NERIS

NERIS Workshop 2015

State-of-the-art and needs for further research for emergency and recovery preparedness and response

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PROCEEDINGS

EDITORIAL

In 2014, the NERIS Platform decided to organise yearly international workshops dedicated to topics relevant for the Platform. The first meeting was held in Milano, Italy on the 27-29 April 2015 and organised in cooperation with the University of Milano. The Workshop gathered 68 participants from Europe and Japan. 37 papers dedicated to the three research areas of the NERIS Strategic Research Agenda and the implementation of the Basic Safety Standards on emergency and recovery issues were presented. The Workshop was an opportunity to discuss and exchange with NERIS Members, International organisations, and European and Japanese Research communities on research priorities in the frame of nuclear and radiological emergency preparedness and recovery. It was an event rich in discussion and debate on the current results of the research and identification of evolving topics.

Session 1 on modelling highlighted the need for improvements in atmospheric dispersion models notably to better address multi-scale modelling, urban dispersion and confined spaces, and source term assessment. Related to the aquatic modelling the necessity was identified to provide better models for decision-makers, as measurements are generally not sufficient in the emergency phase to characterise the situation. For the marine environment, although models are already available, there is a need for developing more accurate costal dispersion model as well as improving the modelling for radionuclide transfer to sediments and biota. For freshwater, models already exist but may need better adaptation tools to customise them for specific environments, e.g. Japanese rivers and reservoirs.

Session 2 focussed on existing decision support systems. The major issue identified was the limited treatment of uncertainty in model parameters. It was stated, that work has to be devoted in future to reduce model and parameter uncertainty. In addition communication to decision makers on the complexity of the models and their limitations has to be improved. This includes the uncertainty in prognostic results and advice provided by the tools.

Session 3 provided feedback on experiences and challenges concerning the decision-making processes and the implementation of the European Basic Safety Standards. In this context, the development of monitoring strategies was discussed as well as work on external exposure assessments notably following the Fukushima accident. For the recovery phase, the optimisation of countermeasures and the soil vulnerability were debated. Key challenges for the following years are the better management of uncertainty, notably for the measurements, and the degree of conservatism to be considered by the decision makers. First lessons from the Fukushima accident identified the importance of all practical aspects of decontamination and the use of the reference levels.

Session 4 was dedicated to stakeholder engagement and dialogue. It is worth to notice that this issue is now clearly at the agenda for emergency and recovery preparedness and response. The presentations during the workshop revealed the need for flexibility in approaches to decision-making, open to identification of new and unanticipated problems and issues. Such approaches should take into account local knowledge and experiences, and be grounded on stakeholder engagement processes and dialogue. Understanding the local situation is crucial. In addition, it is essential to keep in mind that in the management of the situation, radiological protection issues are important, but others such as socio-economic, health and cultural issues related to day-to-day life in affected territories are equally important. For the future, it is notably expected to further investigate methods for societal deliberation, bringing together science and values in policy support, and to develop mechanisms for co-expertise between local stakeholders and experts. This should address, among other, people's concerns and behavioural patterns ; the sustainability of countermeasures; and the issue of trust and credibility of the expert in the context of emergency and recovery situations.

Session 5 focussed on information tools and channels, in particular social media. Provision and ensuring access to reliable information was clearly acknowledged. In this perspective, it was mentioned that a long-term information and data collection process might be more effective if relying on local stakeholders themselves. The recent evolution of social media provides various ways and methods for collecting information. In order to improve the quality and reliability it is essential to anticipate mechanisms of cooperation in this domain. To support this, a number of research topics were identified, such as the analysis of information needs in the different situations and for the different stakeholders as well as the development of risk communication tools. To set up reliable and accessible information in a pro-active way has also been mentioned together with further investigations on approaches for data interpretation.

This workshop clearly contributed to reinforce the NERIS strategic research agenda, taking into account the preliminary feedback from the Fukushima accident and the results of on-going research projects in emergency and recovery situations. It was also an important step to reinforce NERIS cooperation with other European Research Platforms in the area of radiological protection (MELODI, ALLIANCE and EURADOS), in the context of the European research projects OPERRA and CONCERT.

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Strategic Research Agenda

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Introduction

Created in 2010, the aim of the NERIS Platform is to establish a forum for dialogue and methodological development between all organisations and associations taking part in decision making of protective actions in nuclear and radiological emergencies and recovery in Europe. The objectives of the Platform are to contribute to improving the effectiveness of current approaches for preparedness, promoting more coherent approaches, identifying gaps and needs for further developments, addressing new and emerging challenges and maintaining and improving know-how and technical expertise in this field.

The NERIS Platform has been registered on the 28th of August 2012 as a legal European Association under the French Law to reinforce its structure and to ensure its sustainability. Currently, 54 organisations from 24 different countries are members of the NERIS Platform, with 26 organisations (called “NERIS supporting organisations”) being legally members of the NERIS Association and supporting it financially.

