder concerns and needs, by confronting them with the possible decisions – accounting for the uncertainties – that could be taken according to existing local, national, international decision-making processes, policies and frameworks related to mid and long-term recovery (i.e. several months or years after the accident occurred). To exchange with local actors on this topic, several workshops have been set up in Europe. In France, a stakeholder panel has been organized by CEPN and IRSN in collaboration with the Local Liaison Commission of Nuclear Information (CLIN) of the Blayais Nuclear Power Plant. This deliverable aims to present the main outcomes raised from this panel.

The French stakeholder panel was organised in Bordeaux city on 11th and 12th of December 2018. During the first day, testimonies and feedback experiences were reported by Japanese and Belarusian stakeholders involved in the rehabilitation of living conditions after the Fukushima and Chernobyl accidents. During the second day, the panel, which were composed of local French actors (local elected people, winegrowers and vineyard unions, farmers, representatives of the local Chamber of Agriculture, the Regional Health Agency, Local Liaison Commissions of Nuclear Information, members of environmental protection NGOs, etc.), discussed about health, social and environmental issues that could be at stake in their territory, as well as the conditions for the recovery of economic activities (e.g. agricultural recovery). More specifically, uncertainties that the local stakeholders would face following a hypothetical nuclear accident at the Blayais Nuclear Power Plant have been described and discussed by the local interested parties. For the simulation of this hypothetical event, OPAL – a specific tool developed by IRSN for improving awareness of local actors toward post-accident issues – was used and the potential impacts and consequences on the territory were put into the French context of post-accident management (e.g. using post-accident zoning criteria as proposed by CODIRPA in its "Policy elements for post-accident management in the event of a nuclear accident")12.

Discussions with the French panel were organized in working sessions, addressing four main issues: (i) the monitoring of the radiological situation, (ii) the future of the agricultural sector, (iii) the challenges of restoring the quality of life of residents, (iv) the conservation and resumption of socio-economic activities. The main outcomes of these discussions are summarized in the following paragraphs.

- **The monitoring of the radiological situation of the people and the affected territory**

All members of the French panel agreed on the fact that, in case of an accident, various actors like citizens, socio-economic actors (e.g. farmers, winegrowers, agricultural coops, unions), environmental protection NGOs, etc. would take initiatives to measure their own products and environment. Given the diversity of the measurements that would be implemented, the panel participants wonder how to coordinate all these results and how to integrate all the data into only one system. Indeed, according to the participants, it would be relevant to have a legitimate structure that would seek to integrate all the results in order to notably analyse the trends over time.

The discussions also highlighted that specific procedures of control would have to be implemented to ensure that the measurement protocols are well respected and therefore that results are more reliable. According to the participants, the population may not have the means to respect strict measurement protocols, as professionals usually do. Then, participants think that as far as possible, radiation specialists should accompany people on the field in order to train them to measure radioactivity and analyze the results.

- **The future of the agricultural sector in the affected territory**

In the event of an accident at the Blayais NPP, participants agreed to say that the wine sector would be the main economic sector to be impacted, as it represents one-sixth of employment in the region. Therefore,  

---

12 [Policy elements for post-accident management in the event of nuclear accident](5 October 2012)
the economic impact would be immediate with huge and longstanding effects on all the vineyards of Bordeaux wines. The panelists also emphasized the risk that the nuclear accident may have an economic impact on the entire French wine production and exports.

In such a context, the participants considered that it would be necessary to develop key and common messages, jointly prepared with wine unions, the nuclear operator, authorities and experts. The overall goal of this communication process would be to disseminate as quickly as possible a reliable and accurate information related to the area affected by the radioactive deposits and its precise delimitation. Panel participants expect that this would help to avoid a possible stigmatization of the whole Bordeaux region.

During the discussions, winegrowers and farmers also pointed out that they are not aware of the possible countermeasures to implement in the event of a nuclear accident. They insisted on the need to be accompanied and trained by experts to understand the decontamination processes, and how radioactive contamination can evolve over time, notably according to the different stages of production.

