Fourth NERIS Workshop

"Adapting nuclear and radiological emergency preparedness, response and recovery to a changing world"

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PROCEEDINGS

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Edito

The 4th NERIS Workshop addressed different topics related to "Adapting nuclear and radiological emergency preparedness, response and recovery to a changing world". Hosted by the Irish Environmental Protection Agency on 25-27 April 2018 in Dublin, it allowed to have fruitful inputs from on-going European research and challenging debates on the way forward on emergency and recovery issues. This on-going research, largely developed within the CONCERT project, relies on the NERIS Strategic Research Agenda and the NERIS First Research Roadmap, adopted at the end of 2017. Part of this research is focussed on further investigation of uncertainty assessment and management as well as on the analysis of stakeholder engagement processes. They largely adopt a multidisciplinary approach, covering the different facets from health impact, environmental issues, decision making processes and social and ethical considerations.

The proceedings of the 4th NERIS Workshop emphasize the key role of the feedback experience from Fukushima accident, as well as of the new technological and scientific developments to foster research developments in the field of emergency and recovery preparedness and response in Europe and worldwide. These developments contribute to improve the assessment and management of emergency and recovery in case of an accident. The discussions during the NERIS workshop and the interaction with international organisationds pointed out the needs for going a step further for harmonizing national approaches or at least promoting common understanding and methods.

Thierry Schneider (CEPN), President of the Platform

Session 1 – Radiological Monitoring and Citizen Monitoring

Organisation of the environmental monitoring: lessons learnt from Fukushima

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1. GENERAL INTRODUCTION

In post-accident situations, the implementation of the environmental monitoring is essential for characterising the radiological situation of the affected territories, as well as, allowing people living in such territories to understand what is at stake in their own environment and helping them to become actors of their own radiological protection [1, 2, 3]. In this context, roles playing by institutional and non-institutional actors are determining factors to set up a sustainable monitoring, reach a consensus and so encourage the citizen vigilance. Besides, the recent feedback from the Japanese situation - 7 years after the Fukushima accident –also shows that, thanks to the progress of digital technologies, there is the possibility for people living in contaminated territories to have now the means to measure the radioactivity of their environment, share these results through various networks and so, regain progressively control of their daily life [4].

In this context, this paper focuses on the Japanese situation, in order to provide feedback experiences and analysis of the environmental monitoring implemented after the Fukushima accident. This analysis consists in (i) identifying the environmental schemes implemented following the Fukushima accident, (ii) mapping the different actors who come into play in such situations and (iii) highlighting some local experiences developed by local associations or municipalities within the affected territories.

These overall goals have been achieved by interviewing different Japanese actors involved in the practical setting up of the environmental monitoring within the Fukushima prefecture. In this way, feedback experiences, points of view and comments have been collected from both institutional actors (e.g. Japan Nuclear Regulatory Authority, Health and Labour Ministry, Fukushima prefecture, etc.) and local actors (e.g. local associations, municipalities, citizens, etc.) in November 2016.

Therefore, the following paragraphs present the results obtained from these interviews as well as from documents review and analysis of public environmental data bases available on the internet. These results focus essentially on two parts:

- The official monitoring set up at national level by the Japanese government;
- Highlight from some local initiatives.

2. THE OFFICIAL ENVIRONMENTAL MONITORING SET UP IN JAPAN: THE *Comprehensive Radiation Monitoring Plan* (CRMP)

2.1. Historical and objectives of the national environmental monitoring programme

Following the accident of the Fukushima-Daïchi Nuclear Power Plant (NPP) in March 2011, the government decided to develop and implement a national environmental monitoring programme, with the help of actors and institutions already involved in environmental monitoring before this accident (e.g. ministries, national agencies, *etc*.). Thus, on August 2, 2011, the *Comprehensive Radiation Monitoring Plan* (CRMP) - was created [5]. Based on the environmental monitoring programs implemented before March 2011, the CRMP aims to set up a global monitoring of the environment with a special focus on the radiological situation of the whole Japan. Each year, this national programme is reviewed and adapted according to the radiological evolution of the territory. Note that since the creation of the Nuclear Regulation Authority (NRA) in September 2012, the CRMP is directly coordinated by this national authority.

2.2. The environmental monitoring implemented in the framework of the CRMP

To ensure the best monitoring of the radiological quality of the environment, the CRMP declines different monitoring on each environmental compartment: ambient air, soil, lakes, rivers, drinking water, forests, wildlife and flora, marine environment, *etc.*

As already mentioned, this global monitoring concerns the entire Japanese territory. However, the frequency of the measurements and the sampling grids are adapted as the distance to the NPP decreases. In this way, measurements are concentrated within a radius of 250 km around the NPP, and are more and more intensified within radius going from 80 km to 20 km around the plant.

2.3. Various actors involved in the CRMP

Coordinated by the NRA, the CRMP brings together various actors involved in environmental monitoring. Among these actors, there are in the first instance the different ministries (Ministry of Environment - MOE, Ministry of Agriculture, Forestry and Fisheries - MAFF, Ministry of Education, Culture, Sports, Science and Technology - MEXT, Ministry of Health, Labour and Welfare - MHLW) which were chosen to supervise various environmental studies depending on their own specificities as well as the monitoring that they implemented before 2011.

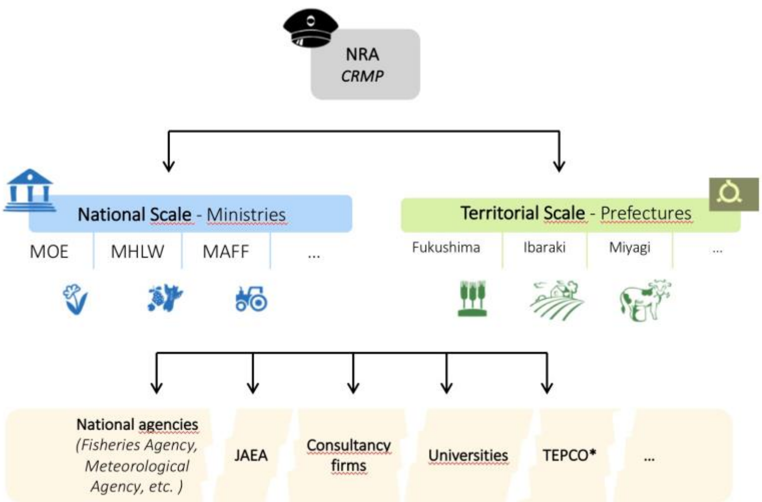
However, it is worth to mention that, in order to obtain adequate results and be able to transmit them to the NRA, the ministries convened additional actors much more qualified to carry out field works and environmental measurements. So, the ministries rely on:

- the support of national agencies and institutes (Japan Atomic Energy Agency - JAEA, National Institute of Environmental Studies - NIES, Forestry and Forest Products Research Institute - FFPRI);
- private providers (consulting firms) or public providers (universities);
- territorial administrations (prefectures) that focus on developing surveillance systems adapted to their territory, relying also on national agencies and institutions, or public and private providers.

Note that, considering the large number of actors convened for this CRMP, and in order to ensure the coherence and the harmonization of the obtained results, ministries and NRA have drown up since 2011 recommendations and guidelines, defining the methodology and prerequisites to respect.

The Figure 1, illustrates the previous paragraphs by showing the general organization of the national environmental monitoring system set up in Japan, since the Fukushima accident.

Figure 1 – Overall structure of the national environmental monitoring programme set up in Japan since the Fukushima accident.



However, from this general organization, a number of special cases has to be mentioned. First, it should be noted that for environmental monitoring in the 20 km radius around the Fukushima Daïchi plant, only TEPCO and the NRA are in charge of the field studies. It should also be noted that, in their own initiatives, national agencies and institutes (JAEA, AIST for example) have launched research programs dedicated to the evolution of the environmental quality of affected territories in parallel with the CRMP. Therefore, they are carrying out additional environmental measurements.

2.4. Publication of various results in the framework of the CRMP

NRA, as coordinator of the CRMP, is responsible for collecting all the results obtained by the different actors implementing environmental studies. Then, these results are published on the NRA website[1], which, for the occasion, has set up mapping tools for better visualizing the radiological quality of the Japanese territory. For the same purpose, the NRA also asked JAEA to publish the obtained results on a dedicated website[2] proposing various interactive maps with the latest measurement results (e.g. ambient dose rate, soil, water) over the whole of Japan.

1 http://radioactivity.nsr.go.jp/en/list/309/list-1.html

2 https://emdb.jaea.go.jp/emdb/en/

In addition to this ‘official dissemination’, ministries also publish the results obtained as part of their own environmental studies on their own websites. These results are often disseminated as tables of data without specific explanation or information on the general trend observed. Territorial administrations (prefectures) also disseminate the results of their monitoring on their own websites. Again, these results can take various forms: from the ‘simple’ data table to an interactive map of ambient dose rates.

In conclusion, it is interesting to note that multiple actors, from national to territorial scales, are involved in the implementation of the CRMP. This organisation allows to obtain a precise monitoring of the radiological quality of the whole Japanese territory, by notably embracing all the environmental compartments.

However, it should be noted that multiple and abundant data are published by the different actors of the CRMP without seeking homogenization of the results or putting them into perspective. And this abundance of information, with often no explanations, may lead to some confusion for the users. Therefore, a better standardization and integration of these data seems necessary.

3. LOCAL INITIATIVES TO MEASURE THE ENVIRONMENTAL QUALITY

3.1. Precisions concerning the environmental monitoring implemented by the prefectures

As mentioned above, the prefectures are in charge, in the framework of the CRMP, of the environmental monitoring of their own territory. Thus, this monitoring is carried out in all the municipalities belonging to the prefectures and concerns more particularly the aquatic compartment (drinking water, river and lake water and bathing water), the atmospheric compartment (fallout) and the measurements of ambient dose rate.

To ensure such follow-up, public agencies and institutes (JAEA for example), as well as universities support the prefectures. Then, this can lead to the construction of joint measurement laboratories, as is the case of the *Center For Environmental Creation*, inaugurated in Miharu (Fukushima Prefecture) in October 2015.

3.2. Environmental measurements set up by the local municipalities

Although prefectures ensure the environmental monitoring of each of their municipalities, many of these municipalities have launched, on their own, additional environmental studies. Thus, various universities or consultancy firms have been solicited directly by these municipalities to carry out radioactivity measurements on their local territories. Then, the results provided by these initiatives allow the municipalities to obtain a second expertise which completes the ones performed by the prefectures, the final objective being to check the veracity of the official environmental monitoring.

In addition to these studies, some municipalities also decided after the Fukushima accident to provide monitoring devices to their local populations, in order to give them the means to measure their own environment (*e.g.* ambient dose rate, foodstuff, *etc.*). This is how we can find around the Fukushima NPP some local municipalities which, for example, have developed their own contamination map of their local territory. It is worth to mention that, in many case, these local communities are often accompanied by Radiation Protection experts, who give them advises and try to respond to their expectations and concerns related to their daily life in affected territories.

3.3. Local citizen initiatives

In addition to the environmental monitoring implemented in the framework of the CRMP, or at the municipal scale, local initiatives developed by citizen networks or NGOs have been also implemented since March 2011.

These initiatives aim in particular to carry out additional measurements of the radiological quality of the environment in general (*e.g.* ambient dose rate, river, soils, *etc.*) or of the local foodstuff (*e.g.* fruits and vegetables from gardens, mushrooms, fish, *etc.*).

Concerning the NGOs, two main types of actions are proposed:

- Conduct independent measurement campaigns (soils, rivers, ambient dose rate) and disseminate the results on their websites and (sometimes) to the local municipalities;
- Propose measures (which have to be paid) of the radiological contamination of foodstuff brought by local citizens.

In general, these associations work thanks to private subsidies and contributions from their members. Quite often, these funds allow them to buy measuring devices.

It should be noted that, despite the multitude of NGOs committed to the radiological characterisation of the territories affected by the Fukushima accident, there is no significant sharing and networking of the results produced by these various associations. Indeed, each of these NGOs produces and publishes results on its own, with no attempt to compare them with the results obtained by other NGOs on the one hand, or by the official institutions on the other.

However, some exceptions can be highlighted and particularly concern the citizen networks. Indeed, based on the current digital progress, these networks have developed innovative approaches which try to better share environmental results, at least among their users. This is for example the case of the SAFECAST network[3], which offers to users to measure their environment using a mobile and connected device. The obtained results can be shared with the entire users' community through an interactive map, displaying the various results in real time. The approach of the 'Minna No Data Site'[4] also seeks to gather and disseminate results of foodstuff measurements produced by more than 30 independent laboratories.

4. MAIN LESSONS LEARNT

4.1. The multiplication of measurements and actors

The analysis of feedback experiences from the Japanese situation reveals that various actors, from local to national scale, intervene in the implementation of a post-accident environmental monitoring. At the national level, the CRMP -coordinated by the NRA- brings together more than twenty actors (ministries and national institutions) taking care of different types of environmental studies. The obtained results are then posted on the websites of these different actors, without adding comments or explanations that could facilitate their interpretation. This implies a profusion of raw data accessible from all sides, and which can be presented in very different formats depending on the platform (*e.g.* data table, real-time mapping, simple mapping, *etc.*). Thus, this lack of coherence and uniformity can cause confusion and loss of the users.

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[3] https://blog.safecast.org/

[4] http://en.minnanods.net/

Besides, since the Fukushima accident, the government is facing a deep loss of confidence from local citizens and communities. Thus, private consultancy firms or universities are solicitated by local municipalities to carry out additional radiological measurements of their environment. The objective is to obtain counter-expertise results, even as these results are most often consistent with those produced within the CRMP. Generally, these data are neither exploited nor exchanged between neighbouring municipalities, nor even communicated to the public.

In addition to that, there are also the environmental measurements produced by the local NGOs, who do not seek to exchange their results with other NGOs, or with local municipalities or even with public institutions.

So, the current situation leads to a post-accident environmental monitoring involving multiple actors without a framework allowing them to share the results of their actions (with the exception of institutional actors involving in the CRMP). This leads to an environmental monitoring which is heterogeneous and sometimes redundant. *'Some places are measured 10 times by 10 different people while other places have never been measured since the accident'* says one of the interviewees, regretting the lack of coordination and information between actors of the environmental surveillance.

However, it is worth to highlight innovative approaches like SAFECAST networks or the Mina No Data Site project which seek to create a common and open database collecting results produced by independent citizens.

4.2. The data produced by local initiatives

In the context of mistrust towards authorities and official institutions since March 2011, citizens and local communities have developed their own radiological characterisation of the territory, resulting today in the production of abundant local data. However, the question of the scientific robustness of these data remains unsolved. In fact, citizens who carry out these measurements are not always trained in radioactivity measurement protocols. Although guidelines have been produced by the NRA and ministries, these recommendations remain generally unsuited to the local communities, which do not have the adequate means. In this way, the quality and veracity of these measures can be questioned. However, these results have all the confidence of the local populations. Therefore, even without scientific robustness as such, these data represent for citizens the information on which they adapt their behaviour.

Also, it is important to have in mind that these local data could represent for researchers a rich and interesting source of information to understand the evolution of the radiological state of the environment at the local scale and for the radiation protection experts a crucial source for favouring the involvement of local stakeholders in the recovery programme.

4.3. What is the evolution of the Japanese environmental monitoring system?

The multiplication of the measurements carried out on the territory affected by the Fukushima accident is an element admitted and recognized by many actors involved in the environmental monitoring process. The argument that, the radiological quality of the environment follows unsurprisingly the radioactive decay of caesium 134 and 137, could argue in favour of a decrease in the frequency of environmental measurements. NGOs that we have interviewed also acknowledge that visits from local inhabitants are decreasing. As a result, some NGOs have closed down their local offices because of a lack of attendance.

In this context, the question of the medium to long-term evolution of the environmental measurements can be raised, as well as the sustainability of the current system. Some interviewees believe that it is up to local citizens to decide about the future of the environmental monitoring: *'when people will feel safe at home and they will no longer need environmental measurements to reassure themselves, environmental surveillance could be reduced. In the meantime, we must continue'.*

5. GENERAL CONCLUSION AND PERSPECTIVES

Seven years after the accident at the Fukushima plant, the analysis of the post-accident environmental monitoring implemented in Japan reveals the multiplication of actors from local to national scales. If - through the CRMP - the national surveillance system seems coherent and complete, the abundance of results posted online can cause some form of confusion. It might be interesting to accompany each publication of results with comments explaining the observed trend.

At the local level, the mistrust towards authorities and official institutions has induced citizens and local communities to implement their own monitoring, which leads today to the production of abundant local data which can represent a very interesting source of information.

In this context, the remaining issue consists in knowing how to go towards a better sharing between results produced by institutional and non-institutional actors. It appears that scientific experts, often involved in both sides, could play a key role in sharing these results, which represents a strong lesson learnt for the preparedness phase.

6. REFERENCES

[1] LOCHARD, J. (2013). Stakeholder Engagment in Regaining Decent Living Conditions after Chernbyl, Social and Ethical Aspects of Radiation Risk Management, Radioactivity in the Environment, Vol. 9, Elsevier, 2013, pp. 311-331

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[5] NRA (2016). Comprehensive Radiation Monitoring Plan

Citizen Monitoring in the Czech Republic progress achieved during the last year

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Introduction

Involvement of the stakeholders and the general public plays one of the key roles in the process of effective solving problems in emergency preparedness, response and remediation on affected territories. To accomplish these tasks, it is necessary to gain the participants´ confidence to information on radiation situation provided by the authorities.

This paper presents the progress in approach to these problematics in the Czech Republic consecutive to presentation given basic information on the project during the NERIS 2017 meeting in Lisbon, Portugal [1]. Project RAMESIS (Radiation Monitoring Network for institutions and schools to assure early awareness and enhancing safety of citizens), part of Security Research supported by Ministry of Interior, solved by research (SURO & UTEF CTU) and commerce (NUVIA) subjects, is aimed to improvement safety of population through introducing of radiation monitoring system at level of institutions, schools and citizens in accordance with current international trends. Instrumentation including central application for receipt, storage, administration and publication of monitoring results will be analyzed, projected, developed, tested and obtained. The RAMESIS system will be implemented at selected institutions and schools, including training and informational materials for understanding radiation problems.

Objectives of the project are a) design, development, operational testing and implementation of tools for supporting citizens radiation monitoring networks (detectors, communication, central database/application for local and web data presentation), b) preparation of information materials, methodic, manuals, guides etc. for users and public, c) preparation the system for possible integration of results of citizens monitoring into official Radiation Monitoring Network.

Achievements during the last year covers adopting final decision on design and technology for the fixed stations and prepare their production, preparing advanced detectors (based on pixel Si/GaAs detectors) implementation for schools, nation-wide implementation of detectors for mobile monitoring (Safecast bGeigie Nano) for both schools and public. The development of central application for data collection, storage, processing and presentation on web pages is expected to be finalized until the end of this year. Tools for local presentation of data from mobile measurements are ready and available based on open-source approach (legal installation and usage free of charge), as well as a wiki web for publishing information materials, guides, and for communication with public.

To attract general and public to radiation problematics and protection press conference was organized in August 2017, supported by the chairman of the Regulatory body of the Czech Republic, with participation of 4 main nation-wide TV channels (one of them perform about a 1 hour on-line broadcast) and more than 10 other media channels representatives (resulting into a lot of press notice (even a full-page article in one of most wide-spread news).

Figure 1. Press conference on the RAMESIS project, example of full-page press output

These activities result info significant increase of citizen-performed measurements

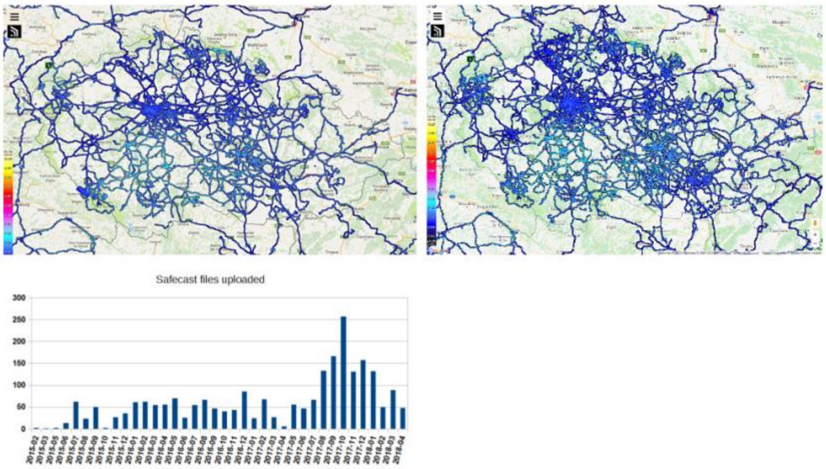


Figure 2. Example of increase of measurements following the press conference.

As a part of support to users a set of tools for semi-professional data processing has been developed in cooperation with the GeoForAll Lab as plugins for QGIS.

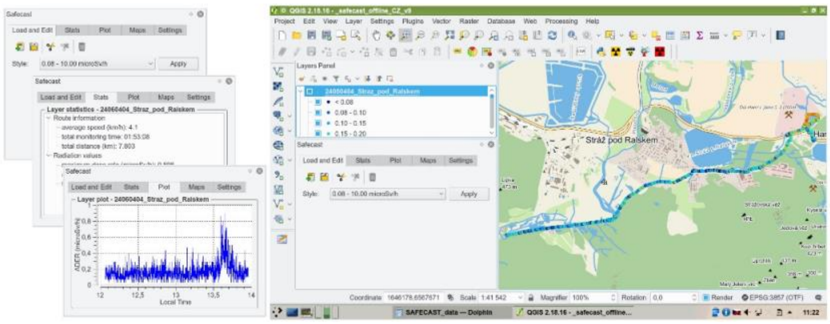


Figure 3a. QGIS plugin for basic Safecast data presentation and processing - overview

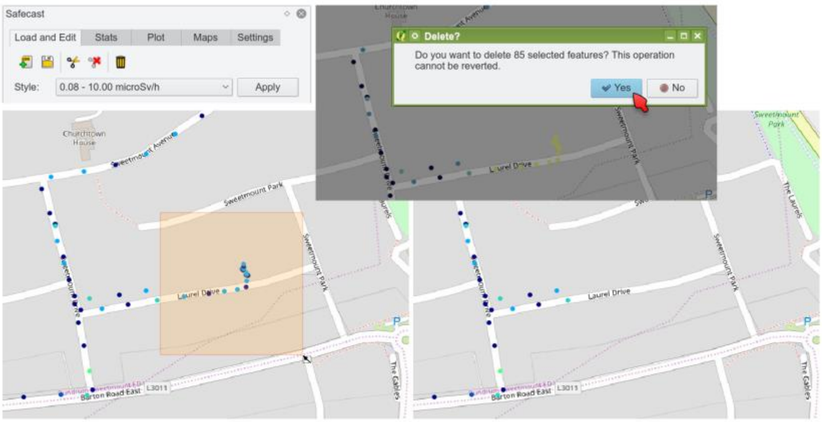


Figure 3b. QGIS plugin for basic Safecast data processing – selected data removal

Information materials for users and public prepared by SURO are available on webpages: www.suro.cz, on Wikipedia (synchronized), on WIKI

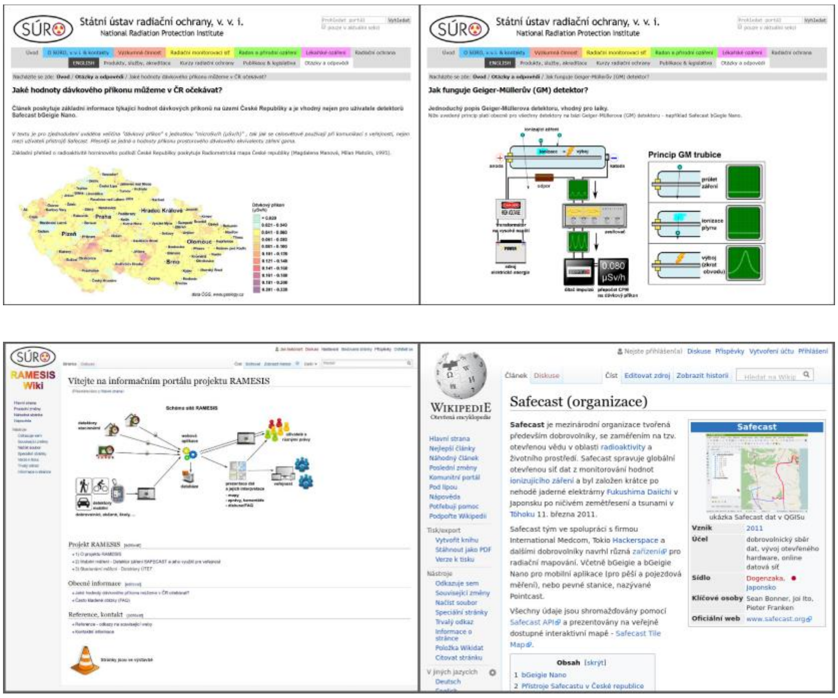


Figure 4a). Examples of information material for users and public - general

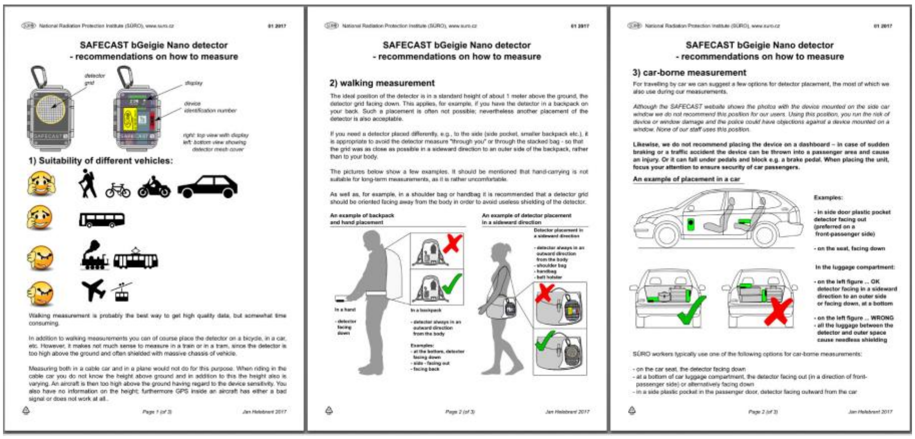


Figure 4b). Examples of information material for users and public – guides

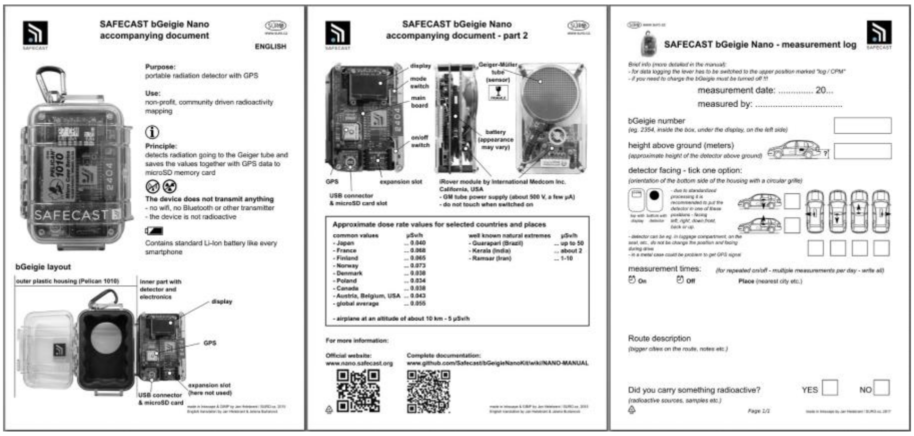
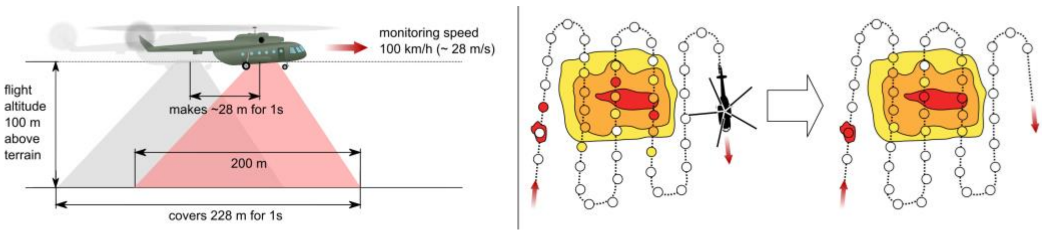


Figure 4c). Examples of information material for users and public – technical info and forms

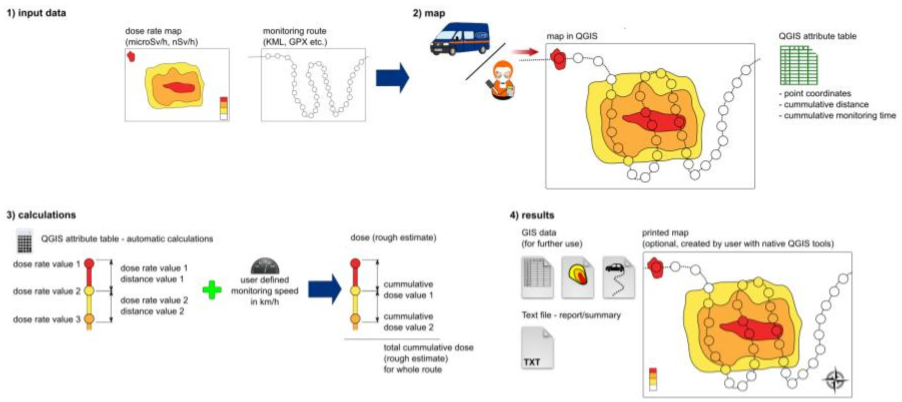
Other support tools for professional monitoring teams were developed:

<u>GPS Position Lag Correction Plugin</u>



Problem to solve: during airborne monitoring, the GPS coordinates are recorded at the beginning or at the end of the 1 second interval of the spectrometric measurement, thereby shifting the coordinate of the measured point.

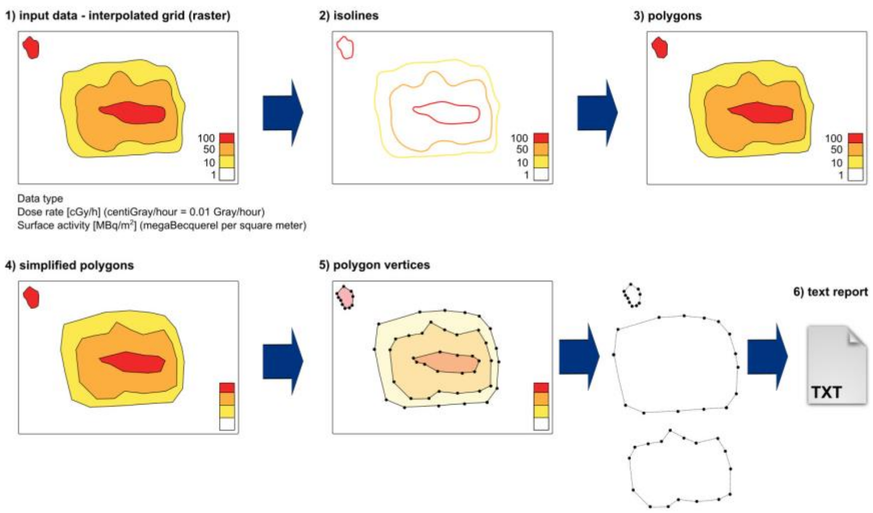
Ground Radiation Monitoring Plugin



Calculation of the obtained dose estimate for the monitoring vehicle crew using - interpolated dose rate map and - planned monitoring route. Input data is dose rate map from prediction with SW like JRodos or interpolated real measurements (airborne etc.) and routes planned for example with Google - (KML, GPX formats)

Plugin performs calculation of dose estimate with constant monitoring speed considering distance between route points calculated from the coordinates for solving problems cause by only a few point in a few-kilometer sections when using routes from Google etc. Solution: creating additional “measuring points” along the route.

Radiation Reconnaissance Result Plugin



Problem to solve: create contour lines (according to specified parameters) from a raster map of dose rates or of surface contamination.

Solution: converting contours to polygons and simplify them to ensure that the number of vertices per polygon is not exceeded, and converting coordinates of the extracted vertices to the MGRS military system and generate text report according to NATO / Czech Army specifications.

Conclusions

The basic idea of our approach to motivate schools and general public for participation in monitoring through participation in performing citizen monitoring networks on voluntarily basis, and in the problematics of radiation protection in general can help keeping or even raising credibility of public to recommendation on implementing of protective measures given by authorities, resulting into effective coping the emergency.

We believe that for proper understanding the radiation situation, giving chance for wide adopting necessary radiation protection measures by the public, the public must get appropriate information and education in advance – successful building of this confidence during the normal situation can help keep the trust of public to authorities in emergency situations,

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Citizen-science involvement after nuclear accidents: SHAMISEN SINGS project

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Abstract

Citizen-science participation has been widely used for supporting projects related to biodiversity and environmental monitoring. The first attempts in using citizen-science for dosimetry measurements after nuclear accidents were made by Safecast and D-shuttle projects. One key purpose of the latter, conducted after the Fukushima accident, was to promote well-being among individuals returning to evacuation areas through voluntary participation in personal exposure measurements and interaction with facilitators that provided adequate counseling and basic knowledge on radiation protection and dosimetry.

The SHAMISEN SINGS EC-funded project aims to analyse existing tools that can be used by citizens to perform radiation measurements and measure health and well-being indicators in the aftermath of a nuclear accident. This kind of citizen participation could be useful for collecting data on exposure doses, complementing environmental monitoring, and providing real-time information covering more areas. On one hand, this information could be analysed and used by relevant stakeholders such as ministries of environment, agricultural and urban planning sectors for effective land-use and decision-making processes. On the other hand, personal information collected could be used by scientists for individual dose assessments in medical and epidemiological surveillance studies. In addition to dosimetry measurements, SHAMISEN SINGS will analyse existing tools that could be used by affected citizens for the assessment of health and well-being indicators as well as for obtaining practical information and professional support.

Thus, in addition to contributing to data collection for research projects, citizens can benefit from these tools by obtaining basic knowledge on dosimetry and radiation protection issues that will help them adopt safe behaviors and create a radiation protection culture.

SHAMISEN SINGS will propose how to improve existing tools (mobile applications, for example) or, if necessary, design new ones that include environmental and health monitoring for populations affected by nuclear accidents, while assessing the ethical challenges and implications.

I. Introduction

Citizen-science participation was first used in biological and ecological sciences for supporting projects related to biodiversity and environmental monitoring. The first attempts in using citizen-science for radiation dose measurements after nuclear accidents were performed by *Safecast* [1] and *D-shuttle* projects [2]. One key purpose of the latter, conducted after the Fukushima accident, was to promote well-being among individuals returning to evacuation areas through voluntary participation in personal exposure measurements and interaction with facilitators that provided adequate counseling and basic knowledge on radiation protection and dosimetry.

