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NERIS Roadmap on medium and long-term research on preparedness for nuclear and radiological emergency response and recovery

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Medium and Long-Term Research on

Preparedness for Nuclear and Radiological Emergency Response and Recovery

NERIS The European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery, Fontenay-aux-Roses, France,

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TABLE OF CONTENTS

Foreword

The NERIS Platform (The European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery) was established in June 2010 in Helsinki. The vision of the Platform was published in 2011 (http://www.eu-neris.net/). The Platform was established to be a forum where joint European arrangements for nuclear and radiological emergencies can be developed and improved in the future. The Platform addresses all notable trends, arrangements and capabilities in the area of response to and recovery from nuclear and radiological emergencies.

Since August 2012, the NERIS Platform has been registered as a legal association under the French Law of the 1st of July 1901. Today, the NERIS association comprises 67 organisations, with 28 supporting organisations and is driven by a management board of 10 organisations. The participating organisations represent stakeholders with a wide range of backgrounds, e.g. authorities, emergency centres, research organisations and the academic community.

The main objectives of the NERIS Platform are to improve the effectiveness of current European, national and local approaches for preparedness concerning nuclear or radiological emergency response and recovery, promote more coherent approaches in Europe through the establishment of networking activities, maintain and improve know-how and technical expertise among all interested stakeholders in Europe by developing a supranational training programme, and to identify needs for further research and development and address new and emerging challenges.

The Platform intends to enhance confidence in the solutions, reduce overlapping work, produce savings in total costs of research and implementation, and make better use of existing competences and research infrastructures in Europe.

Following the publication of the updated NERIS SRA in November 2019, the process of updating the NERIS long-term roadmap was initiated in parallel to the preparation of the Joint Roadmap on Radiation Protection Research established in 2020 within H2020 CONCERT EJP. While the Joint Roadmap intend to define priority areas and strategic objectives and a vision for mutual cooperation for a European radiation protection research programme to 2030 and beyond, the NERIS Roadmap aims at emphasizing long-term objectives for developing research addressing the key challenges to improve preparedness for nuclear and radiological emergency response and recovery in Europe and to contribute to the international development in this field.

The present Roadmap is an update of the first NERIS Roadmap established in November 2017. A series of exchanges was organised after the European Radiation Protection Week meeting held in October 2019 in Stockholm. Initially, the process envisaged for updating the NERIS Roadmap included the organisation of an open meeting prior to the NERIS workshop to be held in Barcelona at the end of May 2020. Due to COVID-19 crisis, the NERIS management board decided to organise a series of video-conference meetings between mid-March and end of May 2020 and to establish 3 working groups, involving mainly members of the NERIS management board and R&D committee, to address each of the challenge areas defined in the NERIS SRA. Following the consultation of the NERIS community, the updated NERIS roadmap has been published on May 29, 2020.

The experience gained during the last decades, largely based on the lessons from the Chernobyl and Fukushima accidents, points out the complexity of the management of nuclear or radiological emergency response and recovery. To address this complex situation, the experience shows that it requires among others to:

- Establish a robust, transparent and inclusive decision making-process addressing the different phases of the accident from early response to the long-term phase;
- Assess the consequences of the accident and the efficiency of the protective actions, relying on good science, advanced monitoring tools and framework and powerful and adequate assessment and simulation models;
- Elaborate strategies to protect the people and the environment;
- Challenge the protective strategies based on the evaluation provided by advanced decision-support systems;
- Adopt good ethical values;
- Address properly economic, societal and environmental challenges and set up an adequate health surveillance.

For this purpose, developing preparedness for managing the different phases of an accident is crucial and a large number of national organisations in Europe as well as international organisations have developed dedicated programmes to improve preparedness.

An integral part of the mission of NERIS is to identify gaps and needs for further research and development and addressing new and emerging challenges in the field of preparedness for nuclear or radiological emergency response and recovery. The NERIS Strategic Research Agenda identifies three main challenges:

1. Challenges in radiological impact assessment during all phases of nuclear and radiological events

Within this area all research challenges are aimed to improve the radiological impact assessment in all phases of a nuclear or radiological event. It includes improvements in modelling, monitoring and the combination of both (data assimilation for e.g. source term estimation) for human dose and environmental impact assessment. This includes research related to impact assessments for planning, real-time impact assessments during the response phase, dose reconstruction in a later phase, uncertainty quantification of the impact assessment and visualization.

2. Challenges in countermeasures and countermeasure strategies in emergency & recovery, decision support & disaster informatics

This research area covers all challenges related to decisions on and implementation of protective actions during an emergency, including justification and optimization. It comprises: countermeasures and countermeasure strategies including lifting of countermeasures and transition from emergency to existing exposure situation; formal decision support, including multi criteria analysis and disaster informatics; the study of the use of information technology in the preparation, mitigation, response and recovery phase of a nuclear or radiological disaster.

3. Challenges in setting-up a trans-disciplinary and inclusive framework for preparedness for emergency response and recovery

The third research area focuses on the overall emergency response and recovery framework, including reference levels, stakeholder engagement, the involvement of the public, communication research and non-radiological perspectives such as health, ethical and societal aspects. This area also integrates multidisciplinary research to cope with incomplete information, typical for of emergency situations, and improved decision making under high uncertainty.

To face effectively future challenges and make efficient use of resources (at both national and European levels), a common and shared vision for European radiation protection research has been developed within the European Joint Programme CONCERT in cooperation with the research platforms (MELODI, EURADOS, EURAMED, ALLIANCE, SHARE and NERIS). This vision, published as the Joint Roadmap, defines priority areas and strategic objectives for mutual cooperation and provides a vision and role for a European radiation protection research programme to 2030 and beyond. The Joint Roadmap presents 'game changers', defined as research issues that, when successfully resolved, have the potential to impact substantially and strengthen the system and/or practice of radiation protection for man and/or the environment through 1) significantly improving the evidence base, 2) developing principles and recommendations, 3) developing standards based on the recommendations and 4) improving practice. In total, 20 game changers have been identified covering the different challenges of radiation protection.

With regard to the challenge aiming at optimising emergency and recovery preparedness and response, two main gain changers have been identified addressing the evolution of the scientific, technological and societal contexts:

- Change of radiological impact assessments, decision support and response and recovery strategy by Artificial Intelligence and big data;
- Further development of risk assessment and risk management approaches and technological capabilities to cope with novel threats and accident scenarios arising from new and future nuclear and radiological technologies

Other challenges developed in the Joint Roadmap will also contribute to the implementation and the development of the challenges identified by NERIS. Among them, it is worth to mention the scientific development in different areas:

- Radioecology: Better understand radiation-related effects on non-human biota and ecosystems and to further develop an integrated approach to environmental exposure and risk assessment from ionizing radiation;
- Low dose: Integrate epidemiological estimates of cancer risk with a more complete understanding of radiological disease pathogenesis to improve cancer risk assessment and define the risks of non-cancer diseases at low and intermediate dose levels (100 - 500 mGy and below);
- Dosimetry: Improve the understanding of spatial correlations of radiation interaction events by improved measurement and simulation techniques;
- Social Science and Humanities: Better alignment of research and practice in RP with the values, needs and expectation of society.

The NERIS Roadmap, presented in this report, relies on the three challenges adopted in the NERIS SRA and addresses a number of the game changers identified in the Joint Roadmap (see Annex). These three challenges are detailed in 9 "Key Topics" (KT) and 33 sub-topics. All of them have been defined and broken down into needs (or challenges) for research at different time horizons over the next two decades or so. Three different timescales which may last from 3 to 8 years, have been considered, mainly based on:

- Phase 1: research based on former EU projects' recommendations;
- Phase 2: research in the framework of future European Framework programmes;
- Phase 3: combination of research programmes and operational needs.

For the better structure of research, a "Vision" has also been defined for each subtopic that can be seen as NERIS goal for that research area. In this respect, it needs to be kept in mind that these research areas

have to be considered in their globality and not exclusively one from the other. A meaningful, robust, efficient and coherent research programme to improve preparedness for emergency response and recovery from nuclear or radiological accident has to be developed combining research programme addressing the different issues together as well as integrating adequate education and training activities. It is worth to mention that these developments need to take advantages of the evolution of the scientific knowledge in radiation protection (i.e. low dose effects, medical issues, radioecology, dosimetry, social sciences and humanities in RP), and to draw the lessons from past experience the management of the consequences of nuclear or radiological accidents as well as from preparedness programmes in different countries. Besides developing good sciences to address these research challenges and taking into account the game changers as presented in the Joint Roadmap, the NERIS roadmap emphasizes the importance of setting up a multi-disciplinary and multi-stakeholder approach for improving preparedness.

Challenge Area 1

Challenges in radiological impact assessment during all phases of nuclear and radiological events

Key topic 1: Improved Modelling

a. Atmospheric transport and dispersion modelling (ATM/ADM)
b. Hydrological modelling
c. Terrestrial modelling
d. Dose modelling

Key topic 2: Improved Monitoring

a. Monitoring techniques and strategies
b. Data collection and sharing
c. Optimisation

Key topic 3: Data assimilation - Data science - Artificial Intelligence

a. Improved source term estimation
b. Improved impact assessment
c. Big Data, Data fusion, Artificial Intelligence

Challenges and achievement in	Vision
Radiological impact assessment during all phases of nuclear and radiological events	
Key topic 1: Improved Modelling	
Atmospheric transport and dispersion modelling (ATM/ADM)	A tested and validated ATM/ADM modelling suite, suitable for operational use, applicable in all environments (urban, confined spaces, agricultural, forests, mountainous areas, etc.) in all spatial and temporal scales, including computation of uncertainties of various origins and inverse source-term estimation (*in connection to Key Topic 3*)
Hydrological modelling	A hydrological model suite that is applicable to inland and coastal areas in Europe and world-wide, to assess contamination due to atmospheric deposition and direct liquid release, including watershed runoff and improved food chain models (in close collaboration with ALLIANCE)
Terrestrial modelling	A suite of radio-ecological models that is fit for purpose in emergency management at all levels including inhabited areas and food chain contamination (in collaboration with ALLIANCE)
Dose modelling	A suite of models for assessing the exposure of the public, of emergency workers and helpers during all phases of the event and based on all available data; including the above transfer modelling capabilities, measurements and dynamic behaviour of the exposed population

Key topic 2: Improved Monitoring	
Monitoring techniques and strategies	New devices, techniques and guidelines for monitoring in Europe and world-wide being harmonised for cross-border application and monitoring information supplied by professionals, NGOs and lay people. Harmonised monitoring strategies for Europe for all phases and for all types of radiological and nuclear events
Data collection & sharing	Comprehensive data base of radiological data for model validation and open for wider use
Optimisation	Optimise the measurement strategy combining monitors and modelling capabilities
Key topic 3: Data assimilation - Data science - Artificial Intelligence	
Improved source-term estimation	Validated operational computation capabilities to estimate unknown locations of radionuclides emissions and source terms with use of ATM/ADM as defined in Key Topic 1 and advanced measurement-data assimilation
Improved impact assessment	Improved capabilities to assess the radiological situation in all phases of an accident or incident (e.g. medical follow-up or other long-term actions)
Big Data, Data fusion, Artificial Intelligence	Advanced tools for improved decision-making exploiting Big Data and Artificial Intelligence technologies within Decision Support Systems *(in connection to Challenge Area 2)*

Key topic 1: Improved Modelling

Challenges and achievement in	Phase 1	Phase 2	Phase 3
1a. Atmospheric transport and dispersion modelling ATM/ADM **VISION**: A tested and validated ATM/ADM modelling suite, suitable for operational use, applicable in all environments (urban, confined spaces, agricultural, forests, mountainous areas, etc.) in all spatial and temporal scales, including computation of uncertainties of various origins and inverse source-term estimation *(in connection to Key Topic 3)*	● Research and development on advanced methods and tools (e.g., Computational Fluid Dynamics – CFD – modelling) for simulation of dispersion in complex settings (e.g., urban, industrial sites, complex topography and confined areas) aiming at their operational applicability to nuclear emergency management in comparison to simpler approaches; research on optimisation of input data requirements, numerical schemes, turbulence modelling, spatial and temporal resolution, quality of results, computational efficiency, computational resources, etc.; research on advanced exposure assessment methodologies ● Assess existing and develop new methods and tools to address specific phenomena such as low wind speed and very stable atmospheric conditions ● Validated and operational approaches to quantify and properly take into account uncertainties of ATM/ADM results in operational response, including application of ensemble approaches, computational time saving, visualization and output products. ● Review and refine deposition process and modelling	● Quantification and assessment of ATM/ADM uncertainties from all origins (e.g. source term, meteorology, modelling assumptions) by using measurements, exploiting Big Data technologies and improved complex mathematical techniques (Bayesian emulators, etc.) ● Inclusion of non-conventional emissions (explosions, aerosol sprays, fires, etc.) in ATM/ADM ● Research on application of Artificial Intelligence in all topics related to ATM/ADM (e.g., forward and inverse modelling, estimation of uncertainties) ● Assess existing and develop new methods and tools to address specific precipitation events (high precipitation, drizzle, snow, hail, fog) ● Develop operational models to better take into account radioactive aerosols and gas behaviour in the atmosphere from short to long distance, in particular for iodine species	● Advanced ATM/ADM models (including integrated multi scale – local to regional – models) with uncertainty estimations, combined with advanced methods for inverse source-term estimation modelling *(in connection to Key Topic 3),* employing Big-Data and Artificial Intelligence technologies in operational application ● Aerosols/gas behaviour models covering most of radioactive species

1b. Hydrological modelling **VISION**: A hydrological model suite that is applicable to inland and coastal areas in Europe and world-wide, to assess contamination due to atmospheric deposition and direct liquid release, including watershed runoff and improved food chain models. *In close collaboration with ALLIANCE*	● Urban run-off models ● Urban water supply models ● Urban waste water modelling to estimate the contamination of water from urban decontamination ● Improvement of local coastal models (2-D and 3-D) and confined areas such the Baltic sea and the Arabic Gulf ● Link to global hydrological models, to feed better local 3-D models ● Better approaches for surface runoff ● Development of mechanism to adapt hydrological models to local conditions ● Improvement in marine food web modelling (link ALLIANCE)	● Subdivision of dispersion and radiological part (as in atmospheric dispersion). Development of uncertainty quantification for hydrological models, similar to approaches used in atmospheric dispersion modelling ● Combination of all components of aquatic modelling into one comprehensive modelling suite ● Development of test procedures for such a complete model suite to gain experience in the application of the hydrological models in situation assessment	● Compilation of a comprehensive aquatic model suite fit for emergency management and validated with reduced uncertainty ● Test the model suite with cases from Chernobyl and Fukushima
1c. Terrestrial modelling **VISION**: A suite of radio-ecological models that is fit for purpose in emergency management at all levels including inhabited areas and food chain contamination. *In close collaboration with ALLIANCE*	● Improved database for radio-ecological models ● Identify regional parameters and values characterising the radionuclide behaviour and the transfer soil-to-plant and raw-to-product in poorly studied environments (Mediterranean climate, arctic and sub-arctic, complex systems as agro-pastoral, forestry, etc.) and for areas that might need further consideration due to new reactors (e.g. gloating reactor) ● Further develop process-based food chain models based on the results of the CONFIDENCE project ● Consider appropriate uncertainty estimation in the model –propagation of uncertainties in environmental model chains	● Development of a local model for assessing individual farms ● Incorporating the behaviour of hot particles in radio ecological models based on the findings from the CONFIDENCE project ● Investigate multiple stressors (*together with ALLIANCE*)	● Linking of local and global models for better decision-making ● Improved radio-ecological model suite that has to be integrated into a DSS and tested with the countermeasure approaches from Area2

1d. Dose modelling **VISION:** A suite of models for assessing the exposure of the public, of emergency workers and helpers during all phases of the event and based on all available data; including the above transfers modelling capabilities, measurements and dynamic behaviour of the exposed population. *In close collaboration with EURADOS*	● Dose assessment (including reconstruction of doses and protective measures effectiveness) based on all available environmental monitoring data ● Individual dose assessment considering the real behaviour of the population and the efficacy of protective actions and remedial measures in reducing doses; specific models can be developed for target groups such as first responders/firefighters ● Improved assessment of thyroid doses, their uncertainties, in particular among those exposed in utero, when newly born and in infancy, based on an analysis of thyroid measurement data and internal dose reconstruction ● Implementation of shielding factors for new house types characteristic of modern urban areas, with new construction materials (e.g. much glass), and material factor dependence	● Dose assessment combining input from environmental monitoring and individual monitoring (e.g. personal dosimeters, thyroid monitoring, whole body counting, bio-dosimetry) ● Develop practical guidance to people and populations who want to assess their individual doses, recommending reliable methods and data sources	● 'Highly accurate' individual dose assessment ● Research in individual dose modelling combining all information to develop information tool (cf. Challenge Area 2)

KT1a - Atmospheric transport and dispersion modelling (ATM/ADM)

VISION: A tested and validated ATM/ADM modelling suite, suitable for operational use, applicable in all environments (urban, confined spaces, agricultural, forests, mountainous areas, etc.) in all spatial and temporal scales, including computation of uncertainties of various origins and inverse source-term estimation (in connection to Key Topic 3).

CA1KT1a - Research and development on advanced methods and tools (e.g., Computational Fluid Dynamics – CFD – modelling) for simulation of dispersion in complex settings (e.g., urban, industrial sites, complex topography and confined areas) aiming at their operational applicability to nuclear emergency management in comparison to simpler approaches; research on optimisation of input data requirements, numerical schemes, turbulence modelling, spatial and temporal resolution, quality of results, computational efficiency, computational resources, etc.; research on advanced exposure assessment methodologies

CA1KT1a - Assess existing and develop new methods and tools to address specific phenomena such as low wind speed and very stable atmospheric conditions

CA1KT1a - Validated and operational approaches to quantify and properly take into account uncertainties of ATM/ADM results in operational response, including application of ensemble approaches, computational time saving, visualization and output products.

CA1KT1a - Quantification / assessment of ATM/ADM uncertainties applying big data and improved mathematical techniques for complex mathematical approaches

CA1KT1a – Inclusion of non-conventional emissions (explosions, aerosol sprays, fires, etc.) in ATM/ADM

CA1KT1a - Research on application of Artificial Intelligence in all topics related to ATM/ADM (e.g., forward and inverse modelling, estimation of uncertainties)

CA1KT1a -Assess existing and develop new methods and tools to address specific precipitation events (high precipitation, drizzle, snow, hail, fog)

CA1KT1a -Develop operational models to better take into account radioactive aerosols and gas behaviour in the atmosphere from short to long distance, in particular for iodine species

CA1KT1a - Advanced ATM/ADM models (including integrated multi scale – local to regional – models) with uncertainty estimations, combined with advanced methods for inverse source-term estimation modelling, employing Big-Data and Artificial Intelligence technologies in operational application

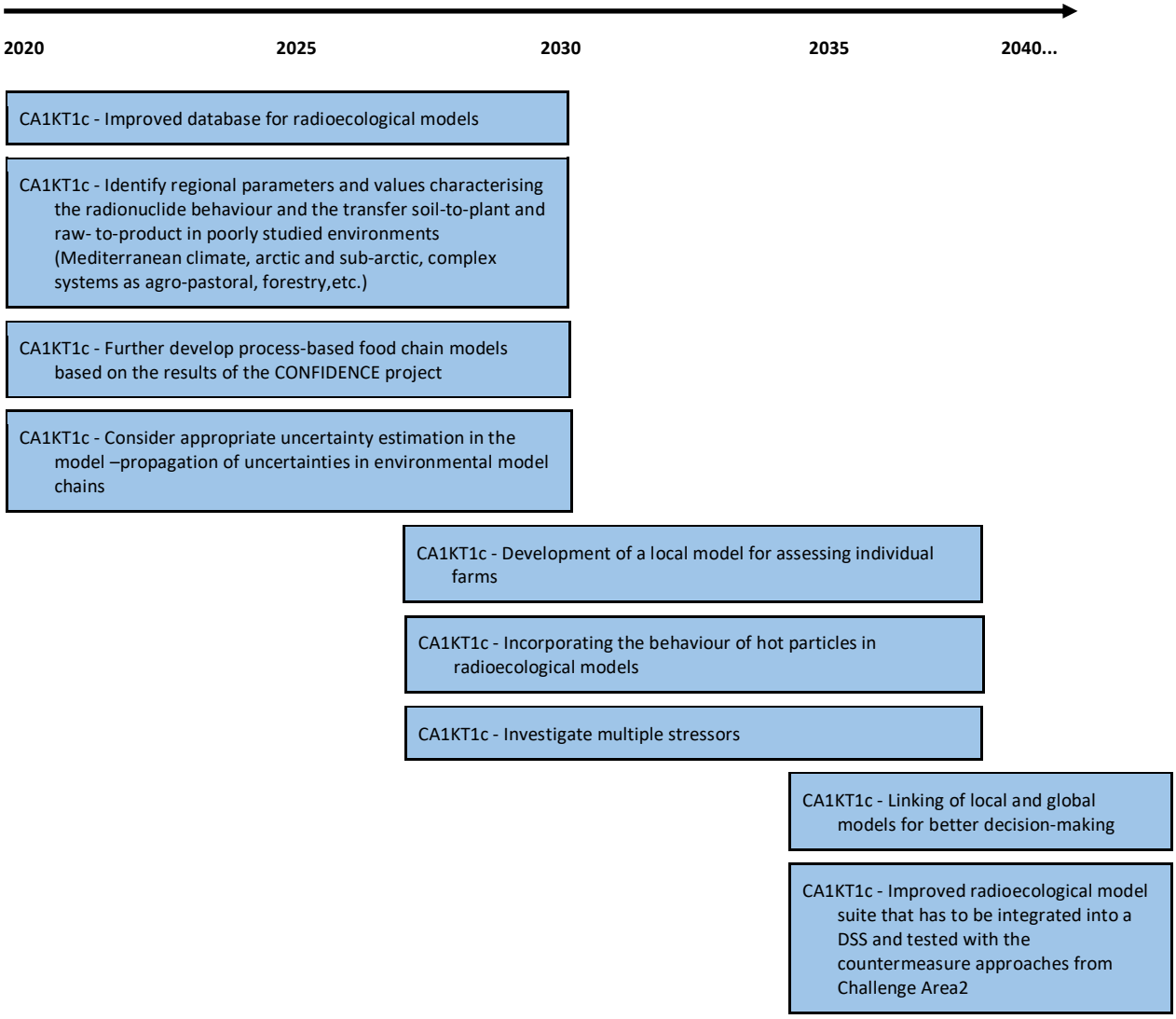
CA1KT1a - Aerosols/gas behaviour models covering most of radioactive species

KT1b - Hydrological modelling

VISION: A hydrological model suite that is applicable to inland and coastal areas in Europe and world-wide, to assess contamination due to atmospheric deposition and direct liquid release, including watershed runoff and improved food chain models (in close collaboration with ALLIANCE).