- **The challenges for restoring the quality of life of residents in the territory**

In preamble, the French panel pointed out that the ‘quality of life’ is quite a philosophical concept, which depends on the values and expectations of each individual. The members of the panel also agreed on the fact that, before considering the restoration of the quality of life, it is necessary to ensure that living in contaminated territories is safe and that there is no longer risks of health impacts. An absolute transparency, a sustainable communication about health issues, and the comprehensive presentation of the updated radiological situation would also be essential.

According to local actors, restoring the individual quality of life would rely on public authorities’ actions, by for instance, financing new infrastructures and supporting and redeploying the local economy. The French panel also raised the fact that restoring individual quality of life would depend on restoring the quality of living together (“vivre-ensemble”). The panelists think that local and national associations may be the driving forces to revitalize the life in the affected territories. Indeed, in France, these non-profit and non-governmental associations are very active and diverse. Thus, participants feel that associations could be key actors to launch local projects and to engage collective actions aiming at improving the future of the territory. It is also important to note that structures of dialogues and interactions between residents and experts could also be a lever, allowing local inhabitants to get answers to their questions and concerns.

- **The conservation and the resumption of socio-economic activities in the territory**

The participants insisted on the fact that the wine sector is the major socio-economic activity of the Blayais region. The occurrence of a nuclear accident would certainly have an economic impact on this sector and they wondered how much this would cost. However, it also appears that other activities in the Blayais region could also be drastically impacted. For instance, tourism and other agricultural activities (such as: forest, fishing or market gardening) have been mentioned several times as vulnerable sectors of activity. According to the participants, the levers to limit the impact of an accident on these sectors are difficult to find as a lot of uncertainties are at stake (e.g. duration of the restrictions, loss of image, etc.). Nevertheless, the discussions stressed out that there would be a need to support the local economic sector as early as possible in the occurrence of an accident. In such a context, economic compensation would be indispensable. Therefore, participants insisted on the need to have a better vision of the existing financial support mechanisms that could be activated in such circumstances. They also strongly encourage authorities to create a compensation fund (or reinforce the existing one), which could be quickly available in the event of a nuclear accident.

On the basis of these discussions as well as those carried out in other countries, key lessons and recommendations have been prepared for the final deliverable of the TERRITORIES project (D.9.71).
D9.69 SERIOUS GAME - PATHWAY EVALUATION PROCESS (PEP)

The D9.69 report “Critical evaluation/remediation pathways” documents the work undertaken in CONCERT sub-sub-task 9.3.3.3.4 (TERRITORIES project). It aims at presenting the results of the test of an innovative approach (a serious game called “Pathway Evaluation Process in post-accident context” or PEP-PA) to assess management strategies and to engage pluralistic discussions among various stakeholders on key issues related to post-accident situations.

Firstly, the document presents the key principles, the objectives, the different steps of the elaboration, the mechanisms and the methodology of the new approach PEP-PA that was elaborated on the basis of the work of identification of remediation strategies and decision pathways, i.e. public management strategies in post-accident situations. The aim of the PEP approach is to discuss, in the form of a “serious game”, different alternatives for dealing with a complex situation with focus on the most uncertain decision factors and criteria which could impact the people’s living conditions in affected areas. The PEP is not intended to promote consensus building or to select the best available technical solution from among those studied. Rather, the PEP allows for a nuanced understanding of the issues at stake and a better understanding of the arguments of the various participants, without prejudice to their position with regard to a particular option. The PEP is based on a freedom of expression of views and the absence of imposed solutions. It allows participants to situate their understanding in a set of complex socio-technical issues associated with management of post-accident situation. The PEP brings together several players around boards (representing two type of public strategies: a directed strategy and an open strategy) and cards ("disrupting events" and “evaluation criteria”) putting in situation local actors and describing conditions, challenges or changes likely to occur as part of the policy for managing situations. Each participant is invited to test the robustness of a pathway by choosing a disrupting event that he or she locates on the board (specific location) and at a specific period of time. Two evaluation criteria are associated to the event in order to assess the management strategy (is it able to deal with the event or not) and to orient this evaluation on specific aspects of the problems: the aim is to avoid overly generic conversations by preferring to address two aspects in depth. This combination of disrupting events and evaluation criteria constitutes the basis of concrete scenarios that are discussed through a two round table discussion system: Each participant is invited a first time to give its opinion when the other participants listen. When each participant has given its opinion, a synthesis is done, and a second turn of discussion begins where each participant has the possibility to complete what he said in the first round after having heard the point of view of the other participants.