II. Scope and structure of the SHAMISEN-SINGS project

SHAMISEN (Nuclear Emergency Situations - Improvement of dosimetric, Medical And Health Surveillance) SINGS (Stakeholder INvolvement in Generating Science)
SHAMISEN-SINGS builds on the recommendations of the EC-OPERRA funded SHAMISEN project [3], with the aims of enhancing citizen participation in preparedness for and recovery from a radiation accident through novel tools and APPs to support data collection on radiation measurements, health and well-being indicators.

The specific objectives are to:
1. ***Interact with stakeholders to assess their needs*** and their interest in contributing to dose and health assessment, and evaluate how new technologies could best fulfil these needs. Consider lessons from current issues in Fukushima related to lifting evacuation orders and medical care for vulnerable population;
2. ***Review existing APPs for citizen-based dose measurements***, and establish minimum standards of quality;
3. ***Review existing APPs/systems*** to monitor heath and develop a core protocol ***for a citizen-based study on health, social, and psychological consequences of a radiation accident***;
4. ***Build upon existing tools to develop the concept/guidelines for one or more APPs*** that could be used to:
   - monitor radiation doses to empower affected populations and contribute to radiation assessment after an accident, including visualisation of radiation conditions;
   - log behavioural and health information that can be used, with appropriate ethics and informed consent, for citizen science studies
   - provide a channel for practical information, professional support and dialogue
5. ***Assess the ethical challenges*** and implications of the APPs and citizen science activities through a consensus workshop.

SHAMISEN-SINGS brings together an experienced multi-disciplinary and multi-national consortium to improve countermeasures for nuclear emergency preparedness and provide important knowledge on stakeholder engagement in radiation protection, including a critical assessment of the benefits and challenges of citizen science. By taking a practical ethics approach and fostering co-reflection between natural and social scientists, the project will strengthen the integration of social science in radiation protection. It will also set the basis for providing an independent channel for collection and management of data for use by authorities for decision making, assessment of doses, evaluation of health/social condition and health surveillance in general, and support in the implementation of BSS.

SHAMISEN SINGS Work Packages:

Figure 1. SHAMISEN SINGS Project structure.

WP1 - Stakeholder needs (consultation, engagement and feedback on proposals)
Lead: ISGlobal, Partners: WIV-ISP, NMBU, CEPN, ISS, IRSN, Experts: V. Chumak, Ph. Pirard, N. Novikava

The need for information and the implication of different segments of society after a disaster is an important issue to address, since people have many different information needs and different degrees of scientific literacy. Exposed populations need to know where and when they can receive assistance or answers to their questions, the primary question being "will they be alright living where they are?" On the other hand, decision makers can use this information when evaluating the needs of the population and the relevance of interventions aimed at mitigating the consequences of the accident.

In the **early phase of a radiation accident**, there is an important and diverse need for information about:

- radiation contamination levels, areas of exposure, behaviours to decrease exposure risk, and the health consequences of radiation exposure;
- social issues, such as where to meet families, access medical care and social facilities;
- actions taken and planned, such as evacuation zones and routes;
- If and how to provide personalised information for census-taking.

In the **long term**, there will be a need for information exchange on ambient contamination levels, food contamination, health monitoring results, local decisions particularly in relation to the lifting of evacuation orders and the return of populations to their homes.

Objective: The objective of this WP is to engage stakeholders (representatives of local populations, teachers, medical personnel as well as local and national authorities) to identify their needs in the immediate and long-term phases of an accident and propose a tool (or framework for a tool) using new information technologies to optimise interactions between technical capacities offered by the applications, citizens and expert resources.

Approach: This requires the following actions:

Task 1.1. Stakeholder meeting and consultation to identify unmet needs
An online consultation with stakeholders will a series of issues including:
- Previous identifying of relevant stakeholders
- Possible gathering of personal continuous measurements of ambient radioactivity and inputting in cartographies (WP2), allowing (if methodologically reliable and relevant) cumulative doses assessment, comparisons of results, time and space monitoring of results.
- Possibilities with GPS of space-time budget monitoring and localization
- Possibilities for bottom up gathering of concerns and issues for experts or management teams, and adapted answers for exposed persons from chatbot or expert teams, etc.

Task 1.2. Focus group assessment of proposals (from WP2 and WP3) by stakeholders
A focus group meeting will be held in the second half of the project's life to present and discuss the deliverables of WP2 and WP3 (requirements and specificities of APPs and devices for dose measurements and monitoring of health and well-being indicators) in order to determine if they correspond to the needs specified during task 1.1.

Task 1.3 SHAMISEN-SINGS Consensus Workshop (Lead NMBU)
A two-day consensus workshop will be arranged in Oslo to address the societal, ethical and technical challenges with the development and use of the APPs, as well as their contribution to citizen science. This will have a multidisciplinary international participation, including ethicists, social scientists and philosophers as well as representatives of affected populations (Norway, Fukushima). The aim will be to stimulate co-reflection between social scientists, natural scientists and the public. The exercise will aim at discussing issues, and drafting areas of consensus (as well as disensus and reasons therefore). A publicly available report will be produced shortly after. The set-up will build on previous consensus workshops arranged by NMBU/CERAD (e.g. debates on whether ionising radiation is harmful or not to wildlife). This kind of output has a higher potential of impacting policy than a standard stakeholder meeting.

WP2 – Citizen participation in radiation measurements.

Lead: ISS; Partners FMU, IRSN, UAB, ISGlobal; Expert: V. Chumak

Experience from Chernobyl and Fukushima has clearly shown that self-made radiation measurements can create opportunities for providing information to individuals and empowering them to take an active role in their own decisions, thus regaining control on their lives. It also facilitates comprehension of individual exposure and official limits. Therefore, the use of these technologies should be encouraged, while ensuring minimum standards of quality and reliability and avoiding misuse. At the same time, data collected by general public can be used to compare and integrate data from conventional off-site monitoring and modeling tools. Self-measurement approaches represent thus one of the several actions that need to be taken in order to build trust between affected communities and RP authorities and technical experts. In addition, both in Chernobyl and Fukushima (and with A-bomb survivors), reconstruction of individual doses and estimation of group doses was based on surveys of affected populations to determine their whereabouts (locations, migration routes, stay in- or outdoors, administration of stable iodine and application of other countermeasures). With modern technologies most of these data could be collected automatically, using mobile devices and appropriate APPs.

Objectives: To improve available plug-in devices and apps that enable different sectors of the population to perform self-made measurements with smartphones, tablets and other smart devices, and to provide necessary data for dose reconstruction.

Approach: This will require the following actions:

Task 2.1 Critical review of existing plug-in's and apps to turn smart devices in radiation detectors

The last years have seen a rapid development of plug-in devices or APPs that enable smartphones (in particular through the built-in telecameras) to become radiation detectors. Some devices/APPs are already available for sale or patented. The plug-in devices are diodes, Geiger counters, scintillators and can consequently detect external radiation as counts or dose rate. Other devices are under development, e.g. spectrometry of radioisotopes or measurements of iodine in thyroid, but these are for professional use (e.g. for rescues personnel), since they use sophisticated technologies and are costly. The quality, accuracy, reproducibility and limitation of these technologies is expected to be greatly variable, especially if they are used in real situations.

Task 2.2 Improvement of the appropriateness (accuracy, robustness and user friendliness) of self-measurement connected devices and the integration of citizen measurements into existing monitoring networks at the national and European level

Once the available technologies are reviewed and, where feasible, tested under in-lab conditions (Task 2.1), these must be tested in the real life, i.e. how they are perceived, used and understood by public and how they can be integrated in the decision support systems.

Task 2.3 Based on needs learnt from WP1 (stakeholder consultation), improve or develop interactive platforms or tools for communication and dialogue on radiation measurements and results

This task will focus on defining the concept/guidelines of an APP for measuring radiation exposure that is at the same time rigorous and comprehensible for all segments of society.

Task 2.4 Optimization of proposals based on WP1 feedback

WP1 will provide feedback on the proposal from tasks 2.3 and 2.4, particularly concerning the adequacy of the proposed tools for stakeholders (citizens, local communicators, authorities), in particular whether the proposed tools meet their needs, and whether they are appropriate and easy to use. Stakeholders will also suggest modifications (possible items to remove, change or add).

WP3 – Citizen Participation in health and well-being monitoring

Lead FMU. Partners: ISGlobal, IRSN, WIV-ISP, NMBU, CEPN, Ph Pirard (expert)

Objectives:

To develop a tool and protocol for:

- The use of novel technologies (e.g. interactive APP) for communication and dialogue on radiation effects on health;
- The use of an interactive APP to collect information on health, diet, social, and psychological status of participants in order to 1) provide support (medical, advice) to affected populations and information to local mediators and public health authorities; and 2) set-up a citizen-based study, to be run by radiation protection, public health and social scientists in consultation with local stakeholders, with the aim of evaluating health and social consequences of the accident,
- Translating dose information into meaningful information on health risks. Evidence to date suggests that information on short-term and cancer risks to children are more important than lifetime cancer risks.

Task 3.1 Review of existing apps and tools on the monitoring of health and well-being

There is a wealth of validated and translated questionnaires on quality of life, diet, stress, health in general and somatic symptoms. Simple and short questionnaires will be selected and adapted for use in a Mobile APP where participants would be asked to provide information at regular intervals.

Task 3.2 Based on consultation from WP1, incorporate communication and dialogue on radiation effects on health within the App or tool

This would involve:

- defining the information and advice that could be useful to different populations at different phases of the accident. This will be supported by focus group discussions and a web-based survey on the best way to translate dose measurements into meaningful health risk data;
- defining ways in which dialogue can be established (real-time monitoring by local physicians or nurses, FAQs and screening of questions, live forums),
- defining mechanisms for reporting specific needs or situations needing intervention (i.e. shortage of stable iodine pills).

Task 3.3 Based on needs identified in WP1 (stakeholder consultation), adapt the tools identified to gather information on health and behaviour of populations exposed to radiation

This would involve:

Anticipation of agreement from pertinent ethical and data protection authorities in order to create an electronic database, and share individual data between different partners.

Data collection on

- Behaviour at time of accident and subsequently (GPS for space time budget) – this would be useful for dose estimation, adaptation of health surveillance as well as to inform authorities in quasi real-time based of possible risks based on the whereabouts of the participants;
- Perception and health complaints and worries of the participants;
- Diet - also important for dose estimation-, especially in the early phase of an accident;
- Life style, including physical activity;
- Health status including wellbeing.

Data usage, objectives:

- Obtaining support and/or alerting appropriate medical or social personnel in case of need;
- Conducting a citizen- based health/stress monitoring programme involving voluntary registering to a data base (with very strict data protection) for eventual further health and social follow-up of the population.

For this purpose, the tool (APP/Website) would provide information on the study objectives including goals, limitations, what answers it can and cannot provide, legal and data protection framework. It would provide the possibility of choosing not to share the information for those who do not wish to do so. For those who agree to share their information, an electronic informed consent will need to be signed indicating whether participants agree to link their time and motion data with databases of contamination/doses; link personal identifiers (to be defined) with those in the dosimetry APP (if separate) and existing dose monitoring networks as well as with national / local registries (including hospital discharge, etc) to move from active health surveillance to passive follow-up; link their data across countries, if relevant.

Task 3.4 Optimization of tools from WP3 based on feedback by WP1

WP1 will provide feedback on the proposal from tasks 3.2 and 3.3, particularly concerning the adequacy of the proposed tools for stakeholders (citizens, local communicators, authorities), in particular whether the proposed tools meet their needs, whether they are appropriate and easy to use. Stakeholders will also suggest modifications (possible items to remove, change or add). Discussions will also cover whether there are differences in approaches to new technologies and in their cultural acceptance across populations (between countries as well as within countries in different population groups including different age groups). Recommendations will be made on how to modify the tools and approaches in consequence. Based on this feedback, WP3 will modify its proposals, as needed, and feed them into WP4.

WP4 - Concept and specifications of App(s) and/or tools

Lead: WIV-ISP (as per proposals); Partners: IRSN, ISGlobal, ISS, experts: V. Chumak, Ph. Pirard, O. Bondarenko)

Task 4.1 Development of guidelines/concept for apps and tools

- Based on the input of WP 1 and 2, the guidelines/concept for dose measurement apps and tools will be developed. Special attention will be given to data integration and data visualization, to provide quasi real-time feedback to the users.
- Based on the input of WP1 and 3, the guidelines/concept for health and well-being monitoring apps/tools will be elaborated. Special attention will be given to conceptualize user-friendly tools in order to track people and obtain information from them over longer periods as well as to provide support to the users. As such, data integration will be primordial.
- Wherever feasible, the system should contribute significantly to the implementation of the BSS requests as far as information of public and to increase effectiveness of the protective actions
- Further building on Task 4.1, the specifications (including tutorials) for the APP(s) or tools will be developed. To this purpose, a workshop will be organized in Brussels by WIV-ISP,
- Depending on the feasibility as outlined by the previous WPs, a demonstration/prototype APP will be developed for some of the outcomes (feedback, data collection on space-time, diet, stress, health concerns).

Task 4.2 Development of specifications (including tutorials) for the App(s) or tools, or if feasible, development of demonstration/prototype App

Task 4.3 Development of database management plan

A major issue will be the need for support and maintenance of the APP in the future and recommendations will be made for this. The characteristics of the infrastructure for storing and managing the collected data will also be described. Given the vast quantities of sensitive data that will be collected, data storage and protection is a major issue in this project. A Data Management Plan will be developed in WP4.

Task 4.4 Economic evaluation of the proposed approach

An economic evaluation of the proposed approach will be performed. The resulting strategy could be considered as a public health intervention. As know and suggested also by National Institute for Health and Clinical Excellence (NICE, 1), economic evaluations of public health interventions are to be treated appropriately in terms of determining their cost-effectiveness. It would be ideal to compare costs and benefits of the proposed approach with the approaches adopted for the Chernobyl and Fukushima events.

As far as costs are concerned, it is quite straightforward to estimate costs of the proposed strategy. They include (but are not limited to): apps development; datasets access needed to use the app; storage of the collected information; citizen training for the use of the apps both for technical issues and for information interpretation to avoid unnecessary anxiety; other costs to be included during the project

Estimating benefits will be more challenging. The evaluation will focus on the benefits of: involving the citizen in this process (e.g. improving spirit of cooperation and trust between governmental agencies and the public; using “smart” technologies to reach citizens more promptly; using “smart” technologies to overcome language barriers using pictures, videos; and other benefits that will be identified during the project).

Furthermore, an attempt will also be made to estimate the benefits for different subpopulations, for example different age groups and social classes that might have a different access to new technologies.

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Metrology for mobile detection of ionising radiation following a nuclear or radiological incident – Overview of the European joint research project EMPIR - 16ENV04 “Preparedness”

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Presentation of the project

The protection of the public against ionising radiation and radioactive contaminations caused by nuclear accidents or other radiologically relevant events, including terrorist attacks, is of major importance and may affect thousands of people. Following such a radiological event, radiation protection authorities and other decision makers need quick and credible information on affected areas. Therefore, the joint research project “Preparedness”, funded within the framework of the European Metrology Programme for Innovation and Research (EMPIR, https://msu.euramet.org/calls.html) by EURAMET and the European Commission, will develop reliable instrumentation and methods needed, so that correct decisions on countermeasures of legal authorities, responsible for preparedness in nuclear and radiological emergency response will be possible. In addition, new measuring devices and methods will be developed to quickly gather quantitative data on contaminated areas and dose rate levels by aerial measurements, and to analyse contamination of the air by flexible transportable systems. This project will further work on improved methods for long-term monitoring of contaminated areas using passive dosimetry and will investigate whether non-governmental networks could support official data or undermine it. The results of this project will enable an adequate response for the protection of the public and the environment against dangers arising from ionising radiation during and in the aftermath of a nuclear or radiological event.

The presentation gave a general overview of the main objectives of the Preparedness project, its work package (WP) structure and of some of the challenges concerning (WP1): the mobile detection of ionising radiation, (WP2): transportable air-sampling systems, (WP3): dose rate and radioactivity monitoring by the public, (WP4): long-term passive monitoring of affected areas, and (WP5): the generation of impact and the dissemination of results to the stakeholder community. Further information on the Preparedness project is given in [1] and on the project’s website [2].

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Individual thyroid monitoring following nuclear or radiological accidents by means of dose rate meters

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Introduction

The progressively ageing of nuclear power plants (for instance existing European nuclear reactors are today around 30 years old) and the possibility of deliberate terrorist attacks, even on nuclear power plants themselves, stress the need to protect the public from harmful effects of exposure to ionizing radiation. Therefore it's necessary to arrange and test procedures in order to conduct a large scale individual monitoring of internally contaminated individuals. Difficulties in implementing such monitoring in the field can be represented, besides considerable organizational and logistical issues, by the need to arrange suitable mobile measurement systems to be quickly assembled, easily transportable and usable for a long period, also in power outages and in absence of connection to specific supplies (cooling gas). Such systems must moreover be able to acquire useful data in a very short time in order to monitor a large group of contaminated people [3][4].

In a nuclear accident the gamma emitting radionuclides 131I, 132Te-132I, 137Cs, 134Cs and 103Ru represent the main contributors to the radiation dose that may be absorbed, mainly through inhalation, by members of the public. After an acute inhalation the radionuclides 132Te, 137Cs, 134Cs and 103Ru are typically distributed in the human body with no specific organ accumulation, whereas all isotopes of iodine concentrate one day later almost exclusively in the thyroid gland. Therefore, for the correct dose assessment to members of the public, specific whole-body and thyroid measurements are required.

Concerning whole-body measurements, the spectrometric instruments are necessary because, in cases of incidents involving mixtures of radionuclides, they can identify and quantify at the same time different gamma emitters retained in the human body [5]. Concerning thyroid measurements, the use of simple portable non-spectrometric equipment, such as dose rate meters, offers an alternative to the preferred gamma-ray spectrometry technique [6]. Since only radioiodine isotopes are retained in the thyroid gland, it is not strictly necessary to have instruments able to perform spectrometry. Therefore dose rate meters could be enough sensitive to be used to scan thyroids of internally exposed individuals, allowing thus to give prompt thyroid medical treatment. Dose rate meters have the advantage that they are much cheaper than more sophisticated (spectrometric) instruments, readily portable to be available close to the incident area and simple to operate (just required a simple training) [5][6].

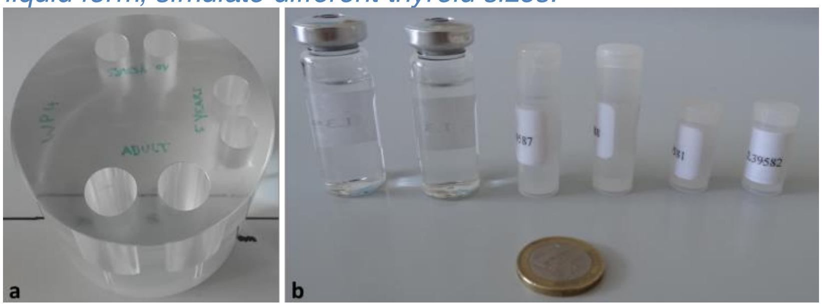
In this paper we propose a detailed procedure for fast monitoring members of the public for contamination of the thyroid with dose rate meters in order to assess committed equivalent doses due to inhalation of 131I (the major contributor to the committed dose to thyroid) in the aftermath of national or transboundary nuclear or radiological accident with spread of radionuclides in the environment. Specific attention is paid on individual monitoring of children, being the sensitive population group with an increased risk of developing thyroid cancer.

Materials and methods

Devices widely used in dose rate mode (μSv/h) for environmental surveys could be in principle employed for thyroid measurements following nuclear or radiological accidents. Planning to scan thyroids in the field, they have to be hand held instruments and simple to operate. A cylindrical 3” diameter by 3” plastic scintillator dose rate meter - model Automess 6150 AD-b, calibrated in ambient dose rate equivalent H*(10) (reading values in nSv/h) - was used for the purpose.

Rate meter thyroid calibration was carried out by means of an age-dependent neck phantom, proposed in a recent project called Child and Adult Thyroid Monitoring After Reactor Accident (CAThyMARA) [6]. It consists of a plexiglass cylinder [7], representing the neck (shown in the part a of Figure 1) with a diameter of 13 cm and height of 12 cm. In the phantom the thyroid gland of three representative age groups is simulated by three pairs of holes with different dimensions for inserting the vials (shown in the part b of Figure 1). In particular the two vials of volume 1.6 ml each simulate the thyroid lobes of a 5 y/o child, the two vials of volume 3.75 ml each simulate the thyroid lobes of a 10 y/o child and the two vials of volume 9.5 ml each simulate the thyroid lobes of an adult (>17 y/o) [7]. Aiming to quantify equivalent 131I activity in thyroid, the filling solution contained a 131I liquid source.

Figure 1. (a) Age-dependent neck plexiglass phantom used for thyroid calibrations. (b) Three pairs of vials, whose content is in liquid form, simulate different thyroid sizes.

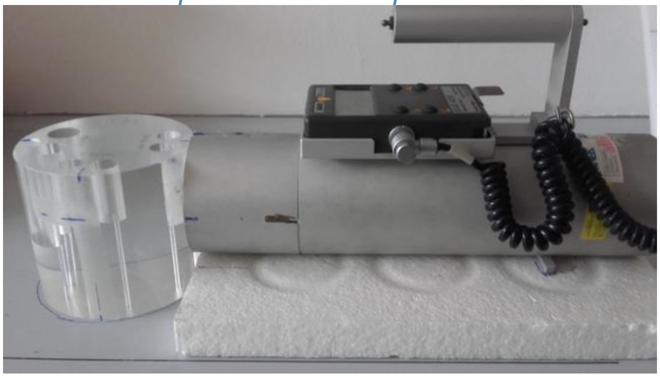


After waiting for a sufficient period to let 131I decay, the activities of all these vials were obtained by means of similar vials filled with 133Ba certified liquid source (relative uncertainty equal to 0.75% with coverage factor k = 1), being 133Ba the most suitable radionuclide because of its gamma-ray emission at 356 keV which greatly reduces the need to apply efficiency corrective factors (the main gamma emission of 131I is equal to 364 keV). All the acquisitions were carried out positioning the vials 10 cm far from the surface of a N-type crystal HPGe gamma-ray spectrometer (44% relative efficiency and 2 keV energy resolution at 1332 keV), in order to reduce systematic activities uncertainties due to the coincidence-summing effect of 133Ba.

Concerning the positioning of the device with respect to the phantom, the neck phantom was placed in vertical position, i.e. as if the person would be in standing or sitting position, and the sensitive area surface of the rate meter was positioned close to the neck phantom surface, with its longitudinal axis parallel to the ground level (Figure 2 shows the positioning of the scintillator probe 6150 AD-b with respect to the neck phantom).

Before performing any assessment, the detector response in terms of H*(10) (μSv/h) was corrected by applying, to the value read from the instrument, the dimensionless calibration factor related to 137Cs reported in its own certificate of calibration, being the detector energy response essentially stable between 131I and 137Cs gamma-ray photon energies. No further correction (e.g. environmental conditions) was applied to the value read from the instrument.

Figure 2. Positioning of the scintillator probe 6150 AD-b with respect to the neck phantom surface.



Thyroid Calibration Factors (CFs) expressed in terms of kBq/(μSv/h) were evaluated for each age. The total uncertainty (k = 1) to CFs was estimated by means of error propagation, considering the one associated to the dimensionless calibration factor related to 137Cs, the one associated to the 131I liquid source (~3%), the one associated to the standard deviation among all the related values, the one related to a not perfect angular response of the detector (~5%) and the one associated to the thyroid mass (~10%).

Device performance was evaluated by measuring mock-iodine sources (mixture of 133Ba and 137Cs in combination with a 1 mm Ag filter) provided in the CAThyMARA intercomparison and by means of acquisitions of 60 s counts each of different healthy volunteers. In particular twenty-four acquisitions of adult male thyroids (51.7 ± 10.4 y/o, 80.6 ± 10.7 kg), twenty-seven acquisitions of adult female thyroids (48.9 ± 7.3 y/o, 60.1 ± 9.0 kg), eight acquisitions of 10 y/o male thyroids (48.3 ± 12.2 kg) and thirteen acquisitions of 10 y/o female thyroids (38.5 ± 6.2 kg). For these acquisitions the device was positioned at contact with the volunteers' neck, reproducing the positioning shown in Figure 2. Before and after each thyroid acquisition, the rate of the background gamma radiation was estimated as well by means of the same scintillator probe. All the acquisitions of the adult thyroids were carried out in two consecutive days in an indoor environment, whereas all the acquisitions of the 10 y/o child thyroids were carried out in one day in a different indoor environment.

Concerning Detection Limits (DL) for each age, their values expressed in terms of 131I activity (Bq) were evaluated on averaged parameters of the acquisitions using the ISO 11929 methodology [8]. DL-intakes (i.e. the intake corresponding to an in vivo amount of 131I equal to a DL value) and related committed equivalent doses to thyroid HT (thyroid weighting factor equal to 0.05) were evaluated for members of the public with particle AMAD equal to 1 μm by using the MONDAL3 software [9], assuming an acute inhalation intake occurred five days before the measurement and type F absorption behavior.

Results

The employed dose rate meter showed a remarkable accuracy (deviation ≤ 5%) in quantification of equivalent 131I activity in thyroids of all ages (see Table 1, where age-dependent CFs in terms of kBq/[μSv/h] are also reported).

The overview of the DL-dose performance of the scintillator probe 6150 AD-b is shown in Table 2. The rate of the background gamma radiation in terms of nSv/h is reported, and, for each volunteer group, the body weight in terms of kg, the dose rate of the thyroid gamma radiation in terms of nSv/h, the DL value, the related 131I DL-intake as well as the corresponding HT values are reported too. All the related uncertainties associated to the mean values were evaluated with k = 1.

Table 1. Thyroid Calibration Factors (CFs) for different ages and results of the CAThyMARA intercomparison.

Age	CFs (kBq/[μSv/h])	Mock-iodine source (Bq)	Provided results (Bq)	Deviation (%)
5 y/o	50.8 ± 6.0	2483 ± 124	2359 ± 307	-5.0
10 y/o	55.4 ± 6.8	5642 ± 282	5638 ± 451	-0.1
adult	70.6 ± 8.9	14063 ± 703	13549 ± 881	-3.7

Table 2. Overview of the Detection Limit (DL)-dose performance (intake occurred five days before the measurement). M = male, F = female and H_T = committed equivalent dose to thyroid.

Age group	Body weight (kg)	Background (nSv/h)	Thyroid dose rate (nSv/h)	DLs (Bq)	^{131}I DL-intake (kBq)	H_T (mSv)
10 y/o M	48 ± 12	212 ± 3	185 ± 3	912	14	5.2
10 y/o F	38 ± 6	212 ± 3	189 ± 3	914	14	5.2
Adult M	81 ± 11	152 ± 4	114 ± 4	1261	20	3.0
Adult F	60 ± 9	152 ± 4	122 ± 5	1701	27	4.1

For adult acquisitions the dose rate of the thyroid gamma radiation, compared to that one of the background gamma radiation, decreases of an amount equal to 20% and 24% for female and male thyroids, respectively. On the contrary, concerning the 10 y/o child acquisitions, the dose rate decreases of an amount equal to 11% and 12% for female and male thyroids, respectively. Considering both the detector and the individual positioning, the human body works as a shielding, therefore reducing the overall response values when the detector is arranged close to the neck surface. This feature has to be taken into account when evaluating the net values of the thyroid scans, in order to avoid systematic underestimations of 131I. However in order to evaluate net values, instead of using the background gamma radiation with correction indicated above, another solution can be represented by the use of individual measures of his own thigh as background; the thigh has a thickness similar to that one of the neck, and thus can have a similar shielding against ambient gamma radiation [4][10]. Moreover the acquisition of the thigh could take into account other gamma radionuclides (if retained) distributed in the human body, and thus can be also used to delete from the thyroid measurements the contribution not due to 131I.

In these specific environmental conditions, for adult thyroids the scintillator probe shows DL values of the order of thousand Bq, resulting in a maximum HT due to an acute inhalation of 131I occurred five days before the measurement equal to 4.1 mSv (related to female thyroids). On the contrary for 10 y/o child thyroids the scintillator probe shows DL values of the order of several hundreds of Bq, resulting in a HT due to 131I in the same exposure scenario equal to 5.2 mSv. Supposing most likely same dose rate deviation of the thyroid gamma radiation for 5 y/o children as for 10 y/o children, we would obtain for 5 y/o children a DL value equal to 837 Bq, resulting in a HT value equal to 10 mSv. Considering the level of HT values associated with the calculated DL activities (the generic criterion recommended by IAEA to be used to take urgent response actions based on the HT is equal to 100 mSv [11]), the observed performance level makes the rate meter a very useful tool to be used for fast thyroid monitoring in nuclear or radiological emergencies. The adopted rate meter can easily identify individuals who have been received a HT greater than 10 mSv, and then could need medical follow-up. To this purpose, Operational Intervention Levels (OILs) in terms of net thyroid gamma radiation can be calculated [11]. For instance an OIL equal to 0.15 μSv/h can be set, if the CF value for 5 y/o child is adopted. Individual values greater than this OIL indicate that the individual under investigation may have inhaled sufficient radioiodine to require the implementation of iodine thyroid blocking agents and/or medical follow-up [11]. Needless to say, priority has to be given to children monitoring, being the individuals at higher risk of developing radiation-induced thyroid cancer compared to adults.

Conclusion

In this paper a field procedure for large scale individual thyroid monitoring after nuclear or radiological accident by means of dose rate meters is proposed. This procedure can be used when a large number of persons may need thyroid assessments. The adopted rate meter, much cheaper than spectrometric systems, guarantees an assessment of committed equivalent doses to thyroid greater than 10 mSv due to 131I inhalation if monitoring is carried out within five days after intake. Therefore they can easily identify individuals who may require iodine thyroid blocking agents and medical follow-up. Such a system could also provide key information to any future epidemiological study.

Before starting any kind of in vivo acquisitions, it is recommended to carry out measurements of ambient dose equivalent rate to identify the most suitable site (better if indoor environment) to perform thyroid measurements. A measure on the thigh to evaluate the contribution of non-radioiodine isotopes in thyroid is also recommended.

This procedure can be included in a national program of response in a nuclear or radiological emergency. However the procedure here proposed cannot be exhaustive. This kind of measurements has to be carried out in conjunction with whole-body measurements in order to fully assess a committed effective dose due to all the gamma emitters involved in a nuclear accident. Nevertheless, an easy and relatively cheap system, able to perform in 60 s thyroid screening for possible contamination, also for young children, can play a key role as part of the emergency planning as well as to prevent ill-based panic during a nuclear or radiological emergency.

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Session 2 – Novel approaches to communication & stakeholder engagement

Awareness of local stakeholders to the post-accident issue
The example of the CLIn of Blayais using the cartographic tool OPAL

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1. Common action of ANCCLI and IRSN to raise the awareness of local stakeholders to the post-accident issues

Chernobyl and Fukushima accidents have shown the importance of the commitment of the inhabitants, the local authorities and local professionals. This approach has been taken into account in the French doctrine named CODIRPA which indicates that the post-accident phase must involve the public, elected representatives, the economic and social support stakeholders. But local stakeholders may have difficulties to grasp post-accidental zoning on which this doctrine is based. Moreover, the French law gives new responsibilities to the municipalities but they don't always have the means of expertise and financial resources to prepare themselves to these responsibilities.

That is the reason why the French Association of the Committees and Commissions of Local Information (ANCCLI) and the Institute of Radiation Protection and Nuclear Safety (IRSN) have decided in 2010 to launch together an action to raise the awareness of local stakeholders to the post-accident issues. The objective of this approach is to foster the commitment of local actors around nuclear facilities for better understanding and preparedness to the consequences of a potential accident in their territory.

2. A tool to interest and help local stakeholders

In order to interest local actors to these issues and help them to find what is at stake, IRSN and ANCCLI have chosen to develop a cartographic tool to provide, in a given region, map information on the medium-term consequences of generic accidents: OPAL (tool to post-accidental issues for local actors).

The specifications of OPAL have been defined together with members of ANCCLI and IRSN. It can be seen as a training tool representing case studies and impact of meteorological conditions (wind, rain...). It presents post-accidental zoning that can be exported in a Geographic Information System (GIS).

Figure 1. Case studies as shown by the tool OPAL.

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This tool can be used to aware and train local people about the post-accidental consequences of an event affecting a French nuclear facility but also to prepare them for an accidental situation by identifying post-accidental issues of their territory.

OPAL has been made available to Commissions of Local Information (CLI) so that they can engage local stakeholders to reflect together at the issues of a post-accident situation in their territory and develop with these actors a culture of risk dealing with long term issues. This awareness-raising process can take different forms such as:

- presentation in CLI meetings
- meetings with local representatives (mayors...)
- working group to exchange on the stakes of a post-accident situation in their territory
- representation of this stakes using a GIS

Several CLI have already been interested by such an approach (Marcoule-Gard, Saclay, Gravelines, Paluel-Penly, Blayais...). This paper will just present the experience of the CLIn of Blayais located near Bordeaux in France.

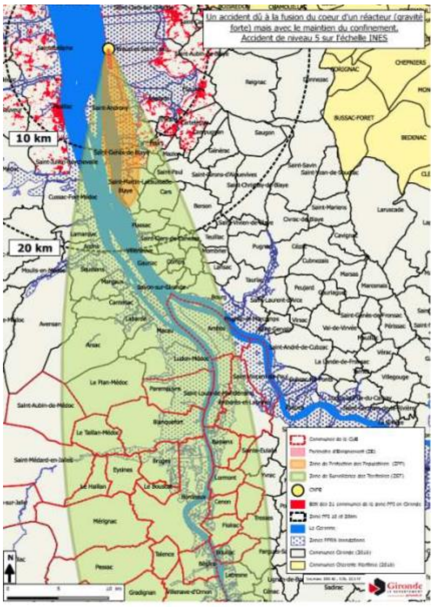
3. Example of the CLIn of Blayais using the tool OPAL

After an observation of an emergency exercise in november 2016, the CLIn of Blayais found disparities in understanding and organization for locally elected officials. After this exercice, the CLIn of Blayais started in 2017 an approach to raise awareness of local stakeholders on emergency and post-accidental preparedness.

An agreement has been signed between the CLIn of Blayais and IRSN for the use of OPAL. During six months a trainee accompanied the project of the CLIn which includes two parts.

The first part was to collect data in order to draw a representation of the stakes of the territory and of major risks, which can be combined with the zoning provided by the tool OPAL, using a GIS.

Figure 2. Cross between stakes of the territory and post-accident zoning given by the tool OPAL.



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The second part was to prepare and to carry out interviews with the Mayors of 23 municipalities around the nuclear power plant. The purpose of these interviews was to gather their perception of the nuclear risk, to exchange with them and to keep them informed on the preparation for the management of the crisis, for the emergency phase but also for the long- term phase. About post-accidental phase, they have showed to the mayors both the consequences with OPAL and the stakes involved in the territory, such as health issues for the population, economic issues including viticulture.