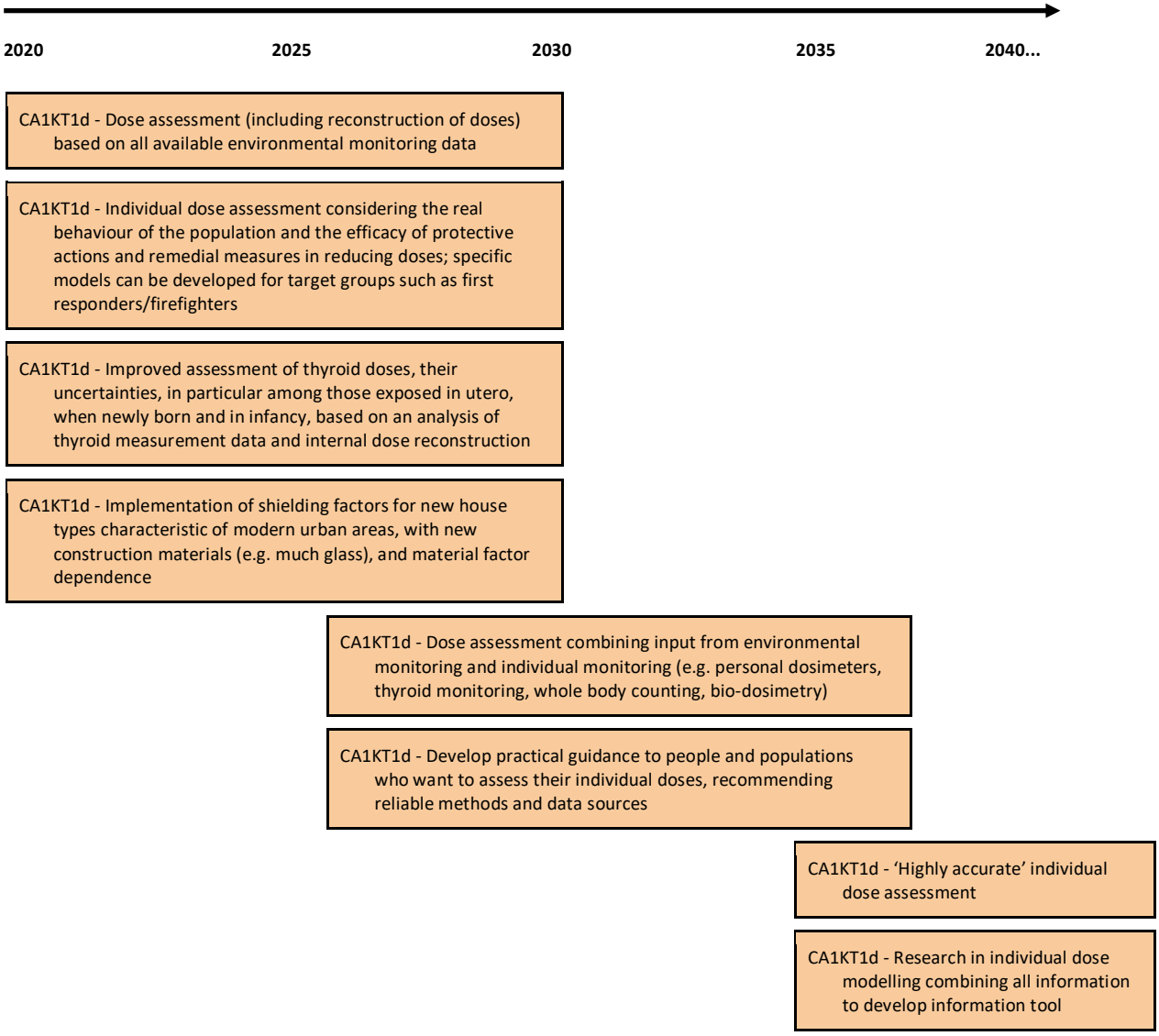
KT1c - Terrestrial modelling

VISION: A suite of radio-ecological models that is fit for purpose in emergency management at all levels including inhabited areas and food chain contamination (in collaboration with Alliance).



KT1d - Dose modelling

VISION: A suite of models for assessing the exposure of the public, of emergency workers and helpers during all phases of the event and based on all available data; including dynamic behaviour of the exposed population.



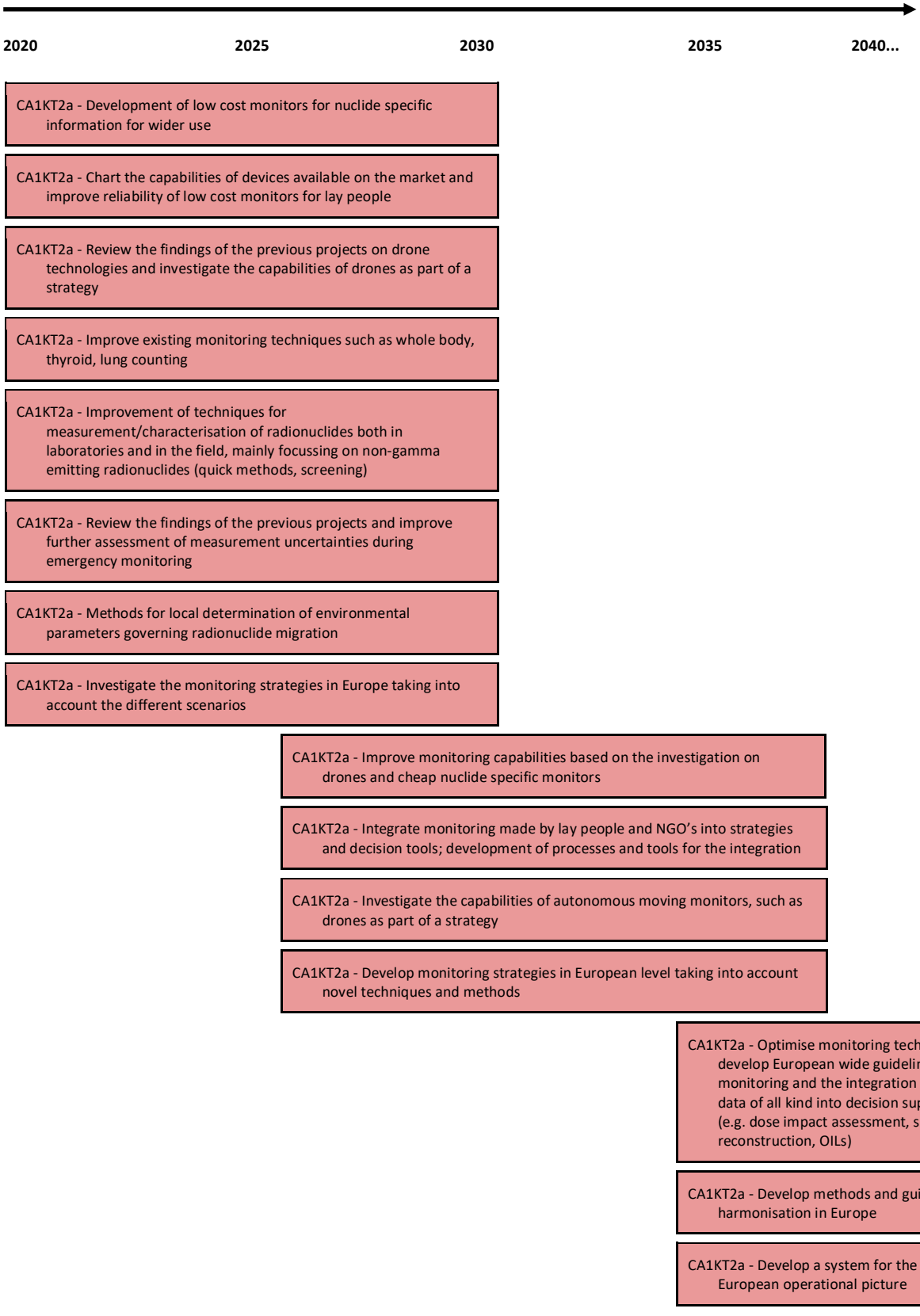
Key topic 2: Improved Monitoring

Challenges and achievement in	Phase 1	Phase 2	Phase 3
2a. Monitoring techniques and strategies **VISION:** New devices, techniques and guidelines for monitoring in Europe and world-wide being harmonised for cross-border application and monitoring information supplied by professionals, NGOs and lay people; Harmonised monitoring strategies for Europe for all phases and for all types of radiological and nuclear events	● Development of low cost monitors for nuclide specific information for wider use ● Chart the capabilities of devices currently available on the market and improve reliability of low cost monitors for lay people ● Review the findings of the previous projects on drone technologies and investigate the capabilities of drones as part of a strategy ● Improve existing monitoring techniques such as whole body, thyroid, lung counting (together with EURADOS) ● Improvement of techniques for measurement/characterisation of radionuclides both in laboratories and in the field, mainly focussing on non-gamma emitting radionuclides (quick methods, screening) ● Review the findings of the previous projects and improve further assessment of measurement uncertainties during emergency monitoring ● Methods for local determination of environmental parameters governing radionuclide migration (pH, soil type, etc.) ● Investigate the monitoring strategies in Europe taking into account the different scenarios	● Improve monitoring capabilities based on the investigation on drones and cheap nuclide specific monitors ● Integrate monitoring made by lay people and NGO's into strategies and decision tools; development of processes and tools for the integration ● Investigate the capabilities of autonomous moving monitors, such as drones as part of a strategy ● Develop monitoring strategies in European level taking into account novel techniques and methods	● Optimise use of monitoring resources (including e.g. mobile units, reach back, trans-border issues) and develop European wide guidelines for monitoring and the integration of monitoring data of all kind into decision support systems (e.g. dose impact assessment, source term reconstruction, OILs) Link with optimisation ● Develop methods and guidance to support developed joint monitoring strategies in Europe ● Develop a system for the common European operational picture

2b. Data collection and sharing **VISION:** Comprehensive data base of radiological data for model validation and open for wider use	● Data collection for model validation & development, based on historical and new data ● Good radiation background information and variability of background ● Overview of / guidance on which data should be collected for recovery operations to be considered ● Identification and use (proof-of-concept) of (new) data of interest outside standard data for radiological impact assessments	● Data collection for model validation & development, based on historical and new data ● Robust system for collecting and sharing data campaigns ● Integration and Identification (including proof-of-concept) of (new) data of interest outside standard data for radiological impact assessments	● Data collection for model validation & development, based on historical and new data
2c. Optimisation **VISION:** Optimise the measurement strategy combining monitors and modelling capabilities	● Development of reach-back for analysing radiation measurements from intervention teams ● Development of methods and tools that allows to optimise the placement of monitoring stations (both fixed early warning networks and mobile systems) regarding the needs of the expertise and decisions markers ● Investigate the interlink with dispersion modelling capabilities to optimise your monitoring network and the measurement strategy	● Further optimization of monitoring resources link with monitoring techniques and strategies ● Research on advanced techniques (link with KT3) to optimise measurements strategy (mobile and stationary) all along the emergency and post accidental situation combining measurements results and simulations capabilities (air and water dispersion) ● Develop procedures and methods based on scenarios for different emergencies	● Develop operational tools that optimise the deployment of all measurements resources available in situation, combining measurements results carried out and dispersion simulations

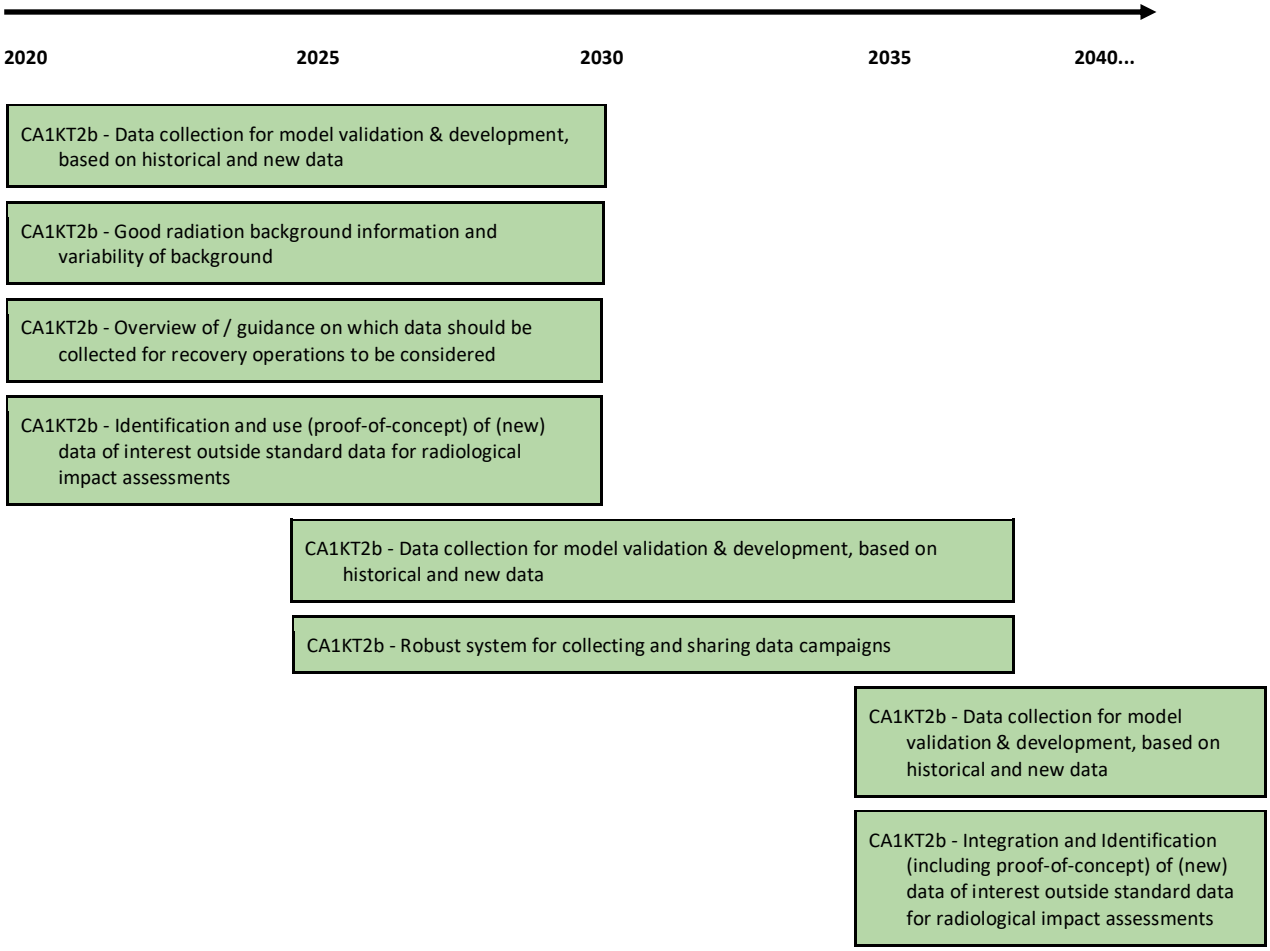
KT2a - Monitoring techniques and strategies

VISION: New devices, techniques and guidelines for monitoring in Europe and world-wide being harmonised for cross-border application and monitoring information supplied by professionals, NGOs and lay people. Harmonised monitoring strategies for for all phases and for all types of radiological and nuclear events.



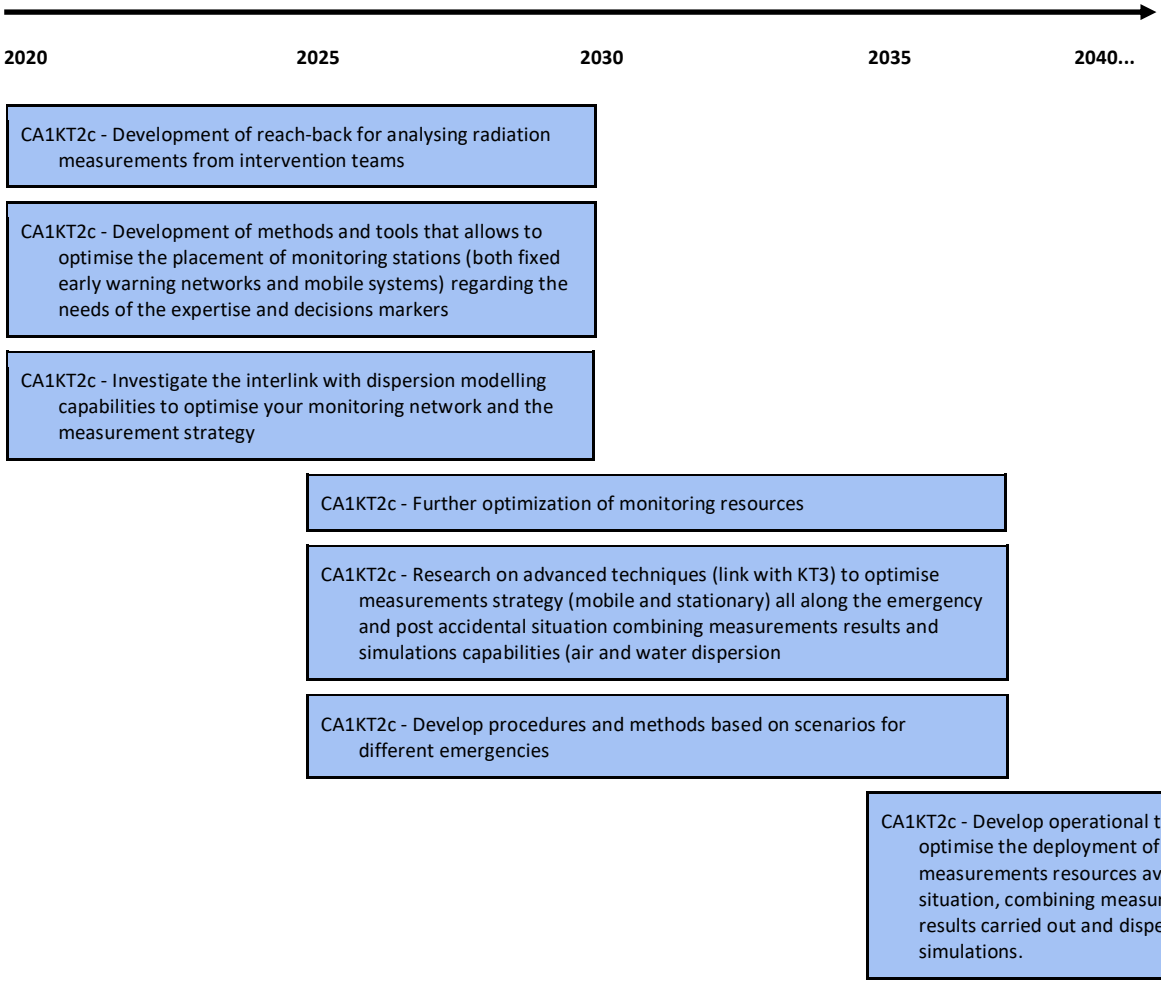
KT2b - Data collection and sharing

VISION: Comprehensive data base of radiological data for model validation and open for wider use.