Secondly, the report also brings the main outputs of the workshop held on 04 April 2019 in Brussels aiming at testing the PEP-PA and collect the views of the participants on the potential future uses of this tool as a way to organise pluralistic exchanges (notably between technical experts and civil society representatives) and as a mean to allow better understanding of the key issues regarding elaboration and implementation of post-accident strategies. The workshop involved 18 participants coming from 8 countries and representing institutions (technical support organisations, national safety authority, European Commission) and NGOs. The PEP was tested in a “free” format: the scenarios questioning these two strategies were proposed by the participants on the basis of the material made available by the organizers. All the participants agreed on the relevance of this tool, considered as “an interactive and horizontal process” enabling “fruitful exchanges between participants with different background and level of expertise”. It was underlined by the participants the PEP-PA could be played with different kind of actors, not only the local populations but also the technical experts, the decision-makers. It allows testing new orientations of the doctrine with pluralistic panels in order to enable the emergence of concrete solutions. It has been identified several possibilities of further development of the PEP.
methodology on some more specific aspects of the post-accident situation: major accident with larger scale, accident including problematic contamination (e.g. alpha radionuclides), proximity of large city, border nuclear accident.

Thirdly, a second workshop was held on 05 April 2019 in Brussels. It gathered 17 participants including French experts from the TERRITORIES project, a representative of the French Safety Authority (ASN), representatives of ANCCLI, the French Federation of Local Commission of Information (gathering members of NGOs, local elected officials, trade unionists and CS experts) and a representative of NTW. The objective of this **additional workshop was to test an exploratory format of the PEP-PA**. The exploratory format is a method allowing focusing the exchanges during the PEP exercise on specific issues and some identified uncertainties in the frame of the TERRITORIES project (earlier TERRITORIES deliverable D9.65 Decision processes/pathways). It was considered as a way to elaborate an interesting input (based on concrete elements) for the production of guidance and recommendations on uncertainties management and public authorities’ strategies in post-accident situations (D9.71 and D9.72 of the TERRITORIES project). In this version of the PEP, the question was whether the exploratory version could improve the management of uncertainties by identifying their concrete consequences on the living conditions of populations according to strategies (open and driven) and different scenarios. With this in mind, several scenarios have been selected to test themes such as the use of standards. The aim was to identify the sources of uncertainty that could impact the decision-making process and consequently call into question management strategies. The PEP exploratory format makes it possible to anticipate the concrete problems linked to the uncertainties of a post-accident situation and the role that each of the actors (and particularly the public authorities) can play.

Anticipating the areas of uncertainty opened up by public policy makes it possible to considerably reduce negative effects through appropriate detailed treatment on a case-by-case basis. The analysis of the workshop results sometimes leads to the identification of possible levers that could reduce the impact of a management strategy on people’s lives in order to maintain dignified living conditions. The lack of visibility on the future is a huge factor of uncertainty for stakeholders. The analysis of a sample of scenarios makes it possible to identify the elements of complexity associated with the two strategic categories of post-accident management (driven approach and open approach). On this basis, it makes it possible to improve the management of uncertainties by identifying their concrete consequences on the living conditions of populations. Building upon the results of the present research, it appears that a management policy should, as far as possible, allow affected individuals and communities to develop projections and representations of their possible future and thus reduce the impact of the high uncertainties they face. This possibility of anticipation is therefore a very important issue for the actors concerned (inhabitants, local elected officials, economic operators, etc.). Public policy can therefore make a significant contribution to mitigating the consequences of these uncertainties (which are sometimes unavoidable) by creating a context in which preparatory measures are taken on the basis of future uncertainties that can be identified in advance.