4. First results of the approach: from the interviews of 23 mayors

From these interviews, the CLIn of Blayais found a variability of risk perception with some differences due to seniority of elected, to distance from the nuclear site and to border effects (geographical border with the estuary, administrative border with two districts in another department). They observed a lack of information and knowledge for a majority of elected representatives (operation of a nuclear power plant, kinetics of an accident, radioactivity seem usually abstract subjects). But they also noted an interest to obtain more information.

Municipalities have also some difficulties to elaborate the compulsory documents (such as safeguard municipal plan) and to inform the population about major risks.

Mayors widely request crisis exercises and most ask for a form of participation or association of the population. They also wonder about the acquisition of sirens to alert the population.

More specifically about post-accident issues, most elected representative discovered the magnitude of the affected areas after an accident (even for a level 4 or 5 on the INES scale as shown by OPAL case studies). That gave them a feeling of helplessness which raises a lot of questions when considering a return.

5. Perspectives for the CLIn of Blayais

After this first approach, the CLIn of Blayais decided to continue this work in 2018, with a new trainee.

The first part is to complete the data layers on the economic activities and to meet agriculture and economic stakeholders (Chamber of agriculture and Chamber of commerce and industry) to develop their awareness.

The second part is to meet mayors of municipalities more distant from the plant to exchange on the nuclear risk and to collect their perception.

The third part is to exchange with some municipal councils about nuclear risk and post-accidental issues.

The CLIn of Blayais also wishes to engage the local academic and to establish a working group for an appropriation of issues such as agriculture (vineyards, forests or cereals) or production of manufactured goods (quarrying).

Knowledge base for stakeholder engagement in radiation protection

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Introduction

Over two decades of experience in the use of different forms of stakeholder engagement in emergency preparedness, response and recovery led to the development of a proposal for building a knowledge base reporting on stakeholder engagement in radiation protection collecting information on workshops, public participation under the NERIS Platform and other related projects. Some organisations, for instance OECD/NEA, have also made efforts to document exemplary cases of stakeholder engagement practices around the world. Experience from practices that have previously been undocumented because they were not 'officially' part of radiation protection will also be considered in this process.

Building on this experience, the ENGAGE project (ENhancinG stAkeholder participation in the GovernancE of radiological risks for improved radiation protection and informed decision-making) aims at supporting the development of a joint knowledge base for stakeholder engagement in Radiation Protection. This will cover three exposure situations: medical exposures to ionizing radiation, post-accident exposures and exposure to indoor radon. Specific focus will be given to the conceptualisation of stakeholders and stakeholder engagement, the rationales for and expectations from participatory processes, the level of engagement (e.g. with respect to the impact on policy-making), the instruments used (e.g. workshops, focus groups, surveys, panels, …). Designing and building the knowledge base can contribute to learning from past experience, highlighting challenges and opportunities for stakeholder engagement and identifying good and bad practices, thus helping to shape and improve future processes. The knowledge base will allow comparing and contrasting stakeholder engagement processes in the three aforementioned exposure situations.

The paper summarises the work undertaken under the NERIS-TP (Towards a self-sustaining European Technology Platform (NERIS-TP) on Preparedness for Nuclear and Radiological Emergency Response and Recovery) and PREPARE (Innovative integrated tools and platforms for radiological emergency preparedness and post-accident response in Europe) projects, as well as relevant projects in non-nuclear areas as a basis for further development and discussions. The approach developed for documenting the experience in stakeholder engagement in helping to plan for emergency response and recovery will be reviewed under the ENGAGE project.

The foreseen ENGAGE project report on the knowledge base will propose a structured reporting of participatory activities carried out within the radiation protection platforms NERIS, MELODI, ALLIANCE, EURADOS and EURAMED as well as within Social Sciences and Humanities community and members of the CONCERT stakeholder group. The presentation of ENGAGE activities in the area of knowledge base development opened the floor for discussions and co-operation in the area of building a joint knowledge base for stakeholder engagement in Radiation Protection.

Background: overview of activities

Over the past 20 years there has been a growth in stakeholder engagement in many areas of societal decision making associated with radiation protection issues:

- Environment
- Waste Management
- Emergency planning, response and recovery

In the area of emergency preparedness, the participation landscape covers a wide range of processes and interactions aimed at opening spaces for dialogue, building capacities for response and recovery, and the co-development of robust and practicable restoration strategies. Such activities are initiated by mandated actors, researchers, international organisations, local communities or citizens.

Stakeholder engagement in the research could be split into the areas of emergency response and accident management:

- Preparedness phase: exercises, case studies -> building network and trust between partners;
- Management strategies: many stakeholder networks were involved in evaluating concrete strategies (EU FARMING, STRATEGY, NERIS, etc. projects);
- Real situations: ETHOS in Chernobyl; ICRP co-expertise dialogues in Fukushima; reindeer herder dialogues in Norway.

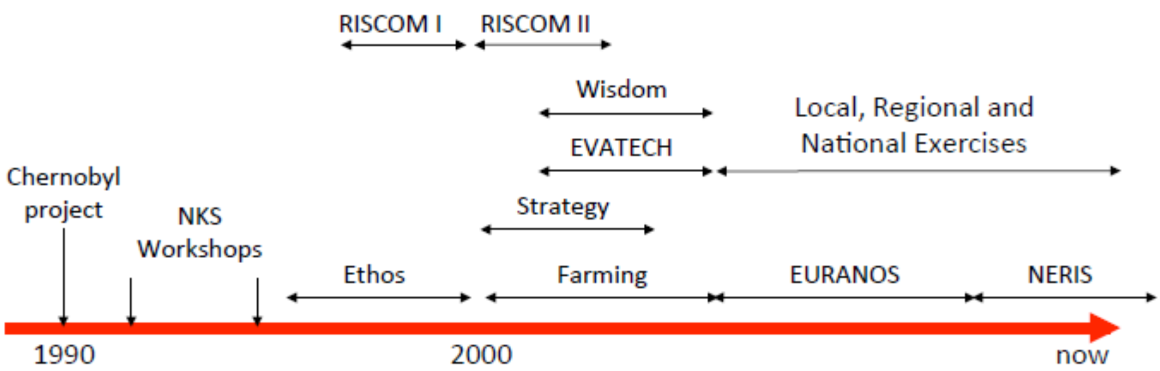

Figure 1. Stakeholders engagement within the international, national, regional and local activities and projects

Based on the experience and project results the report has been developed under the NERIS working group on Emergency Preparedness and Stakeholder Participation [1]. This report proposed a structure for documenting stakeholder and public engagement processes run by NERIS partners in relation to nuclear or radiological emergency and post-accident recovery. The aim is to build a knowledge base so that we have a repository of experiences and can identify and assess good practice, thus helping to shape and improve future processes.

ENGAGE is building on the existing database composition and will broaden it conceptually and domain-wise. The original intention was that any event which involves interaction with stakeholders or the public might be entered into the knowledge base. We are seeking for sharing experience in which such interactions take place in order that we might learn from each other and gradually identify good practice [1].

Database composition

We envisage that in reporting each exercise, activity or event four classes of information and material will be uploaded:

- Basic factual information;
- More general description;
- Evaluation according to several criteria;
- Other relevant documents and material uploaded as files.

The originally designed database structure introduced by NERIS [1] will be modified under ENGAGE project taking into account new areas included – medical exposures and radon.

The outline of the information which might be included in the knowledge base is following:

<u>Basic factual information</u>

- Topic
- Participants and stakeholders, organiser, location
- Participation instruments and/or approaches: e.g. public information or education events, moderated table-top exercises, scenario-based workshops, stakeholder workshops, citizens' juries, co-expertise seminars, town hall meetings, information web-sites, blogs, discussion forums, informal participation
- Facilities used
- Chronology and dates: planning start date, beginning of process of inviting, date of event, date process completed and results issued
- Costs (venue, accommodation, transportation, social events), staff time

<u>General description</u>

- Context: geographical, technical, economic, political and social contexts, political governance structures;
- Main players and stakeholders; who were the main players, note any players who chose not to take part or interact…
- Aims, objectives and deliverables
- Process: chronology, general protocol, general process of communication, how was the process decided upon, and why
- Outcomes (factual rather than evaluative): who received the results and what happened subsequently; who in fact, took part: not just who was invited

<u>Evaluation criteria</u>

- Information sharing: e.g. freedom to express viewpoints, information flow, effectiveness of communication, task definition
- Participation ideals: e.g. transparency, accountability, representativeness
- Influence on final policy
- Resource accessibility: e.g. information, access to scientists, time available for making decisions
- Level of independence of true participants

- Practicability: cost effectiveness, timescale, frequency
- Decision quality: framing, structured decision-making
- Key learning points: what do practitioners learn from engagement and about engagement? and how do we learn more about SH engagement?

The structure and particular elements of the knowledge base will be clarified taking into account other exposure situations and different groups of stakeholders involvement, engagement and active participation based on the results of WP2 and WP3 of ENGAGE focusing on the case studies in the area of stakeholder engagement in practice and on radiation protection culture in relation and in the context of medical field, emergency and recovery preparedness and response, and natural sources of radioactivity.

The first ideas for knowledge base of stakeholder engagement in radiation protection in relation to emergency and recovery preparedness and response were discussed at round table held jointly with the NERIS WG 'Information, Participation and Communication' at the 4th NERIS Workshop on April 25 2018, in Dublin. The discussions were based on two questions:

a) Which form of knowledge base for stakeholder engagement will make it meaningful for you?
b) Which information is most useful for you?

<u>Which form of knowledge base for stakeholder engagement will make it meaningful for you?</u>

The first suggestions related to the form of the knowledge base focused on following key aspects:

- Easily searchable, not a bunch of reports (e.g. post-accident info, list of stakeholders for issue, etc.)
- Electronic form
- Artificial Intelligence (Professor too expensive)
- Maintained repository of records (successful experiences, stakeholder panels, reports from organizations)
- Case studies (e.g. Fukushima and Chernobyl)
- Knowledge management techniques (compiled and analyzed reports, common repository, accessible to everyone)

For the form of knowledge base, it is important to have it searchable by keyword and with report capabilities, rather than compact documents.

Machine learning and artificial intelligence (AI) offer search functionalities (see e.g. image search). However, context is also needed, e.g.: Who wrote the report? Why? When? How? What is the history of the document? Links to the authors are needed as well as links to related articles (e.g. in Research Gate).

An important question is how to transfer this knowledge to next generation? The question is who the target audience for the knowledge base is. The target audience depends on the area of interest, on the stakeholders engaged. For instance, "decision-maker" could be a keyword, with the search results pointing to e.g. the goal of stakeholder engagement, the country, and the participants.

Within NERIS platform, work led by Simon French developed a database structure that could be a good starting point for ENGAGE. This has been tested based on local forums (e.g. Norway, France, Slovak Republic). Stakeholders from different platforms and projects could be contacted, to ask about their interest in using the knowledge base.

Building the pilot for the ENGAGE knowledge base starting from CONFIDENCE activities could be good start.

<u>Which information collected in the knowledge base is most useful for you?</u>

The following information was suggested by participants as most useful:

- objectives,
- (types of) stakeholders,
- situation / topic / subject,
- methodology:
    - type of material used,
    - participatory method, e.g. discussion, survey, scenarios,
- information from previous projects, previous experiences, synthesized such that it can be used in more efficient ways,
- which type of questions should be addressed to which type of stakeholder,
- type of stakeholder to target in which situation.

It was suggested to add a set of basic concepts so that everyone is on the same page; everyone speaks the same language or at least understands each other. This could be ensured with links to existing documents where these concepts are used.

It was stressed by some participants that it is important to see that the process of engagement is not so simple and that it cannot deliver everything. It is important to be clear about the questions people are facing and to have stakeholders' views, provide examples drawing attention on real experience, highlighting things that (do not) work and what contributed to a good stakeholder process. The knowledge base should point out how were stakeholders engaged, how was the process kept alive or, opposite to this, why it failed.

The view was presented that discussions among stakeholders should allow everybody to "take off their hat", facilitating open discussion where each stakeholder has the same right to talk, The power symmetry, with focus on ethics, and cooperation was stressed as an important aspect. It was agreed that it is important to establish rules of communication, not that someone tries to be above the rest. Among the stakeholders there can be controversial issues (e.g. disagreement on priorities). Not only vertical, also horizontal power asymmetries have to be followed during the discussions.

Connected to that, information on power asymmetries and the need for an independent mediator or facilitator in contact with stakeholders should be given in the knowledge base.

Two positive practices coming from Belgium were presented. Basic information on nuclear risk can be found at: www.nucleairrisico.be/ of the Crisis Centre. Anyone can access information, but the website includes also sections for specific target groups: pharmacists, healthcare professionals, first responders. The other example is the partnership approach for the low-level radioactive waste in Belgium, involving several local community stakeholders. The process proved to be successful, and at the same time long and challenging and it allowed finding an agreement.

It was suggested to the group to start with documenting experiences from the CONFIDENCE and TERRITORIES projects. An important point is to emphasize that there is no one best approach and stakeholder engagement approaches have to be adapted to the situation.

Test case studies - further steps in knowledge base development

Several case studies already exists which could be helpful in knowledge base development. There are:

- Norwegian EURANOS (CAT3) Strategy Stakeholder Dialogues
- ICRP Fukushima Dialogues

Some case studies could be developed based on the results available, such as:

- PREPARE Project Stakeholder Panels
  - could be documented under the NERIS WG ConGoo: Contaminated Goods
- CONFIDENCE National Stakeholder Panels
  - could be documented under the NERIS WG IPC: Information, Participation and Communication

The case studies under development within the ENGAGE project could be also valuable input to the knowledge base development, notably ENGAGE Case Studies on practical experiences of stakeholder engagement in Radiation Protection issues (WP2) and on Development of RP Culture (WP3).

DRAFT Knowledge base report (available in April 2019) will be discussed with relevant stakeholders from the platforms NERIS, MELODI, ALLIANCE, EURADOS, EURAMED, members of CONCERT stakeholder group and outside 'nuclear community' in a form of webinar or other activities during the platform workshops.

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Tools and Approaches for Improved Communication of Uncertainty in Emergency Situations

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Introduction

Addressing scientific and societal uncertainties in a nuclear emergency during pre-and-post radioactive release is not only an issue of decision-making, but also of public information and communication. Therefore, developing tools to deal with communication about uncertainties, be it of technical or social nature, is crucial to improving protection, health and well-being of the affected population, and to enable informed decision making by the affected population as well as by experts.

There are many definitions of uncertainties in a literature, a common definition of uncertainty related to risk doesn't exist (Aven and Renn, 2009). In fact, the risk literature often defines risk concept with expression of uncertainty e. g. (Hoffman et al., 2011; Rosa, 2003) as well as, a probability distribution e.g. (Graham and Weiner, 1995; Paté-Cornell, 1996) and as an event, e.g. (Abbott et al., 2006; Verhaegen and Bergmans, 2015). If risk is defined by risk probability or as an event, the understanding, interpretation and judgement of risk may also lead to uncertainties, since is risk usually expressed in numerical form as odds or subjective probabilities, which is difficult for many people to process, especially in stressful situations, e. g. (Schwartz et al., 1997; Sohn et al., 2001). Due to this, systematic error in making judgements under uncertainty often appears. This systematic error has been investigated extensively, mainly by information processing scholars. For instance, Tversky and Kahneman (1974) classified heuristics in the decision-making process related to uncertainties in three categories depending on the situation when this systematic error can appear: 1.) representativeness, which is employed when people need to judge probability of instances or scenarios; 2.) availability of instances or scenarios, which is employed when people need to assess the frequency of the plausibility of a particular event; and 3.) adjustment from an anchor, which is usually employed from an anchor, which is employed in numerical prediction (Tversky and Kahneman, 1974).

Different interpretations of uncertainties are acknowledged also in the CONFIDENCE project. The uncertainty as defined in the CONFIDENCE project "*can include stochastic uncertainties (i.e. physical randomness), epistemological uncertainties (lack of scientific knowledge), endpoint uncertainties (when the required endpoint is ill-defined), judgemental uncertainties (e.g. setting of parameter values in codes), computational uncertainties (i.e. inaccurate calculations), and modelling errors (i.e. however good the model is, it will not fit the real world perfectly). There are further uncertainties that relate to ambiguities (ill-defined meaning) and partially formed value judgements; and then there are social and ethical uncertainties (i.e. how expert recommendations are formulated and implemented in society, and what their ethical implications are)*" (French et al., 2018, c.f. French 2017). The following definition of uncertainty is used in the project:
"*Uncertainty is a situation which involves imperfect and/or unknown information related to the investigated nuclear emergency case. Uncertainty is the lack of certainty, a state of having limited knowledge or information where it is impossible to exactly describe the existing state related to the emergency, a future outcome, or more than one possible outcome including consequences. Due to a lack of knowledge, lack of information or lack of trust in information*

the emergency stakeholders have difficulties to make informed decisions what to do or not to do, how to react and what actions (advised or not advised) will they take. In such situation stakeholders need to make decisions under uncertainty" (Perko and Abelshausen, 2017).

To include communication about uncertainties in public communication strategies is highly advised by different EU projects as well as by risk communication researchers, for instance in PREPARE, EAGLE, ARGOS etc. since it helps people to make informed-decisions (Perko et al., 2015; Perko et al., 2017; Perko et al., 2016a; Perko et al., 2016b; Ropeik, 2011; Sandman, 1987; Shirabe et al., 2015). It is also advised to emergency actors to admit uncertainties in communication to public(s) (IAEA, 2012, 2014; OECD/NEA, 2015; Perko, 2016; Perko et al., 2016). However, systematic removal of uncertainty from public information is common in practice, especially related to emergency situation. Jensen et. al. (2017) found that though scientists often try to thread uncertainty into their discourse (e.g., a limitations section), it has been observed that this information is systematically removed as scientific discovery is prepared for public communication (Jensen, 2017). The FP7 project EAGLE found out in discussions with experts that this systematic removal of uncertainty from public information related to ionising radiation is often done due to lack of methods and tools to communicate uncertainty information (http://eagle.sckcen.be/en/Deliverables).

This study was conducted to identify and analyse the methods and tools to improve the communication of uncertainty in crisis situations such as nuclear emergencies. Therefore, a systematic overview of international literature and an online search of communication tools have been conducted.
Results show that methods and tools suggested for nuclear emergencies differ significantly in what procedures and communication tools are seen as appropriate and recommendable. There are many suggestions of how to address uncertainties during a crisis communication. The report summarizes these suggestions, documents the evidence provided with each suggestion and draws some lessons for improving communication before and in crisis situations.

Method of the study

The following steps were conducted:
(1) A systematic review of the literature on methods and tools for communicating uncertainty was performed to get an overview about the current state and focus of crisis communication;
(2) A categorization of tools and approaches for communicating about risk and uncertainties in relation to ionising radiation;
(3) An identification of relevant evaluation criteria for testing information and communication approaches;
(4) An evaluation of the identified tools on the basis of the evaluation criteria.

Review of literature and approached tools
The authors conducted a literature search in the Web of Science focusing on methods, online tools, reports of projects and communication campaigns of how uncertainty in the event of nuclear emergency has been communicated. The search produced around 80 sources which seemed relevant to analyze (step 1).

Categories
The sources have been compared for identifying elements and components that are common in all the listed tools and approaches. The grouping of the elements led to the identification of seven categories used to classify the approaches and tools (step 2):

(1) *Visualisation*, such as the traffic light model, uncertainty maps, or animations;
(2) *Specific design* of the message, for instance placing certain information in the front, while uncertain information at the end of the message;
(3) *IT and apps*, like disaster apps, individually tailored crisis information, partly connected with GPS;
(4) *Improved organization* by trainings of volunteers, inclusion of opinion leaders, fast distribution of crisis messages by various means (sirens, mobile phones, radio, TV etc.);
(5) *Role models* that put emphasis on recruiting ambassadors with high trust potential;
(6) *Decision making* to support communication managers to get to sound (and quick) decisions based on good judgements;
(7) *Multi-tools* that cover more than one of the above-named categories.

Evaluation of the tools and evaluation criteria
In a third step a review of the state-of-the-art literature on criteria for risk communication has been performed. Numerous studies in the last 30 years have suggested different criteria to evaluate and describe risk communication. The authors searched in the Web of Science by using keywords such as criteria, risk communication, risk governance, uncertainty in different combinations and selected around 40 peer-reviewed articles, book chapters or reports. These articles were checked if they included the criteria for communicating risk and uncertainty.

Error! Reference source not found. presents the 11 criteria which have been chosen as the most relevant for the performed study from the initial list of 37 criteria. As part of the selection process the researchers decided to focus on those criteria that relate to methodological characteristics and highlight approaches such as “uncertainty analysis”, “quality of communication”, “resilience”, “social acceptance”, “ethical acceptability” or “trust“.

In the fourth and last step the categorized tools and approaches that have been identified in the review of the available literature were evaluated using the criteria reported in **Error! Reference source not found.**. At this point it is important to note that the criteria are not applicable or suitable for assessing all the tools equally, since these tools have been developed for different purposes and in response to different stakeholder needs.

Table 1: Evaluation criteria for uncertainty and radiation

Criterion	Explanation	Selected references
Uncertainty analysis	Addresses uncertainty as a knowledge gap and describes the level of robustness of the found data, models, distribution, and effects.	Refsgaard et al. 2007, Renn 2008, Kasperson 2014, Uuotalo 2015
Radiation	Covers radiation and protection especially in nuclear emergency situations as a topic	Perko 2016, 2916 a, 2016b
Effectiveness	With respect to (a) the exposure of detected information, (b) the expected degree in understanding the given information, (c) resulting behavioural changes of people that were confronted with certain information, and (d) induced social impacts in a wider field.	Rowe and Frewer 2000
Efficiency	As the highest effect resulting from a certain effort, which is using a certain tool in case of this study.	Leiss 2002, Aven and Renn 2010
Quality of communication	The form of exchanged information, degree of dialogic communication and opportunity of participation.	Lundgren 1994, Leiss 2002, Renn 2006, Renn 2008,

Resilience	As a characteristic that defines the tool as unsusceptible against external overloading.	Renn and Klinke 2015, IRGC 2005, 2017, Renn 2008
Social acceptance	Decision if a new technology/method is accepted or merely tolerated by a community (Taebi 2017).	Sjöberg 2004, Flynn and Bellaby 2007, Aven and Renn 2010, Taebi 2017
Ethical acceptability	In order not to discriminate any social group, including a fair and social equal treatment.	IRGC 2005,2017, Aven and Renn 2010, Perko, Raskob and Jourdain 2016
Politically and legally realizable	Feasibility as the possibility to implement tools in the real world, taking political and legal reservations into account.	IRGC 2005, 2017, Aven and Renn 2010
Quality of the message	Meaning to be understandable and clear to everyone in the target group.	Chess et al. 1989, Weinstein et al. 1992, Lundgren 1994, Renn 2006, Weinstein et al. 2006,Renn 2008
Trust	Judgement whether the institution/source matches the expectations of social actors and public (after Renn 2008).	Renn and Levine 1991, Renn 2008, Siegrist et al. 2000, Löftstedt 2003, Peters et al. 2007, Tateno and Yokoyama 2013

The fit of methods and tools was rated separately for each criterion on a scale from zero to three. Addressing uncertainty was rated on a scale ranging from zero (meaning that the connection is not clear), over one (meaning there is no link to uncertainty), over two (partly addressing uncertainty to three (stating the tool is clearly addressing uncertainty).

The extent to which the tools cover radiation was coded as zero (no clear connection); one (no link to radiation), two (partly connected to radiation but not specifically designed for radiation); three (clear coverage of radiation protection during nuclear accidents).
All other criteria were treated similarly, zero: (can't be clearly analysed), one (no explanation given), two (partly given) and three (strong connection to research criteria). All collected data was evaluated by using Excel software.

Results and Discussion

The literature and online research resulted in a database of 80 communication tools, linked to scientific articles and studies. All tools were assigned to the seven categories (see figure 1) and rated in their fit to the evaluation criteria (compare table 1 and 2).

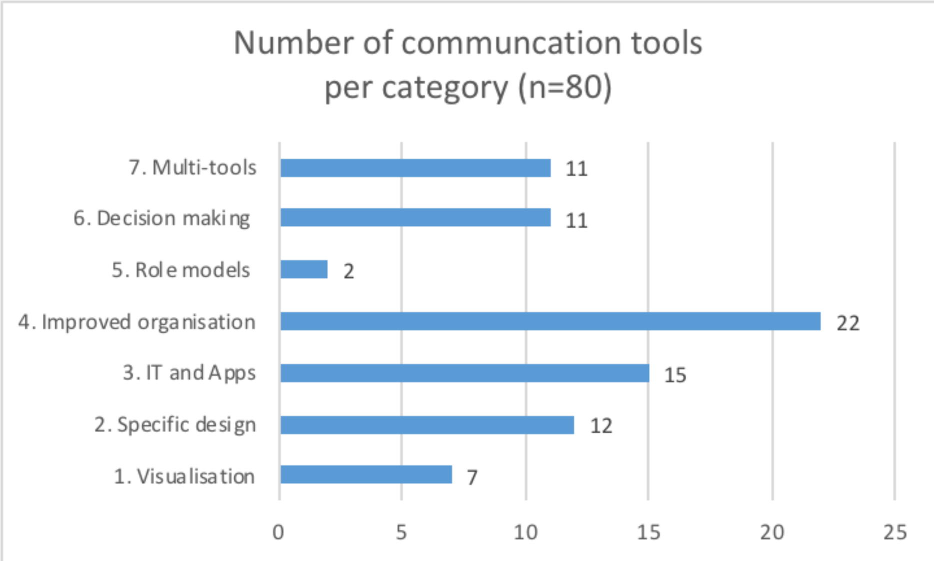

Figure 1: Number of communication tools per category (n=80)

The analysis of tools shows that the categories of improved organization and IT and Apps yielded the highest score for communicating uncertainty followed by specific design, multi-tools and decision making.

Table 1: Categories of tools and their characteristics to communicate uncertainties

Category	Characteristic of the category	Communication of uncertainties
1. Visualization	• usage of visualization tools, • suitable to synthesise and communicate complex information to people, but bears the risk of failing to engage users, • enables experts to communicate changes that might cause uncertainty of risks to citizens in a simple and understandable way, • no dialogic communication possible, • could assess risks wrongly and can confuse users.	Covers the criteria only partly (e.g. mapping), needs to be combined with other tools of communication, addresses stochastic, epistemological uncertainty
2. Specific Design	• risk/crisis communication collage, • written or numeric format communication as “Answer Fact Sheets”, technical or numerical uncertainty • using message maps containing only key messages to educate and inform a specific audience, • question and answer sections.	Addresses technical or numerical uncertainty, but poor performance on criteria, especially social and ethical uncertainty, partly communicative aspects
3. IT/Apps	• IT and apps which are suitable for communicating with a broader population, • specially designed apps for risk communication,	Many criteria met, high for effectiveness, efficiency, partly trust, social acceptance, for communication suitable for broader population, but not for “hard-to-reach” target groups, ethical aspect is critical,

	• warning apps (e.g. NL-Alert, NINA, KATWARN and FEMA), Wireless Emergency Alerts (WEAs) tweets • app for specific groups or organisations internally with information (e.g. CrisisGo).	addresses many uncertainties for example modelling, epistemological
4. Improved organization	• combined tools used by improved organization in different ways informing, engaging with the public using the other categories such as visualization, specific design of Apps	Huge effect due to coverage of many criteria, but less effective on communication quality, stochastic, epistemological, judgement uncertainty
5. Role models	• integrative Risk Governance Approach with the need of a new and wider form of risk definition and emergency communication throughout different social fields, including trust, capacity of understanding, transmitter-receiver-models, systemic risks or epistemological uncertainty, • public Outrage that describes a gap between the risk perception and experts and citizens	Only few are available, for instance Risk Governance Model or Public outrage performance on criteria effectiveness and efficiency, addresses ambiguities, social and ethical uncertainty
6. Decision-making	• Tools (e.g. RODOS or ERICA) for decision making, these are more useful for experts and public authorities and internal communication.	Not as stand-alone, more useful for experts and public authorities and internal communication, complicated to understand for non-experts, but tailored messages are feasible for public use during crises, value judgements
7. Multi-tools	• all instruments and approaches that combine various categories, • by providing sound emergency-response information, • e. g. guidelines	Combination of various categories, broader use and very practical, high diversity, however, possibility of confusion, many uncertainties covered for instance ambiguities, social and ethical uncertainty

Visualization

Most of the recognized visualization tools covered the criteria only partly. Although most tools assess uncertainty, they lack the connection to radiation risks. Additionally, tools are created to provide only partial information, which means that they need to be combined with other communication tools in order to get a full range of information responding to risk perception and behaviour. Visualisation of environmental changes thus seems suitable to synthesise and communicate complex information to people unfamiliar with the topic but bears the risk of failing to engage users (cf. Grainger et al. 2015, 315). To sum up, these tools are helpful to provide complex general information, but do not especially match the challenges present in emergency situations, as they can confuse users (social uncertainty).

Specific design

All collected tools with a “specific design” address uncertainty but include only partly communication aspects. Most of the tools have a rather poor performance on the demanded criteria. As the main difference between the tools referred to the extent of possible interaction, tools are described in order from low participation/ unilateral communication to higher participatory options.

One major difficulty in creating a proper design is the wide variety of people being confronted to the message. The response on numeric and verbal terms differs widely, depending on the personal understanding of probability and time windows. Thus, information can be under- or overestimated, which results in inappropriate reactions (social uncertainty). The best way to design messages is to use only short forecasts, accompanied by detailed action plans (cf. Doyle et al. 2014, pp 97).

IT and Apps

IT and apps meet many criteria, as they rate high for effectiveness, efficiency, partly trust (depends on the topics and the source, API 2016), and social acceptance. They are suitable for communicating with a broader population, except "hard-to-reach" target groups for instance no-internet users, elder population, socially vulnerable groups (ethical aspects and uncertainty).

Although apps were supposed to be useful and credible, the problem may arise that participants feel too safe to use them (cf. Reuter et al. 2017, 7). Thus, crisis management via social media, although having a wide range and being easy and fast to distribute information, is not a simple tool when it comes to its effective use. There are risks of false information spreading, exclusion of specific groups and misunderstanding of the message (cf. Stern 2017, pp.11). Online communication additionally leads to less secondary crisis communication than conventional mediums (cf. Utz et al. 2002, 45): people in directly affected areas wish to inform others about risks but have low effectiveness as they miss a useful information-traceability system (cf. Acar and Muraki 2011, 399).

Improved Organisation

In total 5 out of 22 tools have been categorized under "improved organisation". These tools are rated highly effective according to coverage of "uncertainty" and "radiation" (especially social and ethical uncertainties). They include a broad approach to informing people, engaging with the public, and therefore educating and sensitizing citizens for risks in the case of nuclear emergencies (Matahri et al. 2017). Traditional tools such as annual reports, newsletters, websites, magazines, Press data centre, press conferences can be integrated in this approach. The tools in this category work best if various channels, including those in social media, such as YouTube, twitter, Facebook are addressed simultaneously.

There are only two tools available for role models, but they showed a good performance on most criteria, especially on effectiveness and efficiency and illustrating conceptual or social uncertainty, but role models need a lot of effort to use in practice.

Decision-making

Looking at tools for decision making, these are more useful for experts and public authorities and internal communication than for the general public. They do not stand-alone and need in-depth background knowledge. Tailored messages are feasible for the public during crises situations.

Multi-tools

The category of multi-tools includes all instruments and approaches that combine various categories. As such, they normally have a broader use and are very practical, especially in accomplishing a high diversity of utilization possibilities.

Conclusion

The tools vary significantly, ranging from sophisticated online and app solutions to approaches of behavioural change through role models, internal and external improvement of organizational structures and decision making directed predominantly to experts and authorities.

Promising areas for communicating uncertainty in emergency situation are the IT and Apps for emergency and Multi-Tools for broader usage of various target groups. They include a wide scope of uncertainties, such as social and ethical uncertainties, on the one hand, and scientific (technical and model or conceptual) uncertainties, on the other hand.

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Mental models of EP&R for improvement of plans

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Introduction

Emergency Preparedness and Response (EP&R) plans are prepared for many radiological threats at different levels: national, regional, local, off-site, on site, for individual organisation, for facilities etc. All these plans are usually prepared by responsible authorities/institutions and very rarely developed based on the public involvement or with consultations. As a consequence, they are sometimes lacking the appropriate information, not addressing relevant uncertainties and public concerns and are not prepared to fulfil the needs of the possibly affected public in case of accident.

As part of the CONFIDENCE project [1] which is aimed to understand, reduce and cope with the uncertainty in modelling and predictions, also consideration of social, ethical and communication aspects of emergency management is planned. As part of the socio-psychological study of understanding, processing and management of uncertainties therefore an investigation on the mental models of EP&R will be performed with the aim to improve communication tools and planning. Some similar studies were already performed in relation to other related topics, such as mental models of radioactivity and radioactive waste management [2]. In addition, also comparison of findings with similarities and differences on radioactive and waste management models between countries [3] have been conducted, therefore some related experiences already exist.

Methodology

The work will assess differences in mental models of uncertainty management in emergency situations for lay citizens and emergency actors in various national contexts (Germany, Greece, Slovenia, Slovakia, Spain). Mental models are cognitive schemas through which people explain individual processes or phenomena in which they are participating. The investigations on mental models started in 1980's and '90's mainly with studies of how people conceptualize different domains in physics such as moving bodies, liquids or electricity. Later research in other areas sought to elicit and map out mental models with the aim of improving learning processes and adapting information or teaching materials. Studies were related for example to mental models related to farming, economics and planning policies, complex man-machine systems, such as aviation or computers. Mental models research has been used to prepare information strategies in the case of risky installations.

The research on mental models is performed in several stages: it is based on the mental model approach to the risk perceived projects developed by Morgan and co-workers [4] and adjusted to the emergency and response management. *Firstly,* the expert model is created, based on the available expert knowledge of radioactivity, repository design and process which are assumed in such a facility. The expert model is an attempt to pool in a systematic manner everything known or believed by the community of experts that is relevant for the risk decisions the audience faces. *Secondly,* mental models of lay people about the processes and properties are obtained through the individual open-ended interviews with a different public, eliciting people's beliefs about the hazard, expressed in their own terms. The responses are analyzed in terms of how well these mental models correspond to the expert model. *Thirdly*, based on captured beliefs expressed in the open-ended interviews and in the expert model the main differences are pointed out and the risk communication is developed and evaluated in support to the EP&R management, specially identifying the uncertainties.