KT2c - Optimisation

VISION: Optimise the measurement strategy combining monitors and modelling capabilities.



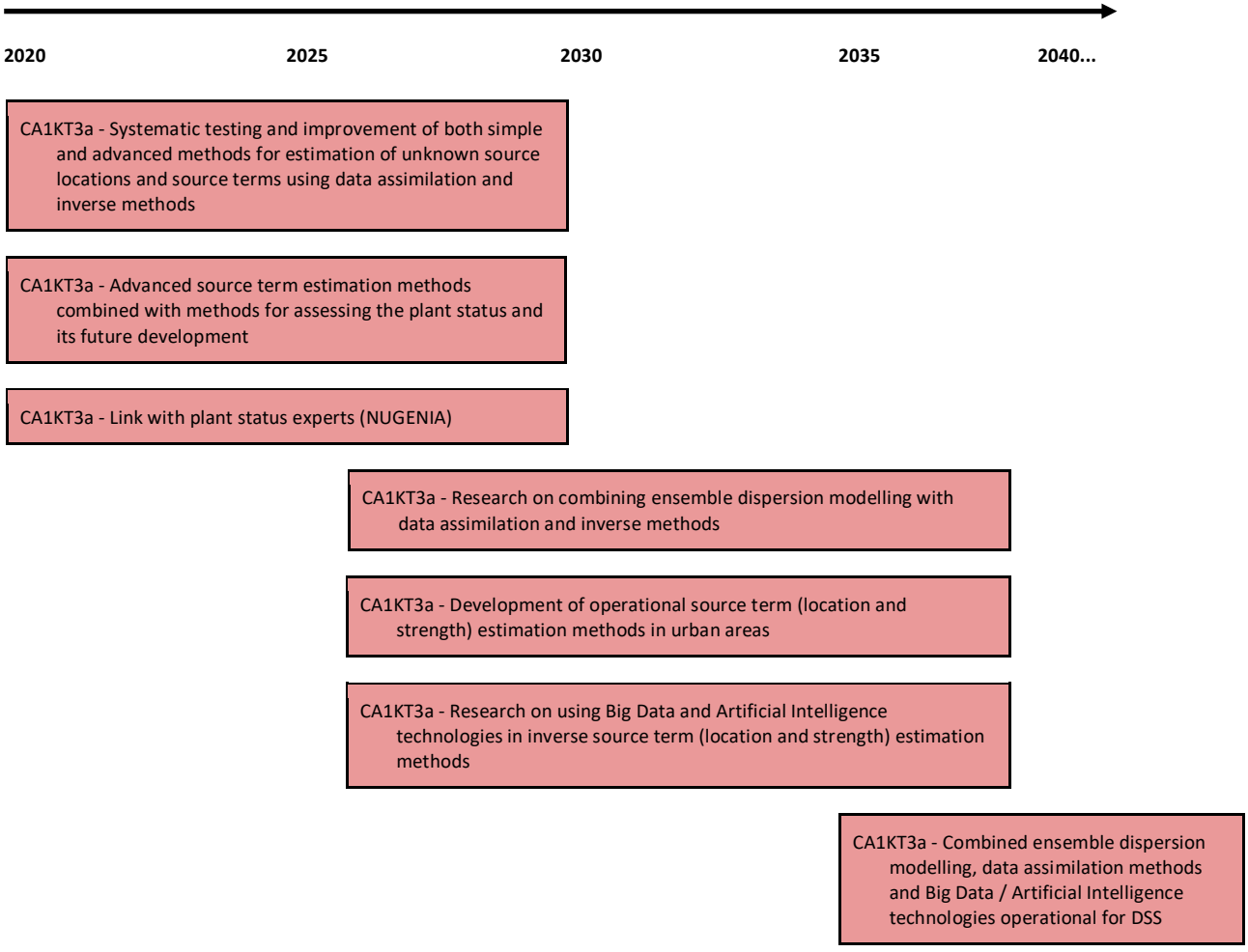
Key topic 3: Data assimilation - Data science - Artificial Intelligence

Challenges and achievement in	Phase 1	Phase 2	Phase 3
3a. Improved source term estimation **VISION:** Validated operational computation capabilities to estimate unknown locations of radionuclides emissions and source terms with use of ATM/ADM as defined in Key Topic 1 and advanced measurement-data assimilation.	● Systematic testing and improvement of both simple and advanced methods for estimation of unknown source locations and source terms using data assimilation and inverse methods (cost functions, Bayesian inference, …) ● Advanced source term estimation methods combined with methods for assessing the plant status and its future development ● Link with plant status experts (NUGENIA)	● Research on combining ensemble dispersion modelling with data assimilation and inverse methods ● Development of operational source term (location and strength) estimation methods in urban areas ● Research on using Big Data and Artificial Intelligence technologies in inverse source term (location and strength) estimation methods	● Combined ensemble dispersion modelling, data assimilation methods and Big Data / Artificial Intelligence technologies operational for DSS
3b. Improved impact assessments **VISION:** Improved capabilities to assess the radiological situation In all phases of an accident or incident (e.g. medical follow-up or other long-term actions)	● Review the findings of the CONFIDENCE project to combine modelling and monitoring for a better radiological consequence assessment in the early and intermediate phase of an emergency (considering uncertainty as explicit parameter) ● Explore the applicability of the risk model developed in CONFIDENCE for early risk assessment in emergency management ● Explore together with EURADOS new developments in dosimetry to improve the estimation of the radiological picture in all phases of an emergency	● Refine the assimilation approach to better estimate the dose of individual people for dose reconstruction and medical follow-up ● Explore the applicability of smartphone APPs based on findings from SHAMISEN-SINGS and CONFIDENCE for operational use in emergency management ● Combine bio-dosimetric approaches with others in an emergency situation for to make individual impact assessments for large groups of people	● Integrate all tools into the DSS for better impact assessment in all phases of an emergency including a medical follow-up and test the new approach with data from Chernobyl and Fukushima

3c. Big Data, Data fusion, Artificial Intelligence **VISION:** Advanced tools for improved decision-making exploiting Big Data and Artificial Intelligence technologies within Decision Support Systems *(in connection to Challenge Area 2)*	● Development of computational structures (e.g., platforms, aggregators) that would allow storing, processing and exploiting in real-time large volumes of heterogeneous data from different origins and of different quality (e.g., modelling, measurements, social networks, mass media)	● Development and testing of procedures for exploitation of Big Data and Artificial Intelligence technologies in different aspects of computational models (dispersion, inverse source term estimation, estimation of uncertainties, impact assessment, etc.) ● Research towards operational applicability in decision-making and integration in Decision Support Systems	● Integration of Big Data and Artificial Intelligence technologies within Decision Support Systems

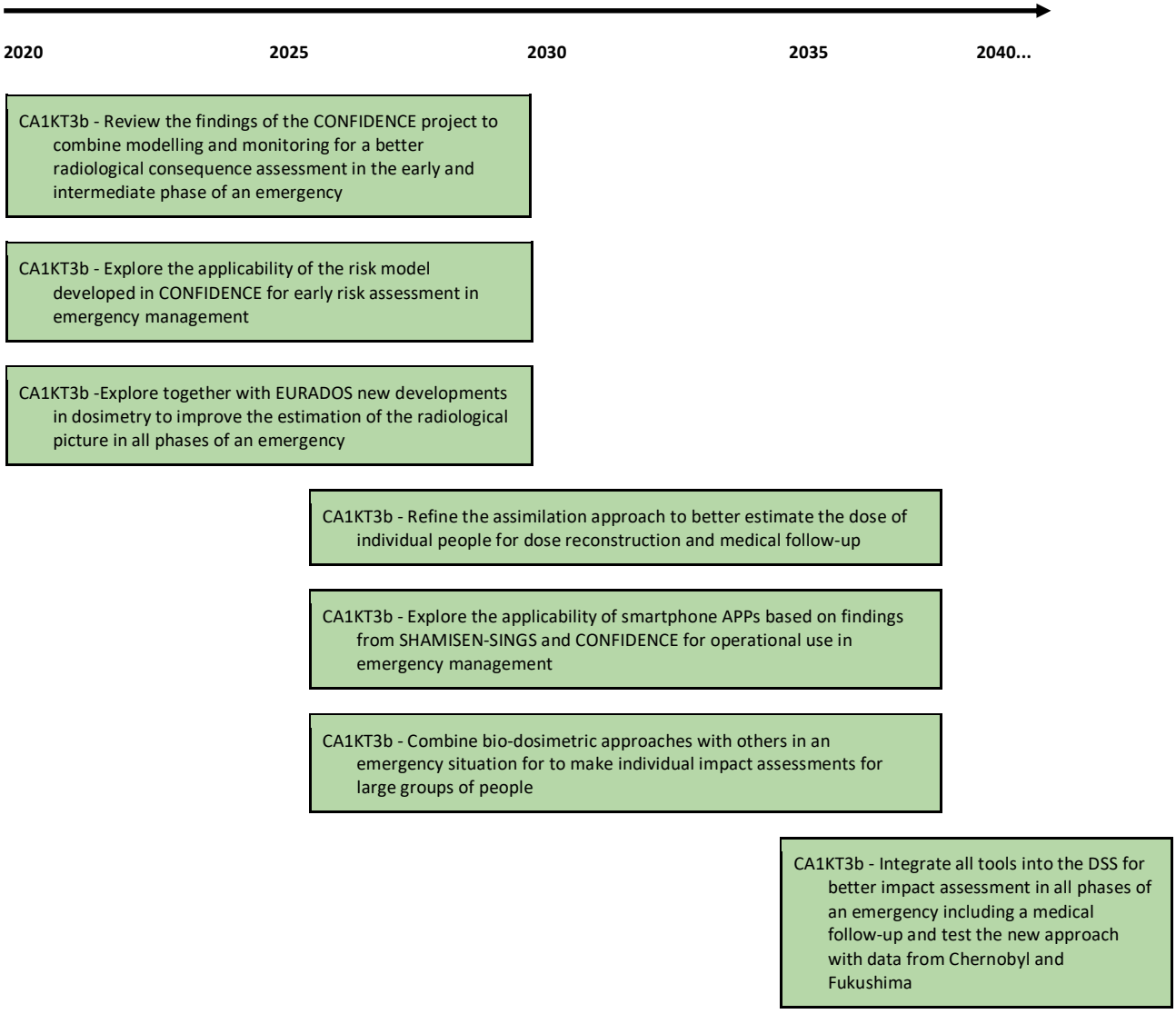
KT3a - Improved source term estimation

VISION: Validated operational computation capabilities to estimate unknown locations of radionuclides emissions and source terms with use of ATM/ADM as defined in Key Topic 1 and advanced measurement-data assimilation.



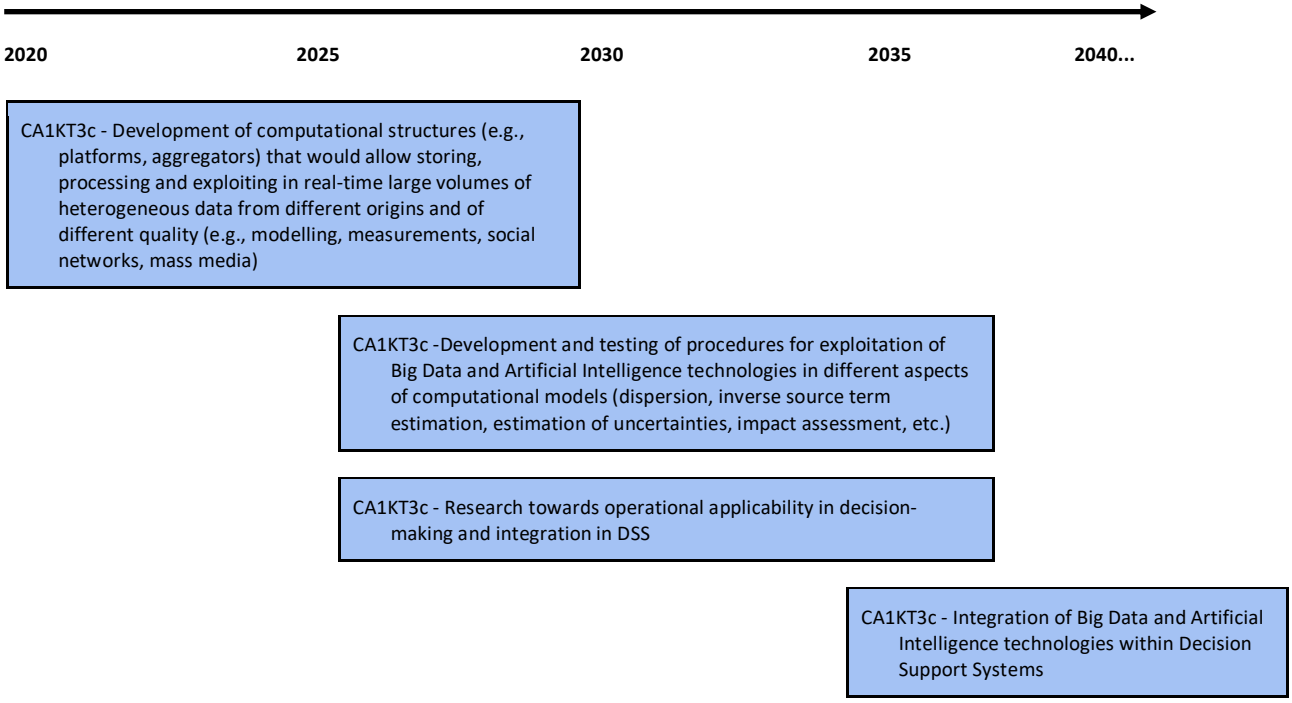
KT3b - Improved impact assessments

VISION: Improved capabilities to assess the radiological situation in all phases of an accident or incident (e.g. medical follow-up or other long-term actions).



KT3c - Big Data, Data fusion, Artificial Intelligence

VISION: Advanced tools for improved decision-making exploiting Big Data and Artificial Intelligence technologies within Decision Support Systems (in connection to Challenge Area 2).



Challenge Area 2

Challenges in countermeasures and countermeasure strategies in emergency and recovery, decision support and disaster informatics

Key topic 4: Countermeasures & countermeasure strategies

a. Countermeasures/management options
b. Implementation of countermeasures, lifting of countermeasures, transition from emergency to existing exposure situation

Key topic 5: Formal decision support

a. Decision-making methods and tools
b. Decisions under high uncertainty

Key topic 6: Disaster informatics

a. Analytical platform
b. Knowledge databases
c. New generation Decision Support Systems (DSS)
d. Virtual and augmented reality

Challenges and achievement in	Vision
Challenges in countermeasures and countermeasure strategies in emergency and recovery, decision support and disaster informatics	
Key topic 4: Countermeasures & countermeasure strategies	
Countermeasures/management options	Improved understanding of countermeasures to better build and implement countermeasure strategies (preparedness, response, recovery)
Implementation of countermeasures, lifting of countermeasures, transition from emergency to existing exposure situation	Methodological framework for the implementation and lifting of countermeasures based on monitoring (e.g. Operational Intervention Levels), modelling (Decision Support Systems) and guidance on optimisation supporting ICRP recommendations (including stakeholder interaction, see challenge 3)
Key topic 5: Formal decision support	
Decision-making methods and tools	Formalised methods and tools that structure and improve the decision-making process in all phases of an accident /incident
Decisions under high uncertainty	Formalised methods that support robust decision-making under high uncertainties

Key topic 6: Disaster informatics	
Analytical platform	Establish the analytical platform as part of the emergency management toolbox
Knowledge databases	Knowledge databases becoming operational allowing to support decision-making in all phases of an accident/incident
New generation Decision Support Systems (DSS)	New generation Decision Support Systems for integrated decision-making (tactical, operational, strategic)
Virtual and augmented reality	Suite of new training facilities using virtual and augmented reality for preparedness and testing of first responders, decision makers and other stakeholders

Key topic 4: Countermeasures and Countermeasure strategies

Challenges and achievement in	Phase 1	Phase 2	Phase 3
4a. Countermeasures and countermeasure strategies **<u>VISION</u>:** Improved understanding of countermeasures to better build and implement countermeasure strategies (preparedness, response, recovery)	• Generic improvement of European handbooks, and addendum to cover other contamination scenarios than NPP accidents such as alpha emitters accidents, long lived radionuclides (without iodine) as in reprocessing processes or contamination resulting from a malicious act. Those handbooks should address waste management issues • Improve or start research on regional/local parameterizations of models which support countermeasures and associated strategies in order to improve realistic assessments • Improve concepts and parameters of existing countermeasure models such as ERMIN and AGRICP implemented in JRODOS and ARGOS • Improve user-friendliness of tools as well as readiness of end-products to be used for decision-making and countermeasure implementations (*in connection with KT6c)* • Review and investigate if new protective actions and strategies for remediation and restoration can be derived from the Fukushima experience. Investigate other new countermeasures for other environments such as urban environments, surfaces (such as glass, concrete) and enlarge the spectrum of radionuclides to consider in relation with other accidents, and consider appropriate physicochemical forms for e.g. malicious dispersion. Waste production and management should also be investigated in this regard • Investigate how the use of uncertainties in models may affect/improve the effectiveness of countermeasures *(in connection with KT5b)*	• Embed countermeasure strategies in an all-hazard approach to be able to face induced situations such as natural disasters or pandemics. Develop combinations of countermeasures in a multi-stressor environment • Development of electronic versions that are linked to knowledge databases and Big Data *structures (in connection with KT6b)* • Develop a better estimation of factors that characterise countermeasures and countermeasure strategies (effectiveness, costs, non-radiological effects, waste management, etc.) as function of environment, region and affected population *(in connection with KT9a-c, KT9e)* • Development of countermeasures strategies for a wider range of accidents • Strategic analyses of countermeasures for relevant scenarios ensuring parameters governing radiological consequences can be identified in time for optimised remediation – including analyses of timelines of implementation	• Development of intelligent wizards that propose optimised countermeasures / countermeasure strategies based on available information from a DSS *(in connection with KT6c)*

	• Improve models for the contamination behaviour of different surfaces and in food and feed for an improved evaluation of ingestion dose for the public • Generation of practical information sheets for countermeasures implementers (including 'self-help' volunteers) for maximising the effectiveness of the countermeasures and to improve the protection of these implementers		
4b. Implementation of countermeasures, lifting of countermeasures, transition from emergency to existing exposure situation **<u>VISION</u>**: Methodological framework for the implementation and lifting of countermeasures based on monitoring (e.g. Operational Intervention Levels), modelling (Decision Support Systems) and guidance on optimisation supporting ICRP recommendations (including stakeholder interaction, see challenge 3)	• Analyse needs of local actors for local-national interaction for implementation of mitigating actions in response and recovery phases: needs for development of compatible tools *(in connection with KT8a-b)* • Development of framework and guidance for setting up criteria to lift countermeasures (particularly for the early phase). This includes guidelines for returning people but also compensations schemes *(in connection with KT8a and KT9b-c)* • Develop monitoring strategy to support or help adapt the countermeasure implementation. Thereby it can be secured that the countermeasure implementation is optimised in practice – not just on paper. • Investigate how the use of operational radiological criteria such as Operational Intervention Levels (OILs) may improve the decision-making process for different phases of a situation (preparedness, release, recovery). In particular investigate this concept for using during a time evaluating situation. • Develop OILs for non-nuclear scenarios in cooperation with the IAEA • Develop catalogues and check-lists to facilitate timely implementation of countermeasures	• Develop criteria and methods to determine the start and end of countermeasures. Take all relevant factors into account • Include conclusions from CONFIDENCE, TERRITORIES and ENGAGE to better define the transition phase and the methodological and technical needs for preparing the recovery phase *(in connection with KT8a-b, and KT9b-e)* • Investigate representation of OILs concept into Decision Support Systems in conjunction of monitoring results and investigate optimisation possibilities *(in connection with KT6c)*	• Development of the methodological framework *(in connection with KT8a-b and KT9b-e)*

	• Development and application of criteria, indicators and methods to optimise the management options and/or the protective strategies and to review the effectiveness of the selected countermeasure *(in connection with KT5a, KT7b, KT8a, KT9a-e)*		

KT4a - Countermeasures and countermeasure strategies

VISION: Improved understanding of countermeasures to better build and implement countermeasure strategies (preparedness, response, recovery).

2020 **2025** **2030** **2035** **2040...**

Improve the European Handbooks and development of information sheets

- CA2KT4a - Generic improvement of European handbooks, and addendum to cover other contamination scenarios than NPP accidents such as alpha emitters accidents, long lived radionuclides (without iodine) as in reprocessing processes or contamination resulting from a malicious act. Those handbooks should address waste management issues.

Improvements of countermeasure models/tools, databases including uncertainty handling

- CA2KT4a - Improve or start research on regional/local parameterizations of models which support countermeasures and associated strategies in order to improve realistic assessments.
- CA2KT4a - Improve concepts and parameters of existing countermeasure models such as ERMIN and AGRICP implemented in JRODOS and ARGOS
- CA2KT4a - Improve user-friendliness of tools as well as readiness of end-products to be used for decision-making and countermeasure implementations
- CA2KT4a - Review and investigate if new protective actions and strategies for remediation and restoration can be derived from the Fukushima experience. Investigate other new countermeasures for other environments such as urban environments surfaces (such as glass, concrete) and enlarge the spectrum of radionuclides to consider in relation with other accidents, and consider appropriate physicochemical forms for e.g. malicious dispersion. Waste production and management should also be investigated in this regard.
- CA2KT4a - Investigate how the use of uncertainties in models may improve/affect the effectiveness of countermeasures
- CA2KT4a - Improve models for the contamination behaviour of different surfaces and in food and feed for an improved evaluation of ingestion dose for the public.
- CA2KT4a - Generation of practical information sheets for countermeasures implementers (including 'self-help' volunteers) for maximising the effectiveness of the countermeasures and to improve the protection of these implementers

Develop an all hazard approach und expand strategies and databases for new threats, regions and environments, including links to Big Data and knowledge databases

- CA2KT4a - Embed countermeasure strategies in an all-hazard approach to be able to face induced situations such as natural disasters or pandemics. Develop combinations of countermeasures in a multi-stressor environment.
- CA2KT4a - Development of electronic versions that are linked to knowledge databases and Big Data structures.
- CA2KT4a - Develop a better estimation of factors that characterise countermeasures and countermeasure strategies (effectiveness, costs, non-radiological effects, waste management, ...) as function of environment, region and affected population.
- CA2KT4a - Development of countermeasures strategies for a wider range of accidents.
- CA2KT4a - Strategic analyses of countermeasures for relevant scenarios ensuring parameters governing radiological consequences can be identified in time for optimised remediation – including analyses of timelines of implementation.

Combine results to develop more intelligent countermeasure models applicable to a wider range of scenarios, including an all hazard approach

- CA2KT4a - Development of intelligent wizards that propose optimised countermeasures / countermeasure strategies based on available information from a DSS

KT4b - Implementation of countermeasures, lifting of countermeasures, transition from emergency to existing exposure situation

VISION: Methodological framework for the implementation and lifting of countermeasures based on monitoring (e.g. Operational Intervention Levels), modelling (Decision Support Systems) and guidance on optimisation supporting ICRP recommendations (including stakeholder interaction, see challenge 3).

2020 **2025** **2030** **2035** **2040...**

Analyse the needs of local stakeholders for local-national interaction

- CA2KT4b - Analyse needs of local actors for local-national interaction for implementation of mitigating actions in response and recovery phases: needs for development of compatible tools.

Develop a framework for lifting of countermeasures, including monitoring strategies, OILs, indicators and evaluation of strategies

- CA2KT4b - Development of framework and guidance for setting up criteria to lift countermeasures (particularly for the early phase). This includes guidelines for returning people but also compensations schemes.
- CA2KT4b - Develop monitoring strategy to support or help adapt the countermeasure implementation. Thereby it can be secured that the countermeasure implementation is optimised in practice – not just on paper.
- CA2KT4b - Investigate how the use of operational radiological criteria such as Operational Intervention Levels (OILs) may improve the decision-making process for different phases of a situation (preparedness, release, recovery). In particular investigate this concept for using during a time evaluating situation.
- CA2KT4b - Develop OILs for non-nuclear scenarios in cooperation with the IAEA
- CA2KT4b - Develop catalogues and check-lists to facilitate timely implementation of countermeasures
- CA2KT4b - Development and application of criteria, indicators and methods to optimise the management options and/or the protective strategies and to review the effectiveness of the selected countermeasure.

- CA2KT3b - Develop criteria and methods to determine the start and end of countermeasures. Take all relevant factors into account

Improve the management approaches for the transition phase based on former EC projects

- CA2KT3b - Include conclusions from CONFIDENCE, TERRITORIES and ENGAGE to better define the transition phase and the methodological and technical needs for preparing the recovery phase

Investigate how the framework can best be implemented in a DSS

- CA2KT3b - Investigate representation of OILs concept into Decision Support Systems in conjunction of monitoring results and investigate optimisation possibilities

Complete the framework for operational use and test its applicability with end users

- CA2KT3b - Development of the methodological framework

Key topic 5: Formal decision support

Challenges and achievement in	Phase 1	Phase 2	Phase 3
5a. Decision-making methods and tools **VISION**: Formalised methods and tools that support, structure and improve the decision-making process in all phases of an accident /incident	• Consolidate the results from CONFIDENCE and TERRITORIES with respect to decision-making in the various phases • Develop multi-criteria analysis tools that are fit for purposes • Support the structuring process in decision-making with focus on optimisation/selection of countermeasure strategies • Development of guidance material for "good decision-making practice"; development of structured methodologies to define generic scenarios for preparedness and planning taking into account different driving forces (technical, societal, economic, environmental, etc.) *(in connection with KT7b, KT7f, KT9b-c)* • Development of training and support material and activities (practical courses, field visits, etc.) for decision makers and other stakeholders	• Review the progress and develop a research program for the way forward, in particular a large-scale research project to identify methods that have potential for operational use • Perform research as defined in the program	• Support the development of operational solutions • Research projects to test operational solutions in the different phases and application scenarios

5b. Decisions under high uncertainty **VISION**: Formalised methods that support robust decision-making under high uncertainties	• Consolidate the results from CONFIDENCE and TERRITORIES with respect to decision-making under high uncertainty. This includes model sensitivity, validity, and inter-comparison with measurements • Develop methods and criteria to identify indicators that are robust with respect to uncertainties of the prevailing situation (can be used for decision-making even if uncertainty is high) • Assessment of the uncertainty in application/efficiency of countermeasures and their acceptance by the public *(in connection with KT4a, KT8a-b, KT9b-c)* • Assessment and communication of uncertainties (how to transfer data in model chains and how they can best be communicated/presented) • Development of training and support material and activities (practical courses, field visits, etc.) for decision makers and other stakeholders *(in connection with KT7f)* • Develop methods and tools supporting local stakeholders to manage daily life under conditions with high uncertainty (in connection with KT4b, KT8a-b)	• Evaluate the handling of uncertainties in operational procedures and develop guidance for their better integration in official documents • Combination of agent-based simulation systems with Multi Criteria Analysis for uncertainty handling to better integrate the stakeholders' preferences *(in connection with KT8a and KT9b-c)* • Investigate more complex decision analysis tools for use under high uncertainty aiming to move towards big data applications • Development of artificial intelligence / machine learning techniques for decision-making and combine all types of uncertainties (e.g. aleatory, epistemological, computational)	• Develop a large-scale research project to test the methods developed so far for identification of tools and methods which are useful for operational application *(in connection with KT7b, KT8a)*

KT5a - Decision-making methods and tools

VISION: Formalised methods and tools that support, structure and improve the decision-making process in all phases of an accident /incident.

2020 **2025** **2030** **2035** **2040...**

Based on former projects, improve existing tools such as MCDA as well as methods and processes for selection of measures

- CA2KT5a - Consolidate the results from CONFIDENCE and TERRITORIES with respect to decision-making in the various phases
- CA2KT5a - Develop multi-criteria analysis tools that are fit for purposes
- CA2KT5a - Support the structuring process in decision-making with focus on optimisation/selection of countermeasure strategies

Develop guidance and training material for decision makers and other stakeholders

- CA2KT5a - Development of guidance material for "good decision-making practice"; development of structured methodologies to define generic scenarios for preparedness and planning taking into account different driving forces (technical, societal, economic, environmental, etc.)
- CA2KT5a - Development of training and support material and activities (practical courses, field visits, etc.) for decision makers and other stakeholders

Develop a new research program based on phase 1 and perform research as defined

- CA2KT5a - Review the progress and develop a research program for the way forward, in particular a large-scale research project to identify methods that have potential for operational use
- CA2KT5a - Perform research as defined in the program

Support the development and test of operational solutions for all phases of an accident

- CA2KT5a - Support the development of operational solutions
- CA2KT5a - Research projects to test operational solutions in the different phases and application scenarios

KT5b - Decisions under high uncertainty

VISION: Formalised methods that support robust decision-making under high uncertainties.

2020 **2025** **2030** **2035** **2040...**

Based on former projects improve existing methods and tools and develop indicators that can be used if uncertainty is high

- CA2KT5b - Consolidate the results from CONFIDENCE and TERRITORIES with respect to decision-making under high uncertainty. This includes model sensitivity, validity, and inter-comparison with measurements
- CA2KT5b - Develop methods and criteria to identify indicators that are robust with respect to uncertainties of the prevailing situation (used for decision-making even if uncertainty is high)
- CA2KT5b - Assessment of the uncertainty in application/efficiency of countermeasures and their acceptance by the public
- CA2KT5b - Assessment and communication of uncertainties (how to transfer data in model chains and how they can best be communicated/presented)

Improve communication procedures of dealing with uncertainty and develop training material for decision makers

- CA2KT5b - Development of training and support material and activities (practical courses, field visits, etc.) for decision makers and other stakeholders

Improve methods and tools for local stakeholders

- CA2KT5b - Develop methods and tools supporting local stakeholders to manage daily life under conditions with high uncertainty

Investigate and develop more complex approaches such as ABM and AI including big data approaches

- CA2KT5b - Combination of agent-based simulation systems with Multi Criteria Analysis for uncertainty handling to better integrate the stakeholders' preferences
- CA2KT5b - Investigate more complex decision analysis tools for use under high uncertainty aiming to move towards big data applications
- CA2KT5b - Development of artificial intelligence / machine learning techniques for decision-making and combine all types of uncertainties (e.g. aleatory, epistemological, computational)

Evaluate the handling of uncertainty in operation procedures and improve their integration

- CA2KT5b - Evaluate the handling of uncertainties in operational procedures and develop guidance for their better integration in official documents

Develop a large-scale demonstration project for identification of all methods and tools that are ready for operational application

- CA2KT5b - Develop a large-scale research project to test the methods developed so far for identification of tools and methods which are useful for operational application

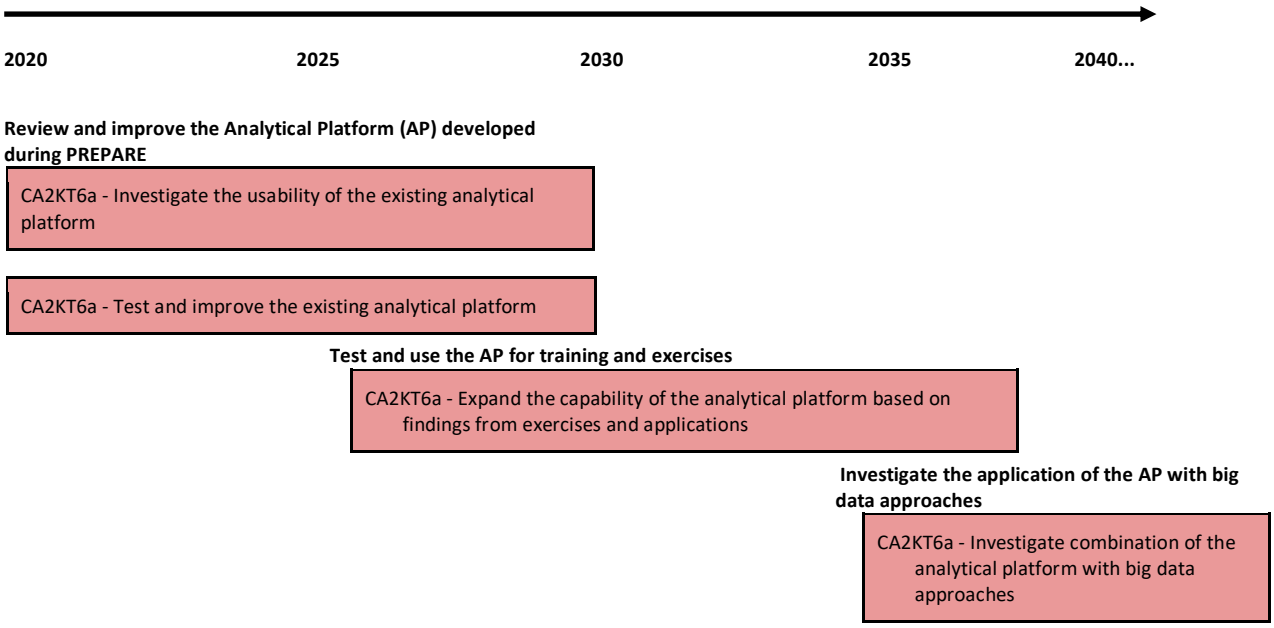
Key topic 6: Disaster informatics

Challenges and achievement in	Phase 1	Phase 2	Phase 3
6a. Analytical platform **VISION**: Establish the analytical platform as part of the emergency management toolbox	• Investigate the usability of the existing analytical platform • Test and improve the existing analytical platform	• Expand the capability of the analytical platform based on findings from exercises and applications	• Investigate combination of the analytical platform with big data approaches
6b. Knowledge databases **VISION**: Knowledge databases becoming operational allowing to support decision-making in all phases of an accident/incident	• Extend the knowledge database with more scenarios for all phases of an accident/incident • Develop more focused similarity approaches	• Investigate how big data analysis can be used for the knowledge database *(in connection with KT4a)* • Develop tools or mechanisms to collect relevant information from social media • Usage of all relevant information from whatever sources (e.g. Twitter, Facebook, scenarios)	• Expand knowledge databases and big data functionalities to develop a focal point for decision support • Investigate if this approach can complement existing DSS
6c. New generation Decision Support Systems (DSS) **VISION**: New generation Decision Support Systems for integrated decision-making (tactical, operational, strategic)	• Improve user interfaces of existing Decision Support Systems for the various phases of an accident/incident *(in connection with KT4a)* • Include modules to calculate source terms based on the description of accidents • Develop new interfaces of DSS's to comply with improved decision-making methods	• If necessary, investigate concepts and advanced informatics approaches to modularise Decision Support Systems for application in different phases including uncertainty handling • Testing of methods for implementing of Artificial Intelligence and Big Data approaches in countermeasure simulation models of a DSS	• Develop new generation of Decision Support Systems based on advanced informatics and with new countermeasure modules allowing the end user to define his or her objectives/goals first and the system identifies the best possible strategies to achieve the specified objectives/goals with pros and cons automatically *(in connection with KT4a, KT7b)*

	• Investigate the need for re-engineered DSS to deal with uncertainty • Investigate the application of Artificial Intelligence and Big Data for application in DSS and support of countermeasure modelling	• Coupling of the existing strategic Decision Support Systems such as ARGOS and RODOS to Command and Control (C2) systems	
6d. Virtual and augmented reality **<u>VISION</u>**: Suite of new training facilities using virtual and augmented reality for preparedness and testing of first responders, decision makers and other stakeholders	• Review and investigate the usability of serious gaming and augmented reality in radiation protection research *(in connection with KT7b, KT9c)* • Development of serious games and augmented reality for preparedness *(in connection with KT7b, KT9b, KT9c)*	• Explore the usage of serious gaming and augmented reality for training of the decision-making processes *(in connection with KT7b, KT8c, KT9b, KT9c)* • Develop appropriate tools to train decision makers and key stakeholders *(in connection with KT7b, KT9b, KT9c)* • Dedicated tools for addressing the key challenges associated with transition and recovery phases *(in connection with KT7b, KT9b, KT9c)*	• Develop better training tools for responders, decision makers and other stakeholders by combining virtual and augmented reality tools with Decision Support Systems *(in connection with KT7b, KT9b, KT9c)*

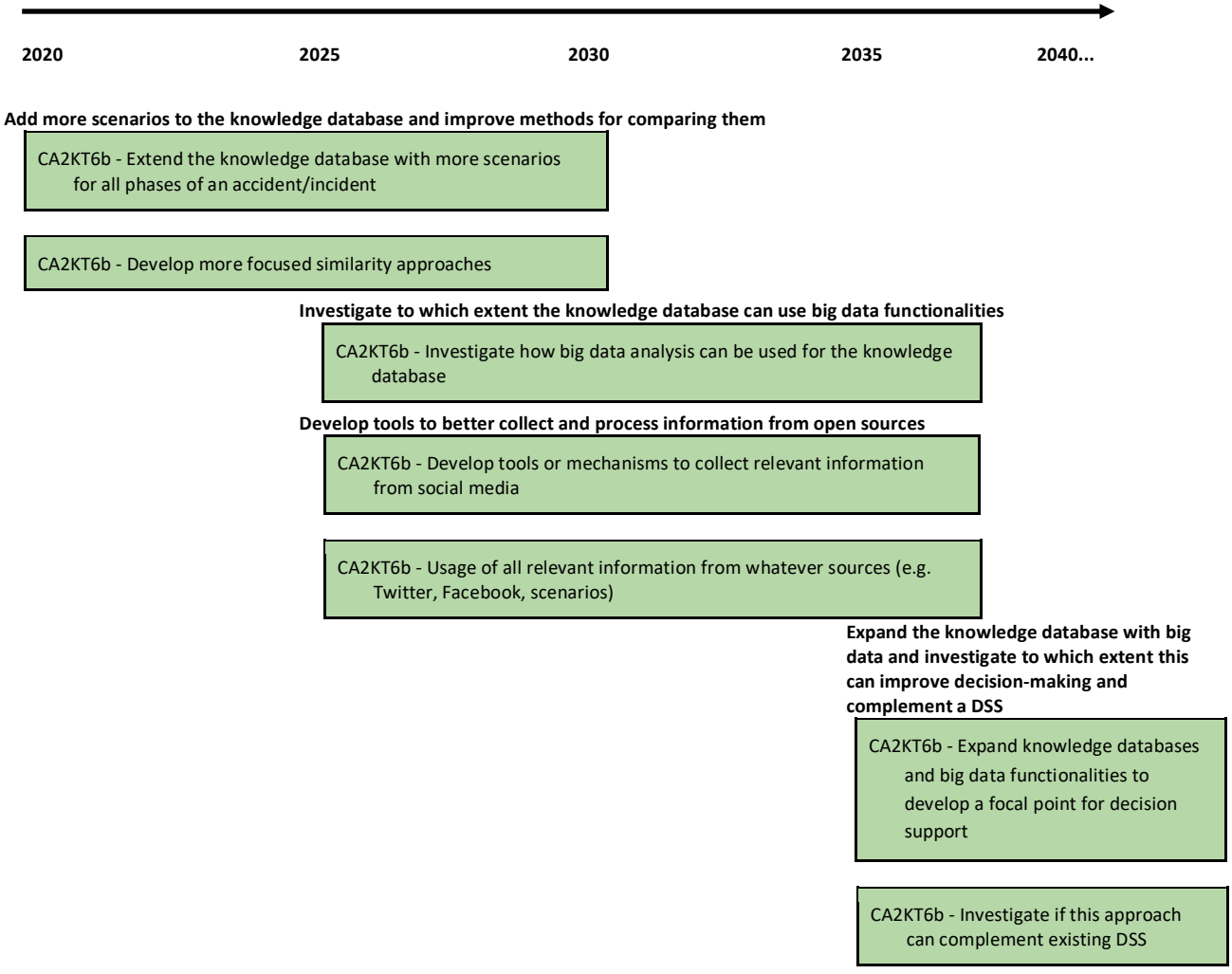
KT6a - Analytical platform

VISION: Establish the analytical platform as part of the emergency management toolbox.



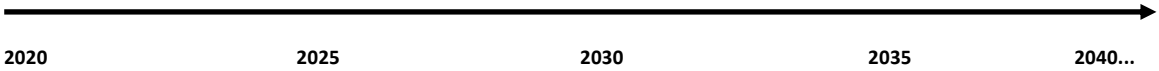
KT6b - Knowledge databases

VISION: Knowledge databases becoming operational allowing to support decision-making in all phases of an accident/incident.



KT6c - New generation Decision Support Systems (DSS)

VISION: New generation Decision Support Systems for integrated decision-making (tactical, operational, strategic).