Presently the research on the mental model approach to EP&R management is still under implementation and the first two stages have been partly completed, while the third stage will be performed after completion of first two. The expert models of EP&R management have been developed based on the review of current approaches in several countries (Slovenia, Ireland, Belgium) and interviews with involved responsible experts. The discussion included responses on three questions: how would you divide the EP&R: which are the areas and topics; can you describe each of this in brief (actions/activities/topics); what uncertainties would you associate with actions/activities/topics within different areas. The protocol for open-ended interviews included several sections and follows the captured mental models of experts on EP&R management. The core section covers questions related to EP&R plan (what is included, what can happen during the nuclear accident, what are risks, what are planned measures), how people understand the foreseen measures and sources of information and trust in them. In addition, also socio-demographic data will be collected. Special considerations is taken with regards to some vulnerable groups such as children, elderly, people in hospitals and others who are ill or cannot move.

The interviews will be performed with approximately 20 different individuals in countries, tracing the concepts and understandings, but also other important points of their mental models. The interviewees should preferably people who live near nuclear facility (nuclear power plant, research reactor, and other nuclear or radiological facility for which Emergency preparedness and response plan is developed). The sample participants for mental model interviews of uncertainty management in emergency situation should be from target audience: in this case they should be representative members (related to gender, age, education) living in the areas for which the EP&R plans are developed and where in general they would be more informed (the areas with radius of 25 km around the nuclear facility).

Previous related results from investigations

Several studies took place which are relevant for the mental model research on EP&R management. Here are mentioned just two. As part of the larger international project, financed by Financial instrument of the EU civil protection, the Municipality of Krško, where in Slovenia the only NPP is in operation for 35 years, ordered the survey on preparedness of local population and institutions for evacuation in case of nuclear accident in NPP Krško. The work was developed by Faculty of Social Sciences and Faculty of Arts, University of Ljubljana [5], and the survey was implemented in October 2012 within local population living in 3-km zone around NPP Krško. The sample was 502 adult persons based on simple random sampling, the method applied was personal interviews with standardized questionnaire, which resulted with 52% female and 48% male responds. In addition, twelve qualitative interviews with leading personnel in companies and institutions in the Krško municipality were conducted. The may findings related to uncertainties of EP&R management were:

- The knowledge of local population how to react and what to do in case of nuclear accident is limited and one important source of uncertainty.
- The reality of foreseen modes of reactions in emergency plans have to be tested as some assumptions are not working (e.g. evacuation of children, appropriateness of defined zones).

- The needs of more vulnerable groups (elderly, people without adequate social support, people with special needs and ill) in emergency plans shall be addressed.

What raises strong concern is the fatalistic view held by some responsible authorities that in the event of a serious nuclear disaster there is nothing that can be done, an evacuation would not be possible or necessary, the consequences would be too serious, and people live too close to the Krško NPP in order to be evacuated in time.

Another investigation conducted in Slovenia during 2005 to 2008 focused on mental models of radioactivity, radioactive waste and waste repository [2] and was performed as a method for development better risk communication strategies with local communities during repository site selection. The representative sample of Slovenian population included 1000 participants, and was enlarged with 200 persons living in municipality with NPP operation for 30 years. The main findings of investigation are presented in table 1. Different topics were discussed with experts and lay people. It can be seen that mental models of lay people on radioactivity, radioactive waste and the LILW repository are mostly irregular and differ from the experts' models.

Table 1: Findings on mental models from experts and lay people

Topic	**Expert models**	**Some of lay mental models that differ from the expert model**
Radioactivity, time dependence, process	Nuclei are unstable and decay exponentially with various half life, they gradually become stable, not radioactive after 300 years, natural and man-made process	Radioactivity is an artificial process Radioactivity increases with time or is not time dependent Natural radiation is different to artificial radiation, since people are used to it. There is no radiation in nature
How radiation effects humans,	High doses can kill or modify living cells, but there are repair mechanisms that correct the damage. Doses compared with natural background (low doses) have no effect. Late (stochastic) and acute (deterministic) effects.	Irradiated objects become radioactive themselves All radiation, even low doses, causes cancer, Hiroshima effect Radiation influences fertility, genetic changes, it stays for many generations A person disappears and burns down, There is a chain reaction of contamination in the cells – like viruses
Processes in the LILW repository,	No active processes in the repository, decay of radioactive waste, possible chemical disintegration, very slow degradation of the barriers, corrosion, then possible release through water and air, ingestion, inhalation, direct contact, all accidents studied and protected …	Processes like earthquake, war, terrorist attack may release inner forces with possibility of atomic bomb, Waste emits radiation which is then transported through the barriers to humans, Psychological consequences, A stroke of lightning that can release radiation, Plants absorb radioactivity, Radiation evaporates from repository
Transport of radioactive waste,	Transport by road or rail, use of special packages and containers with pre-testing. Normal procedure with licensing.	Transport only with special vehicles with police escort In case of accident total contamination of land with many people irradiated, injured or dead Many accidents but not openly reported

The indicative results of these two investigations shows that people do not have the same understanding and models of nuclear related topics, and that it is necessary to find the believes in order to better address peoples' needs.

Future work

The investigation will now focus on performing the interviews with selected individuals in Germany, Greece, Slovenia, Slovakia and Spain. All interview will be recorded and transcripted in English to allow for further analyses, to present results in individual countries, to compare lay people with experts' models, investigate similarities or differences between countries as the have different societal as well as nuclear background and to draw conslusions. As part of further analyses also other results obtained in CONFIDENCE project will be used, like the finding of characterisation and response to uncertainties in past nuclear emergencies (Belgium, France, Norway, Spain, Slovenia) and results of public opinion survey on EP&R in Belgium, Norway and Spain. The preliminary report will be drafted in October 2018 and finalised in December 2018 to provide the bases for improved communication strategies and tools in emergency preparedness and response.

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Session 3 – Inverse modelling & data assimilation

Assessment of source regions and source terms based on the Ru-106 measurements in air in Europe in September and October 2017

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Introduction

On the evening of October 2nd 2017 first reports about the detection of traces of Ru-106 in the air in several European countries became available to the BfS. Since then, several assessments of the source region and source term for the release of Ru-106 to the atmosphere were performed.

Method and results

To allow for a first rough estimation of possible sources of the Ru-106 in air, several thousand backward trajectories were calculated with the HYSPLIT model (NOAA) based on archived GFS numerical weather data. For this purpose backward trajectories were started from several measurement locations that reported observations of Ru-106. This assessment allows to define a first rough guess of a possible area where the Ru-106 release may have occurred (Figure 1).

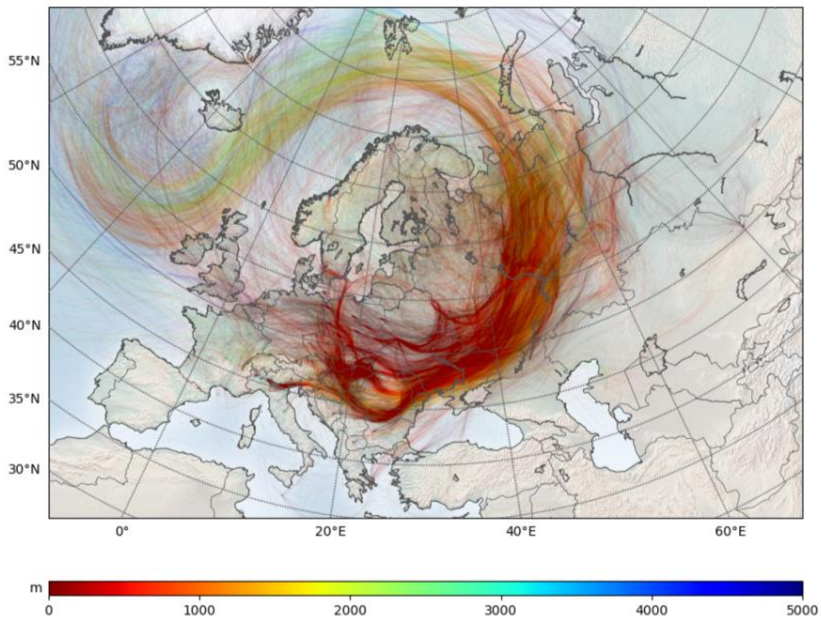

Figure 1. Backward trajectories starting from ~300 positive (> 0.01 mBq m^{-3}) observations of Ru-106 in late September, early October 2017.

An improved assessment of the source region has been made on the basis of several hundred forward atmospheric dispersion calculations from different potential release sites within the "first guess" source region identified with backward trajectories. Atmospheric dispersion calculations were performed with the HYSPLIT model (NOAA) based on archived GFS numerical weather data. The dispersion calculations were started for 162 potential release sites within the first guess source region, covering an area between 30°E-80°E and 45°N-70°N. The dispersion calculations were started for 7 different release periods between 20.09.2017 00h (UTC) and 26.09.2017 00h (UTC), each release period covering 24h.

To date, 470 observations of Ru-106 from Europe, Russia, and Asia are available for the data assimilation to assess the source region and possible source term. For each of the potential release sites and each of the release days the correlation between the measured air concentration and the model results (with the atmospheric dispersion model = ADM) has been investigated using the Pearson Correlation Coefficient R. With this approach those release sites and days can be identified which give the highest correlation of ADM results with the measurements (Figure 2).

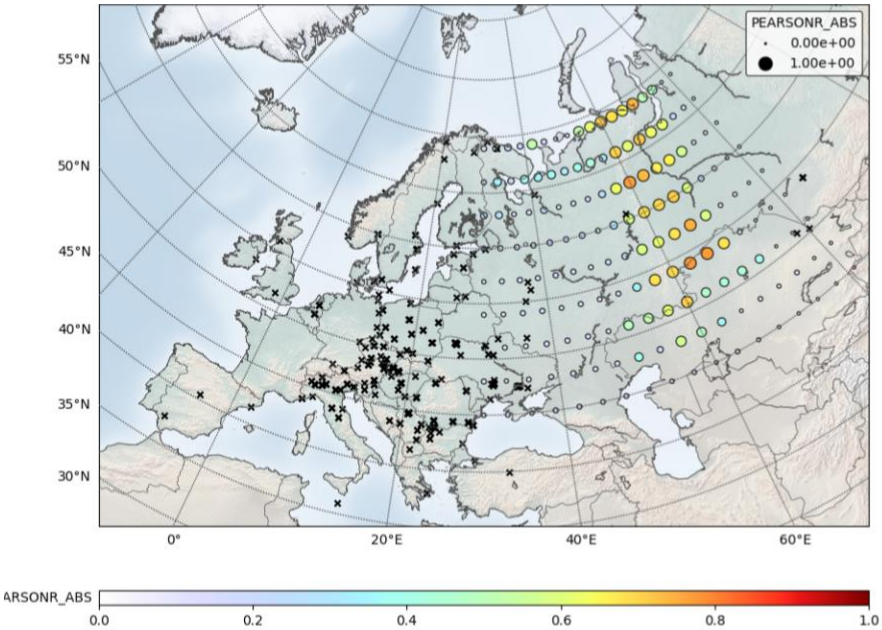

Figure 2. Pearson R correlation coefficient calculated for dispersion calculations from 162 potential release sites and release times between 22.09.2017-26.09.2017. The observation sites are marked with 'x'.

An assessment of the source term has been carried out also based on forward atmospheric dispersion modelling. The ADM results were scaled with various factors to simulate various amount of releases. The scaled ADM results were compared against the full set of measurements by using the FAC2 criteria and the optimal amount of release was identified.

Results and discussion

The analysis of the dispersion calculations suggest an estimation of a potential source region within the wider area of the Southern and Central Ural for a release time between 24.09.2017-26.09.2017. For earlier release times (i.e. between 20.09.2017-23.09.2017) the potential source region extends towards the Northern Ural. The FAC2 analysis provided an estimation for a potential release of Ru-106 of at least 100 TBq. A more detailed localization and source term estimation based on the reported observations and dispersion calculations underlie large uncertainties due to the large distances between the majority of the observations and the potential source regions.

Position optimization techniques for stationary and mobile radioactive incident monitoring

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Introduction

A careful choice of the spatial distribution of the radioactive incident monitoring sites is essential for the monitoring network to work efficiently. On the other hand, an efficient mobile monitoring system is necessary in order to further reduce the dose rate uncertainties and take the appropriate decisions for the protection of the population. As an example, Germany currently operates 2000 stationary sites representing an area of 175 m^2 per station [1]. Despite such a high network density, detecting every tiny atmospheric propagation of released radioactive material and reconstructing the contamination chart within 24 hours appears to be a challenge. Though subsequent mobile monitoring allows to improve the spatial resolution of the measured dose rates, it may be an even greater challenge to identify safe high priority zones for mobile monitoring.

Data from stationary monitoring are important for source term and atmospheric propagation reconstruction methods. For this reason, a two-fold optimization tool has been recently developed on behalf of the German radiation protection service. On one hand, the tool performs a spatial optimization for further stationary monitoring probes, using a linear combination of up to ten spatially dependent optimization criteria, for example the population density, the distance to the next probe or the time between first alarm and exposure. On the other hand, the tool provides a post-incident contamination chart and a chart of the dose rate uncertainty, both based on dose rate measurements collected during the incident and on a collection of propagation simulations (RODOS [2] simulations for the most recent weather forecast models and for several scenarios of radioactive material release). The contamination chart is reconstructed by inverse modelling, resulting in a weighted combination of the simulation models. The weights are computed from the matching probability between the models and the measurements. As a new feature, in order to improve unsatisfactory matchings, the model plumes are subject to tiny spatial deformations compatible with general physical requirements. The resulting overall dose rate uncertainty of the contamination chart is used to obtain the priority chart for mobile monitoring. Realizing so a first step in the complex field of data assimilation, the tool allows to rapidly gain accurate information about the post-incident situation of radioactive contamination and to identify the zones for most urgent mobile monitoring missions. In the early phase after an accidental release, this will help reduce uncertainties for dose assessment tools.

Former development

In the scope of the European DETECT consortium, another tool for spatial optimization of monitoring sites for several European countries has been developed formerly (DOT). It has been conceived to use a large number of cost functions and is based on a classical Kriging algorithm for spatial interpolation [3-5].

General threat monitoring

In the general threat case, the stationary monitoring sites need to be spatially optimized in order to ensure efficient monitoring while keeping the number of sites at a reasonable level. Therefore, for every new site, an optimization procedure is run using up to ten criteria (see Table 1). These criteria depend partly on demographic and geographical data, partly on the positions of already placed sites, partly on the locations of the nuclear power plants to be taken into account and partly on an ensemble of weather conditions (typically 360 real weather conditions recorded over one year for every climatically distinct region). The optimization is based on a technique which was developed by Läderach et al. [6].

Table 1. List of the 10 criteria used for the spatial optimization (general threat).

<table>
<tr><td>10 Criteria</td><td>Depends on already placed monitoring sites</td><td>Conventional sites</td><td>Spectrometric sites</td></tr>
<tr><td rowspan="4">Does not depend on nuclear power plants</td><td rowspan="4">X1: Population density (logarithmic scale)</td><td colspan="2">Uncertainty due to distance to nearest station</td></tr>
<tr><td>X2</td><td>X10</td></tr>
<tr><td colspan="2">Distance between stations</td></tr>
<tr><td>X5</td><td>X11</td></tr>
<tr><td rowspan="3">Depends on the locations of nuclear power plants</td><td>X3: Critical local dose rate around 100 µSv/h</td><td colspan="2">Angular distance to nearest station with respect to incident location</td></tr>
<tr><td>X4: Time between alarm and exposure</td><td>X7</td><td>X12</td></tr>
<tr><td>X6: Distance to incident location</td><td colspan="2"></td></tr>
</table>

Underlined criteria require weather-dependent propagation data (RODOS).

The optimization results shown at the NERIS workshop are analogous to those of the pre-release phase in the emergency mode (see example in the next paragraph).

Pre-release phase monitoring in the emergency mode

In the pre-release phase, the spatial optimization of monitoring sites is performed as in the general threat case, but solely taking into account the nuclear power plant of concern as well as the relevant weather conditions. Figure 1 shows the result of the optimization for an example with the nuclear plant Grohnde being of concern (green star), for one weather condition with propagation towards northeast and using 2 optimization criteria. The recommended 3 top positions for a new site (purple round points) are located in populated areas and within the zone of potential radioactive plume. The total optimization (or cost) function is also shown using colour scales (light colour: advantageous for new sites; dark colour: disadvantageous for new sites). In order to place more than one site at a time, the optimization is run iteratively.

As for all spatial optimization tasks, the run time performance is optimized while achieving a spatial resolution well below the size of the smallest cell of the RODOS radioactive propagation data used. A high level of efficiency is obtained by applying the spatial simulated annealing optimization algorithm [7,8] which behaves robustly as compared to greedy methods [9]. Since the algorithm cannot guarantee that the absolute minimum of the cost function is found for each run, the procedure is repeated several times. E.g. Figure 1 shows 3 repetitions.

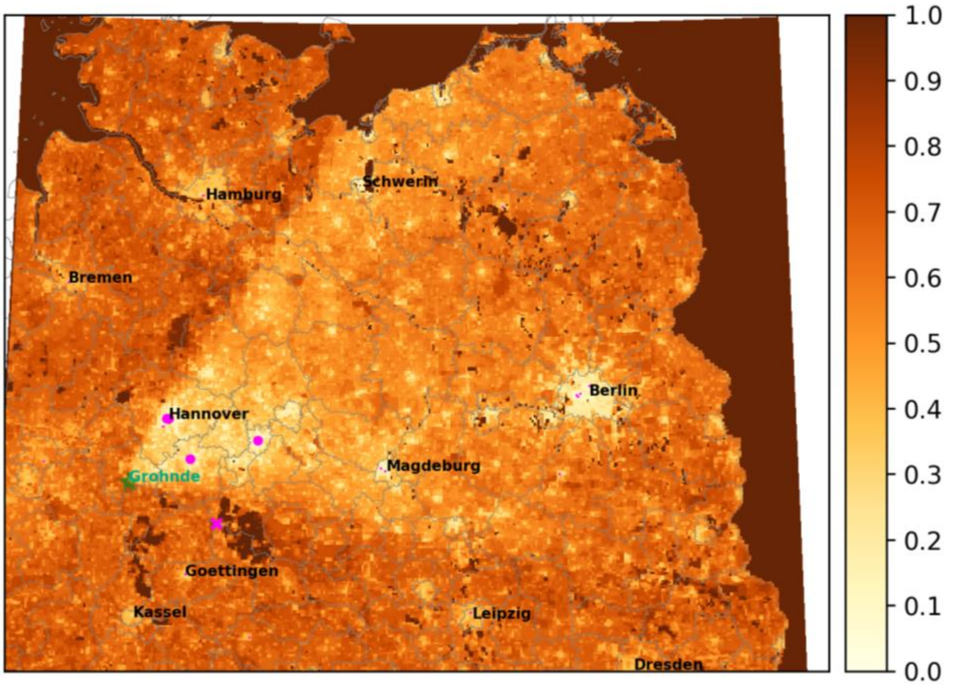

Figure 1. Pre-release phase (emergency mode): Spatial optimization of a new monitoring site for an example with the nuclear plant Grohnde being of concern (green star), for one weather condition with propagation towards northeast and using 2 optimization criteria: the population density (weight 2) and the critical dose rate (around 100 µSv/h) (weight 1). The recommended 3 top positions for monitoring sites are indicated by purple round points, while the total optimization (or cost) function is shown using colour scales (light colour: advantageous for new sites; dark colour: disadvantageous for new sites).

Post-release phase mobile monitoring in the emergency mode

In the post-release case in the emergency mode, it is necessary to refine the knowledge of contamination, particularly with respect to critically contaminated areas and also taking into account the criteria of Table 1. Therefore, mobile monitoring will be scheduled and optimized following priority zones or priority paths (depending on the types of monitoring vehicles used). For this purpose, the optimization tool first computes the contamination chart and the dose uncertainty chart by inverse modelling, and then provides a spatial optimization for the mobile monitoring program. Unlike the source term reconstruction method referred e.g. in [10], inverse modelling in our case is based on a collection of simulated models of radioactive propagation and a chart of measured dose rates (all dose rates refer to the same post-release time).

The contamination chart is calculated as a weighted sum over all the models. The weights represent the matching probabilities between the models and the measured dose rates. In order to ensure acceptable levels of matching probabilities despite the limited number of available models, the models are slightly deformed (orientation and distance rescaling). The deformations are performed while ensuring compatibility with general physical requirements, e.g. radioactive mass conservation. We have found that model improvements of this kind can be essential in certain realistic scenarios [11]. To compute the contamination chart, two weight factors per model are computed, one for the matching (chi-squared technique) and one for the deformation (the acceptance decreases as a function of increasing deformation). As an example, Figure 2 shows a contamination chart obtained using four models and simulated measurements. One of the models dominates due to its matching with the measurements (weight 3.181). For two of the models, slight deformations improve the matchings (stars / red).

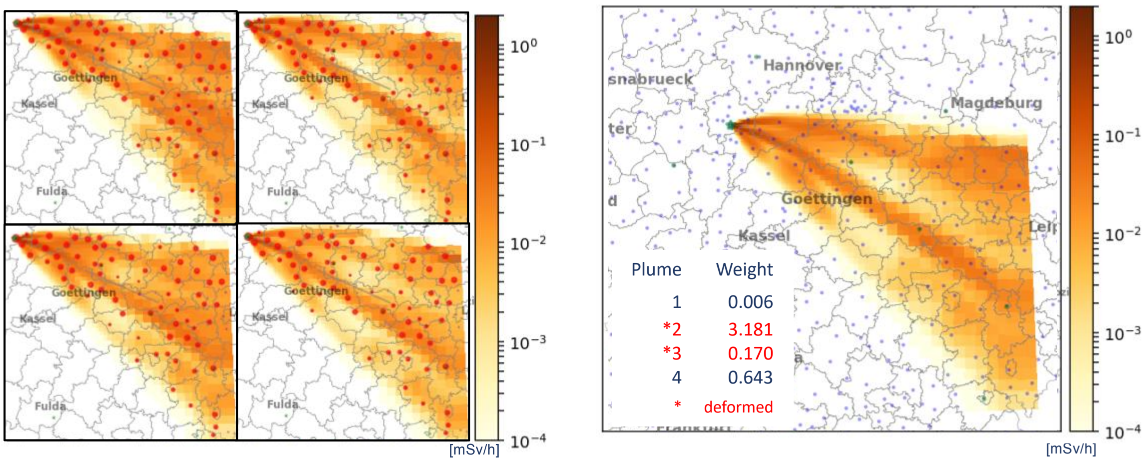

Figure 2. Example with a propagation towards southeast (simulated measurements and four models). Left subfigure: The four models are shown using colour scales (light colour: small dose rate; dark colour: large dose rate), and the measured dose rates are shown by red points (large points mean large dose rates). Right subfigure: The contamination chart is shown using again colour scales; the weights as indicated for each model are normalised to the number of models (4).

For the same example, Figure 3 shows the uncertainty chart, the spatial optimization of mobile monitoring (red round points) and the cost function with same colouring scale as in Figure 1, using the uncertainty chart, the population density and the distance to the incident location as three equally weighted criteria. The dose rate uncertainty is a sum of three relevant contributions: variation between models and measurements at the nearest monitoring site, uncertainty due to the distance from the nearest site, uncertainty due to model deformations. In this configuration, most of the recommended monitoring positions are located in the neighbourhood of the nuclear plant. The narrow zones of dark cost function colouring in the vicinity of the nuclear plant are high contamination zones (prohibited access). The tool also allows to optimize mobile monitoring along given paths.

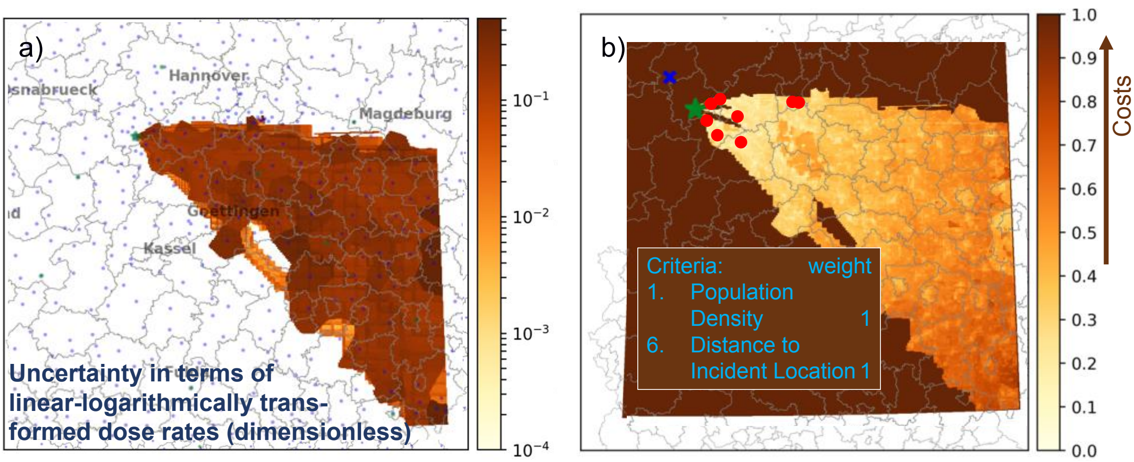

Figure 3. Example with a propagation towards southeast (simulated measurements and four models). The left subfigure shows the uncertainty chart using colour scales (light colour: small uncertainty; dark colour: large uncertainty). The right subfigure shows the spatial optimization for mobile monitoring (red round points) and the cost function with

same colouring scale as in Figure 1, using the uncertainty chart, the population density and the distance to the incident location as three equally weighted criteria.

Conclusions

For the general threat analysis, we have developed an efficient position optimization tool for stationary monitoring. We have developed a second optimization tool for the pre-release emergency situation for deployable automatic systems complementary to stationary monitoring of radioactive incidents. In addition, an optimization tool has been developed for the optimized planning of post-release incident monitoring using data from stationary and mobile devices. In the post-release mode, the most important optimization criterion is the dose rate uncertainty chart. On the same lines, the tool also computes the contamination chart via inverse modelling. The option of model improvements by tiny deformations has proven beneficial or even necessary for certain scenarios, bearing in mind the often limited number of available propagation models. BfS will use the tools for the optimization of existing stationary networks and for the optimization of mobile monitoring planning during emergency preparedness and response exercises. The application of the optimization tools may be extended to the needs of other users and countries. This process mainly requires demographic and geographic information and knowledge on relevant monitoring networks.

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Uncertainty assessment of DIPCOT based on the NERIS ADM experiment

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Introduction

The NERIS near-range atmospheric dispersion modelling (NERIS ADM) experiment has been an initiative coordinated by the Belgian Nuclear Research Centre SCK•CEN. The aim was to evaluate against field experimental data and intercompare results of atmospheric dispersion models in the near spatial range. The computational experiment concerned in particular radioactive pollutants and the calculation of gamma dose rates by the participating models.

The NERIS ADM was a "blind" experiment, in the sense that the experimental data against which the model results would be compared were made available by SCK•CEN only after the participating model results were sent the coordinator. The reference data consisted of gamma radiation dose rate measurements from 7 near-ground stations at a radius of about 200 m around the stack of the experimental nuclear reactor BR1 at SCK•CEN. The gamma dose rate was due to the routine releases of Ar-41 from the reactor's stack. The measurements were taken in 16 different days in one year and each day was made up of a 4-hour period during the steady-state operation of the reactor. The dispersion models participating in the experiment were requested to simulate the 16 4-hour periods and provide the corresponding dose rate predictions at the location of the sensors in 10-min averages.

Measurements from the adjacent meteorological mast at SCK•CEN were distributed to the participants to be used as input to the dispersion models. The meteorological measurements included horizontal wind speed and direction at 69 m above ground, air temperature at 8 and 114 m above ground, vertical wind direction, standard deviation of horizontal and vertical wind directions, all at 69 m above ground. The "source term" data that were distributed included the activity release rate, the stack height and diameter, as well as the exhaust speed and temperature.

The goal of the study presented in this paper has been to partially assess the uncertainties in the results of the atmospheric dispersion model DIPCOT. The sources of uncertainties that have been considered were uncertainties in the input meteorological data and uncertainties due to different modelling options. Uncertainties due to the stochastic nature of atmospheric turbulence will be the subject of a future study.

Method and results

The method employed was to depict the spread of model results – as minimum and maximum values – produced by different probable input data sets or by different modelling options. In regards to uncertainties in the input data two variables have been considered: the atmospheric stability and the ground roughness height. Based on the available meteorological data, the atmospheric stability could be assessed by two alternative methods: either by the vertical air temperature gradient or the standard deviation of the horizontal wind direction ([1]). The results of these two methods were not always coinciding. The ground roughness has been assessed from personal communication with the experiment coordinator. Considering the land cover of the area surrounding BR1, values between 1 and 3 m were most probable, so it was decided to use three values for the ground roughness, namely 1, 2 and 3 m. The combination of the three possible ground roughness values with the two atmospheric stability calculation methods resulted in six input data sets with which DIPCOT was run for each of the 16 4-hours periods. The minimum and maximum calculated dose rate values at each time 10-min interval and sensor were considered to show the spread of model results. Dose rates were calculated at sensor locations at 1-min time steps and then were averaged to 10-min intervals.

In regards to modelling options, two different methods have been used for calculating air concentrations and consequently gamma dose rates: Lagrangian puff and Lagrangian particle. In the Lagrangian puff method the dispersing plume consists of Gaussian puffs and concentrations and doses are calculated at each sampling location by adding the contributions of these Gaussian puffs. In this case the dose rate is calculated by the method described in [2]. In the Lagrangian particle method the dispersing plume consists of fluid particles and concentrations are calculated by adding the particles contained in a specific volume around the sampling location. Dose rates are calculated considering each particle as a radioactive point source. The above sub-models can be combined in DIPCOT with three alternative methods for calculating the random motions of the puffs or particles: random velocities, random displacements with uniform probability distribution and random displacement with Gaussian probability distribution. The random motions of puffs or particles are superimposed to the motion due to the mean wind velocity to simulate turbulent diffusion. In summary two modelling options have been examined: (a) Lagrangian puff or particle model, (b) random velocities, random displacements with uniform distribution or random displacements with Gaussian distribution.

Other modelling options that were fixed and not considered in the uncertainty analysis were the following: plume rise was calculated, building effects were not taken into account and the release rate of Lagrangian puffs or particles was 1 sec^{-1}.

Results and discussion

Some indicative results of the spread in the gamma dose rates calculated by DIPCOT are presented in this section. Figure 1 shows the effects of uncertainties in input meteorological data of the dispersion model, namely using different methods for calculating atmospheric stability (through the vertical temperature gradient or the standard deviation of wind direction). In some cases the two methods give distinctively different assessment of atmospheric stability and this had a noticeable effect in the results of the dispersion model. In general, the method based on the standard deviation of horizontal wind direction tends to give more unstable atmospheric conditions. This results in an increased vertical diffusion of the plume that brings it close to the ground nearer to the stack and produces higher gamma dose rate at the sensors locations.

Figure 2 shows the effects of uncertainty in estimating the surface roughness on the dispersion model results, keeping all other parameters fixed. Higher values of surface roughness produce more vertical mixing of the plume, bringing it close to the ground and finally resulting in higher values of gamma dose rate at the sensors. In these simulations atmospheric stability has been calculated through the vertical temperature gradient. The Lagrangian puff mode for calculating plume dispersion and dose rate has been employed, combined with random velocities of puffs obtained through the solution of a Langevin equation.

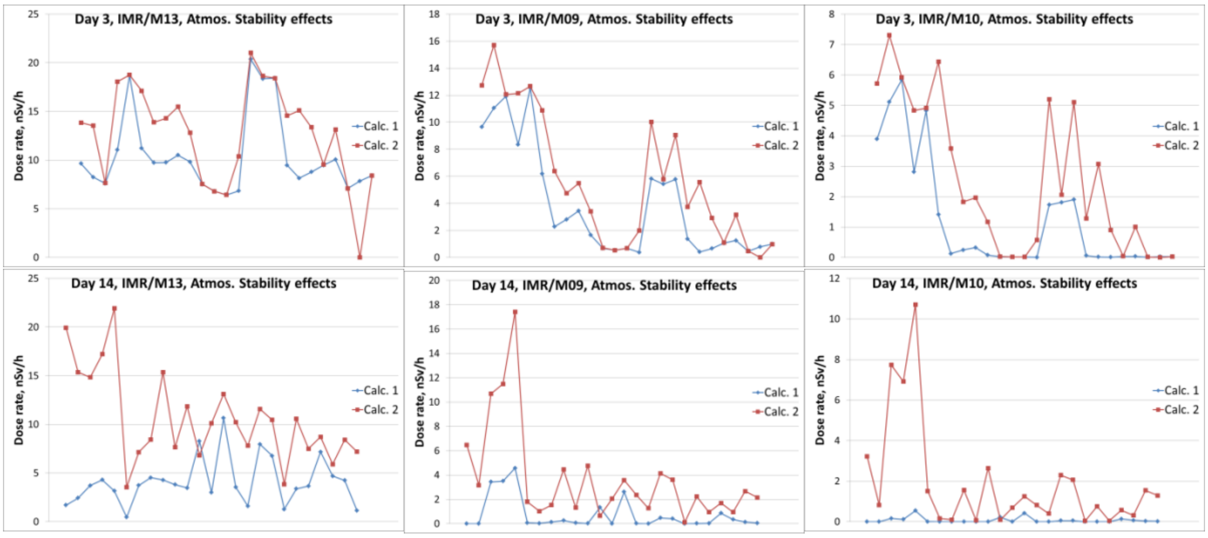

Figure 1. Time histories of calculated 10-min averaged gamma dose rates at three stations (M13, M09 and M10) for day 3 (14/2/2017) and day 14 (3/5/2017); "Calc. 1": atmospheric stability calculated by dT/dz; "Calc. 2": atmospheric stability calculated by σ_θ.