Develop better handling/user interfaces of existing DSS reflecting recent developments in EU projects and if necessary explore reengineering of the DSS

- CA1KT6c - Improve user interfaces of existing Decision Support Systems for the various phases of an accident/incident
- CA1KT6c - Include modules to calculate source terms based on the description of accidents
- CA1KT6c - Develop new interfaces of DSS's to comply with improved decision-making methods
- CA1KT6c - Investigate the need for re-engineered DSS to deal with uncertainty

Improve the DSS with new functionalities and investigate the use of AI

- CA1KT6c - Investigate the application of Artificial Intelligence and Big Data for application in DSS and support of countermeasure modelling

Improve the DSS related to handling uncertainties and test AI and big data approaches

- CA1KT6c - If necessary, investigate concepts and advanced informatics approaches to modularise Decision Support Systems for application in different phases including uncertainty handling
- CA1KT6c - Testing of methods for implementing of Artificial Intelligence and Big Data approaches in countermeasure simulation models of a DSS

Couple existing DSS such as ARGOS and JRODOS with a Command and Control (C2) system

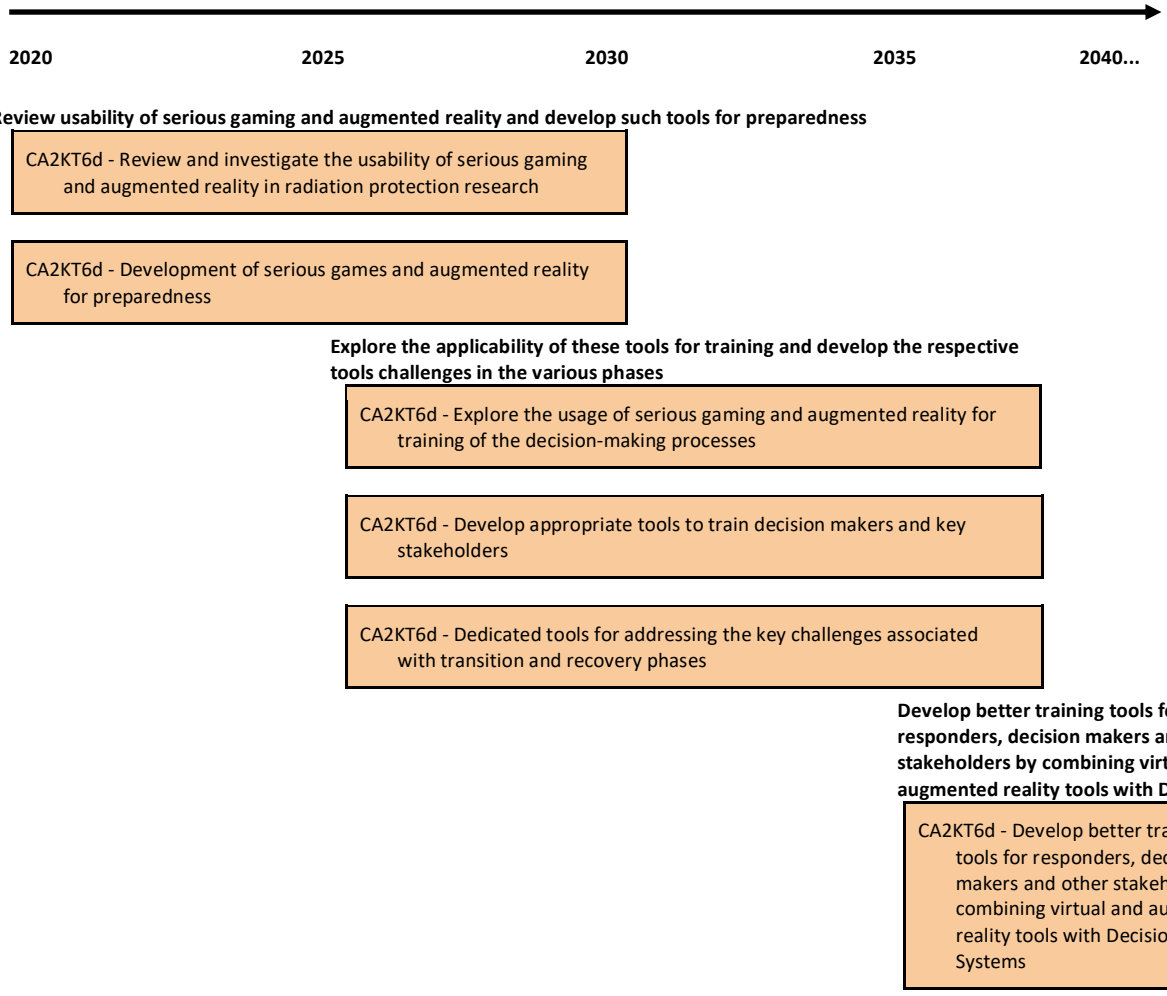
- CA1KT6c - Coupling of the existing strategic Decision Support Systems such as ARGOS and RODOS to Command and Control (C2) systems

Development of a new generation of DSS based on advanced informatics approaches and with better decision aiding components

- CA1KT6c - Develop new generation of Decision Support Systems based on advanced informatics and with new countermeasure modules allowing the end user to define his or her objectives/goals first and the system identifies the best possible strategies to achieve the specified objectives/goals with pros and cons automatically

KT6d - Virtual and augmented reality

VISION: Suite of new training facilities using virtual and augmented reality for preparedness and testing of first responders, decision makers and other stakeholders.



Challenge Area 3

Challenges in setting-up a trans-disciplinary and inclusive framework for preparedness for emergency response and recovery

Key topic 7. Emergency response and recovery framework

a. Implementation of BSS including reference levels and relation with operational radiological criteria
b. Governance of preparedness
c. Long-term management
d. Contaminated goods management
e. Integration in all-hazard approach
f. Exercises and drills

Key topic 8. Stakeholder engagement, involvement of the public & communication (presentation of and addressing uncertainties)

a. Stakeholder engagement processes including the public
b. Communication
c. Citizen Science

Key topic 9. Integrated emergency management – non-radiological aspects (health surveillance, ethical aspects, economic issues…)

a. Health surveillance
b. Ethical aspects
c. Socio-economic aspects
d. Integrated surveillance and monitoring
e. Accident waste management
f. Radiological protection culture

Setting-up a trans-disciplinary and inclusive framework for preparedness for emergency response and recovery

Key topic 7: Emergency response and recovery framework

Objective: **Develop radiological decision criteria and implementation frameworks to improve and ensure the sustainability of emergency response and recovery management, addressing societal and ethical issues**

Expected results: Operational radiological decision criteria and guidance for implementation taking into account societal and ethical issues, and management framework for improve sustainable emergency response and recovery.

Challenges and achievement in	Vision
Implementation and development of BSS including reference levels and relation with operational radiological criteria	Harmonised framework to support countries in applying the BSS and key decision criteria (such as OILs)
Governance of preparedness	Guidance framework and tools to support sustainable strategies of preparedness to the management of post-accident situations
Long-term management	Better guidance for long-term management of contaminated areas including societal aspects
Contaminated goods management	Guidance framework to better manage goods from contaminated areas
Integration in all-hazard approach	Guidance framework to develop global, holistic and optimised emergency preparedness, response and recovery strategies
Exercises and drills	Methodological and practical/technical development of emergency exercises and gathering feedback and incorporating lessons learned from exercising into plans

Key topic 8: Stakeholder engagement, involvement of the public & communication (presentation of and addressing uncertainties)

Objective: **Improve the efficiency and social robustness of emergency response. Ensure that stakeholders are involved in decisions that impact their lives**

Expected results:

- Maintain the inclusion of social aspects of emergency response and stakeholder engagement;
- Greater recognition of the importance of stakeholder and public engagement;
- Improve understanding of the factors and criteria for successful stakeholder engagement;
- Improved preparedness for media and social media communication.

Challenges and achievement in	Vision
Stakeholder engagement processes including *national and local actors* and the public	Guidance framework for establishing a successful stakeholder engagement process
Communication	Guidance framework for efficient communication for different exposure contexts, time scales, cultural and socioeconomic contexts with various target groups
Citizen Science	Guidance framework for establishing a successful integration of citizen science in radiological risk governance

Key topic 9: Integrated emergency management – non-radiological aspects (health surveillance, ethical aspects, economic issues…) Objective: **Better address non-radiological aspects for developing guidance and framework in an integrated way to improve emergency response and recovery management, covering many disciplines** Expected results: Improved knowledge on the role of non-radiological aspects in emergency response and recovery, and procedures and guidance for the development of an integrated approach.	
Challenges and achievement in	**Vision**
Health surveillance	Guidance framework for justification and improvement of health surveillance
Ethical aspects	Guidance framework for including ethical aspects in decision-making in all phases of an emergency
Socio-economic aspects	Guidance framework for including socio-economic aspects in decision-making in all phases of an emergency
Integrated monitoring and surveillance	Guidance framework for an integrated surveillance and monitoring programme articulating health surveillance, environmental monitoring, human dose assessment and food monitoring
Accident waste management	Guidance framework for managing the environmental and socio-economic issues of various types of wastes (e.g. contaminated materials and goods and waste/effluents produced by decontamination, including non-radioactive waste)
Radiological protection culture	Guidance framework for establishing a sustainable radiological protection culture in all relevant areas of radiation protection including means to support education and training as well as supervision

Key topic 7: Emergency response and recovery framework

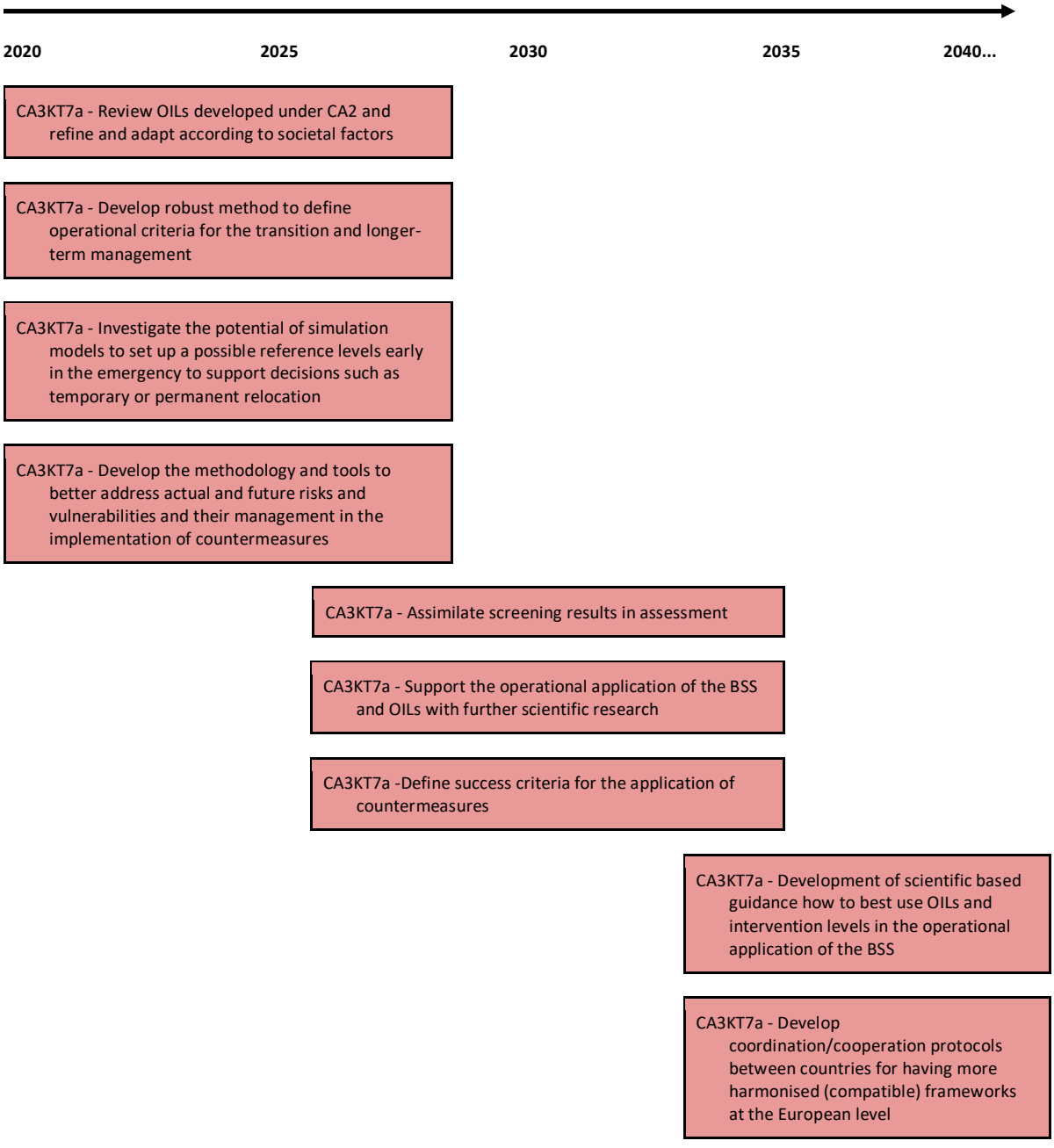
Challenges and achievement in	Phase 1	Phase 2	Phase 3
7a. Implementation and development of BSS including reference levels and relation with operational radiological criteria **VISION**: Harmonised framework to support countries in applying the BSS and key decision criteria (such as OILs)	• Review OILs developed under CA2 and refine and adapt according to societal factors • Develop robust method to define operational criteria for the transition and longer-term management • Investigate the potential of simulation models to set up a possible reference levels early in the emergency to support decisions such as temporary or permanent relocation • Develop the methodology and tools to better address actual and future risks and vulnerabilities and their management in the implementation of countermeasures	• Assimilate screening results in assessment • Support the operational application of the BSS and OILs with further scientific research • Define success criteria for the application of countermeasures	• Development of scientific based guidance how to best use OILs and intervention levels in the operational application of the BSS • Develop coordination/cooperation protocols between countries for having more harmonised (compatible) frameworks at the European level
7b. Governance of preparedness **VISION**: Guidance framework and tools to support sustainable strategies of preparedness to the management of post-accident situations	• Co-develop with relevant stakeholders the processes, methodologies and tools that support sustainable strategies of preparedness • Analyse feedback experience from various types of large-scale catastrophic events (e.g. CRBN hazards) where return to normality is not possible • Analyse and investigate the respective roles of the different concerned stakeholders and the consequences of their interactions • Review public action patterns articulating the public coordination with societal action based on the principles of the Commons, in order to stimulate resilience capacities of the various categories of stakeholders • Based on the review of public action patterns, propose strategies to restore societal capacity to cope with the complexity of post-accident situations • Investigate how normative standards can be used in post-	• Define strategies for reviewing preparatory processes in various national contexts • Refine strategies to address the challenge of sustainability of preparatory processes • Study on which factors can influence and enhance the coordination and harmonization in emergency preparedness, response and recovery in neighbouring countries and at the European and international level in general	• Experiment and test the developed preparedness methodologies at national level while supporting diffusion and coordination of preparedness processes at EU level

	accident situations while not impeding the capacity of the various categories of stakeholders to cope with the complex and multi-dimensional issues to be dealt with • Investigate to which extent serious gaming can be used for training of decision makers; organize experimental processes of preparedness	• Develop training and exercise materials (including serious games) for training stakeholders	
7c. Long-term management **VISION**: Better guidance for long-term management of contaminated areas including societal aspects	• Develop a sustainable stakeholder engagement framework based on a co-expertise process to improve public health and well-being • Develop and analyse criteria for lifting of countermeasures	• Elaborate a guidance including the various considerations for the long-term management and further analyse the societal aspects	• Test the guidance and participatory processes in stakeholder groups and improve the framework
7d. Contaminated goods **VISION**: Guidance framework to better manage goods from contaminated areas	• Analyse the implications of trade and use of goods from contaminated territories in the perspective of a sustainable recovery, including the management of business activities • Develop simulation models that allows the quantification of potential doses from usage of contaminated goods	• Develop guidance on management strategies for goods, addressing health, societal, economic and ethical issues	• Test the guidance in interaction with the stakeholders and evaluate their feasibility
7e. Integration in all-hazard approach **VISION**: Guidance framework to develop global, holistic and optimised emergency preparedness, response and recovery strategies	• Analyse emergency preparedness and responses in sectors different from nuclear or radiological emergency; - evaluate the basis for promoting experience exchange, mutual competences and sharing lessons learned, towards a holistic, multi-hazard preparedness; - contribute to trans-disciplinary cooperation in emergencies and benefit from experiences across sectors • Identify the key components of the multi-hazard approach to emergency planning and response and analyse their contribution to the management of the emergency and recovery strategies	• Elaborate the framework adapted to address the all-hazards approach and performed further analysis to put into perspective the main components for the evaluation of the strategies	• Develop governance approaches at local, national and international levels to better integrate radiation protection into a broader environmental and health protection framework

7f. Exercises and drills **<u>VISION</u>**:Methodological and practical/technical development of emergency exercises and gathering feedback and incorporating lessons learned from exercising into plans	• Develop a methodological framework and practical/technical materials to exercise emergency preparedness, response and post-accident recovery management • Organize national and transboundary simulations and exercises of nuclear post-accident situations involving the participation of local stakeholders and notably civil society representatives together with pluridisciplinary research components in the drawing, operation, and feedback evaluation of such exercises	• Develop exercises and drills based on all-hazard approach	• Train and exercise all relevant stakeholders acting in the decision-making processes

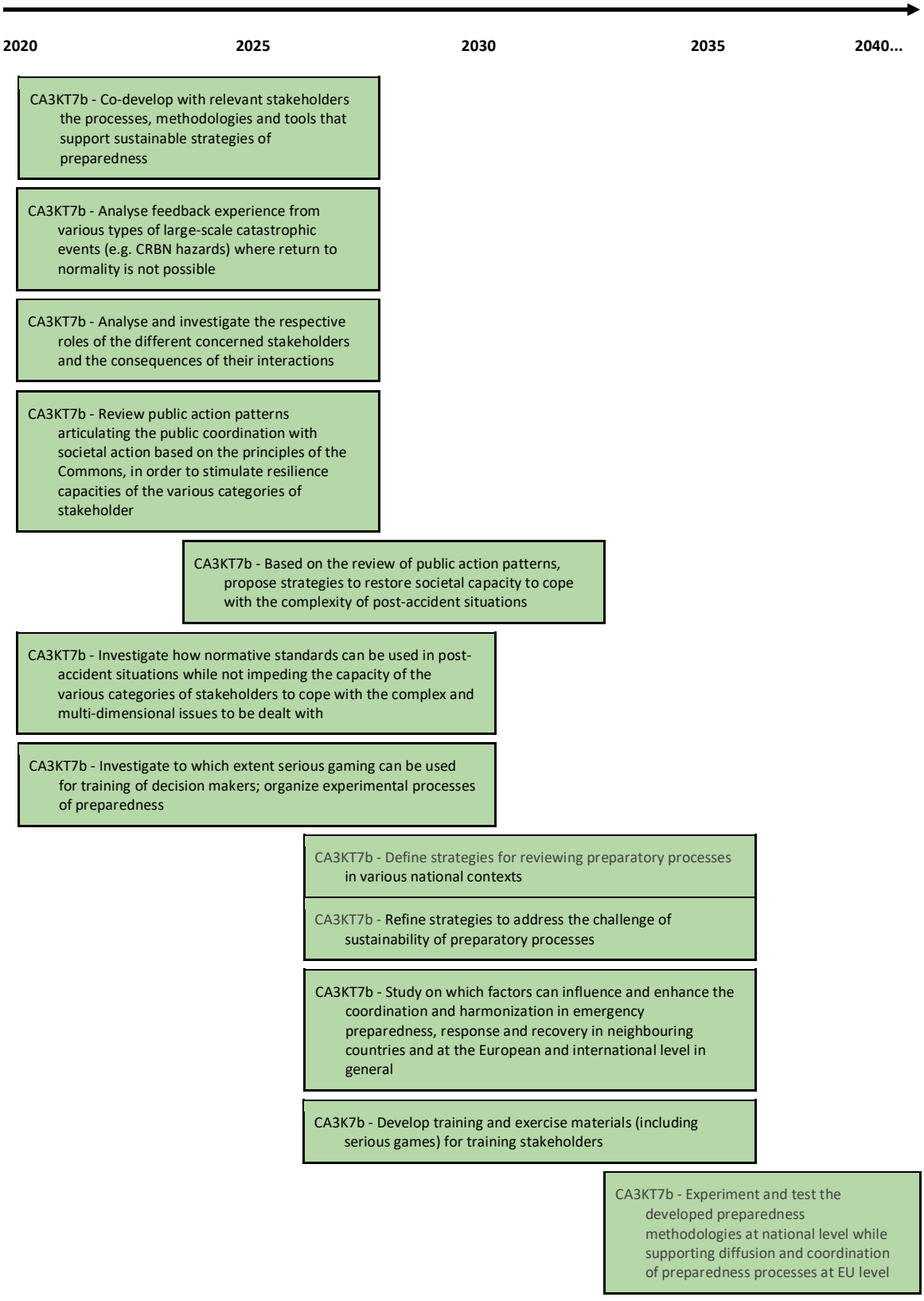
KT7a - Implementation of BSS including reference levels and relation with operational radiological criteria

VISION: Harmonised framework to support countries in applying the BSS and key decision criteria (such as OILs).



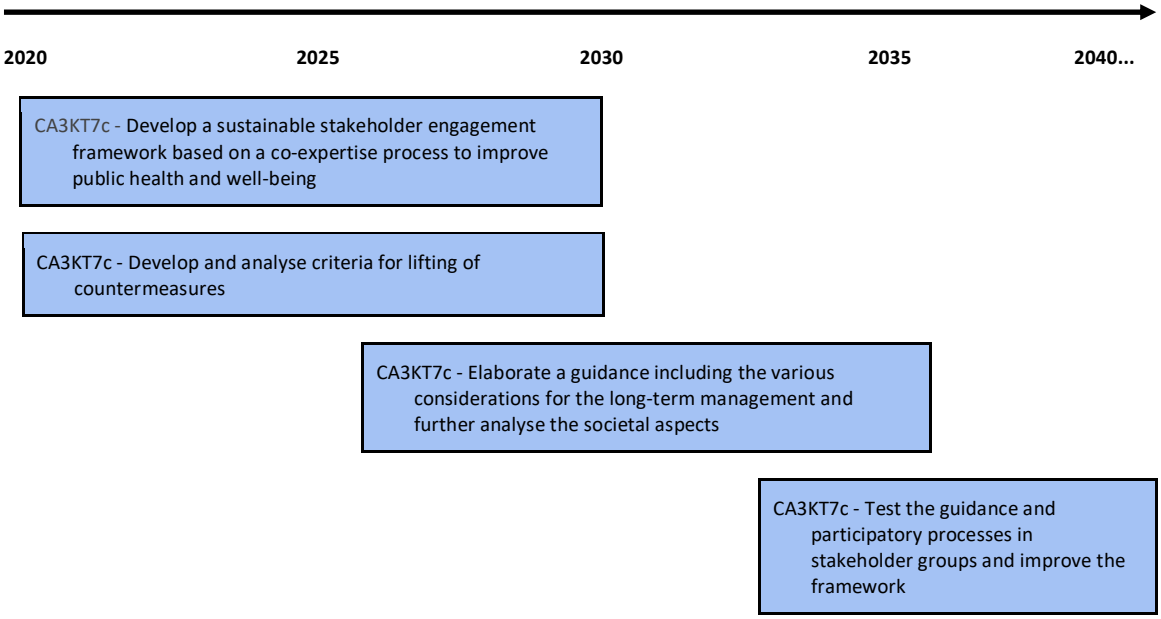
KT7b - Governance of preparedness

VISION: Guidance framework and tools to support sustainable strategies of preparedness to the management of post-accident situations.



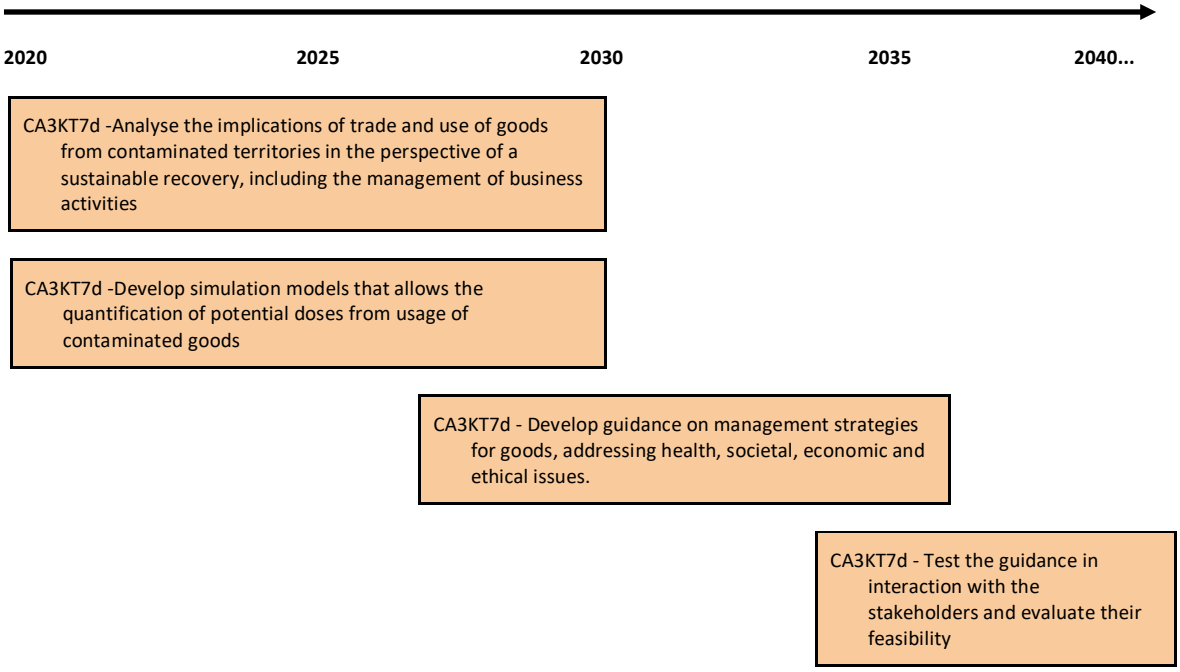
KT7c - Long-term management

VISION: Better guidance for long-term management of contaminated areas including societal aspects.



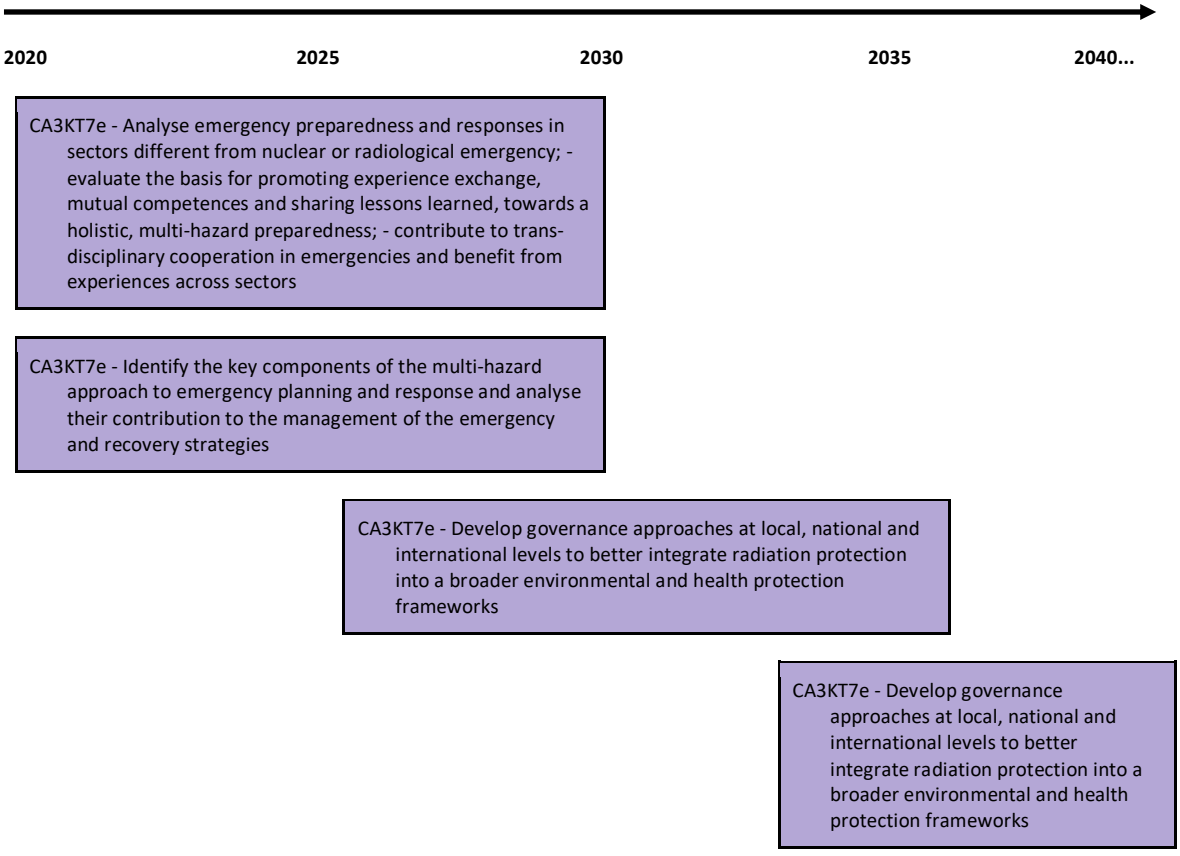
KT7d - Contaminated goods

VISION: Guidance framework to better manage goods from contaminated areas.



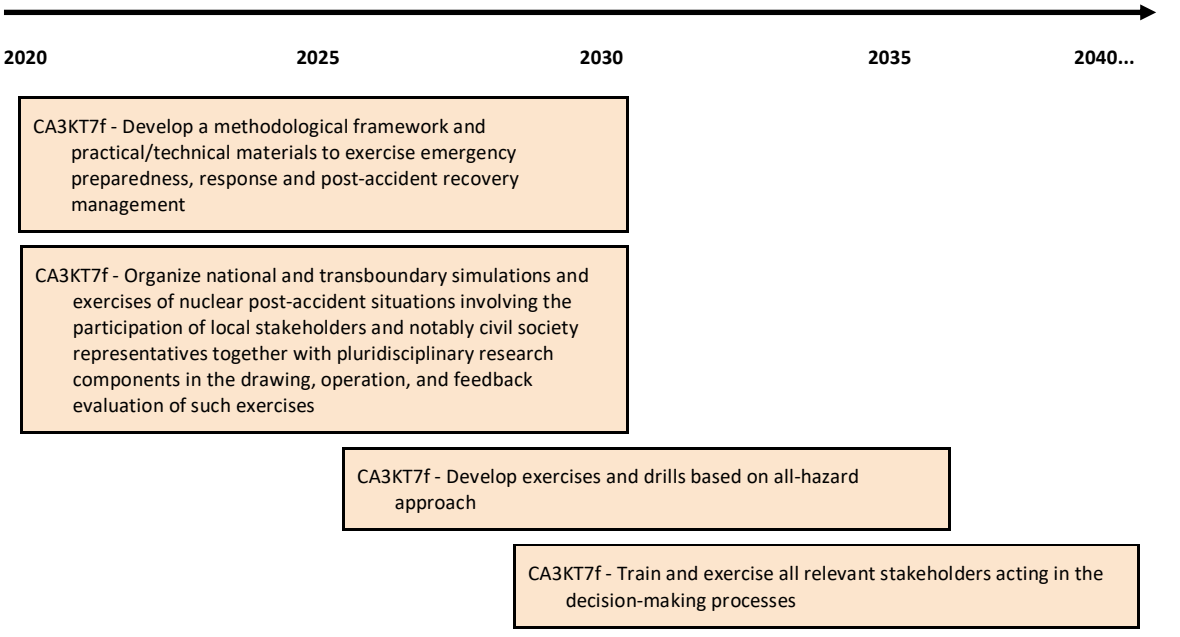
KT7e - Integration in all-hazards approach

VISION: Guidance framework to develop global, holistic and optimised emergency preparedness, response and recovery strategies.



KT7f - Exercises and drills

VISION: Methodological and practical/technical development of emergency exercises and gathering feedback from exercising.



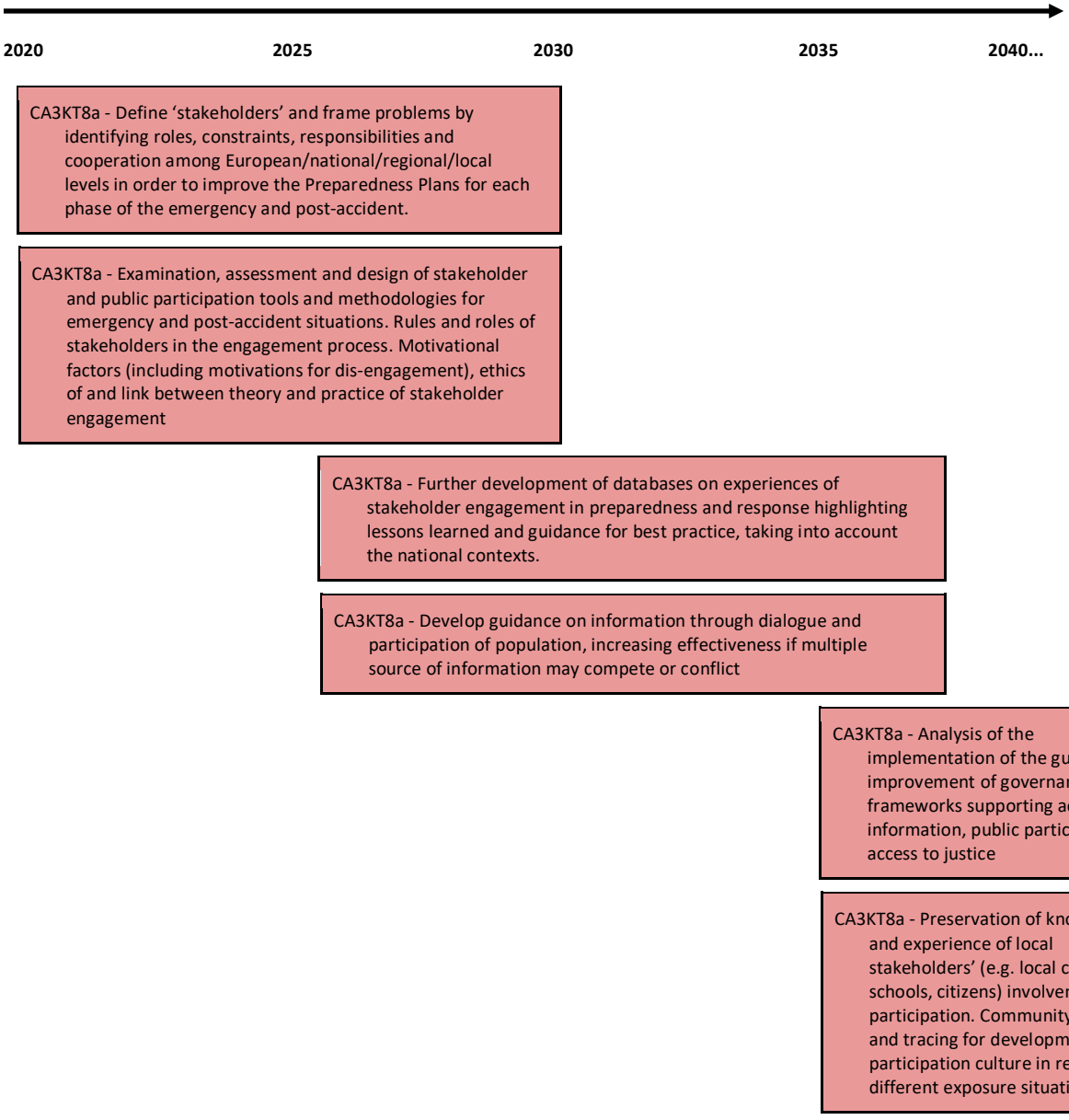
Key topic 8: Stakeholder engagement, involvement of the public & communication (presentation of and addressing uncertainties)

Challenges and achievement in	Phase 1	Phase 2	Phase 3
8a. Stakeholder engagement processes including the public **VISION**: Guidance framework for establishing a successful stakeholder engagement process	• Define 'stakeholders' and frame problems by identifying roles, constraints, responsibilities and cooperation among European/national/regional/local levels in order to improve the Preparedness Plans for each phase of the emergency and post-accident. • Examination, assessment and design of stakeholder and public participation tools and methodologies for emergency and post-accident situations. Rules and roles of stakeholders in the engagement process. Motivational factors (including motivations for dis-engagement), ethics of and link between theory and practice of stakeholder engagement	• Further development of databases on experiences of stakeholder engagement in preparedness and response highlighting lessons learned and guidance for best practice, taking into account the national contexts. • Develop guidance on information through dialogue and participation of population, increasing effectiveness if multiple source of information may compete or conflict	• Analysis of the implementation of the guidance and improvement of governance frameworks supporting access to information, public participation and access to justice • Preservation of knowledge and experience of local stakeholders' (e.g. local community, schools, citizens) involvement and participation. Community research and tracing for development of participation culture in relation to different exposure situations
8b. Communication **VISION**: Guidance framework for effective communication in emergency preparedness, response and recovery with various target groups, and addressing both social and scientific uncertainties	• Investigate the conditions and means for pertinent, timely, reliable and trustworthy communication with the public in nuclear/radiological emergency and post-emergency contexts • Perception of technical information and risk estimates in communication with various publics (lay people, experts, informed civil society) • Media communication of low radiation doses and related uncertainties, including inter-media agenda setting	• Social scientific basis and guidance for the use of social media and other information sources for trustworthy communication and cooperation with the public • Development of methods for analysing the influence of traditional and social media (including citizen journalism) on social trust, risk perception and well-being • Methods and models to assess	• Develop and test tools and methods for two-way communication of uncertain information between experts and non-experts • Communication guidance for operators, regulators, decision makers and journalists for emergency and post-emergency situations

	• Investigate to which extent serious gaming can be used in communication of uncertainties *(in connection with KT6d, KT7b)*	the Influence of citizen journalism on radiation protection behaviours and its integration in radiation protection • Investigate the links between communication and perception of radiological risk and the individual strategies to cope with perceived risks in emergency and post-emergency situations • Investigate how decisions taken under high uncertainty can be communicated to media and general public	
8c. Citizen Science **VISION**: Guidance framework for establishing a successful integration of citizen science in radiological risk governance	• Investigate the potential and pitfalls of citizens involvement in knowledge production and data sharing for radiological risk governance and the mutual influence of citizen science and radiation protection culture. • Determine factors influencing the trust between different actors (data integration, interpretation and accessibility, stakeholder involvement, interaction between partners, assessment of technical aspects on reliability, etc.)	• Develop guidance for successful integration of citizen science in radiological risk governance	• Initiate a platform for sustainable application of citizen science in radiological risk governance

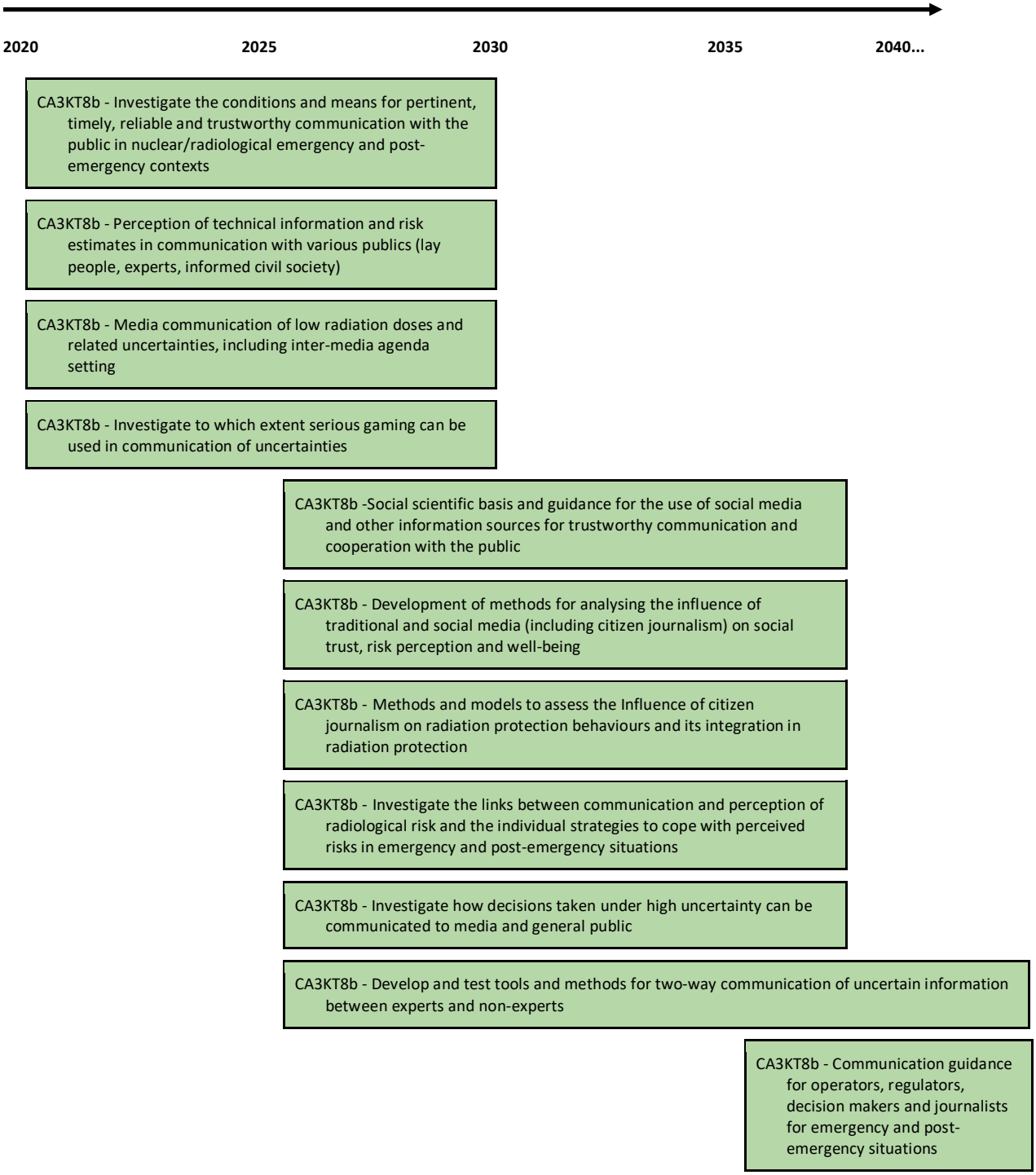
KT8a - Stakeholder engagement processes including the public

VISION: Guidance framework for establishing a successful stakeholder engagement process.