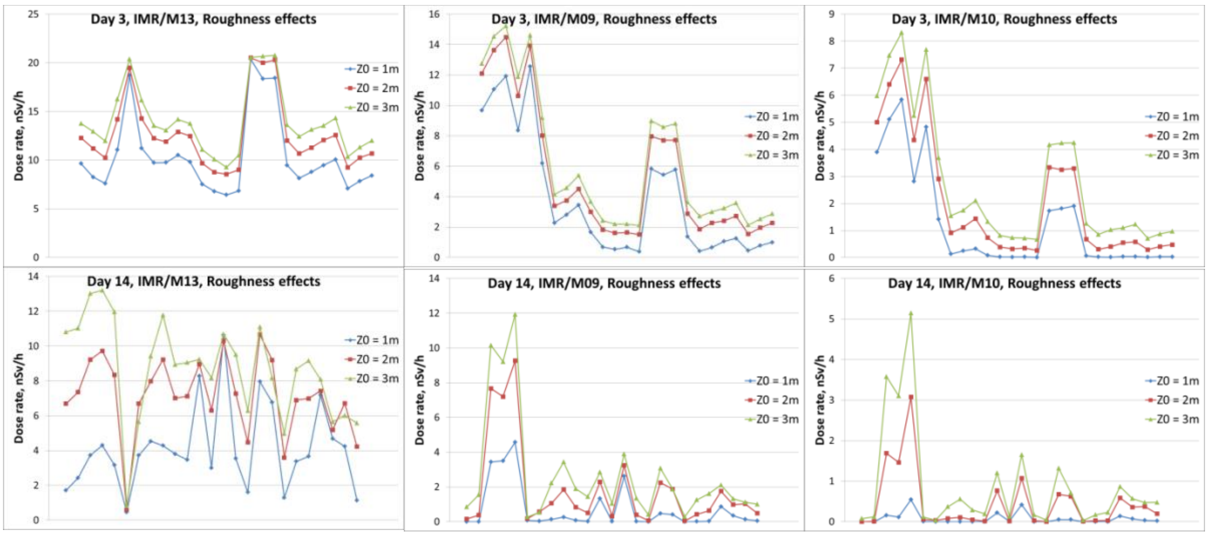

Figure 2. Time histories of calculated 10-min averaged gamma dose rates at three stations (M13, M09 and M10) for day 3 (14/2/2017) and day 14 (3/5/2017) for different values of surface roughness

Figures 3 and 4 depict the effects of using different dispersion modelling options. The gamma dose rates presented in Figure 3 have been calculated by employing different modes for calculating concentrations and dose rates. In "model 1" DIPCOT has been operated in Lagrangian puff mode, while in "model 2" DIPCOT has been operated in Lagrangian particle mode. The particularities of the two modes have been explained in the previous section of the paper. It is evident that the particle mode produces systematically higher dose rates than the puff mode. All other uncertain parameters have been fixed as follows: atmospheric stability was calculated using the vertical temperature gradient, ground roughness height was set to 2 m and random velocities calculated by the Langevin equations were used to simulate the random displacement of puffs or particles.

Figure 4 presents characteristic cases of calculated gamma dose rates at three sensors in two days of the experiment, produced by running DIPCOT in Lagrangian puff mode, combined with different ways of accounting for the puffs random displacement. In “Model 1” random velocities of puffs are calculated through the solution of the Langevin equation. In “Model 2”, random displacements of puffs with uniform probability distribution are considered, while in “Model 3”, random displacements of puffs with Gaussian probability distribution are assumed. The rest of the uncertain parameters have been fixed as follows: atmospheric stability was calculated using the standard deviation of the horizontal wind direction and ground roughness height was set to 2 m. A mixed behaviour of model results is observed with “Model 1” tending to give lower gamma dose rates and “Model 3” higher ones. The time evolution is similar for all three models.

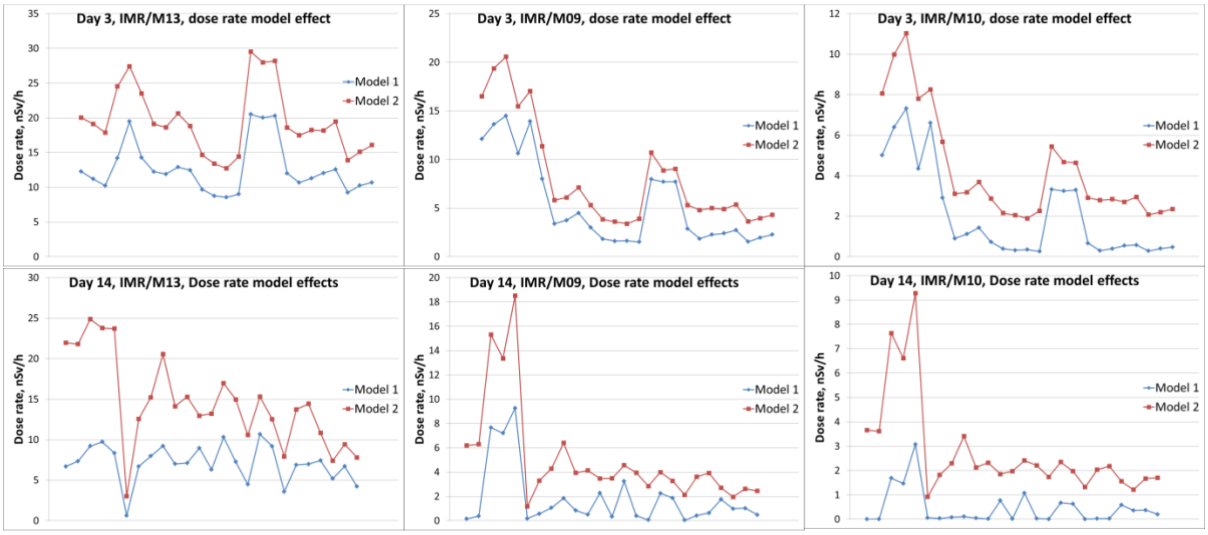

Figure 3. Time histories of calculated 10-min averaged gamma dose rates at three stations (M13, M09 and M10) for day 3 (14/2/2017) and day 14 (3/5/2017) for different dose rate calculation methods; “Model 1”: Lagrangian puff; “Model 2”: Lagrangian particle

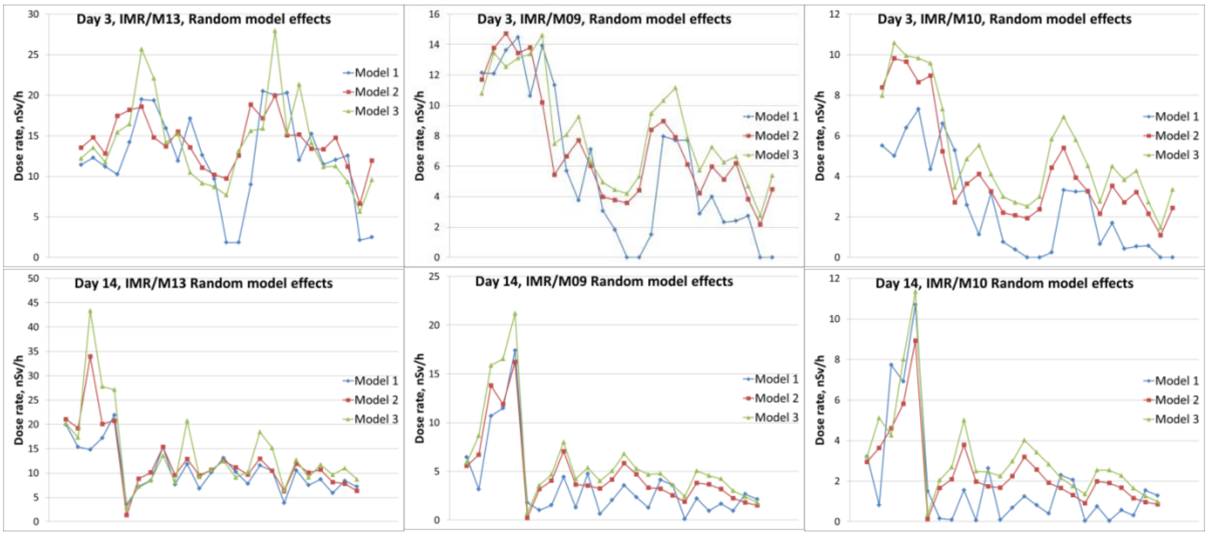

Figure 4. Time histories of calculated 10-min averaged gamma dose rates at three stations (M13, M09 and M10) for day 3 (14/2/2017) and day 14 (3/5/2017) for different methods of random puff displacement; "Model 1": random velocities; "Model 2": random walk with uniform distribution; "Model 3": random walk with Gaussian distribution

In Figure 5 combined results from all input data sets and modelling options considered in this study are presented to show the total spread of possible model results. At each time instant the minimum and maximum calculated gamma dose rate is shown. So each curve contains data points by different input data and modelling options. Measured values are also shown as provided by the exercise coordinator after the completion of the project. It is observed that there is a considerable spread of model results, in the majority of cases the range of model results is below the measured values. Only in few cases the measured values lie in the interval between minimum and maximum model-calculated values. This systematic underestimation of the measured gamma dose rates indicates that some important parameter has not been considered in the present study and this is an element that requires further investigation. On the positive side the evolution in time is similar between measurements and model results, therefore the evolution of the meteorological situation is correctly taken into account.

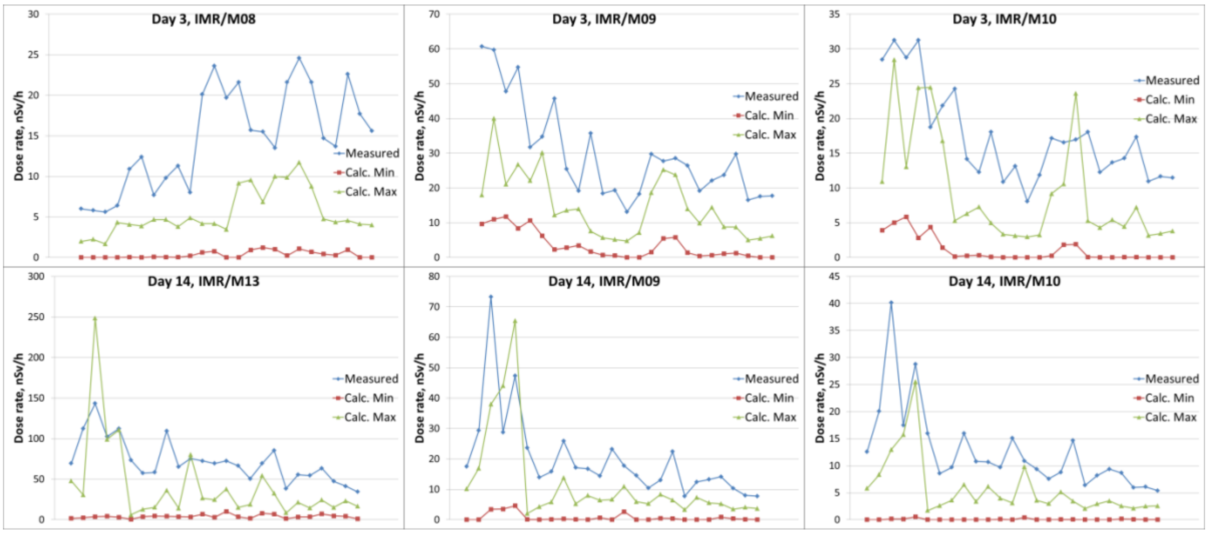

Figure 5. Time histories of measured and calculated minimum and maximum 10-min averaged gamma dose rates at different stations for day 3 (14/2/2017) and day 14 (3/5/2017); calculated minimum and maximum values are derived from all combinations of input data and modelling options

Conclusions

There is a considerable spread in model results produced by uncertainties in input parameters or by selection of different modelling options. However an underestimation of measured gamma dose rate is observed in most cases. Only a in a few cases the measured gamma dose rates lie in the interval between minimum and maximum calculated values. The systematic underestimation indicates that probably some unknown parameter has not been considered in this study. This requires further investigation.

On the positive side, the evolution of the calculated gamma dose rate in time as compared to that of the measured one is well captured in most cases. This shows that the time sequence of meteorological data is correctly accounted for.

Effects due to the stochastic nature of atmospheric turbulence have not been considered yet.

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ANURE project: Towards the implementation of a nuclear risk assessment methodology

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1. Introduction

Radioactive releases threaten public health, ecological systems and economies. The uncontrolled release of radionuclides to the environment may occur as a result of a nuclear or radiological accident [1], and if their consequences are not limited and/or mitigated, they have the potential to initiate a disaster both in the vicinity of and far away from the source [2]. This potential impact continuously triggers national and international efforts to reduce its occurrence and to minimize its impacts.

The risk posed by radioactive releases at any specific place is a function of several factors [3]. The likelihood of a large-scale release of radionuclides, the amount and composition of the radionuclides released, the atmospheric transport and deposition of the released radioactivity, the radiological vulnerability of the affected area (in terms of its potential transfer of the contamination [4]), population and economic assets at risk (involving the number of persons exposed, dose-effects relationship, hectares of agricultural land restricted) and policies that may affect the afore mentioned are factors to be considered in the risk approach. The combination of the deposition probability and the kind and quantity of the release (source term) with other factors related to the environment and socioeconomic structure may influence both the pattern of contamination and the radiological consequences. Information about the deposition probability, combined with detailed information of soil vulnerability and food chain impact, provides the spatial and temporal distribution of the risk associated with nuclear releases.

The elaboration of nuclear risk maps is one of the actions to better analyse the consequence of radioactive releases and to plan the actions to minimize their effects [5]. A risk map helps to identify those areas that would be more affected and most vulnerable to high levels of soil-to-plant transfer. These maps, hence, are used in the preparedness phase to optimize emergency procedures and contingency plans beyond the immediate plant vicinities, to establish where remediation techniques and recovery measures to mitigate the consequences could be feasible and effective, and to determine the potential foodstuff and feedstuff restriction areas. Therefore, this information makes decision makers better informed about possible impacts of accidents and the distribution of adverse effects over the affected population and areas.

For an adequate and realistic optimization of protection, a risk map must take into account the local conditions of the potential affected area: information of site-specific parameters is needed, including the knowledge on the behaviour and fate of radionuclides in soil, the land use and agricultural practices and dietary habits of the affected population. The more specific and local these factors are, the more effective and precise will be the response and less the uncertainties in the decision-making process. How to integrate all the aspects that should be taken into account within a methodology is a huge challenge. The objective of this contribution is to present this methodology and the first results obtained under the specific agreement ANURE: "Assessment of the Nuclear Risk in Europe - A Case Study in the Almaraz Nuclear Power Plant (Spain)" established among JRC Ispra and CIEMAT [6].

2. Methodology and case study

The methodology to contribute to the assessment of the nuclear risk in Europe aims specifically in:

- Assessing the off-site radiological consequences of severe NPP accidents taking into account the varying meteorological conditions that influence the pattern of dispersion and deposition of radionuclides, their accumulation in soils and transfer to plants according to the soil parameters that influence soil vulnerability,

- Establishing the geographical distribution of the risk caused by severe accidents in European NPPs.

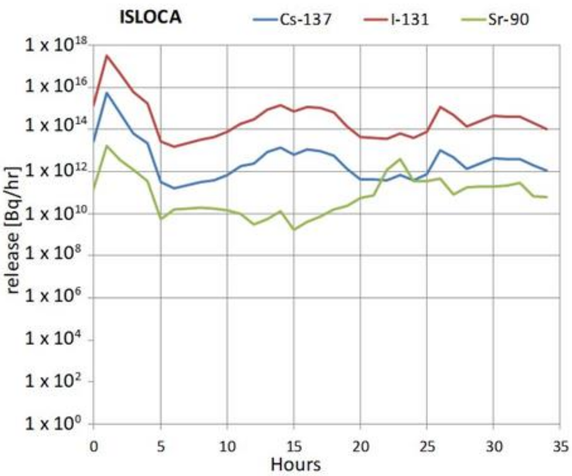
To this purpose, ANURE takes reference the Almaraz NPP in Spain [7], located in the province of Cáceres. It features two Pressurized light Water Reactors and its situation is mainly in a specifically Mediterranean wooded pastureland which are known as "dehesas", with high environmental and socio-economic value. Its location, next to the Portuguese border, could imply a trans-boundary environmental impact from the release.

In the present case study, a severe accident with off-site consequences has been considered. The aim is to analyse the response mechanism of the affected ecosystem by means of examining the dispersion and deposition patterns of the release. This, linked to the local factors that influence the behaviour of radionuclides in soils and its transfer to food chain, supports the elaboration of risk maps, which helps to prioritise the most affected areas and to provide support to the decision-makers to optimise the recovery.

Dealing with nuclear accidents, two large sources of uncertainty exist: one related to the source term and one associated with the meteorological data [8]. The source term determines the timing and magnitude of the radioactive material release to the environment from a specific source. Under ANURE, the information has been derived from existing studies providing a realistic evaluation of accident progression, source term, and off-site consequence releases from nuclear installations. Considering the characteristics of the Almaraz NPP, the Surry NPP (Virginia, USA) with similar characteristics, has been chosen as surrogate for source term estimation purposes.

Surry NPP has been object of an integrated analysis [9], within the State-Of-the-Art Reactor Consequence Analyses (SOARCA) Project. Within this frame, the Interfacing Systems Loss-Of-Coolant Accident (ISLOCA), initiated by an internal event caused by an unisolated rupture of lowhead safety injection piping outside containment, with 35 hours of offsite radionuclide release, accident sequence has been chosen. The source term for Almaraz (Figure 1) for this accident sequence has been obtained, from the given release fractions for the classes of halogens, alkaline earths and alkali metals, [9] grouped on an hourly basis, to which the inventory of ^{131}I, ^{90}Sr and ^{137}Cs of Almaraz NPP has been applied.

The technique in probabilistic studies dealing with releases to the atmosphere is to work with many hypothetical events (e.g. radioactivity releases (source term) to the atmosphere under different dispersion and transport conditions) covering a large range of possible outcomes [10]. Numerical dispersion calculations for the previous explained release (Figure 1) have been carried out for 1825 meteorological conditions taken from five consecutive years (2012-2016) by the Lagrangian mesoscale atmospheric dispersion puff model RIMPUFF [11] of JRODOS System (Realtime Online DecisiOn Support system) [12]. The Global Forecast System (GFS), which is a weather forecast model managed by the National Centres for Environmental Prediction (NCEP), has been used as meteorological input. Predictions of each dispersion calculation consist of ground contamination of ^{131}I, ^{90}Sr and ^{137}Cs on a non-homogeneous geographical grid spacing.



Each simulation was performed for 83 hours (35 hours of release and 48 hours of prognosis period). Due to gaps in the meteorological files and/or missing files, the number of simulations covering the whole simulation forecast is 76 % (1387 simulations), which is a sufficient number to obtain illustrative results. This paper focuses on the ^{137}Cs deposition results.

Figure 1. Release fractions of ^{131}I, ^{90}Sr and ^{137}Cs during the ISLOCA sequence accident.

2.1. Map of ^{137}Cs deposition

The meteorological conditions determine the derived ground contamination, which is reflected in the deposit value obtained in each grid cell. Considering the 1387 simulations, and therefore, the large amount of meteorological conditions influencing the dispersion of the ^{137}Cs released from Almaraz, there is a large variability in the ^{137}Cs deposits in each grid cell. On the contrary, there are also grid cells that were not impacted at all by the plume.

At this point, and to manage this large amount of information, the whole set of ^{137}Cs deposition values predicted in each grid cell have been grouped into categories in order to facilitate its cartographic representation. Under ANURE, these categories have been taken from the contaminated segments predefined in the Nordic Guidelines and Recommendations [13]. These guidelines determine five contamination levels (referred to the activity concentration deposited on soil from β and γ emitters, given in kBq/m^2). Those levels have been identified with a deposition category as it can be seen in table 1. Once grouped in these five categories, the most frequent ^{137}Cs deposition category for each cell have been obtained. The map elaborated considering the most repeated category in each cell is shown in figure 2. This map, as the rest of the maps included in this work, have been created by using ArcMap, a geographic information system software [14].

Table 1. Contamination levels and activity concentration values obtained from the Nordic Guidelines and Recommendations [13], and the deposition categories associated.

Contamination level	Activity concentration deposited (kBq/m^2)	Deposition category
Non-contaminated	>10*	1
Slightly contaminated	10-100	2
Contaminated	100-1000	3
Heavily contaminated	1000-10000	4
Extremely contaminated	>10000	5

*Nordic Guidelines and Recommendations do not define the lower limit, so 10 kBq/m^2 has been used.

Figure 2 shows that those areas with the highest occurrence of receiving the highest ^{137}Cs deposits (> 1000 kBq/m^2) would be located nearby and to the northeast of the Almaraz NPP. In addition, the spatial distribution of the areas affected by whatever ^{137}Cs deposition value is an example of how the geographic factors such as mountain (e.g. Iberian Central System Mountain and Montes de Toledo) influence the dispersion of the contaminated air from Almaraz NPP. Areas presenting a high occurrence of being affected by deposits above 100 kBq/m^2 are mostly located along the southwest-northeast axis from the Almaraz NPP following the Tajo basin.

Once identified the most frequent deposition category for each cell, the probability of this category has been calculated as the ratio between the number of simulations in which the predicted ^{137}Cs deposition value belongs to the most frequent deposition category and the total number of runs (1387).

To combine for each cell both results, the most frequent deposit category (figure 2) and its associated probability, the weighted deposition index for each grid cell has been defined as the product between both. This index reports those areas largely and continuously affected by high deposits of ^{137}Cs. This new index named “Severity Deposition Index” is distributed in five classes ranging from 1, which represents the minimum deposition severity, to 5, which represents the maximum deposition severity. In figure 3, the spatial distribution of this severity deposition index is shown.

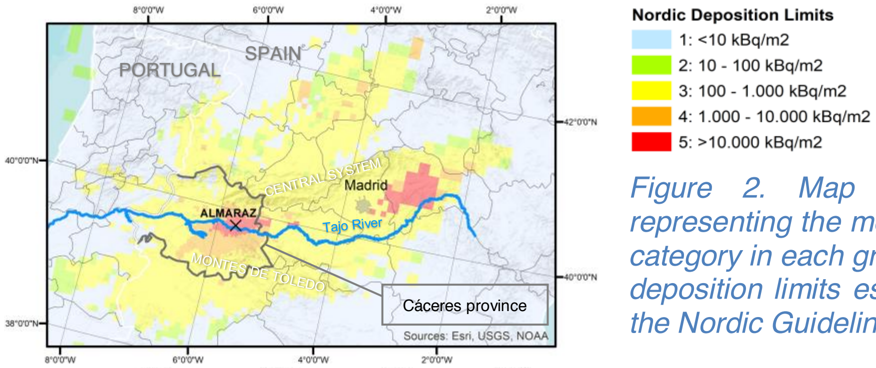


Figure 2. Map of ^{137}Cs deposition representing the most frequent deposition category in each grid cell, attending to the deposition limits established on bases of the Nordic Guidelines.

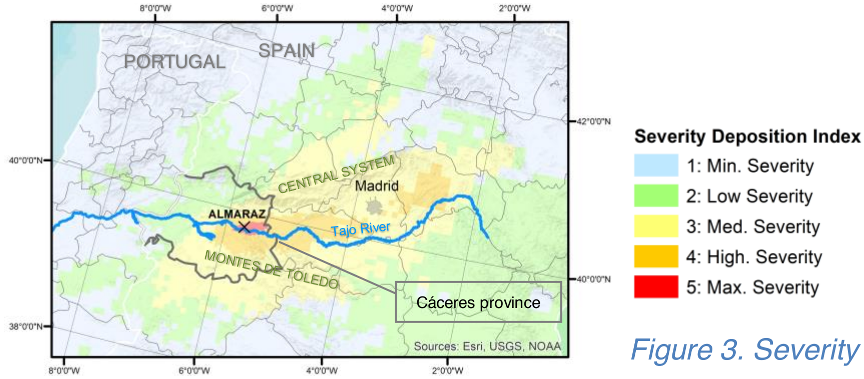


Figure 3. Severity deposition map.

2.2. Prioritisation map

Having obtained the severity deposition map, the following purpose is to estimate the measure of risk by combining it with local factors. The resulting map will identify the areas where the remediation or recovery actions should be applied in a prioritised way. As an example of the methodology developed to produce this prioritization map, an exercise with rainfed cereals, one of the most widely produced crops in Spain [15], has been undertaken. The set of factors taken into account are: soil type distribution and soil properties [16], the land use [17] - in order to assign the cereal crops in the Spanish territory - and the soil to plant transfer factors [18], which quantify the crop root uptake processes and are specific for texture and for crop. Empirical values of them, focussed on the rainfed cereals, which vary according to the soil texture [18], are shown in Table 2.

The transfer factors are also influenced by the soil K content, which competes with Cs in the root uptake process, due to their similar physico-chemical properties, and the clay percentage in soil, because of its retention capacity of K, and therefore Cs in soil [19]. Thus, the transfer factors have been adjusted taken into account the texture of the different soil types in Spain, obtained from the European soil map [16] and the K content for each soil type, taken from a Spanish soil database [20]. The range of the adjusted transfer factors has been categorized in five groups to define a vulnerability index, which measures the soil-crop capacity transfer. This index is used to elaborate the vulnerability maps. Figure 4 shows the vulnerability map for the soil-cereal capacity transfer of ^{137}Cs. This figure points out how low and medium indexes dominate the surfaces where, according to [17] there are cereal crops (in the grey areas there are no cereal crops).

Table 2. Transfer factor values for grain cereals in temperate environments [18].

Texture	Sample number	Mean	Standard deviation	Minimum	Maximum
All textures	470	$2{,}90 \times 10^{-2}$	4,1	$2{,}00 \times 10^{-4}$	$9{,}00 \times 10^{-1}$

Sand	156	$3{,}90 \times 10^{-2}$	3,3	$2{,}00 \times 10^{-3}$	$6{,}60 \times 10^{-1}$
Loam	158	$2{,}00 \times 10^{-2}$	4,1	$8{,}00 \times 10^{-4}$	$2{,}00 \times 10^{-1}$
Clay	110	$1{,}10 \times 10^{-2}$	2,7	$2{,}00 \times 10^{-4}$	$9{,}00 \times 10^{-2}$
Organic	28	$4{,}30 \times 10^{-2}$	2,7	$1{,}00 \times 10^{-2}$	$7{,}30 \times 10^{-1}$

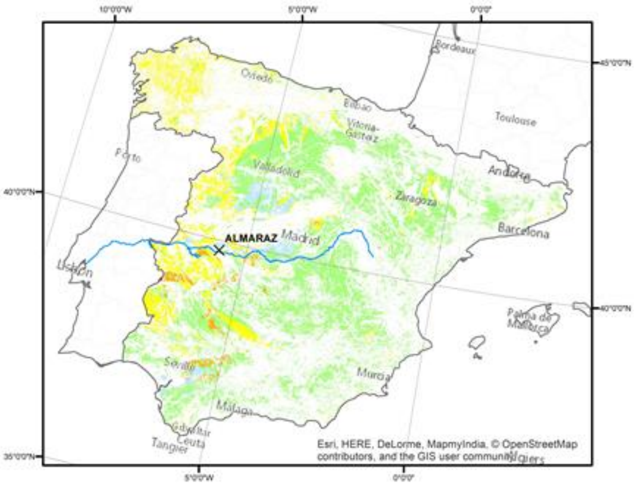


Figure 4. Vulnerability map, which represents the soil capacity to transfer the ^{137}Cs contamination to the cereal crops. Only Spanish agricultural areas with cereals are represented and classified.

The priority index for each grid cell has been obtained by multiplying the corresponding severity deposition index (figure 3) and the vulnerability index for cereals (figure 4). We have grouped the results, which range from 1 to 25, in five prioritisation categories, from maximum to minimum priority (Table in Figure 5). Figure 5 shows the spatial distribution of this priority index. This figure, therefore, represents a risk map for prioritising actions, considering the rainfed cereals affected by ^{137}Cs ground contamination from Almaraz NPP releases. This map raises the overall risk categorization and allows identifying priority areas for actions to be undertaken and making decisions on recovery investment.

As seen in figure 5, the maximum severity is not represented in any spot, however, there are areas classified as medium (yellow-coloured) and high priority (orange-coloured). The first four prioritisation classes (from 1 to 4) are mainly located along the Tajo river valley, where the more frequent prioritisation class corresponds to the low one (green-coloured). The larger high priority areas of action correspond to the Southwest and to the Southeast of Almaraz NPP. There is another small area located in the middle-upper reach of the Tajo, at the Northeast of Madrid, the Spanish capital. In all those spots, both the severity deposition index and the vulnerability index are categorised as level four (high) in each classification. In these areas, the first remediation actions should be applied with the aim to minimize the root Cs uptake for the next year harvested cereals.

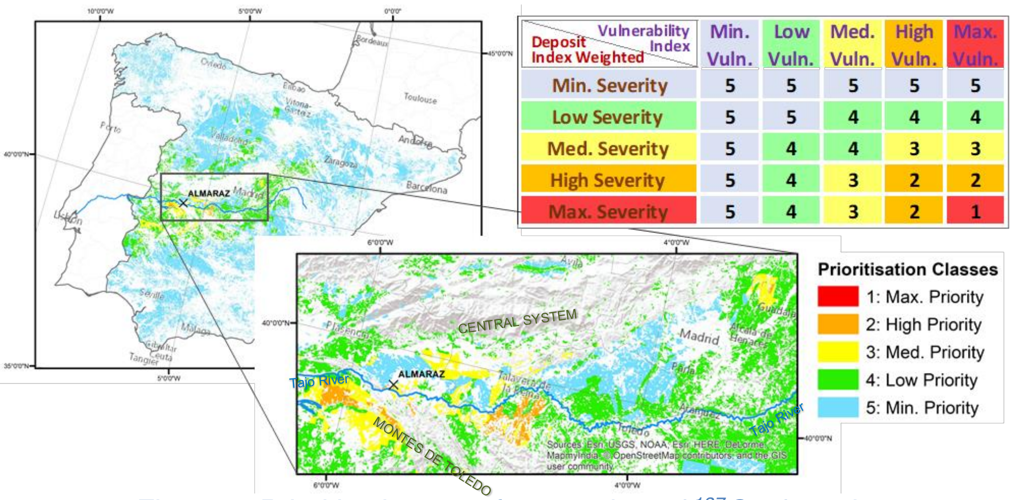


Figure 5. Prioritisation map for cereals and ^{137}Cs deposit.

3. Conclusions

Taking into account: i) the meteorological conditions determining the dispersion and deposition pattern of the radionuclides released after a nuclear accident, ii) the deposition frequency, and iii) the soil potential to transfer its activity concentration to the crop and hence to the food-chain, a methodology to elaborate risk radiological maps for the food chain pathway have been presented.

A case study for cereals and ^{137}Cs deposits has been shown in the present paper taken as reference the Almaraz NPP. This example highlights the importance of considering the local specificities since the dispersion pattern and deposition is highly influenced by geographic factors such as mountains and valleys, but not only. The type of soil and soil specific parameters are also determinant. The prioritization resultant map shows how areas affected by the same quantity deposit have different priorities: less deposit does not imply less risk, and vice versa.

The developed methodology is aimed to prioritize the areas where the remediation or recovery actions should be applied, being a useful tool in Emergency Preparedness and Response, as it can be applicable at any European spot. It also takes into account local specificities reducing the uncertainties in the decision making process.

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Summary of the European joint research project “Metrology for radiological early warning networks in Europe” (MetroERM)

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Presentation of the project

After an airborne spread of nuclear contamination, especially in case of transboundary implications, there is an urgent need for authorities to advise the population on the necessary precautions to be taken against dangers arising from ionising radiation. In the aftermath of a nuclear or radiological emergency, recommendations given by the European authorities could affect millions of people and may have severe economic and sociological consequences. Therefore, metrologically sound monitoring data of ambient dose rate and airborne radionuclide activity concentrations are a prerequisite for well-founded governmental decisions. As an important contribution to nuclear emergency preparedness, all European countries operate radiological early warning networks. Presently, there are approximately 5000 dosimetry monitoring stations and a few hundred air-sampling stations active across Europe. Each dosimetric monitoring station has a detector that is designed to detect ionising radiation, and is linked to other stations, giving a live picture of the radioactivity levels across large areas. The air-sampling stations are designed to measure airborne radioactivity, but only a few have a real-time capability. These national networks of monitoring stations provide important radiological information to enable European authorities to take appropriate actions and counter measures in the event of a nuclear accident. However, many of these stations, especially the majority of the dosimetry network stations, are based on simple detector designs, like Geiger-Muller counters which do not give the required level of accuracy nor any details on the nuclide vector involved, and thus further time-consuming data analysis is needed before any decisive action can be taken.

In the framework of the European Metrology Research Programme (EMRP), jointly funded by EURAMET and the European Commission, the project ENV57 MetroERM “Metrology for radiological early warning networks in Europe” aimed at the development of metrologically sound measurements of fundamental radiological quantities such as ambient dose equivalent rate, radioactivity concentrations in air and ground contamination levels in real-time. This required novel joint multidisciplinary approaches to be taken by a European collaboration of metrology and research institutes, 15 in total, including the Joint Research Centre (JRC) in Ispra which is responsible for the EURDEP database (collecting radiological data for the European Commission), accompanied by stakeholders and manufacturers of radiological monitoring systems.

The presentation introduced the various objectives of this project which ended in June 2017, after a duration of three years, and summarized its main results. Especially the development of novel scintillator-based spectrometry systems capable of both, the measurement of dose rate values in real time, as well as for the provision of nuclide specific information like ground contamination levels were described. The long-term impact of the developments and findings of this project are published in detail in about twenty, mainly peer-reviewed journals.

Summaries of the results of the MetroERM project are given in [1]. Details on partners, stakeholders and collaborators can be found on the project's web-page [2].

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C3X – Exercise : A software platform for data control of nuclear emergency exercises

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Context

In case of a nuclear accident that may release radioactivity into the environment, measurements of radioactivity are made in situ by many different means.

Exercises are essential to train the entire response organization to collect, gather, analyse and share the measurement values in a comprehensive way for experts and decision makers. To make it more realistic, the values collected in the field are replaced with fictitious measurement values corresponding to the scenario and computed by a numerical model. To avoid bias in the response time, the best way is to provide the simulated data to the measurement teams as soon as they are conducting measurements (see Figure 1). This is the job of the scenario data controller.

For decades in France, there have been 12 to 15 nuclear emergency exercises annually at a national level. IRSN is responsible for, or at least participates in, the technical scenario of all these exercises. With this experience in data control, IRSN has developed the C3X-Exercise software platform for this purpose. C3X is also the software platform for emergency response (C3X-Response), which is used in the IRSN Technical Crisis Centre (see Figure 2).

Knowing the meteorological and the release scenarii, C3X calculates all kinds of measurement quantities such as air and soil activity concentrations, ambient dose rates, activities on smears and in other environmental samples (grass, leaf vegetables, water…). C3X also calculates the expected values delivered by most common transportable contamination probes.

As the years go by, measurement means have evolved to be more and more automatic (monitoring network, carborne, airborne…) and deliver frequent values in near real-time to informatics systems. Moreover, we have to use real meteorological fields and large release more often according to exercise specifications. Together, these constraints result in doing the environmental scenario in real time.

Principle

Nowadays, data control needs to be more reactive and to deal with a production of a huge quantity of data. The C3X-Exercise platform has then been adapted to the evolution of data control by adding web-connected tools.

The whole data control platform relies on an original client-server architecture which consists of a calculation server, data controller clients (PCs) and on-field measurement team clients (tablet PC). The technical scenario, computed from a C3X client (generally geographically placed in the emergency centre), is sent to the web app serwX, which presents the results to the whole scenario data controllers (placed near the measurement teams on terrain) and to tablet PCs given to the players. Tablet PCs provide the response of a measurement device at the given time and GPS position of the tablet through an app called mobilX. Web services are also available to be interrogated by any other program through http requests, for example to transform data in any adequate format for automated network for example. This is represented schematically on Figure 3.

Tablets are provided to mobile teams so that they can directly make the readings by themselves and can react just as if the accident was a real one (see Figure 4).

Also, mobilX sends back the data to serwX. Measurement missions can then be visualized on maps through the web server which can be useful for debriefing the responding teams.

Applications

The platform has been used for several years, and more recently in different cases:

- Firstly, for french exercises on power plants. We test MobilX for the EDF measurement trucks. Notably, these trucks deliver the dose rate in real-time. They are also equipped with different devices, and also air samplers.
- We have also contracted with other countries, for example Hong Kong, where a national exercise was organized in December, 2017. We have organized to simulate the accident on the HK Observatory system, and gave the tablets to carborne teams (see Figure 5).
- We also participated in institutional exercises, like the RANET exercise, which took place in Fukushima, Japan in 2017. In this case, tablets have also been given to the different international teams.

Conclusion and perspectives

In conclusion, the C3X-exercise is a tool which facilitates data control during exercises. It simplifies the provision of data by giving tablets to teams, which makes them autonomous. The platform also allows the scenario to be sent directly to automated networks or through any file format.

The platform has been tested and validated during several exercises in France and also in other countries.

In perspective, the ergonomy of mobilX and serwX will be improved to facilitate their use, for players as well as for administrators (data controllers). It has also to be used in different types of exercises : with 3D forecast meteorological data, on a large scale, or for measurement strategy purposes.

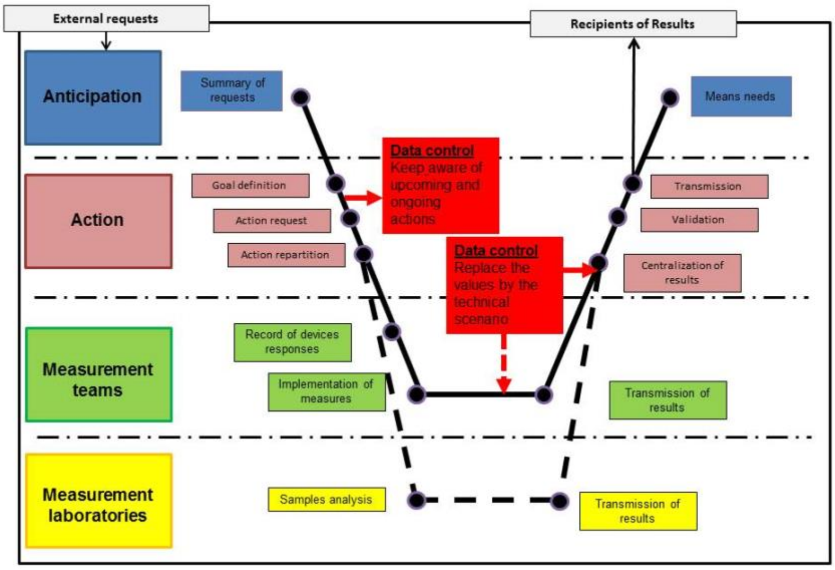

Figure 1. Insertion of data control in the measurement circuit.

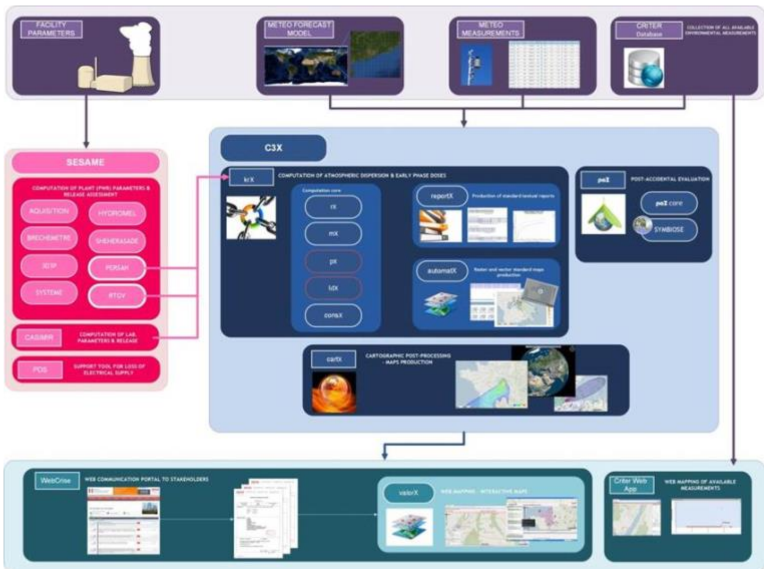

Figure 2. Tools equipping the IRSN Technical Crisis Center.

Figure 3.Principle of the C3X-Exercise platform for data control through the web.

Figure 3. Screenshot of the mobilX app for measurement teams.

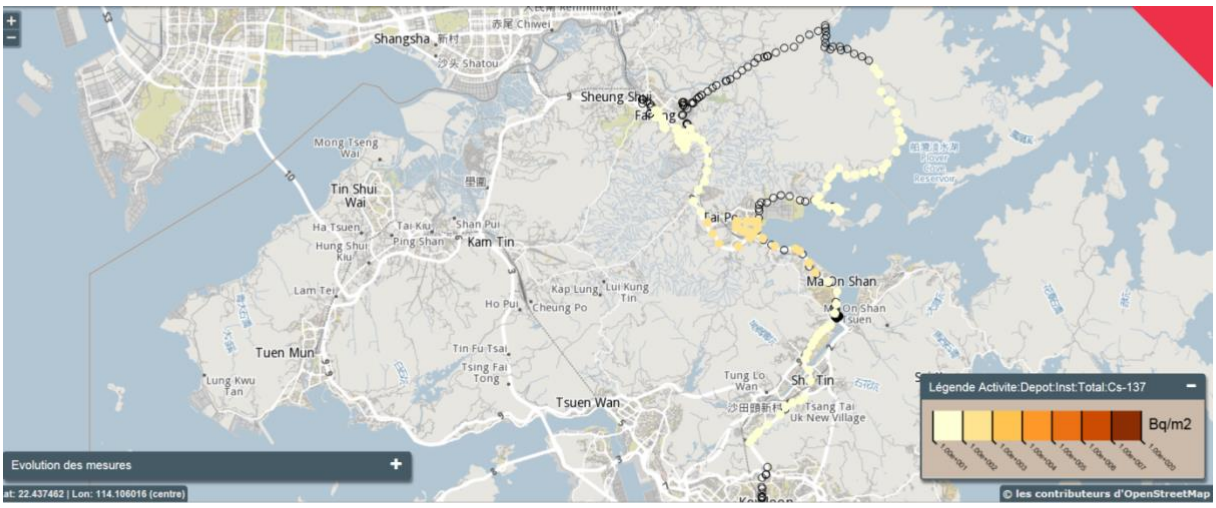

Figure 3. screenshot of a measurement mission in serwX during the HK exercise in December 2017.

Knowledge Database and Regionalization of JRODOS for the HARMONE Project

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Abstract

The first part of this paper discusses the knowledge database generated for remediation options in inhabited areas and food production systems regarding to baseline scenarios in the area of nuclear risk management. By using a web-based decision support system ([1]) the database provides the users with generic strategies on the basis of different contamination levels. The strategies have complete information about the effects when taking specified emergency response measures on various protection targets. The second part of the paper defines the regionalization which crosses European country borders and divides Europe into five generic radioecological regions, namely Boreal, Continental, Atlantic, Mediterranean and Alpine regions. The parameter sets for these regions are updated in the Java based Real-time On-line Decision Support System JRODOS ([2]). The sets include region dependent model parameters such as agricultural yields, food consumption rates or feeding habits of livestock, to improve the terrestrial food chain and dose module FDMT. The comparison of model results for radionuclide activities in different food types shows pronounced differences between the radioecological regions for several release scenarios. The work was supported by the EU project, OPERRA-HARMONE: Harmonizing Modelling Strategies of European Decision Support Systems for Nuclear Emergencies ([3]).

Keywords

Knowledge Database, Regionalization of Dose Assessment, JRODOS, Decision Support System.

1. Introduction

In the field of nuclear emergencies, decision-making is complex and usually accompanied by acute time pressure. IT-based decision support can systematically help to identify response and recovery measures, especially when time for decision-making is sparse, when numerous options exist, or when events are not completely anticipated. In the previous work of our KIT group ([1]), a web-based decision support system has been developed to support the management of nuclear events in different accident phases. A cased-based reasoning algorithm was developed to support case retrieval. The efficient information retrieval depends on the intelligent and appropriate structure of the knowledge database which is used for the storage of the case bases for the core searching algorithm.

In this paper, we describe the knowledge database that contains results obtained with simulation models of JRODOS related to inhabited areas and food production system. In addition the management offered by the EURANOS Handbooks ([4]) and UK Recovery Handbooks for Radiation Incidents ([5]) were taken into account. As a result, a guidance handbook was developed as the deliverable D5.55 in the OPERRA-HARMONE project ([3]).

The second part of the paper deals with radioecological models that are used for the assessment of radionuclide movements in the environment. Since parameters and exposure pathways of those models depend on the location of the area of interest, they should be adjusted to regional conditions to reduce uncertainty. In JRODOS, FDMT is used to predict ingestion doses for the public following the deposition of radionuclides to soil and vegetation. The FDMT conceptual model and its parameters were originally implemented in the radioecological model ECOSYS ([6]) with exposure pathways and site-specific model parameters optimized for agricultural conditions and consumption habits in southern Germany. This data set was so far used as default parameter set in JRODOS. By changing certain model parameters, FDMT could be adapted to different regions ([7], [8], [9], [10]).

The biogeographical regions of Europe as defined by the European Environment Agency were used for the geographical definition of the radioecological regions in our adaptation work. These Mediterranean, Atlantic, Continental, Boreal and Alpine regions have common environmental characteristics such as climate and vegetation type. The assumption was made, that the corresponding radioecological parameters, for example, Leaf Area Indices (LAI), agricultural yields or food consumption rates are also comparable within these regions. The region dependent model parameters were identified and gathered from literature and databases. Since most available parameter sets were country specific, they were weighted according to population or area overlaps between the radioecological regions and corresponding countries.

Our research was supported by the OPERRA-HARMONE project, the goal of which was to reduce scientific, methodological and operational gaps in European decision support system by improving modelling and dose assessment in the first year after a nuclear accident.

In this paper, Section 2 describes the knowledge database, Section 3 defines the regionalization of JRODOS and Section 4 provides the conclusion and possible future work activities.

2. Knowledge database

2.1 Database infrastructure

The knowledge database has been implemented as a relational database using the open source PostgreSQL database management system. In order to deal with different research projects, the database contains many schemas that are indeed collections of tables. A simplified version of the database schema for the OPERRA-HARMONE project is shown in figure 1. It has two parts: the description of scenarios and the strategies. Furthermore, the strategies can also be divided into two parts: the illustrations of countermeasures and the results from the simulations on RODOS about the effects when these chosen countermeasures are taken on the protection targets. Given a scenario, for example, a textual series {summer, dry weather, surface type or food production, lower waste contamination, long-term phase}, the information of suitable strategies can be offered from the knowledge database, e.g. the management options and the corresponding targets, doses assessments, economic expenses, human resources and costs.

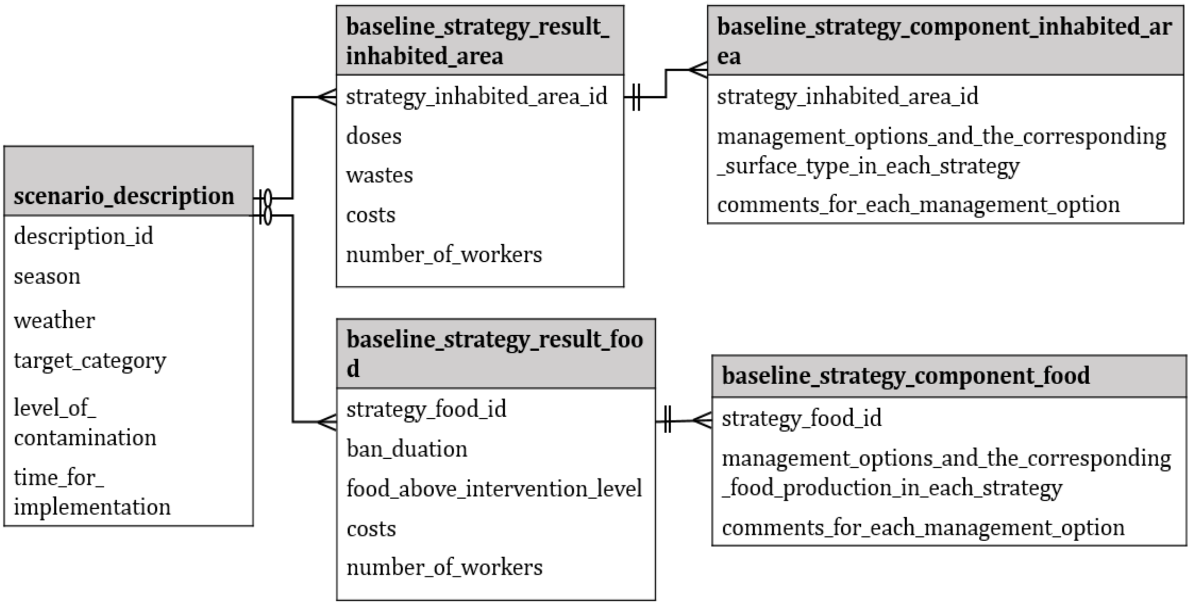


Figure 2: Excerpt of the database scheme.

2.2 Scenarios

To define the baseline scenarios, the source term FKA was applied ([11]). Baseline calculations were performed with JRODOS by using the emergency model chain including the near range atmospheric dispersion model (LSMC), the model for simulating early countermeasures and doses in the near range (EMERSIM), and FDMT for contamination of food products. Results can be visualized as maps and time plots. In particular activities for feed- and food products or are used in subsection 2.3 to discuss the effectiveness of possible strategies in food production and also in subsection 3.2 to show the differences in radionuclide activities for food in various radioecological regions.

2.2.1: Release category

The source term FKA, resulting from a risk study performed by GRS, describes an uncovered steam generator heat pipe leak accident. The release occurs via the open main steam valve at the roof in 30 m above ground and the thermal rise is negligible. The major releases start few hours after reactor shutdown and continue for around 50 hours. Release of Iodine-131 is $3.1 \cdot 10^{17}$Bq and the one of Cesium-131 is $2.9 \cdot 10^{16}$Bq. The calculated frequency of occurrence is estimated by $2.1 \cdot 10^{-7}$per year. The release quantity is of INES level and slightly higher than the Fukushima source term. The FKA source term was used in Germany for determining planning areas for emergency preparedness and emergency response plans ([11]).

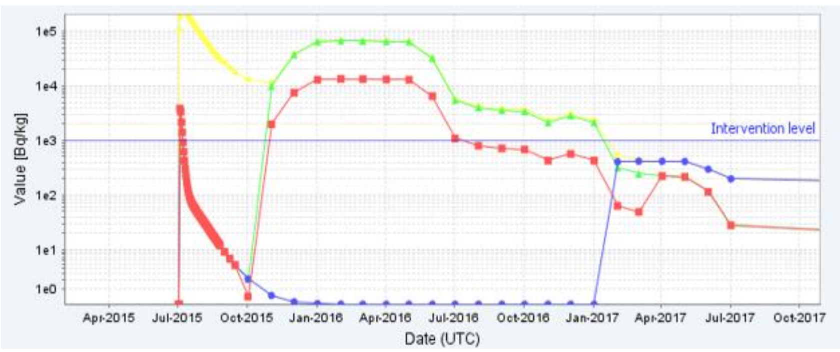
2.2.2: Contamination levels

The contamination of a radionuclides released in the FKA source term were considered. Cesium-137 was taken as representative radionuclide and levels ranging from 10^3 and 10^6 Bq/m^2 were investigated. The deposition level of 10^5 Bq/m^2 of cesium as representative radionuclide would result in a dose to adults of about 10 mSv per year. Contamination levels higher than 10^6 Bq/m^2 were not considered as the resulting dose would exceed 10^2 mSv in the first year and agricultural production is unlikely to be continued.

2.3 Strategy

To evaluate different countermeasures the European model for inhabited areas (ERMIN) and the agricultural countermeasure program (AGRICP) of JRODOS were applied. Countermeasures considered in ERMIN comprise a number of different recovery options including decontamination of urban surfaces, shielding of the population from radiation emitted by radioactive material on urban surfaces, fixing radioactive material to urban surfaces or relocation of the population. Countermeasures implemented in AgriCP related to food production management include stopping production, storing food, removing animals from contaminated feed, addition of sorbents, and changing in land use.

Strategies were derived with the help of the EURANOS handbook, the UK recovery handbook and simulations with the two JRODOS modules. The effectivity of the defined strategies for e.g. food products were checked by the simulation models comparing activity concentration in feed- and foodstuffs with and without management options. Figure 2 shows one example for cow's milk in a summer release scenario. The initial contamination is around 10^6 Bq/m^2 of cesium as representative radionuclide. It is obvious that the strategies illustrated in green and red were not successful to reduce the cesium deposition below the intervention level at least in the first year. The only effective strategy evaluated in this example is indicated by blue curve and consists of removing animals from contaminated feed for up to 540 days.



RMOV: Removing animals from contaminated feed.
ADDS: Addition of sorbents / boil. The sorbent is AFCF and the effectiveness is 80%, but for bull beef it is 78%.
SKIM: Skim and burial ploughing. The effectiveness is 90%.

Figure 3: Comparison of the cesium activities of cow's milk in a summer release. Curves in different colors represent cases in which diverse strategies are adopted. The red curve corresponds to taking RMOV between 0-90 days, and then taking ADDS between 90-540 days and SKIM after 90 days. The blue curve corresponds to the action RMOV between 0-540 days. The green curve corresponds to the action RMOV between 0-90 days, and then applying SKIM after 90 days. The yellow curve corresponds to the action "no measure" and is given for comparison

The summary of the derived generic strategies recommended for inhabited area and food production systems were described in detail in the deliverable D5.55 of the OPERRA-HARMONE project ([3]).

3. Regionalization of JRODOS

In the work package 2 of the EU-project OPERRA-HARMONE parameter data sets were defined for five radioecological regions and will be implemented into FDMT of JRODOS in the next release of the system. The full description of the methods used, the source of the original literature, databases as well as the final parameter lists can be found in the deliverables D5.35, D5.36, D5.37 and D5.41 of the OPERRA-HARMONE project ([3]).

3.1 Regionalization of parameters

The FDMT model of JRODOS is used to predict doses to human populations after the deposition of radionuclides to soil and vegetation. The parameters and exposure pathways in the models used for the current version of this software have been developed for conditions in southern Germany. Therefore it was decided to review the database and revise the content for use in Europe.

Since it is not feasible to implement a parameter set for every individual European country, the approach of dividing Europe into five radioecological regions was used from the beginning. Following the review, it was decided that the radioecological regions should match the biogeographical regions of the European Environment Agency ([12]), which comprise Alpine, Boreal, Continental, Atlantic and Mediterranean areas (Fig. 3). The Pannonian biogeographical region was included into the continental radioecological region to reduce the total number of regions.

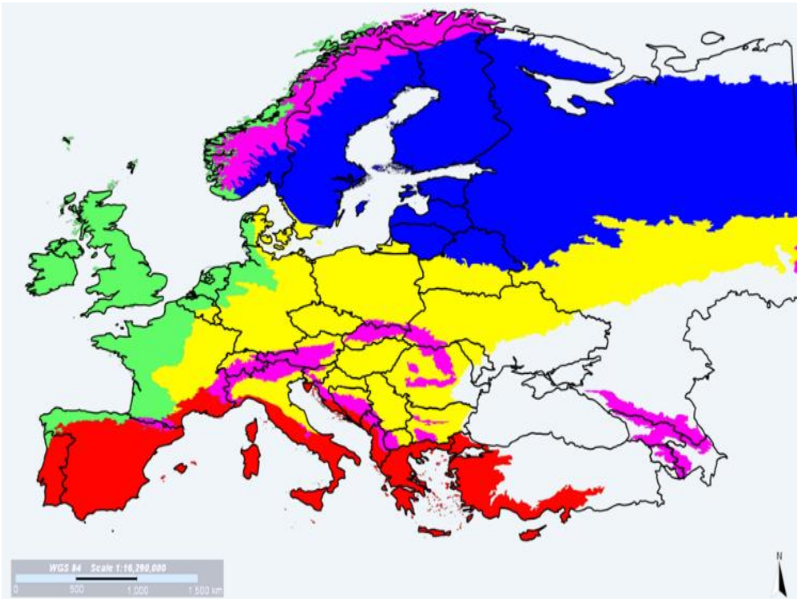


Figure 3: Map of the Mediterranean (red), Atlantic (green), Continental (yellow), Boreal (blue) and Alpine (pink) radioecological regions with country borders from the JRODOS software.

For many parameters, values were available only for for individual countries. For the allocation of the parameters to radioecological regions, these parameters had to be converted.

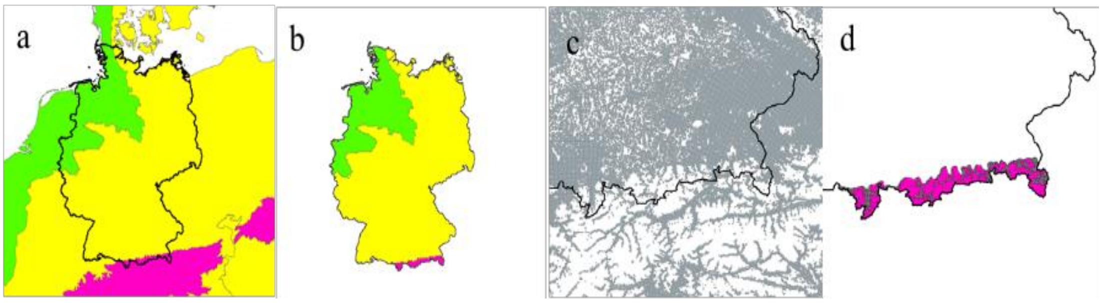


Figure 4: Conversion process in ArcGIS of country, region (a, b) and population (c) data in order to get the population in a certain radioecological region within a country (d). Every gray dot of the population data set has a known population

Depending on the parameter, weighting was performed either on a population or land area basis. For the weighting procedure, shapefiles of European countries ([13]) were linked with the shapefiles of the radioecological regions in ArcGIS (ESRI, Germany) (Fig. 4 a, b). After the intersection, the land area of the resulting shapefiles was calculated in ArcGIS for the weighting according to land area. For the weighting according to population, the shapefiles of the country/radioecological region intersection were additionally intersected with the GEOSTAT demographic dataset ([14]) (Fig. 4 c). This resulted in a number of objects (Fig. 4 d) with assigned population numbers within the area of interest. The population numbers of these objects were added to calculate the total population of each country living in a certain radioecological region. The GEOSTAT data set does not, with some exceptions, cover non-EU countries and for some EU countries, copyright conditions prevented the free use of the GEOSTAT data. For these countries, population numbers were estimated according to the population of administrative regions within the radioecological regions.

3.2 Model results

The results of JRODOS FDMT model runs show pronounced differences in the radionuclide activities in food for different radioecological regions. The radionuclide source term, time and weather conditions were the same for the model runs.

For leafy vegetables the different LAIs, growth periods and transfer factors from soil to plant lead to vastly different contamination levels. For the Atlantic and Continental regions, the JRODOS default value of a LAI of 5 is assumed for the whole year, while a LAI of 0 is assumed for Boreal, Alpine and Mediterranean regions at the time of the contamination event (Fig. 5 A). After the first harvest, the deposition on plant leaves is replaced by radionuclide uptake by plant roots as the dominant contamination mechanism.

For cow's milk the amount and development of the contamination over time is affected not only by the contamination of the different feed types grass and hay, but also by the timing of their use. In the Mediterranean region, cows are assumed to be on pasture for the whole year feeding on grass. Due to this, a steady decrease in contamination can be observed because of reduced activities in grass by weathering. In other regions hay is also used as animal feed especially in winter. This change of feed leads to pronounced activity changes in the animal product over time (Fig. 5 B).

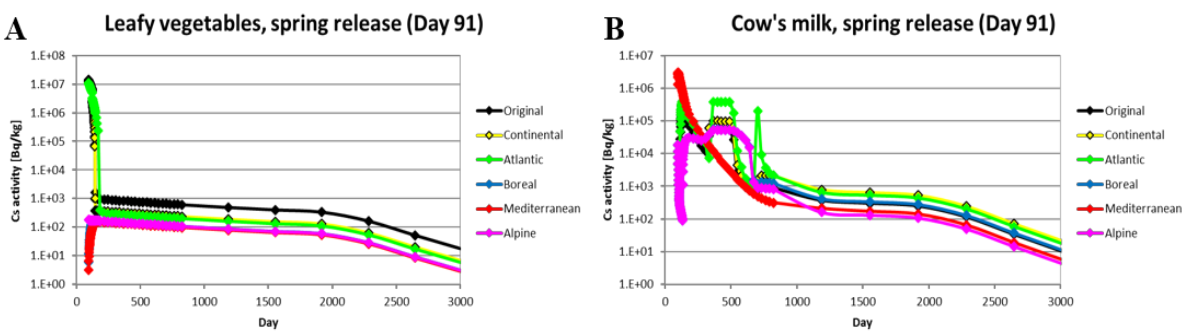


Figure 5: Cesium activities for A) leafy vegetables and B) cow's milk for different radioecological regions and a spring radionuclide release at Julian day 91.

4. Conclusion and future work

In the frame of several research projects, our KIT group has developed a knowledge database that contains historic cases and scenarios to support decision making in the various stages of an emergency. Within OPERRA-HARMONE, scenarios with strategies dealing with inhabited area and food product system were added. We also improved the customization process of the FDMT module of JRODOS by adding five new radioecological regions as baseline dataset for customization in Europe. In future, the knowledge database might be extended to include more types of risk management from the non-nuclear area. We will also work on better representation of uncertainty in these scenarios and the decision making related to the various possible strategies. Finally, we intend to further improve the mechanism to introduce parameters into the JRODOS database to facilitate customization also outside Europe.

Acknowledgement

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Probabilistic assessment of the effect of sheltering and evacuation on the radiological dose for the population – a generic approach

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Introduction

As part of an international collaboration BfS (Germany) and PHE (UK) investigated the effectiveness of the countermeasures sheltering versus evacuation in the plume (i.e. during a release) during a hypothetical accident in a nuclear power plant. The two organizations used different probabilistic modelling approaches for the assessment to retrieve independent results. The method used by BfS and respective outcomes are discussed here.

Method

The RODOS (Real time On-line DecisiOn Support) [1] system was used to calculate the effective dose in the first days after an accident in a nuclear power plant based on several pre-defined source terms and real weather data. Six different source terms - derived from two basic source terms - were used for the simulations to investigate the impact of varying source strengths and release durations (Table 1). 365 model runs were performed per release scenario to cover most possible meteorological conditions and transport patterns throughout one year.

Table 1. Source terms used for RODOS calculations.

Source term	Noble gas (Bq)	Iodine (Bq)	Aerosol (Bq)	Release duration (h)
FKA	2E+18	1E+18	2E+17	50
FKA_10th	~	~	~	5
FKA_1h	~	~	~	1
FKF_mod	6E+18	6E+16	9E+15	40.5
FKF_mod_10th	~	~	~	4.05
FKF_mod_1h	~	~	~	1

All scenarios have in common, that an immediate release is assumed and the potential of an evacuation in the plume is given.

The total effective dose for the emergency measures sheltering and evacuation were assessed at each point within a 20 km radius from the release site. Generic evacuation routes lead to four reception centers located North, South, East, and West of the release site at a distance of 30 km. It was assumed that the evacuated cohorts travel at a constant speed of 5 km/h, which is equivalent to typical walking pace. The population was evenly distributed within the 20 km zone. Simulations included an additional delay of 120 minutes from the start of the release before evacuation was initiated, i.e. the evacuation started 120 minutes after the first release. A shielding reduction factor (RF) of 0.33 was applied during sheltering. For evacuation, people were considered to stay indoors during the 120 minute delay before evacuation and also after arriving at the reception center. The total effective dose was either evaluated for the population located at one point or the whole population located within one of the 13 emergency sectors. Only points or sectors were considered where the estimated effective dose for 7 days for children exceeded the generic dose criteria of 100 mSv in at least one location, i.e. where evacuation would be recommended in Germany.

Results

The results and the effectiveness of sheltering versus evacuation were analysed for the collective and for each individual sample (Figure 1a, Figure 1b, Figure 2a, and Figure 2b). The comparison of sheltering versus evacuation - and the related question which one of the two countermeasures is preferable - largely depends on the selected source term, duration of the release, distance to the release site, and if individual samples are considered for a countermeasure or a whole collective within an affected section. For example, the probabilistic analysis showed that evacuation has a larger benefit for long releases and people living close to the release site and vice versa for sheltering.

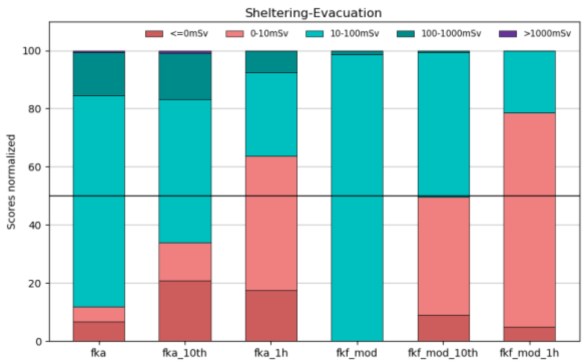

Figure 1a: Normalized scores for different dose saving categories (sheltering minus evacuation) for all six release scenarios. Only affected members are counted.

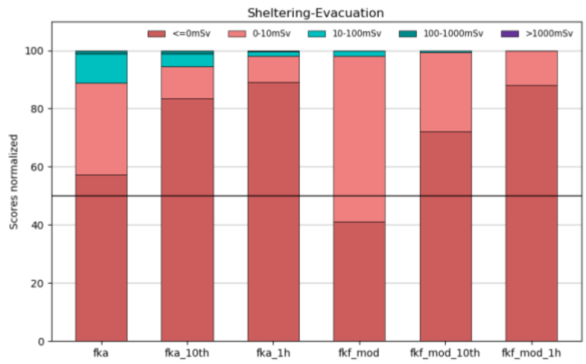

Figure 1b: Same as Figure 1a. All members of affected emergency sectors are counted.

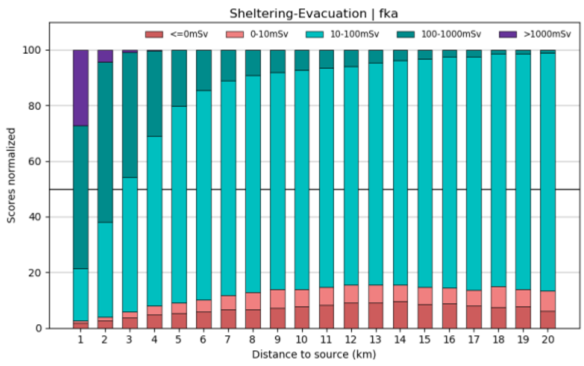

Figure 2a: Normalized scores for different dose saving categories (sheltering minus evacuation) for release scenario FKA versus the distance to the release site. Only affected members are counted.

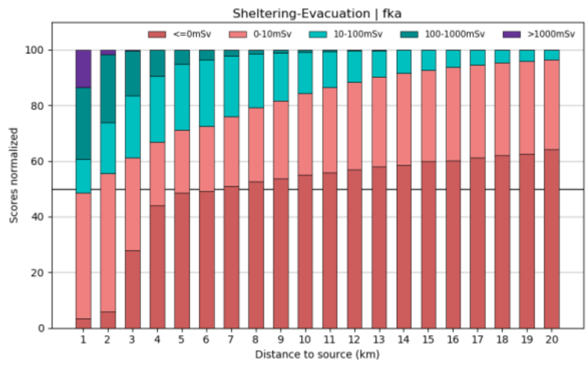

Figure 2b: Same as Figure 2a. All members of affected emergency sectors are counted.

Conclusions

The pure radiological benefit of one countermeasure over the other depends on multiple factors that define the existing scenario and affected cohort, e.g. duration of release and distance of the start position to the release site. The radiological benefit has to be set into the context of other factors that have to be considered by decision-makers, such as disruption, societal impact, economic cost and other hazards.

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Session 6 – Coping with uncertainties

The Various Meanings of Uncertainty

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Introduction

Emergency planning, response and recovery inevitably bring much uncertainty. Although the uncertainties have been acknowledged for decades, based on both scientific insights and also lessons learned from past incidents and accidents, it is only now that the radiation protection community is seriously addressing how procedures and decision support tools, as well as decision-making processes can be modified or adapted to help manage the uncertainties [1]. In many respects, there is still a tendency to treat uncertainty as a homogenous topic, a single concept. But there are many types of uncertainties and different types require different approaches to their identification, modelling, treatment and analysis. Indeed, some are conceptually impossible to model and others require discussion and deliberation rather than any quantitative analysis. A major objective of the CONFIDENCE project (https://portal.iket.kit.edu/CONFIDENCE/) is to introduce more explicit handling of uncertainties in the procedures and decision support tools and processes used in nuclear emergency management. CONFIDENCE also recognizes emergency planning and response as a socio-technical endeavour. This paper summarises the early work that we have undertaken in that project on clarifying the sources and types of uncertainty.

Types of Uncertainty

'Uncertainty' is a word with many different meanings [2]. It is interpreted differently by different people and disciplines. In the context of emergencies, there are external uncertainties relating to analysis of events in the world and their potential negative impacts that the emergency management team are seeking to ameliorate. These can include:

- *stochastic* uncertainties, i.e. physical randomness and variability;
- *epistemological* uncertainties, i.e. lack of scientific knowledge;
- *judgemental* uncertainties, e.g. setting of parameter values in codes;
- *computational* uncertainties, i.e. inaccurate calculations and approximations;
- *modelling* uncertainties, i.e. however good the model is, it will not fit the real world perfectly
- *social and ethical* uncertainties, i.e. how expert recommendations are implemented in society, and what their ethical and social implications are.

Moreover, there are further uncertainties not relating to knowledge and prediction as those above, but relating to lack of clarity, values and ethics which are involved in the management team's understanding and evaluation of the possible impacts. Such uncertainties relate to issues internal to the team: e.g.

- *ambiguities*, i.e. ill-defined meaning, especially *endpoint* uncertainties, when the required endpoint is ill-defined;
- *partially formed value judgements*, i.e. what are the precise objectives in the context of the specific emergency;
- *ethical considerations* underlying the way expert recommendations are formulated, i.e. judgements on what an acceptable level of risk is.

Some of the external uncertainties may be quantifiable, but the attempt to quantify the internal uncertainties is unhelpful. If the emergency team do not know what they mean precisely or how to evaluate potential risks and benefits of the potential consequences, then they need to resolve those uncertainties by inclusive processes of discussion and reflection.