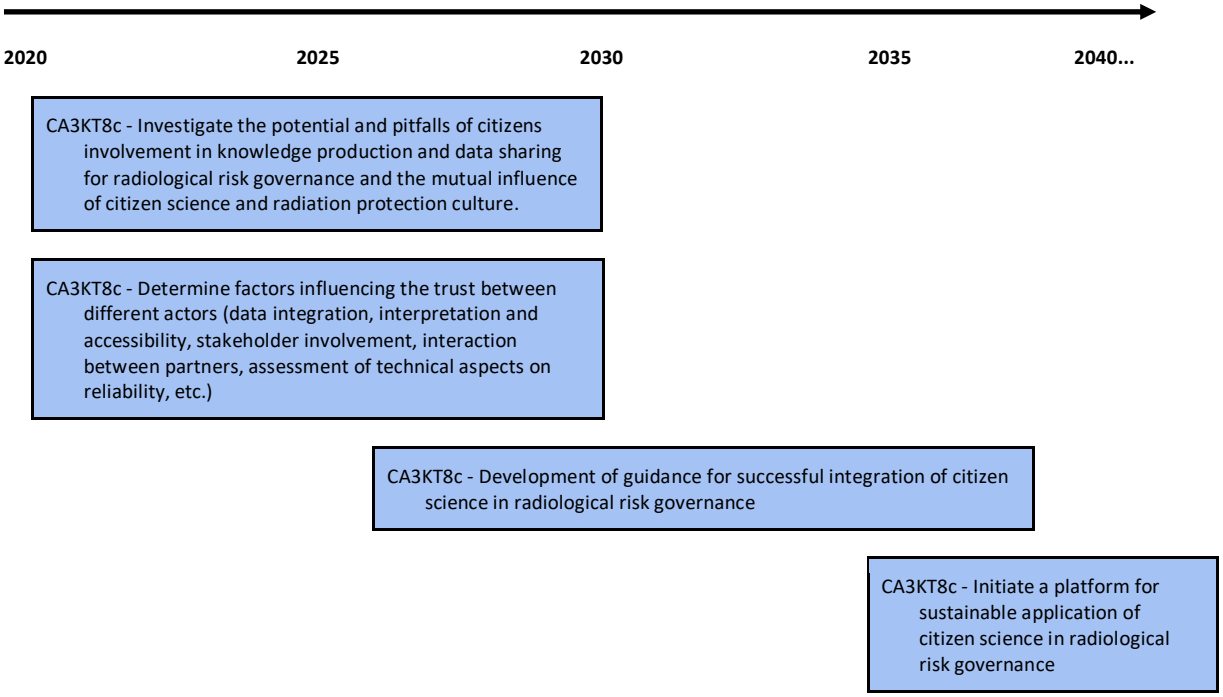
KT8b - Communication

VISION: Guidance framework for effective communication in emergency preparedness, response and recovery with various target groups, and addressing both social and scientific uncertainties.



KT8c - Citizen science

VISION: Guidance framework for establishing a successful integration of citizen science in radiological risk governance.



Key topic 9: Integrated emergency management – non-radiological aspects

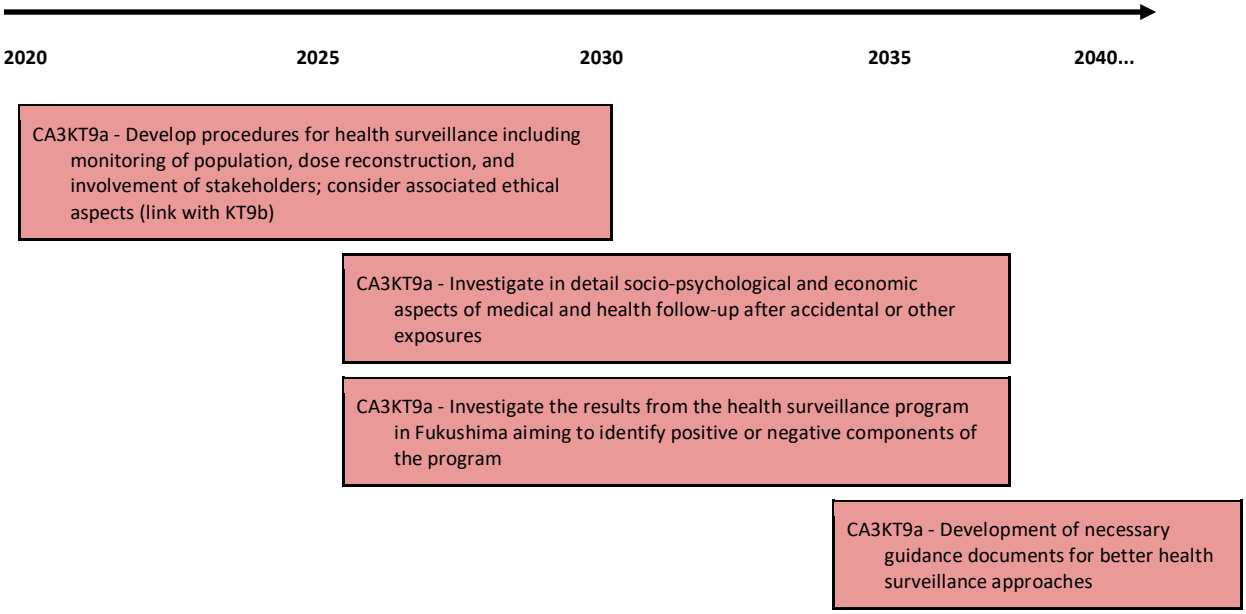
Challenges and achievement in	Phase 1	Phase 2	Phase 3
9a. Health surveillance **VISION**: Guidance framework for justification and improvement of health surveillance	• Develop procedures for health surveillance including monitoring of population, dose reconstruction, and involvement of stakeholders; consider associated ethical aspects (link with KT9b)	• Investigate in detail socio-psychological and economic aspects of medical and health follow-up after accidental or other exposures. • Investigate the results from the health surveillance program in Fukushima aiming to identify positive or negative components of the program	• Development of necessary guidance documents for better health surveillance approaches
9b. Ethical aspects **VISION**: Guidance framework for including ethical aspects in decision-making in all phases (preparedness, emergency and recovery)	1. Ethical aspects of crisis situations, particularly ethical questions of evacuation, and the collection and management of data. Ethical aspects of the transition from emergency to existing radiation exposure situations 2. Investigate the ethical basis and values underpinning risk communication about ionizing radiation exposures	3. Investigate the ethical perspective of compensation for damage incurred due to various situations of radiation exposure and differences among countries	4. Expand the ethical aspect to all questions of decision-making and provide guidance how to deal with it

9c. Socio-economic aspects **VISION**: Guidance framework for including socio-economic aspects in decision-making in all phases (preparedness, emergency and recovery)	• Research on knowledge-action gap (public behaviour response analysis): understand how the population reacts and how socio-economic factors can be used by local-national tools to improve the response • Investigate possible compensation schemes	• Development of comprehensive approaches to studying the perception of radiological risk and environmental remediation actions in post-accident and existing exposure situations. • Investigate the perception of radiological risks from low doses of radiation, accounting for cultural differences in routine, emergency and other exposure situations. • Development of guidance for economic supports for the improvement of living conditions of the population	• Investigate in detail the interplay of psychological aspects associated with radioactivity, social environment and radiation protection behaviours • Development of socio-economic valuation and multi-criteria decision aiding methods to formally structure the evaluation and integration of radiological and non-radiological factors for different ionising radiation exposure situations
9d. Integrated surveillance and monitoring **VISION**: Guidance framework for establishing a comprehensive surveillance and monitoring system addressing health surveillance, human dose assessment, environmental monitoring and food monitoring in meaningful way for local populations	• Investigate connections between issues of health surveillance, human dose assessment, environmental monitoring and food monitoring from the point of view of institutions and local populations in the emergency and post-emergency phase • Investigate connections between these different dimensions of surveillance, healthcare and the development of radiation protection culture	• Develop guidance on the way to set up comprehensive surveillance and monitoring systems articulating health, body, environment and food surveillance and healthcare, taking into account the potential of citizen-based monitoring	• Implement and test the guidance on the way to set up comprehensive surveillance and monitoring systems articulating health, body, environment and food surveillance and healthcare, taking into account the potential of citizen-based monitoring

9e. Accident waste management **VISION**: Guidance framework for managing the various types of waste (i.e. contaminated materials and goods and waste/effluents produced by decontamination)	• Analyse waste management strategies implemented after the Fukushima-Daiichi NPP accident • Analyse the environmental and socio-economic aspects of waste management after accidents and incidents (e.g. collection, transport, treatment, and disposal of solid and liquid wastes) • Investigate channels and technical, economic, societal aspects and ethical issues for managing/treating and/or recycling radioactive materials and wastes	• Progressively improve research on waste management issues by integration of feedback from the evolution of Fukushima waste management framework as well as evolution of policy framework of countries • Explore the feasibility, cost-effectiveness of radioactive waste volume reduction techniques, and associated disposal/storage strategies • Develop tools and methods to inform, debate and deliberate with stakeholders in order to assess various options of radioactive waste management (with a priority for low level and very low activity levels) in various national - political - environmental contexts	• Identify and analyse problematics of long-term waste disposal surveillance
9f. Radiological protection culture **VISION**: Guidance framework for establishing a sustainable Radiological Protection Culture in all relevant areas of radiation protection including means to support education and training as well as supervision	• Investigate the role of radiation protection culture,in particular its contribution to the protection system and whether it can improve health and well-being • Development of tools, methods, processes to build, maintain and transmit RP culture in all aspects of emergency management with due consideration of the needs of stakeholders	• Development of guidance for enhancing RP culture for specific publics (communities around nuclear installations, schools, patients, parents, pregnant women, medical doctors) • Development of appropriate education and training means	• Development of procedures how to use the RP culture in the operational world and develop mechanisms to quantify a successful implementation of RP culture

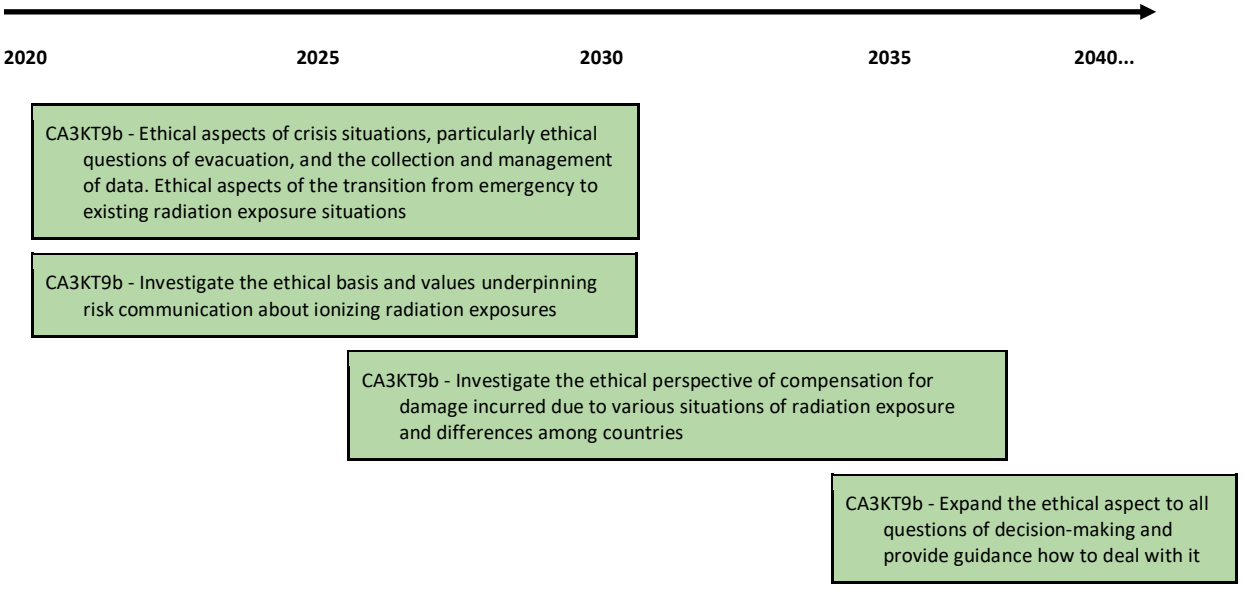
KT9a - Health surveillance

VISION: Guidance framework for justification and improvement of health surveillance.



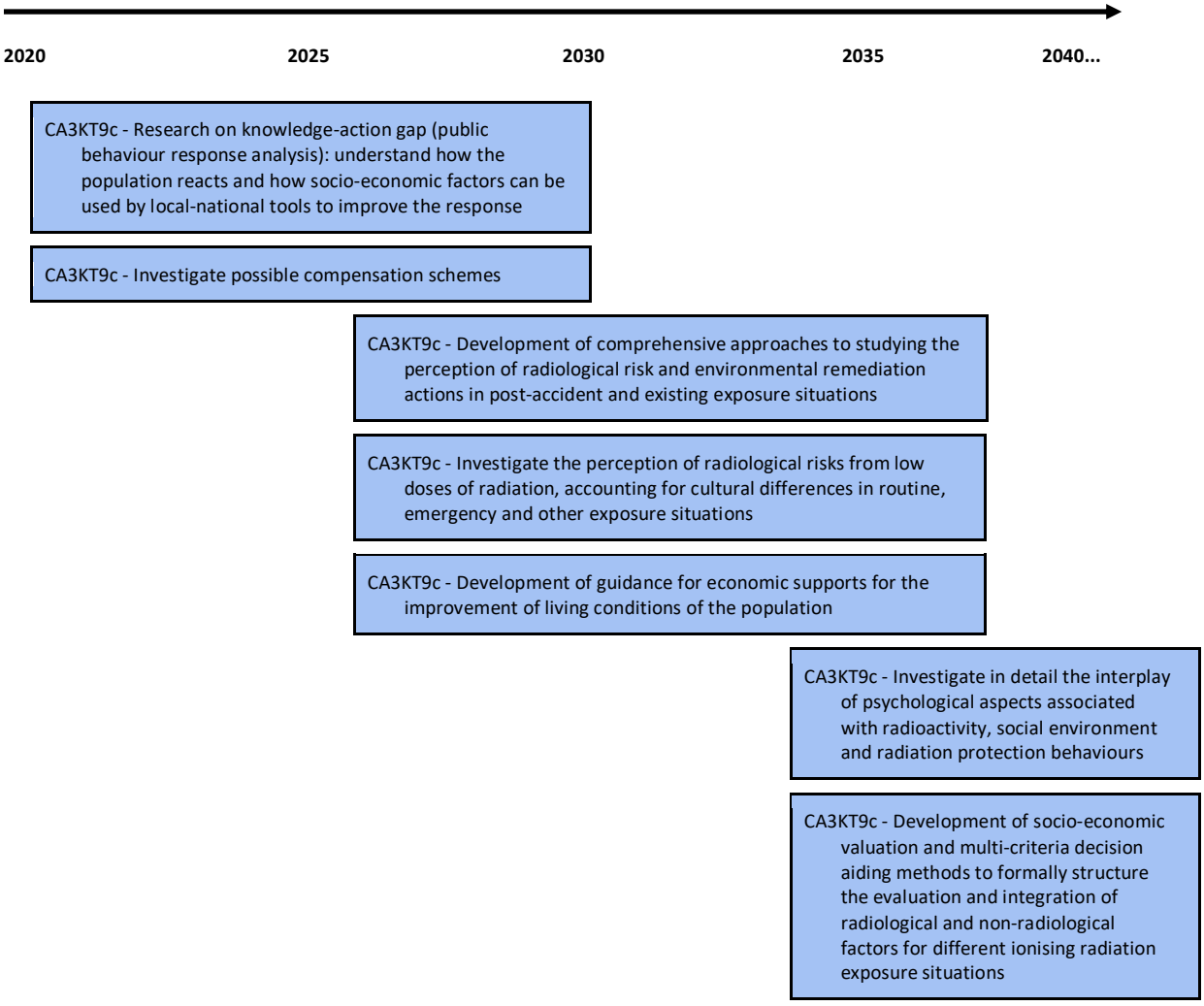
KT9b - Ethical aspects

VISION: Guidance framework for including ethical aspects in decision-making in all phases (preparedness, emergency and recovery).



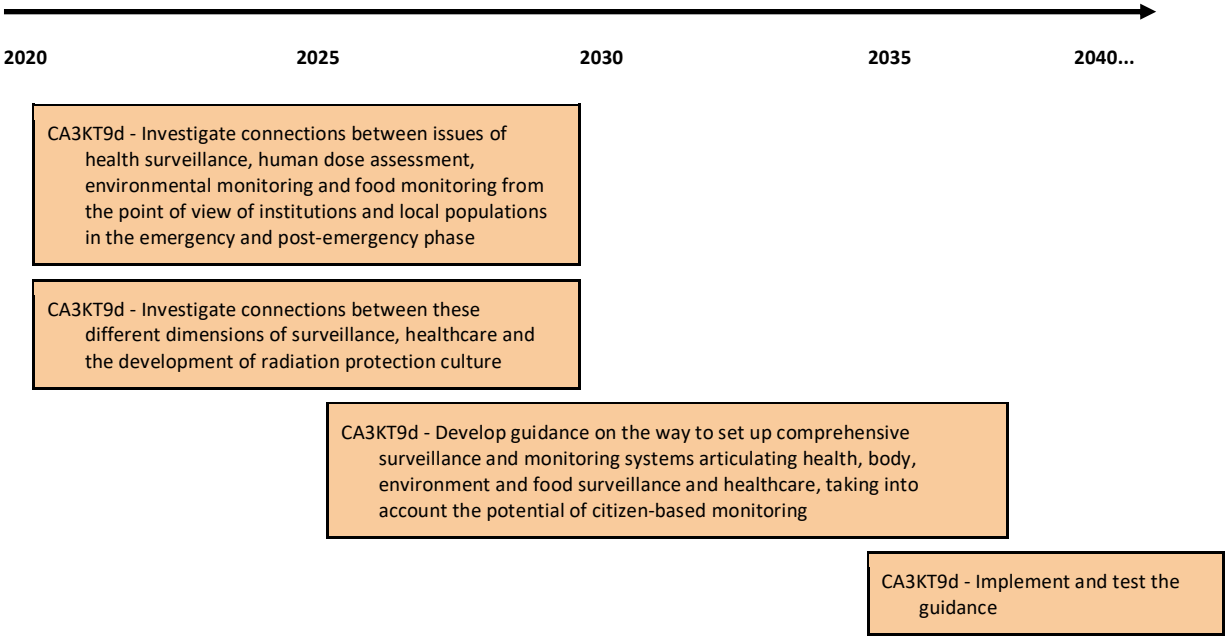
KT9c - Socio economic aspects

VISION: Guidance framework for including socio-economic aspects in decision-making in all phases (preparedness, emergency and recovery).