Bayesian methods, in principle, can help quantify most of the external uncertainties using probability calculus to unify the handling of stochastic, epistemological, judgemental and computational uncertainties [3], [4], [5], [6]. Modelling uncertainties pose a more difficult challenge, although attempts have been made. Ultimately, the judgment on how to formulate a final recommendation is essentially of an ethical nature: analysts and the emergency management team need to rely on experience and deliberation. We should recognise that some uncertainties may be deep, also called severe, i.e. because of the urgency of the emergency management process, the time and data available give little chance of getting agreement on their evaluation or, even less, quantification. In such cases, there is a growing recognition of the value of exploring several alternative scenarios [7], [8], [9].

Internal uncertainties relating to a lack of clarity on what is meant by imperatives such as minimise health effects can only be resolved by discussion and deliberation (e.g. health effects for whom, at what cost, and can reduced health effects for some be balanced against increases for others?). Much of the purpose, although only recently recognised, of emergency planning is to enable the emergency management team to work through the sorts of decisions that they will need to take in a real emergency. Doing so helps them contextualise general imperatives to the specifics of the plant, local demography and topography, social, cultural and other aspects of the region. Moreover, involvement of local stakeholders in the emergency planning process is recommended so that they can contribute their own knowledge and express the concerns and values that they would wish to guide emergency management. Similarly in the recovery phase, when there is more time to deliberate, it is essential to involve local stakeholders in discussions on the values and strategies that should be embodied in the return to normality [10], [11], [12], [13].

Table 1 provides further guidance on how different types of uncertainty could be treated

Uncertainty	Examples	Approaches to modelling and analysing
Stochastic (physical randomness)	• Occurrence and patterns of precipitation • Actual numbers and locations of the local population at the time of the release • Long term radiation related health effects	• Probability modelling and statistical analysis, especially Bayesian approaches
Implementation and compliance, ethical considerations (effectiveness of strategies)	• Compliance of population with advice on protective measures • Individual decision-making • Perception, interpretation and acceptability of risk • Effects of risk communication	• Social psychology studies on risk perception, expected behaviour could help define subjective probabilities or scenarios. • Identification of obstacles and enablers based on stakeholder engagement and communication research. • Analysis of ethical issues, e.g. risk distribution, autonomy, governance, responsibility, transparency

Table 1. Examples of the Different Forms of Uncertainty and Approaches to their Modelling and Analysis.

Epistemological (lack of scientific knowledge)	• Source term characteristics: time profiles of radionuclide mix, energy, etc. • Course and shape of plume and deposition	*Normal uncertainty* • Probability modelling and statistical analysis *Deep uncertainty* • Exploration of several scenarios
Judgemental (e.g. setting of parameter values in codes)	• Choice of models • Parameters within radiological assessment models and computer codes	• Probability modelling drawing on expert judgement. • Sensitivity analysis • Monte Carlo analyses • Consideration of social and ethical implications of choices made, e.g. accounting for vulnerable groups
Computational (inaccuracy in calculation)	• Accuracy of approximations used in atmospheric dispersion and deposition models	• Bounds from numerical analysis • Probability modelling of error distributions if stochastic approximations or statistical emulation used

Modelling (i.e. however good the model is, it will not fit the real world perfectly)	• Discrepancy between model and reality if model based on accurate parameters and data and calculations performed perfectly	• Acknowledging and making explicit the limitations of models • Experience, including model:model intercomparisons
Ambiguity, lack of clarity and endpoints (ill-defined meaning)	• How should endpoints be described, what matters? • Importance of different attributes in evaluating endpoints	• Stakeholder engagement processes • Methods of MCDA
Underlying social and ethical considerations in how expert recommendation s are formulated	• Values and principles underlying expert recommendations • Trade-offs between groups and values	• Naturalistic observation of decision processes • Muliti and transdiscipliary dialogue, • Assessment against recognised ethical principles

Table 1 (cont). Examples of the Different Forms of Uncertainty and Approaches to their Modelling and Analysis.

Discussion

This paper explores very briefly the meanings of different types of uncertainty and suggests various ways of treating these in emergency planning, response and recovery. The topic is a complex one and there is considerable potential for confusion. Indeed, in our experience, most of the discussion of uncertainty in the context of nuclear emergency management has not considered in depth the different forms of uncertainty that arise, nor their inter-connection. As a consequence the treatment of the different forms has not been adequately addressed, and the analysis and support tools prepared to aid emergency management teams have not provided them with the depth of understanding that they truly need.

There is also the issue of communicating the uncertainties to both those managing the emergency, local stakeholders and the wider publics. There has been much work since Chernobyl, and later on Fukushima, on communicating risk [14], [15], [16], though there are still issues to be researched [17]. Considering different types of uncertainty adds a further complexity that needs exploration. For instance, analysts often forget judgemental, computational and modelling uncertainties, although these can be substantial. So communicating those to the emergency management team will pose a challenge. It is also notable that many of the values, e.g. the minimisation of health effects, are difficult to articulate in specific contexts. The use of facilitated participation processes using multi-criteria decision analysis (MCDA) seems to offer the best way forward [18], [19].

A much longer report is available with further discussion [2]. That report is being further extended and revised during the CONFIDENCE Project.

Acknowledgements

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The impact of different Atmospheric Dispersion Models in the results of the European Model for Inhabited Areas after a Radiological Scenario

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Abstract

The European Model for Inhabited Areas, ERMIN, included in the JRODOS Decision Support System, has been used to evaluate the effectiveness of several recovery strategies and to assist in the development of appropriate response strategies for an urban area affected by a hypothetical radiological emergency scenario.

Several dispersion maps were produced using different Atmospheric Dispersion Models (ADM). ERMIN was run with each of these possible deposition cases and the corresponding results for several response strategies were obtained. A comparison of these different strategies was carried out in order to assess the uncertainty of the impacts on an urban area created by different ADM results.

Introduction

Similarly to other countries, the widespread use of ionizing radiation in Portugal, with applications in medicine, industry and research, may generate several scenarios creating radiological emergencies. These accidents may occur during the use, transport or disposal of radioactive materials and the consequences could have a significant social and economic impact, both locally and nationally.

The range and types of radiological emergencies can vary from an isolated overexposure of a single person to a large dimension catastrophe. Regardless of size or cause of an accident, the protection of the Public and the Environment are common concerns.

Planning for real or potential radiological emergencies, whatever their origin, be it an accident, a natural disaster, a negligent or a malicious act, or simply a rumor, will enable a quicker, well-coordinated and therefore a more effective response.

The European Model for Inhabited Areas – ERMIN, included in the JRODOS Decision Support System [1] – dynamically calculates the deposition on surfaces and the behavior of the radionuclides in the urban environment. Therefore, ERMIN may be used as a tool to assist in the development of the appropriate response strategy for an inhabited area. These response strategies may result in a combination of simple counter-measures applied to different types of standardized urban surfaces. Following an event, ERMIN may be specifically applied to select the most efficient strategies in reducing future radiation doses, so that normal living conditions may be resumed as soon as possible within the affected areas.

ERMIN may also be used in the interpretation of limited contamination data collected on-site, as these measurements become available. It may also assist in the development of a measurement strategy in inhabited areas and to identify where further measurements would be most useful, [2-3].

The current work is focused in the downtown area of Porto, a densely populated area where several monuments, recreational and cultural facilities attract numerous people on a daily basis, thus becoming a sensitive spot if an emergency situation should occur. These features also generate an area where several types of urban surfaces may be identified and where different counter-measures should be applied. In these cases, several response strategies may have to be considered, in order to obtain normal living conditions as soon as possible within these affected areas.

The chosen scenario was a radiological emergency caused by an accidental radioactive source melt-down in a steel mill located in the outskirts of this major city. Several deposition maps were obtained using the different Atmospheric Dispersion Models (ADMs) and these were used as inputs into the ERMIN model.

The goals of this study consisted in testing the outcomes of the ERMIN model when using distinct deposition conditions created by different ADMs, more specifically, if the results for different recovery strategies would be affected by using different ADM's. Another goal was assessing the data needs for running ERMIN and coordinate these requirements with national databases.

Methodology

I. Definition of the Emergency Scenario

The impact of a radiological accident such as a source meltdown in a steel mill in the outskirts of a major city like Porto was the chosen scenario. The current work is focused in the downtown area of Porto, a densely populated area where several facilities are used by numerous people on a daily basis, thus becoming a sensitive spot if an emergency situation should occur.

The accident site was designated as a steel mill located in Maia area, about 12 km from Porto downtown area. This facility normally receives scrap metal from various origins and uses it as raw material for producing new steel. This feature turns this location into a likely candidate for such a type of accident, in case a mal-function of their detection systems should occur.

The date of the accident was chosen as February 2nd, 2018, 12:00 UTC. In this time of the year, dry-deposition and wet-deposition scenarios are both very likely to happen, due to local weather conditions.

II. Radiological details of the Emergency

The radiological emergency was considered to be resulting from an accidental melt-down of a radioactive source commonly used in well logging equipment. These sources typically contain: Am-241 as a radionuclide with an initial activity of 740 TBq. Due to this isotope half-lifetime, no corrections to this value were taken into account, considering the possibility that the well logging equipment would be less than 5 years old.

In order to calculate a more realistic source-term activity for the inputs into the different Atmospheric Dispersion Models, partitioning into the “Melt”, “Slag” and “Dust” of these radionuclide was considered. Realistic distribution rations expected for this radionuclide: 0%, 99% and 1%, respectively in the melt, slag and dust, were used [4].

III. Definition of the weather conditions

In order to consider a high impact scenario in the Porto downtown areas, several weather conditions were tested.

Therefore, the wind direction was chosen so that the wind would be blowing from the accident site into Porto downtown and was fixed at 27º. Although this wind direction occurs with a very low frequency [5], it would be the one to cause a higher impact in this area.

According to the climatology studies carried out by the Portuguese Meteorological Office (IPMA) [6], the average wind speed in February in Porto area is about 3.8 m/s. A set of wind speeds below this average value were tested: 1.8 m/s, 2.8 m/s and 3.8 m/s.

Taking into account these same climatology studies [6], the average rain intensity in February in this area is 75mm. This would correspond to daily average of 2.7 mm. Also for this area, during winter season, 58% of days register precipitation below 1mm. In 9% of winter days precipitation is above 10 mm (a yellow alert condition would be considered by IPMA in this case), 2% of the days precipitation is above 20 mm (an orange alert condition would be considered by IPMA) and only 1% of the winter days register a precipitation above 50 mm (a red alert condition would be considered by IPMA in this case). A set of precipitation values (0 mm/day, 2.5 mm/day, 5 mm/day, 15 mm/day, 25 mm/day, 35 mm/day and 55 mm/day) were considered.

These two sets of meteorological variables originated 21 possible combinations of weather conditions. The sets were inputted manually into JRODOS and the RIMPUFF [7] Atmospheric Dispersion Model was used to calculate the dispersion of radioactive material in the Porto downtown area. For these calculation no partitioning of the source was considered.

The projected values for total potential dose effective (TPDE) in mSv were used to probe the impact of each set of weather conditions. These values were plotted as a function of wind speed (in m/s) and rain intensity (in mm/day) and are presented in Figure 1.

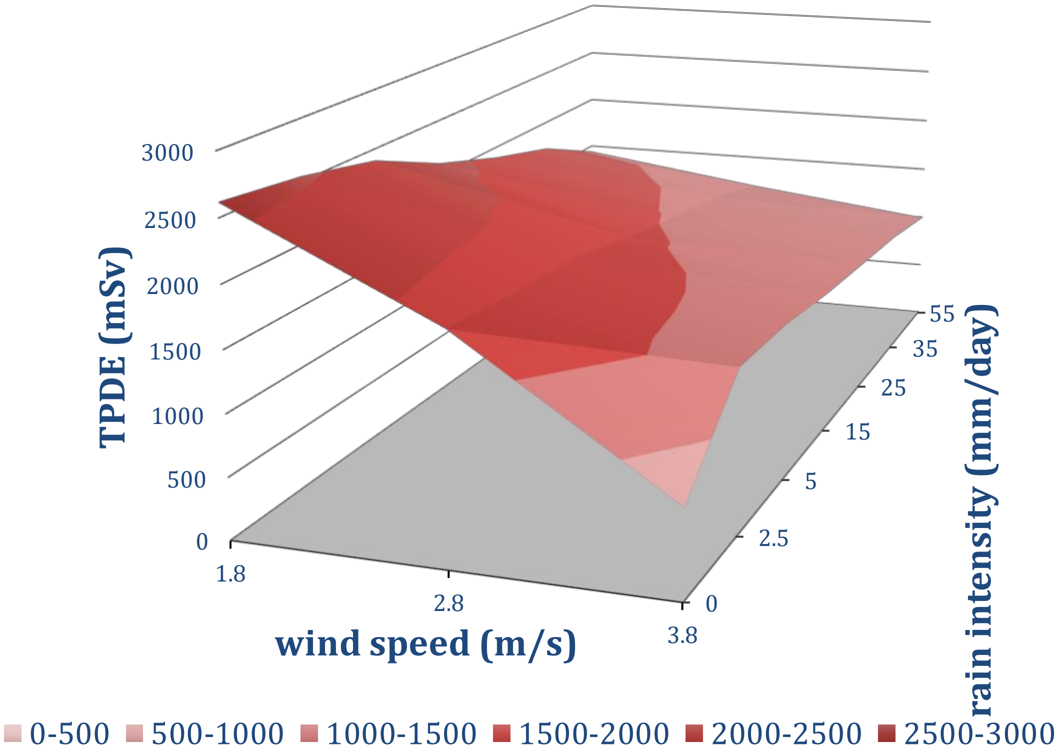

Figure 1. Projected values for total potential dose effective (TPDE) in mSv used to evaluate the impact of each set of weather conditions.

As may be observed in Figure 1, the maximum impact for the designated area would occur if low wind speed, 1.8 m/s, and dry weather conditions were registered. These weather conditions were used in subsequent calculations.

IV. Projected deposition maps using different Atmospheric Dispersion Models

The deposition maps were obtained by running JRODOS-2017 update. The selected Model Chain was the “LSMC+EMERSIM+DEPOM+FDMT“ and the “Radiological Accident with Fire” module was run. Weather data was user inputted and the weather conditions described above were used. The source-term used for these calculation considered partitioning of the radionuclide, as described above (see II.). The Atmospheric Dispersion Models (ADMs) used were the Risø Mesoscale PUFF model (RIMPUFF) [7], Dispersion over Complex Terrain (DIPCOT) [8] and Lagrangian Simulation of Aerosol Transport (LASAT) [9] models. The obtained deposition maps presenting TPDE values are shown in Figure 2 to Figure 4, along with the superimposed ERMIN grid (see below).

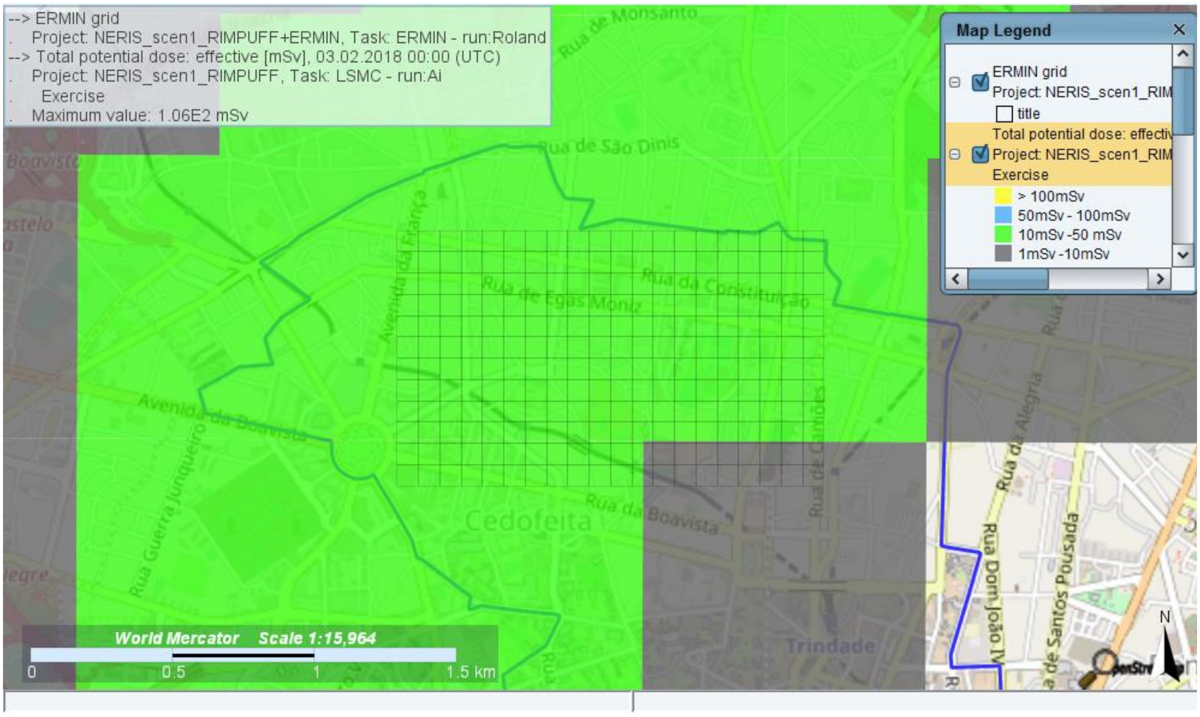

Figure 2. Projected deposition maps showing TPDE values (in mSv) obtained using RIMPUFF ADM.

Legend: 1 mSv to10 mSv; 10 mSv to 50 mSv; 50 mSv to 100 mSv; >100 mSv.

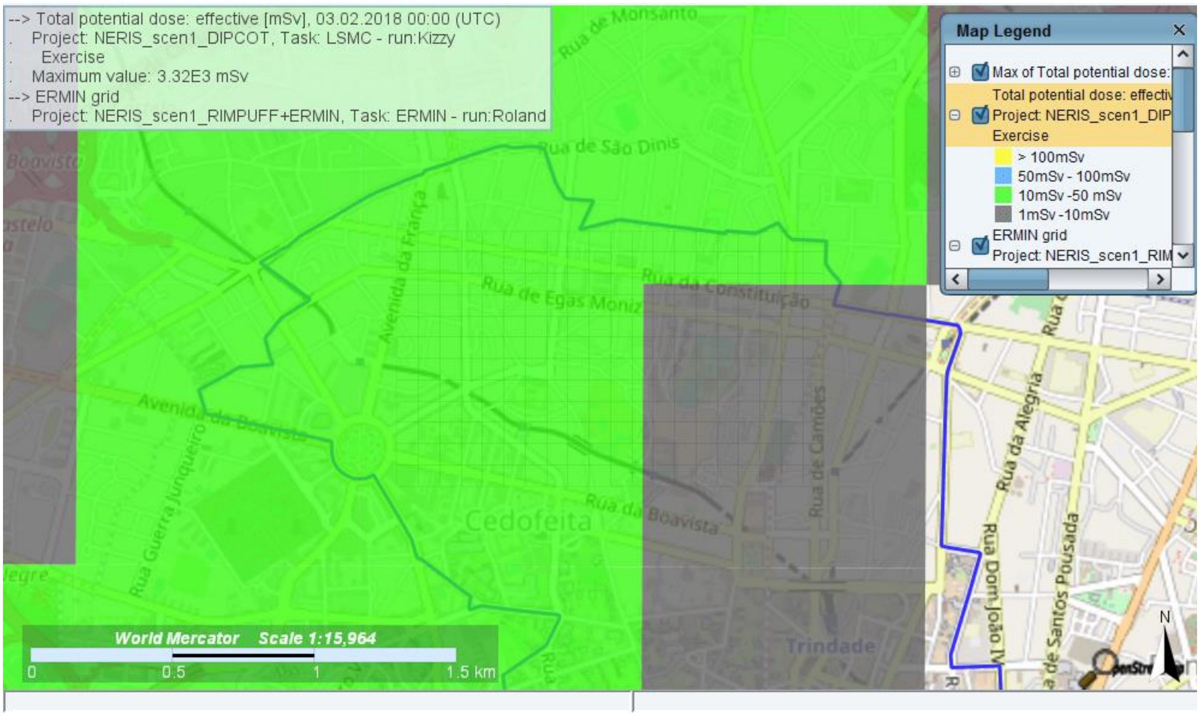

Figure 3. Projected deposition maps showing TPDE values (in mSv) obtained using DIPCOT ADM.

Legend: ■ 1 mSv to10 mSv; ■ 10 mSv to 50 mSv; ■ 50 mSv to 100 mSv; ■ >100 mSv.

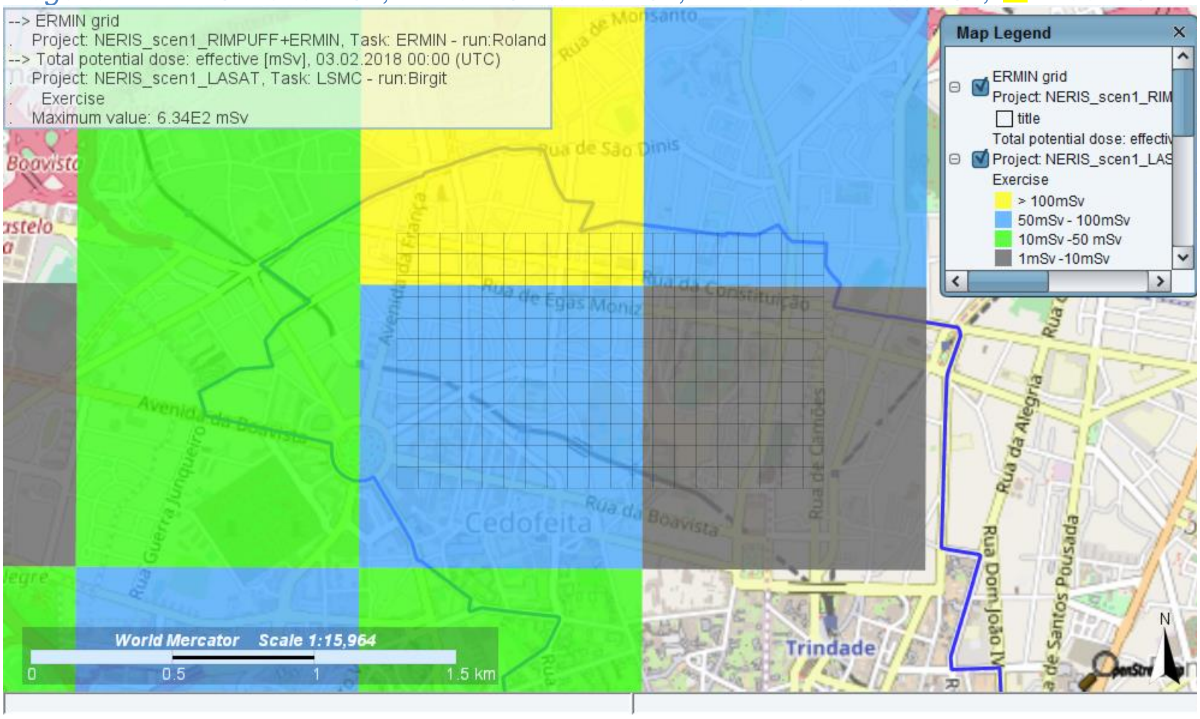

Figure 4. Projected deposition maps showing TPDE values (in mSv) obtained using LASAT ADM.

Legend: ■ 1 mSv to10 mSv; ■ 10 mSv to 50 mSv; ■ 50 mSv to 100 mSv; ■ >100 mSv.

V. The European Model for Inhabited Areas (ERMIN)

The European Model for Inhabited Areas (ERMIN) was used to evaluate and compare different recovery strategies [2]. The ERMIN allows some flexibility in describing the urban environment and the contamination extent.

The "Area of Interest" (AoI) for running ERMIN is shown in Figure 2 to Figure 4 as a mesh (ERMIN Grid). The AoI was chosen to be one with a high variability of predicted deposition results, as may be observed in Figure 2 to Figure 4.

Due to the nature of the accident, it was considered that the release would have been detected sometime after the deposition had occurred, and therefore no early counter-measures could have been implemented in a timely manner.

The National Land Cover database, DGT-COS2010, [10] was used to characterize the land cover in the Porto downtown area and several shapefiles were created by clipping the original database. These small maps were superimposed on the Porto downtown area and used to recognize distinct urban areas, originating the "Environmental Breakdown" for the Area of Interest. After this procedure, 5 distinct Urban Environments were identified:

1. Parks
2. Industrial Areas
3. Residential: Multi-storey block of flats amongst other house blocks
4. Residential2: Multi-storey block of flats opposite parkland
5. Residential3: Street of semi-detached houses without basement

The obtained Environmental Breakdown for this Area of Interest is shown in Figure 5.

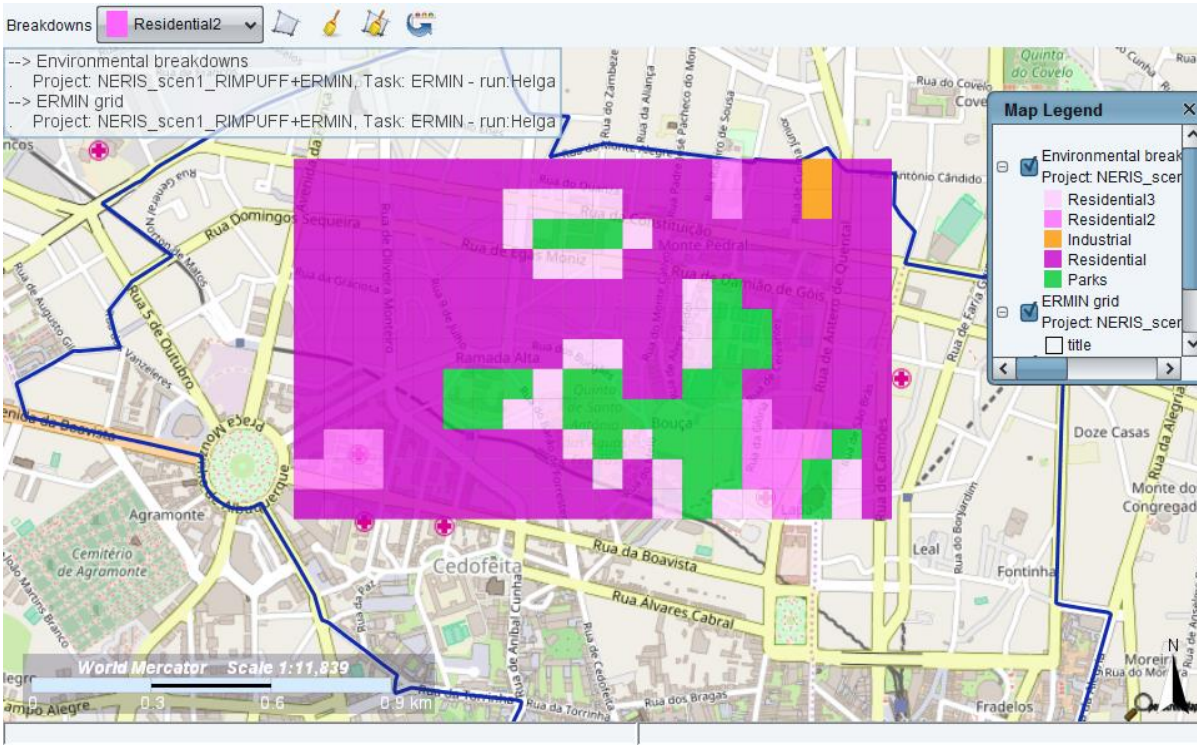

Figure 5. Obtained Environmental Breakdown for the Area of Interest inputted in ERMIN calculations.

Three proposed strategies were considered for this study: a “no action” strategy and two other strategies each of the latter combining 3 counter-measures. One counter-measure for building’s exterior surfaces, one for internal surfaces and another for green areas were included (see Table 1). All these strategies were applied to the entire Area of Interest.

Table 1. Proposed strategies applied in the Area of Interest for ERMIN calculations.

	S0: No counter-measures	S1: Lower cost / lower waste production	S2: Higher cost / higher waste production
exterior surfaces	No-action	Roof Brushing	Fire hosing Roofs
internal surfaces	No-action	Vacuum Cleaning Interior Surfaces	Washing Interior Surfaces
green areas	No-action	Grass cutting	Turf Harvesting

Results

Some of the outputs of the ERMIN were analyzed in order to evaluate the impact of using different ADMs for obtaining dispersion maps that were inputted to this model.

The total waste produced (ton) and the total cost of strategies S1 and S2 are completely independent of the ADM used, as may be concluded from Figure 6 and Figure 7.

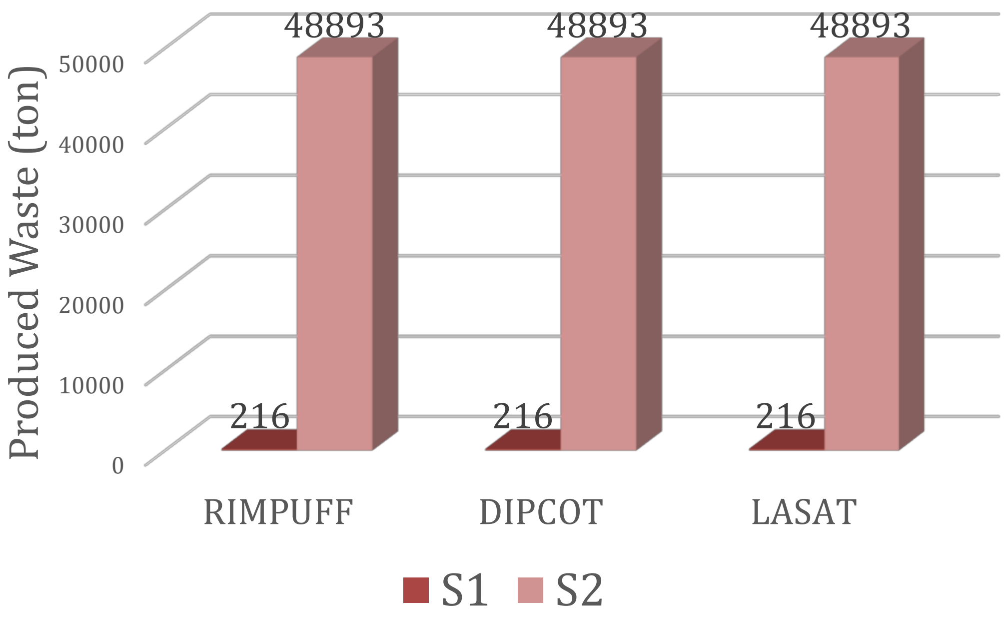

Figure 6. Comparison of the total waste produced (ton) for each strategy and for each ADM used..

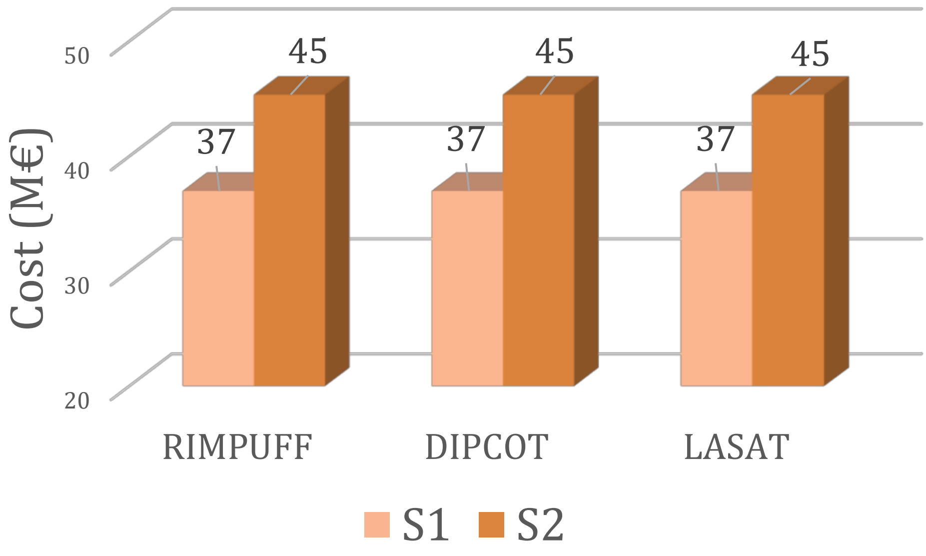

Figure 7. Comparison of the cost (M€) for each strategy and for each ADM used.

In order to evaluate the effectiveness of each strategy, the values of maximum public individual normal living effective dose in the Area of Interest over a 10 year integration period (i.e. the sum of the dose from exposure to external irradiation over the period and committed effective dose from inhalation of radioactivity over the same period) were used. The results are depicted in Figure 8.

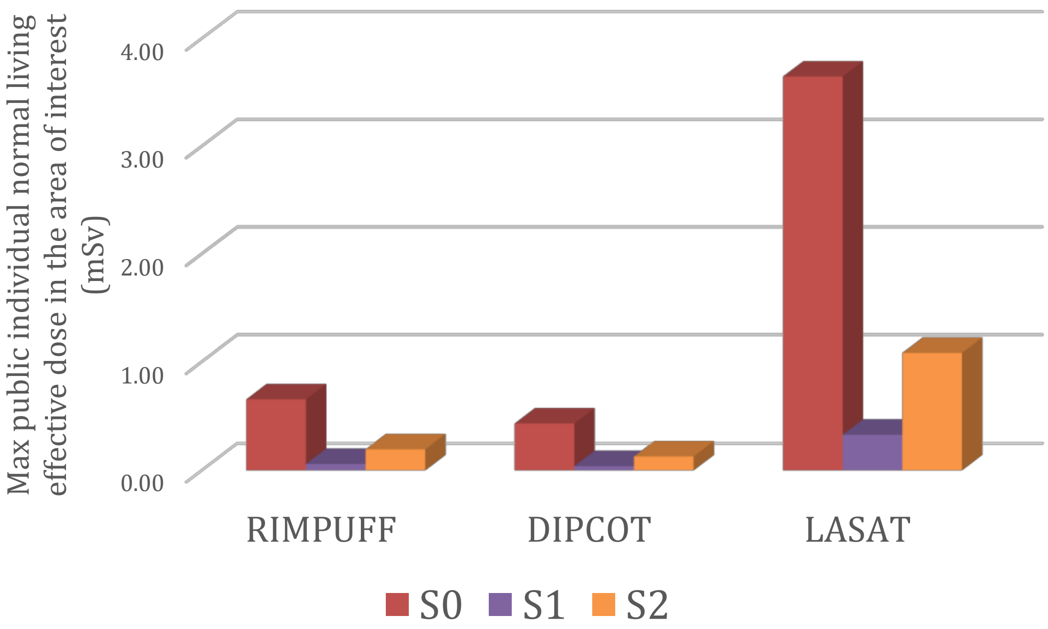

Figure 8. Comparison of the values of maximum public individual normal living effective dose in the Area of Interest over a 10 year integration period for each strategy and for each ADM used.

These values demonstrate that the choice of the ADM and the corresponding deposition map may originate a high dependence on some of the ERMIN outputs.

If we calculate the effectiveness of strategy i ($\boldsymbol{E_{S_i}}$) using the obtained values of the maximum public individual normal living effective dose ($\boldsymbol{D(S_i)}$, mSv) and Equation 1,

$$E_{S_i}(\%) = \frac{D(S_0) - D(S_i)}{D(S_0)} \times 100 \qquad \text{(Equation 1)}$$

We obtain the results shown in Figure 9:

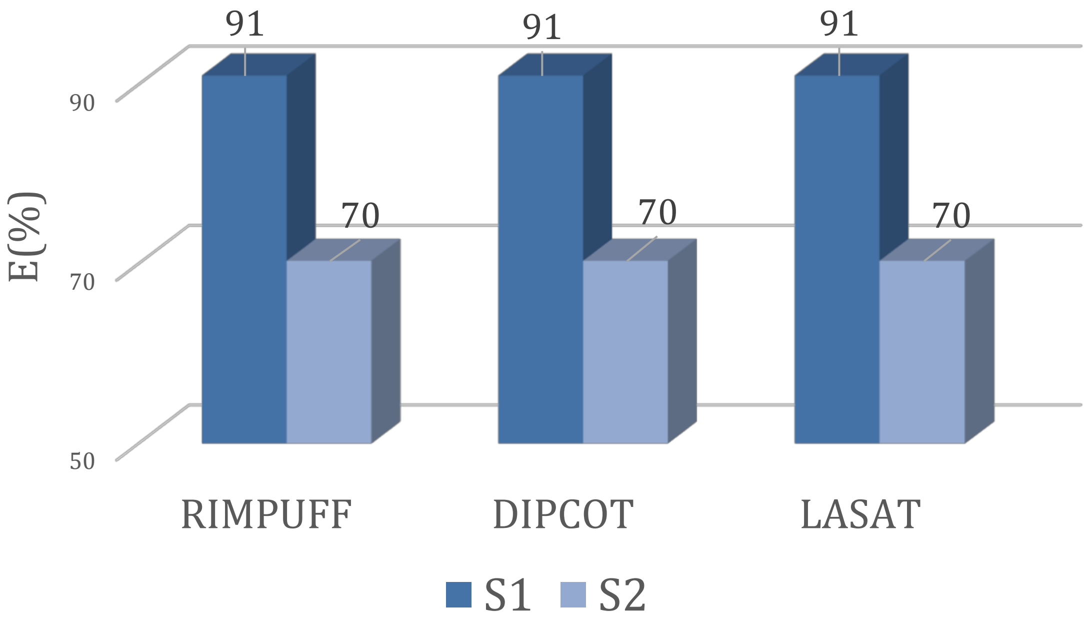

Figure 9. Comparison of the Effectiveness of each strategy when different ADMs are used.

These results show that the effectiveness of each strategy is totally independent of the ADM used to obtain the deposition map.

Conclusions

For this scenario and the proposed strategies, we may conclude that strategy S1 combines a better effectiveness with lower costs, independently of the ADM used and of the corresponding dispersion map. This was anticipated since this strategy incorporates several counter-measures qualified as "low cost / low waste production" and this also turned out to be independent of the inputted dispersion map.

On the other hand, some results, like the values for maximum public individual normal living effective dose, are highly dependent on the type of model used. Thus, the ADM should be carefully selected and suitable to the type of accident typology and localization. This variability may also generate some uncertainties when results are to be presented to decision makers. Nonetheless, whatever the ADM used, the S0 (no action) strategy will always produce a higher value for the maximum public individual normal living effective dose. As a result of the S0 strategy, predicted values for this dose using RIMPUFF and DIPCOT ADMs are in the same order of magnitude, while using LASAT ADM will generate values 5-6 times larger. This may be a direct consequence of the way this last model predicts the spatial distribution of the plume.

The ERMIN model may be considered quite robust when analyzing costs and waste production of the proposed recovery strategies, since these results are clearly independent of the applied ADM and corresponding dispersion map. This may result from the fact that the model calculates the surface area to which it applies and multiplies this by the appropriate coefficients obtained from an internal database [11].

Either in the preparedness or response phases, when different types of recovery strategies must be discussed with decision makers or other stake holders, presenting results in terms of their efficiencies may reduce uncertainties regarding the type of ADM or dispersion map used.

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Scenarios and issues to address with stakeholders in the transition phase. Towards the reduction of uncertainties in the management of long-term recovery.

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1. Introduction

The transition phase is the period of time after the emergency response phase when the situation is under control and a detailed characterisation of the radiological situation has been carried out in order to identify the exposure pathways and assess doses. Figure 1 shows the view of the emergency management timeline and emergency phases, as described recently by IAEA [1]

During this phase, activities are planned and implemented both to enable the emergency to be declared terminated and to prepare the long-term recovery.

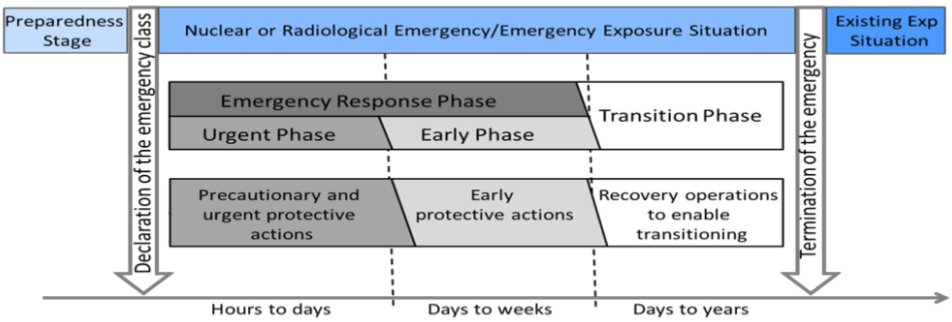

Figure 1. View of the emergency management timeline and emergency phases [1].

The transition phase is not driven by urgency and allows, as emergency evolves:

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

The main objective is to facilitate the timely resumption of social and economic activities, as far as possible. Among the arrangements needed to be carried out to reach this main objective, two issues stand out, on one hand, the identification of the authority, the roles and responsibilities of the different organisations in charge of Emergency Preparedness and Response (EP&R), and the coordination between them all; on the other, the focus has to be the protection strategy of the public, that is the planning, development and implementation of the recovery actions, including the involvement of stakeholders.

2. Decision-oriented scenario analyses

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

- How is the problem addressed?
- Who is involved? (referring type of stakeholders)
- What concerns are considered: health, environmental, social, economic, …?
- What are the objectives, the things that matter, in the context of the decision under consideration?
- What options are possible?

The problem may be addressed by means of decision-oriented scenario-analysis allowing the identification and evaluation of alternatives involving stakeholders, experts and decision makers and dealing proactively with complexity and judgment in decision-making.

Figure 2 shows a scheme review of participatory methods [2], based in the classification of Van Asselt M.B.A. in 2001 [3]. The aspiration and/or motivation of the participation, ranging from the democratization to the advising, is faced against the targeted outputs, that range from mapping out diversity to reaching out consensus; the scenario analysis highlights as a technique that balances in the same way the diversity and the advising and is thought to be suitable to face the success of the recovery plan.

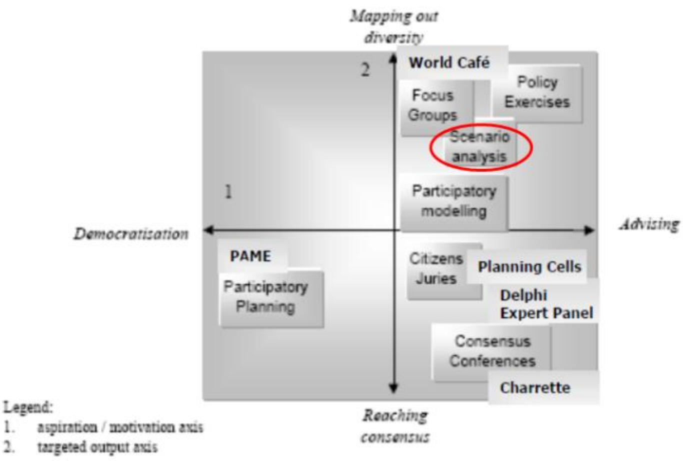

Figure 2. Review of participatory methods (Source: [2]).

The Forum on Stakeholder Confidence [4] uses the term "stakeholder" as a label for any actor, institution, group or individual with an interest or a role to play in the societal decision-making process around a specific issue. Different stakeholders may have different interests. Thus, stakeholders have both different contributions to make and different involvement needs at each stage of a decision process.

The degree of involvement varies in the first place, regarding this classification, but not only. There are other reasons that influence the involvement and that can be grouped regarding:

- Objectives: Reasons for the involvement and expected outcomes
- Topic: The nature and scope of the issue
- Time: Amount of time available
- Budget: Availability of resources

Figure 3 shows The Spectrum of Public Participation developed by the International Association of Public Participation (IAP2) [5], adapted from Sherry Arnstein in 1969 [6], that clarify potential roles of the community in decision-making. Each level articulates a different degree of involvement of stakeholders according to the goals and endpoints to reach in each case, starting from a basic information level and successively increasing the complexity of the involvement towards an empowerment [5]. In the case at hand, the degree of involvement will depend strongly on the concerns, expectations and needs to be treated in the recovery plan.

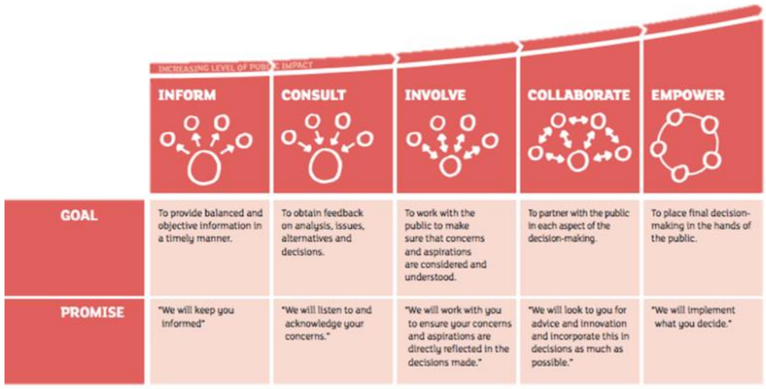

Figure 3. Categorization of the degree of involvement of stakeholders, according to the IAP2 Spectrum of Public Participation (Source: https://www.flickr.com/photos/planspark, licensed under CC BY-NC-SA 4.0).

The decision-oriented scenarios used in this process should be narrative descriptions of potential futures that focus the attention on relationships between events and decisions that have to be taken. A scenario construction process should address:

- The environmental characterisation, which refers to structuring the scenario in basic units in terms of parameters and attributes that affect both the behaviour of radionuclides and their response to recovery actions
- The radiological characterisation, that is zoning of the contaminated area, based on different criteria such as dose criteria, deposition level food maximum permitted levels or radiological impact assessment in the long-term),
- The evaluation models: to assess the space-time evolution of the scenario; they help to define the objectives and quantify criteria for decision,
- The development of a recovery strategy designed to address the objectives defined previously,
- The decision-making process.

Regarding the recovery strategy, there are different types of actions that can be carried out in both inhabited and agricultural areas to reduce the impact of radioactive contamination [7,8].

They are designed to be used at the source of contamination, particular media or at points in the exposure pathways.

A recovery strategy can comprise one or a number of combined actions and its implementation has to be justified and the protection optimised. Optimisation should ensure selection of the best strategy and its process, during recovery, can be implemented step by step. When carrying out optimisation of recovery strategies there are a number of factors that need to be taken into account, these are mainly:

- Target: source of contamination, radionuclide, media, exposure pathway.
- Effectiveness: understood as the reduction in activity concentration in the target.
- Feasibility: equipment, utilities, infrastructure, transport, consumables, operators and duration of treatment and application rates.
- Waste: volume and type of wastes generated and its disposal.
- Incremental doses: that may receive the workers in charge of the implementation of the option but also members of public.
- Side-effects: including direct and indirect environmental impacts.
- Costs: are referred to the direct costs derived from implementing the action.
- Legislation: referred to types of restrictions need to be considered before the implementation of an action.
- Societal and ethical factors: arise from people's behaviours, attitudes and perceptions and are ultimately related to the society's trust and confidence in their national.
- Information and communication issues

3. Uncertainties

The overall process generates uncertainties related to different issues that can be grouped as follows:

Associated to the radiological situation of the scenario contributing to the overall uncertainty associated with the estimated impact. These are mainly due to:

- Space-time evolution of the contamination and the prediction of the radiological situation in the long term
- Results of the monitoring
- Possible changes in the future use of the scenario

Associated to the goals and criteria used in the design of the protection strategy:

- Objectives pursued
- Radiological criteria: reference levels
- Indicator Units (time to carry out the implementation of the strategy, area affected, nº of persons affected…..)

Associated to the protection strategy regarding not only the factors to be taken into account during the optimization process, such as:

- Effectiveness
- Side-effects
- Generated wastes and their disposal
- Costs

Also related to the design of the recovery strategy, is it sufficiently flexible and adaptable to take into account how the radiological situation evolves in time?

Associated to the social pressure regarding:

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

The proper treatment of these uncertainties will benefit the management of the long-term recovery, the question is, how to deal with them. On the one hand, it is necessary to take them into account in the decision-oriented scenario-analysis, allowing to identify and to evaluate, different alternatives. These will arise in different potential endpoints with different values according to the criteria considered.

Another way to treat them is by means of the participation of the stakeholders in discussion panels, the different decision criteria, concerns and viewpoints, can reduce or at least consider the uncertainties in order to foresee the possible changes in the response of the long-term recovery.

In this same sense, by means of surveys as complementary methods, allowing to identify the items of interest for discussion purposes and to prioritise the preferences of the stakeholders.

4 Conclusions

Scenarios help direct attention to motivate the actions to be taken, the possible evolution of the situation and the different possibilities that may be confronted.

The approach based in decision-oriented scenario-analysis allows to identify and to evaluate alternatives that focuses on engaging stakeholders, experts and decision makers and deals proactively with complexity and judgment in decision-making.

It is very useful when many factors need to be considered and the degree of uncertainty is high, as is the case of the preparedness of the recovery during the transition phase.

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Triggering Events and Distributed Responsibilities Capabilities of Web-based Decision Support in Nuclear Emergency Management

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Abstract

It is well known that nuclear accidents may be triggered by other disastrous events impairing emergency management in various directions like disrupted critical infrastructures impeding response as well as increased public uncertainty. Computerized decision support may help advising experts as well as authorities who decide on appropriate strategies. Examples are simulation-based systems already operationally used in nuclear emergency management. However, in case of triggering events, a system capable of analyzing events beyond nuclear accidents opens up new possibilities in decision support. Furthermore, as already experienced in previous nuclear disasters but also with regard to multiple events occurring at the same time, people in charge are often not located at the same place but are rather distributed in different ministries or institutions. A web-based access to an integrated decision support system that allows exchanging individual analyses easily, overcomes barriers of previous local installations or complicated information exchange. This paper takes up these issues and presents a suitable system architecture. By means of example calculations, the application and its value will be emphasized.

1 Introduction

Emergency management and particularly response during the Fukushima Daiichi nuclear power plant accident was impaired by a foregoing earthquake and tsunami which caused a lack of electricity power supply and extensive damage of transport infrastructure. Missing detailed pre-planned arrangements with regard to early management options as well as inconsistent information and some uncoordinated decisions of the local and national authorities contributed to the confusion and uncertainty of the public. In Europe, a lack of cooperation between the different countries became apparent resulting in diverging as well as non-harmonized response and confusion amongst the public [1]. Some of the main discussion topics were: (i) Handling of uncertainty, especially in the early stages of an accident; (ii) Communication between the institutions in charge and the public; (iii) Emergency preparedness with a special focus on severe accidents possibly linked to natural disasters [2].

Various knowledge management systems supporting disaster management exist where the majority focuses on communication and collaboration, shared situation awareness, visualization, evaluation of various data sources, technological requirements, and general design principles [3]. Decision supporting solutions for disaster management have different focus such as scheduling [4], mobile support [5], or humanitarian relief [6]. Furthermore, specific events are investigated such as floods [7] or environmental [8] and technological [9] emergencies. In respect of nuclear emergencies, JRodos [10], Argos [11] or the NARAC system [12] are some well-known decision support systems.

Over the last decades, web technologies have entered the development of decision support systems resulting in many successful application examples [13]. Besides the access to decision supporting tools via a web browser, web technologies particularly facilitate communication and decision-making in distributed teams [14]. Moreover, analysis and computation is platform-independent, remote, and distributed facilitating information exchange. Also, system maintenance is simplified and centralized [13].

The management process of nuclear emergencies is complex involving various activities and corresponding responsibilities [15]. Particularly, the institutions providing support and advice to the decision-makers may be located at different places. Therefore, a system that is accessible from different locations where the input and results can be synchronized and shared between the persons in charge is of great value. A web-based application is well suited to fulfill this task, greatly simplifying the requirements of software and hardware as only a mobile device with a web browser is needed. As some of the scientific discussions revolve around emergency management handling multiple disaster types at same time, new challenges in the system's architecture arise.

This paper presents a solution to the issues of distributed access and triggering events of nuclear emergencies. First, the general purpose and approach of decision support is introduced. Afterwards, the system's architecture and flexible enhancement possibilities are presented. The added value is illustrated by means of an example scenario.

2 Decision Supporting Method

The decision supporting method of the presented system pursues the following objectives for nuclear emergency management: (i) Complementing existing decision support systems and methods in times the source term is not yet available; (ii) Supporting strategy building throughout all accident phases and offering strategies as discussion basis; (iii) Promoting preparedness and particularly scenario construction; (iv) A centralized storage of expert knowledge, experience, and simulation results; (v) Providing these knowledge sources computerized and structured in the course of a current event.

Table 2 sums up existing decision support for all accident phases, some challenges in decision-making the presented system addresses and the concrete decision support it provides.

The decision supporting backend of our system is case-based reasoning (CBR)[16] and a knowledge database. The basic idea is to reuse experience and knowledge of former accidents as well as simulation results of JRodos to identify possibly appropriate strategies in a current accident. Especially, already implemented strategies or those suggested by experts to initiate as well as their consequences in terms of costs, societal disruption, and health effects are reused. This idea contrasts to current decision support systems or methods that prepare decisive information to construct a strategy from scratch. Especially, computerized case-based decision support is new in nuclear emergency management. Further details can be found in [17], [18].

Accident phase	Existing decision support	Some challenges in decision making	Decision support provided by the web-based system

Pre-release	▪ Simulation of dispersion and deposition of radioactive material
	▪ Projected dose
		▪ Uncertainty regarding decisive parameters
		▪ Time pressure
		▪ Public acceptance
		▪ Effectiveness vs. feasibility of management options
			▪ Strategy
			▪ Information on management options
			▪ Implementation areas of management options
			  ▪ Circular area
			  ▪ Sector

Release			▪ Strategy ▪ Information on management options ▪ Area sizes ▪ Number of affected people ▪ Effectiveness ▪ Experience on the implementation of management options
Transition/ Long-term post-accident	Handbooks on the management of contaminated ▪ Inhabited areas ▪ Food production systems ▪ Drinking water	▪ Many stakeholders ▪ Public acceptance ▪ Effectiveness vs. waste and cost	▪ Strategy ▪ Information on management options ▪ Effectiveness ▪ Experience on implementation of management options

Table 2. Overview on how the system complements existing decision support systems and methods focusing on specific challenges in decision-making.

The idea now is to provide means to analyze triggering events in parallel with nuclear emergencies and particularly enable persons in charge to access the decision supporting tool from different locations. In order to determine possibly suitable strategies and assessing damage values, the current nuclear as well as natural event can be described with the help of specific attributes and via input masks. Several users can run calculations from different locations and share their results (Figure 4). Until now, the focus concerning the triggering events has been on natural disasters and their damages. Due to the architectural design, the scope of triggering events can be extended easily by enhancing the database accordingly. Furthermore, the connection to the database, control of the program flow as well as generation of the graphical user interface (GUI) are event type-dependent and configured with XML files supporting flexible and easy modifications.

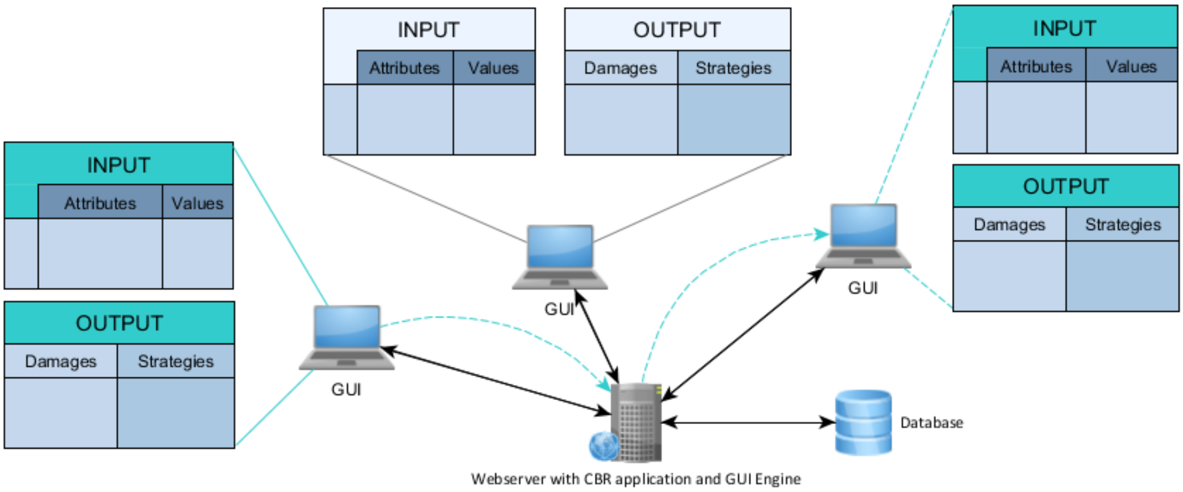


Figure 4. Remote access and sharing of results.

3 Example Scenario

The following scenario is derived from the Fukushima Daiichi nuclear power plant accident, which was analyzed to particularly identify points in time when the web-based system could be applied. The objectives are to compare the results of the system with the implemented management options as well as to emphasize the additional support the system could provide, especially in times when less information is available. For illustration purposes, some specific events were selected and timely ordered (Figure 5) and characteristics of the event to be specified in the user interface, are outlined (Table *3*). For the sake of clarity, only certain points in time and a subset of describing attributes are listed here. The scale of weights ranges from 1 to 10 where 1 indicates almost no relevance and 10 highest relevance.

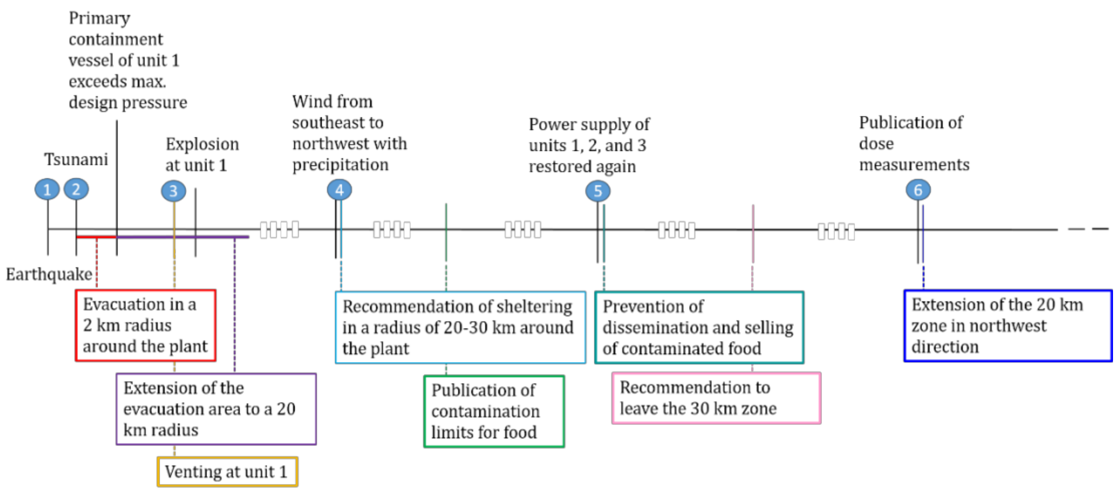


Figure 5. Scenario derived from the Fukushima Daiichi nuclear power plant accident and by means of selected events and management options taken.

Possible use of web-based system (Figure 5)	Characterizing attributes	Values/Weights

1	Magnitude Depth HDI Location	9 Mw/5 25 km/2 0.891/8 Japan/Equal
2	Nuclear power plant type Thermal power Population distribution of affected area Risk of core melt Maintaining of containment integrity Wind direction Estimated release time	Boiling water reactor 2812 MW (average value) Urban Yes or unknown Yes or unknown Variable or unknown Unknown
3	Iodine equivalent Target Time of day of release Season Weather at release Release duration category Cause	4 (published by NISA), 7 used for the system People Day Spring No rain Short Deliberate
...	...	...
6	Contamination Target	I 131; Cs 134; Cs 137 Large area of plants, Large area of grass, Cereals

Table 3. Some characteristics of the event to be specified in the web interface. If not explicitly stated, the attribute weight is 5.

For points 1 and 2, Figure 6 illustrates the input mask, exemplarily for the pre-release phase. In particular, the HERCA-WENRA approach [19] is integrated since almost nothing is known about the nuclear event. Figure 7 shows the HERCA-WENRA recommendations as a discussion basis for the advising experts and similar historical earthquake events. Similar historical events particularly may help in decision-making due to a possible assessment of damage values. Furthermore, this application should particularly stress the benefit of such systems where experts could include their own assessments of event classifications to develop their strategies. At point 4, the official classification of the event was 4 (iodine equivalent). Experts may have worked with a value of 7 for the iodine equivalent. In this case, the suggested strategy is based on a pre-defined INES 7 scenario in an urban area. If an affected area size is specified, the areas for the single management options are adapted accordingly (Figure 8). Furthermore, the Chernobyl accident is listed here where the user can get information on strategies, their effectiveness and experiences with implementation. For the long-term phase, pre-calculated scenarios with JRodos are used as well for decision support.

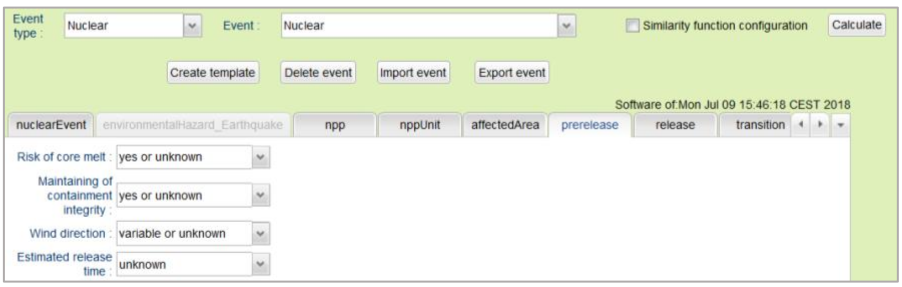


Figure 6. Input mask for the pre-release phase.

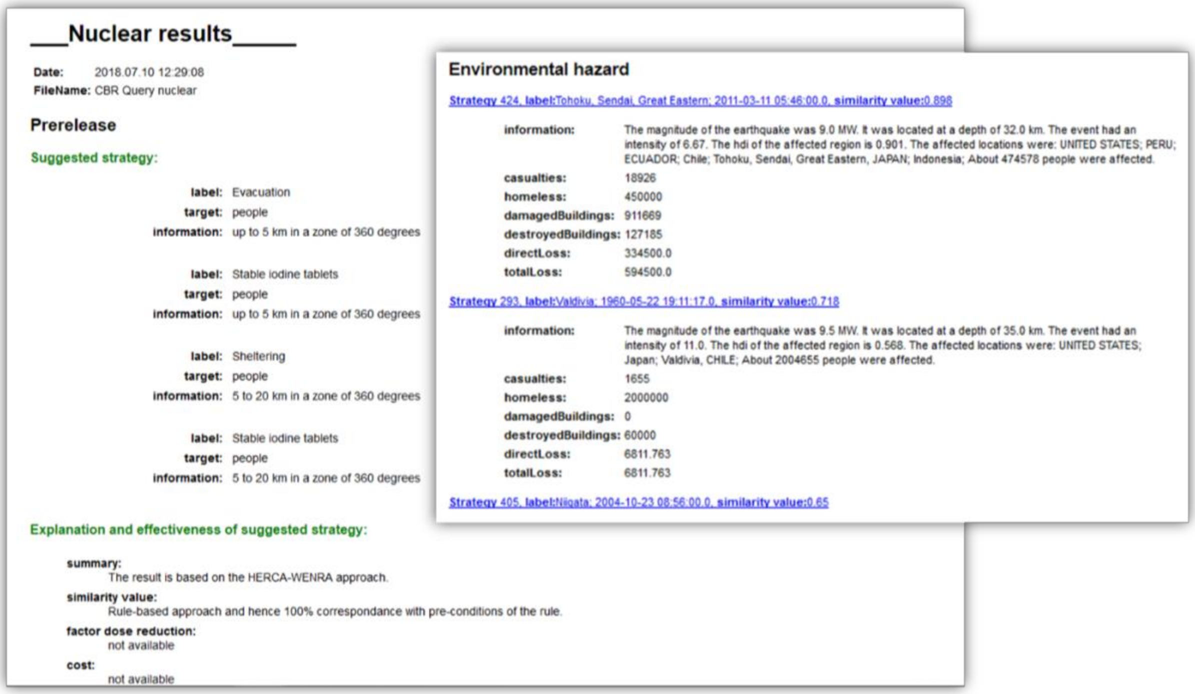
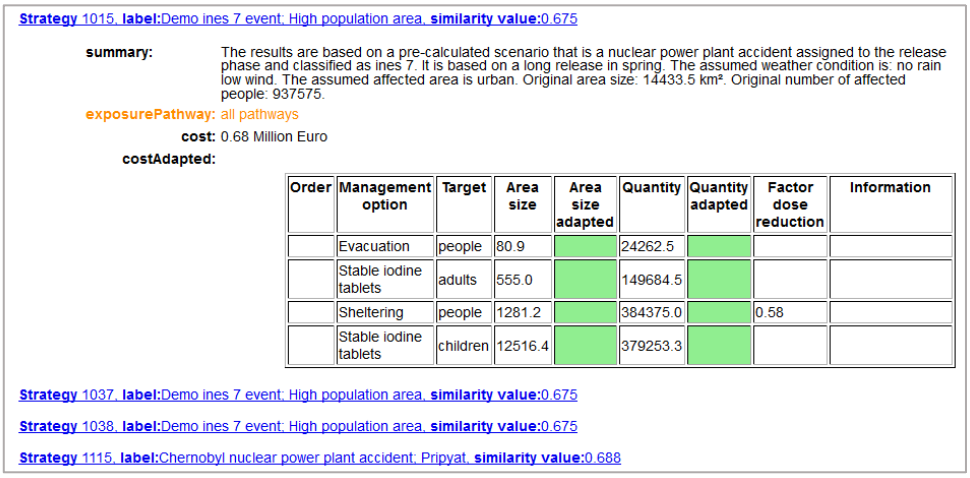


Figure 7. Result for the pre-release phase and similar historical earthquake events.

The following observations can be made: (i) The official classification of the event at this early stage does not correspond to the implemented management options when comparing to the results of the presented system. An iodine equivalent of 4 would result in 'do nothing'. (ii) The HERCA-WENRA approach suggests a smaller evacuation area than applied in Japan, namely 5 km in a zone of 360 degrees. The HERCA-WENRA approach would suggest evacuation up to 20 km if containment integrity is lost and core melt is expected. (iii) The earthquake events from the past range from an earthquake in Valdivia (Chile), which triggered a tsunami that affected the whole pacific region to an event in Japan with less magnitude. Note that more events could be retrieved from the past which can be specified in the interface as well. (iv) The results of the JRodos scenario give more information on particular area sizes and affected people which could be determined for the current event as well, if an area size is specified. In general, the JRodos area sizes are smaller since specific sectors are determined for the management options whereas in Japan the options were implemented in a circular area. Also, different criteria for evacuation, for instance, lead to different area sizes: the intervention level for evacuation refers to an early period of 7 days after release assuming that people are permanently staying outdoors. The decision basis in Japan was a band of 20-100 mSv effective dose (acute or per year) for evacuation. As one may presume, pre-defined scenarios as well as historical events provide a broad discussion basis and first suggestions on potentially suitable strategies as well as hints what might possibly go wrong. Due to the complexity of decision-making, supporting information that is prepared in advance of an event and which can be accessed computerized is of great value.


Strategy 1015, label:Demo ines 7 event; High population area, similarity value:0.675

summary: The results are based on a pre-calculated scenario that is a nuclear power plant accident assigned to the release phase and classified as ines 7. It is based on a long release in spring. The assumed weather condition is: no rain low wind. The assumed affected area is urban. Original area size: 14433.5 km². Original number of affected people: 937575.

exposurePathway: all pathways

cost: 0.68 Million Euro

costAdapted:

Order	Management option	Target	Area size	Area size adapted	Quantity	Quantity adapted	Factor dose reduction	Information
	Evacuation	people	80.9		24262.5			
	Stable iodine tablets	adults	555.0		149684.5			
	Sheltering	people	1281.2		384375.0		0.58	
	Stable iodine tablets	children	12516.4		379253.3			

Strategy 1037, label:Demo ines 7 event; High population area, similarity value:0.675

Strategy 1038, label:Demo ines 7 event; High population area, similarity value:0.675

Strategy 1115, label:Chernobyl nuclear power plant accident; Pripyat, similarity value:0.688

Figure 8. Similar pre-defined scenario calculated with JRodos for the release phase.

4 Conclusion

Supporting systems for emergency management have emerged by and by for several years, often specialized for certain disaster types and mostly with the need to be installed on local machines. Obviously, different fields of applications require their own parameters and result analyses. However, there are common structures that have encouraged the generic system design of this work which can be facilitated individually or extended in an easy way: The connection to the database, control of program flow as well as generation of the input masks are event-type dependent and configured with XML files. Furthermore, the web-based approach provides easy-to-access decision support for users located in different places as well as a comfortable way to exchange already calculated data. The presented architecture of our decision support system addresses the requirements arising in case of preceding natural disasters or other events triggering nuclear emergencies as well as experts that advise decision-makers being at different places. In future, the extension of the database is envisaged as well as further in-depth analysis of uncertainty issues and different event types. Furthermore, end users' needs with respect to visualization as well as a feasibility study of integrating the system into the operational procedures of emergency management are important topics as well.

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