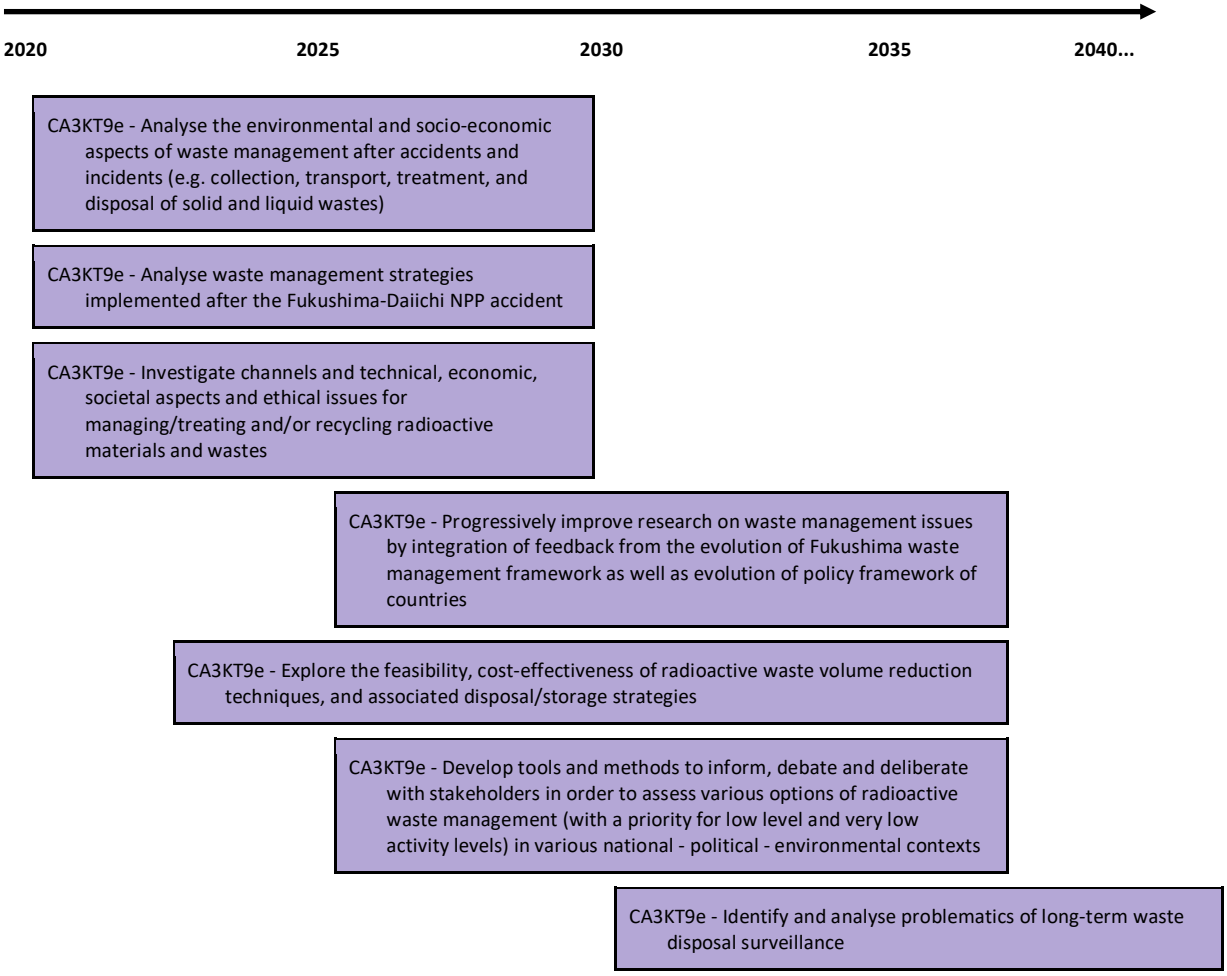
KT9d - Integrated surveillance and monitoring

VISION: Guidance framework for establishing a comprehensive surveillance and monitoring system addressing health surveillance, human dose assessment, environmental monitoring and food monitoring in meaningful way for local populations.



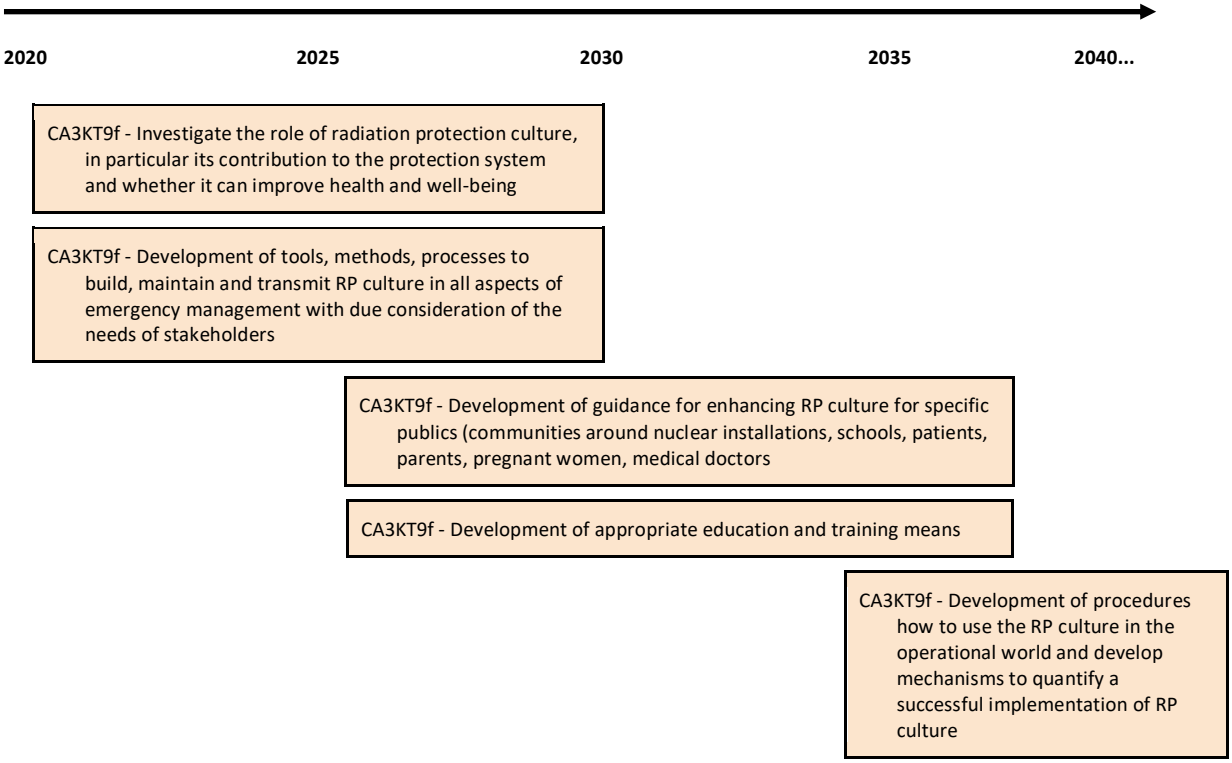
KT9e - Accident waste management

VISION: Guidance framework for managing the environmental and socio-economic issues of various types of wastes (e.g. contaminated materials and goods and waste/effluents produced by decontamination, including non-radioactive waste).



KT9f - Radiological protection culture

VISION: Guidance framework for establishing a sustainable Radiological Protection Culture in all relevant areas of radiation protection including means to support education and training as well as supervision.



Annex: Adequacy of the NERIS roadmap and research challenges with the game changers of the MELODI - ALLIANCE - NERIS - EURADOS - EURAMED - SHARE Joint Roadmap for radiation protection research, and with CONCERT projects' (CONFIDENCE, TERRITORIES, ENGAGE, SHAMISEN, SHAMISEN-SINGS) recommendations

SOURCE	GAME CHANGERS / THEMATICS	RESEARCH TOPICS / RECOMMENDATIONS	Links with NERIS key topics (KT) of Challenge Areas (CA) for research		
			CA 1	CA 2	CA 3
JOINT ROADMAP - C. Understanding radiation-related effects on non-human biota and ecosystems	C1. Resolving the controversy with regard to the effects on wildlife reported in the Chernobyl and Fukushima exclusion zones	• Characterize the influence of exposures on populations in contaminated environments • Identify the key factors determining the variation in population's sensitivity to radiation • Identify and validate biomarkers of exposure and effects that are relevant at the population's level	KT3 b	KT4	
	C2. Determine the effects of radiation on ecosystem functioning	• Effects at community level (micro/meso/cosmos) & exposure characterization under realistic conditions • Ecological models for risk assessment • Ecosystems dynamics modelling	KT3 KT1	KT4 KT4	

JOINT ROADMAP - F. Integrated approach to environmental exposure and risk assessment from ionising radiation	F1. Getting a robust prediction of the human food chain radiological contamination, for an integrated dose and risk assessment of (post)emergency situations	• Meta-analysis and data re-interpretation, data management • Identify most promising models and adapt • Upgraded models for dispersion and transfer assessment in marine and surface water ecosystems • Upgraded models for dispersion and transfer assessment in terrestrial ecosystems (agricultural, natural, urban)	KT3 KT1 d KT1 KT1 b KT1	 KT4 KT4	
	F2. Identifying and quantifying the key processes that influence radionuclide behavior in existing environmental contamination situations	• Meta-analysis and data re-interpretation, data management • Identify most relevant mechanistic models and adapt • Upgraded models for dispersion and transfer assessment in ecosystems • Upgraded models for dose impact and assessment • Guidance for sustainable management (including remediation approaches) of contaminated sites	KT3 c KT1 KT1 KT3 b	KT4 KT4 KT4 KT4	 KT7d
	F3. Integrating risk assessment and management (consistent exposure assessments for humans and wildlife; risk integration for radiation and other stressors)	• Identification stages of different assessment processes to be integrated and structure/construct datasets, models, DSS • Dispersion, transfer, impact assessment models • Integrate uncertainty and variability from exposure and effects characterization into characterization • Integrate human and environmental protection frameworks • Integrate the risk assessment frameworks for ionising radiation and chemicals • Provide a multi-criteria perspective including DSS for an optimised decision-making		KT4 KT6 KT4 KT5 KT4 KT4 KT5	 KT7b KT7e KT7a KT9c

JOINT ROADMAP - G. Optimise emergency and recovery preparedness and response G1 - Change of radiological impact assessments, decision support and response and recovery strategy by Artificial Intelligence and big data	G1a. Radiological impact assessments, decision support and response and recovery strategy	● Development of better methods for decision-making under high uncertainties ● Use of AI and big data to developed DSS allowing end users to define their objectives/goals and the system identifies the best strategies to achieve the specified objectives/goals with pros and cons automatically		KT4 KT5 KT6	KT9c
	G1b. Participatory processes	Further developments on the participatory process in emergency and recovery situations		KT5	KT7b KT7c KT8a KT8c KT9f
	G1c. Holistic management of the radiological situation	• Improve the understanding of secondary effets health consequences, economic, societal and ethical aspects including environmental characteristics • Development of better mechanistic models that better predict the evolution of the contamination • Improved countermeasures strategies with better implementation and lifting strategies tailored to the area and situation (e.g. use of OILs) • Development of improved decontamination strategies and waste management procedures		KT4 KT4 KT6 KT4 KT6 KT4 KT5	KT7b KT7d KT9b KT9c KT7d KT7a KT7d KT9e

JOINT ROADMAP - G. Optimise emergency and recovery preparedness and response G2- Further development of risk assessment and risk management approaches and technological capabilities to cope with novel threats and accident scenarios arising from new and future nuclear and radiological technologies	G2a. Novels threats and accident scenarios arising from new and future technologies	Development of processes and tools for integrating the monitoring results from experts and lay people, use of advanced monitoring	KT2	KT4 KT6	KT8c KT9d
	G2b. Combination of modelling and simulation	Combination of inverse modelling and monitoring techniques via data assimilation techniques for source term reconstruction and detecting of unknown release locations	KT1 KT2 a KT3 a	KT6	
	G2c. Improved modelling	Development of inverse modelling techniques	KT1	KT6	KT9a

JOINT ROADMAP - H. Radiation Protection and Society H1 - Better alignment of research and practice in RP with the values, needs and expectation of society, through effective research translation mechanisms, development of systematic approaches to inclusion of societal dimensions at all levels of the RP system and methodological innovation enabling transdisciplinarity in RP research	H1a. Better alignment of research and practice in RP with the values, needs and expectations of society	Co-create integrated research design to address priority research topics		KT5	KT7b KT7c
		Development of better conceptual frameworks and models to integrate diverse radiation protection knowledge		KT4 KT5 KT6	KT7b KT7c
		Gap analysis of ethical and societal dimensions of emerging technological research and responses			KT9b
	H1b. Effective mechanisms for RP research translation into practice, policy or further research	Develop and implement novel forms of civic engagement, including advancement of innovative technological interventions		KT5	KT7b KT7c KT8c KT9f
		Characterise and embed reflexive research and innovation RP practices		KT6	KT7b KT7c
		Build capacity for anticipatory research culture and RP structures		KT6	KT7b KT7c KT9f
		Build and test new approaches to build and maintain trust		KT5 KT6	KT7b KT7c KT8a KT9f
	H1c. Development of systematic approaches to inclusions of societal dimensions at all levels of the RP system	Further advance theory on science and society interactions in RP		KT5	KT7a KT7b KT7c KT8a KT9c
		Develop tools for anticipation, integrating perspectives from multiple voices (expert and lay)		KT5 KT6	KT7a KT7b KT7c KT8c KT9f
		Develop combination of qualitative and quantitative methods via novel research designs for holistic understanding of RP situations		KT5	KT7b KT7c KT7e

CONFIDENCE 1	I. Governance	Clarify roles and responsibilities of the different actors involved in the decision-making process to better coordinate their actions in a context of uncertainty			KT7b KT7c
CONFIDENCE 2		Set up a stakeholder network to facilitate the involvement of local actors in the preparedness of emergency response and recovery			KT7b KT7c KT8c KT9f
CONFIDENCE 3		Develop a dynamic approach to implement more flexible decision-making processes			KT7a KT7b
CONFIDENCE 4	II. Environment	Better consider the seasonality and characteristics of agricultural and animal productions to adapt countermeasures and protective actions to the actual situations	KT1c		KT7c KT7d
CONFIDENCE 5		Further develop or maintain a comprehensive and effective monitoring capability	KT2		KT9d
CONFIDENCE 6		Anticipate the waste consequences linked to the protective decisions and prepare the means for an appropriate management			KT9e
CONFIDENCE 7	III. Human health and safety	Set up a framework for implementing health surveillance strategy			KT9a KT9d
CONFIDENCE 8	IV. Social	Gather information on post-disaster behaviour of the population and adapt, if necessary, the emergency response strategies.			KT7b
CONFIDENCE 9		Investigate innovative strategies of communication on uncertainties related to the implementation of protective actions			KT8b
CONFIDENCE 10	V. Economy	Further develop decision support tools integrating potential economic impacts of protection strategies			KT7a KT7d KT9c
CONFIDENCE 11		Identify financial supports and mechanisms rapidly available to resume economic activities as of the transition phase			KT7d KT9c

CONFIDENCE 12		Consider the needs of socio-economic actors to promote an early resumption of economic activities			KT7c KT9c
CONFIDENCE 13	VI. Transversal issues	Foster the production and the provision of comprehensive information for the decision-making process			KT7a KT7d KT8c KT9f
CONFIDENCE 14		Improve the support of information reflecting uncertainties inherent in the situation to better guide decision-makers			KT7a KT7d
TERRITORIES 1	I. Governance	Develop tools and criteria to foster human resilience in governance			KT7b KT7c KT9f
TERRITORIES 2		Design post-accident governance patterns to foster human resilience, clarify the actors role and responsibilities and enhance coordination			KT7b KT7c KT9f
TERRITORIES 3	II. Rehabilitation of living conditions	Engage dialogue with local stakeholders to better address the notion of “affected community” and anticipate post-accident provisions			KT7b KT7d KT9f
TERRITORIES 4		Better understand the financial mechanisms that can help the affected community			KT9c
TERRITORIES 5		Develop decision support tools to enlighten decision and choices of remediation strategies and options			KT7a
TERRITORIES 6		Anticipate waste management difficulties in building a strategy in relation with populations			KT9e
TERRITORIES 7	III. Reliable co-constructed monitoring	Sustain long-term citizen awareness with the creation and intergenerational transmission of a radiological protection culture			KT7c KT8c KT9d KT9f
TERRITORIES 8		Encourage an integrated radiological monitoring system and the implementation of a joint database platform			KT8c KT9d KT9f

TERRITORIES 9		Develop hubs of co-expertise for monitoring data interpretation and analysis			KT8c KT9d
TERRITORIES 10	IV. Technical tools serving post-accident governance	Use measurement and modelling appropriately to characterise the contamination	KT3		KT7d
TERRITORIES 11		Consider the complexity in assessing radiological exposures to non-human biota	KT1 d KT3 b		
TERRITORIES 12		Establish a dialogue about uncertainties and their impact on assessment			KT7d KT8c KT9f
ENGAGE 1	I. Governance	Broaden the motivations for stakeholder participation to create more meaningful participation			KT7b KT7c KT8a KT9f
ENGAGE 2		Broadening the scope of participation in radiation protection EPR & R			KT7b KT7c KT8a KT9f
ENGAGE 3		Recognise the role of informal stakeholder engagement in EPR & R			KT7b KT7c KT8a KT9f
ENGAGE 4		Integrate stakeholder engagement in EPR & R plans and policies			KT7b KT7c KT8a KT9f
ENGAGE 5	II. Communication	Establish strategies for continuous 2-way communication about emergency and recovery planning, tailored to specific stakeholders for both local and wider areas			KT7a KT8b KT9f
ENGAGE 6	III. Culture	Elaborate a strategy to foster the development of radiological protection culture in the preparedness phase			KT7b KT7c KT8a KT9f
SHAMISEN 22	I. Evacuation	Have plans for lifting of evacuation orders as soon as possible to minimise the adverse effects of			KT7c

		evacuation on physical and mental health of evacuees, and communities.			
SHAMISEN 3	II. Health surveillance	Encourage a health surveillance strategy that targets the overall well-being of populations and not only addresses radiation effects, but also psychosocial and socio-economic impacts induced by the consequences of a nuclear accident.			KT7c KT7d KT9a KT9f
SHAMISEN 6		Adapt dosimetry and individual exposure monitoring to the exposure pathways, the phase of the accident, the general situation and the different concerns and needs of people and society, and where needed, improve or establish new approaches of dose assessment			KT8c KT9a
SHAMISEN 7		Build a radiation protection culture between radiation protection experts, healthcare workers, professionals and the general public.			KT7b KT9f
SHAMISEN 24		Expand support for affected populations to take into account social and economic upheavals caused by the accident on infrastructures and community welfare			KT9a KT9c
SHAMISEN 8	III. Communication and Training	Establish early response and communication protocols with responsibilities and roles clearly laid out. Engage relevant stakeholders in the establishment of these protocols, and prepare the necessary material and channels to communicate with the public (including social media).			KT7c KT8b KT9f
SHAMISEN 10		Prepare and facilitate training and education material and resources adapted to healthcare and other professionals, as well as other stakeholders.			KT7c KT7f KT9f

SHAMISEN 14		Ensure prompt sharing of accurate and reliable information (e.g., plant conditions, radiation dose, radiation protection actions) between nuclear plant representatives, authorities, experts and the population.			KT7f KT8b KT8c KT9d
SHAMISEN 21		Build networks of experts – local facilitators – population to assist with the dissemination of scientific information and facilitate two-way communication through the creation of dialogue spaces where affected people can voice their needs and worries and receive practical advice on everyday life.			KT7b KT7c KT7d KT8a KT8b KT8c KT9f
SHAMISEN 23		Consider the preferences of people living in affected areas when deciding whether mitigation actions should be revised, lifted or extended according to the evolution of the situation (e.g. individual dose monitoring, decontamination of living places, psychosocial assistance, foodstuff surveillance).			KT7c KT7d KT8b
SHAMISEN 28		Foster long-term participation of affected populations and communities by engaging them in decision-making, particularly with regard to health surveillance, with the aim of improving the relevance, efficiency and acceptability of the interventions and maintaining radiation protection awareness.			KT7c KT8a KT9d KT9f
SHAMISEN 18	V. Dose assessment	Provide support to populations who wish to make their own measurements, recommending reliable equipment and resources (e.g., apps, social media, information centres) that can contribute to the characterisation of population exposure and its evolution.	KT2		KT8c KT9d KT9f

SHAMISEN 12		Prepare action frameworks focused on dose assessment for workers and populations, with the objectives of: 1) monitoring as many individuals as possible, in particular among critical groups; and 2) collecting and maintaining the results and other relevant data for future needs.			KT9a
SHAMISEN SINGS	1. Dose measurement apps	Recommendations for decision makers, public authorities and professional associations for improving *self-monitoring*	KT3b		KT9 KT9d
SHAMISEN SINGS	2. Health monitoring apps	Recommendations for collecting information on health and well-being as a core structure of an app			KT9a KT9b KY9d