The NERIS R&D Committee (composed of 12 members) elaborates the strategic orientation of the Platform based on the new areas of interest identified by the Working Groups and the expectations and demands of the NERIS partners. This paper presents the current version of the NERIS Strategic Research Agenda, as updated on April 2014.

1. KEY TOPICS OF THE NERIS STRATEGIC RESEARCH AGENDA

The Strategic Research Agenda (SRA) has been structured in three main research areas covering new challenges in atmospheric & aquatic modelling, new challenges for better dose assessments and decision support based on improved knowledge and new challenges in stakeholder involvement and local preparedness and communication strategies.

1.1. Area 1: New challenges in atmospheric & aquatic modelling – Needs for improvement.

Area 1 deals with dispersion of radioactive materials (in solid or gaseous form) in the atmosphere or in water systems. Most of the challenges in atmospheric dispersion are related, on one hand, to dispersion in urban and confined environments, and on the other hand to very short- or very long-duration releases (explosions and Fukushima type releases). New programming techniques and more efficient algorithms enable today modelling of different urban environments and very short-duration releases. Development of rapid data assimilation techniques and inverse modelling are associated with all kind of dispersion modelling and should be further improved to obtain better situation awareness in the very early phase of an emergency. The same applies to source term estimation.

The Fukushima accident proved the importance of dispersion of radionuclides in coastal environment, pointed out a real need to develop site-specific models. Furthermore, any coastal dispersion model should be linked with an ocean model as driving force. Contamination of drinking water with radionuclides in intentional or accidental releases is also an area which requires further research. In general, the linkage between transport and dispersion modelling and dose assessment models has to be intensified and interfaces harmonised.

1.2. Area 2: New challenges for better dose assessments and decision support based on improved knowledge: source term, scenarios, etc.

Area 2 deals with Decision Support Systems (DSS) and the decision-making processes in case of nuclear or radiological emergencies including the longer term rehabilitation issues. On one hand, the DSS include several simulation models such as dispersion and dose assessment models, and in this respect they are closely related to topics in Area 1. Source term estimations are of primary importance, particularly the knowledge of the composition to develop appropriate countermeasure strategies. In this respect, estimation of the source term based on in plant data, dose rate monitoring and in general applying optimised monitoring strategies is of high priority. Developing computational models to simulate the recommendations for the countermeasures on the operational/tactical level can better link the crisis centre to the commander in chief locally (Command and Control (C2) systems).

The Fukushima accident demonstrated the need for a European platform where data and information of governmental and non-governmental organizations can be collected on one hand and on the other hand made available to all interested parties. This kind of access/exchange platform might be an important tool in order to achieve more coherent decisions. On the other hand, the analyses of the management of the consequences of the Fukushima accident point out the importance to understand and possibly improve/foster the decision-making processes at the local, regional and national levels. Various issues have been identified to better structure the decision processes and to provide further guidance for their implementation. This comprises providing accurate information, favouring efficient use of existing DSS and tools and allowing a better allocation of resources for reaching efficient protective strategies responding to the expectations of the various stakeholders in emergency and recovery phases.

1.3. Area 3: New challenges in stakeholder involvement, local preparedness and communication strategies.

Area 3 deals with stakeholder involvement, local preparedness and communication strategies in an emergency and recovery situation. In this area, communication and information issues are of great importance due to requirements for huge amount of information and measurements, use of modern social media through Internet, and possible contradictory information being available. The Fukushima accident demonstrated on one hand that new European stakeholders were engaged in decision making to protect European citizens in Japan. Foreign governments advised different protective actions to their citizens, which created confusion within the public. Iodine tablets were sold out in Europe without proper justification; some countries introduced restrictions on food import, many embassies relocated from Tokyo, etc. On the other hand, the follow-up of the management of the consequences of the Fukushima accident in Japan leads to revisit the existing framework for public participation notably in the perspective of the Aarhus Convention and ways for improving the implementation of protection strategies. In this context, the objective in this area is to further improve the strategies for ensuring appropriate stakeholder engagement, information exchange and dialogue between different actors (stakeholders, public, authorities) in emergency and recovery response and preparedness,

2. Perspectives

For the future, one of the key challenges is the organisation of the common road map on radiation research in Europe with the other research Platforms (MELODI, ALLIANCE and EURADOS) in the perspective of European research programme Horizon 2020. This road map will have to be elaborated taking into account the first lessons drawn from the management of the consequences of the Fukushima accident, as well as the evolution of international and national organisations' emergency and recovery strategies. In this perspective, the work performed in the NERIS Platform will have to be deepened and shared with all interested stakeholders.

References

NERIS: Strategic Research Agenda of the NERIS Platform. Version 2 (Draft04), April 8, 2014

NERIS Web site: www.eu-neris.net

NERIS TP final report. NERIS-TP(WP6)-(14)-03

SESSION 1 – CHALLENGES IN ATMOSPHERIC AND AQUATIC MODELLING

Atmospheric dispersion modelling to locate the source of airborne radioactivity – do we use all the know-how we have?

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Abstract

Year 2014 proved that, despite modern and sophisticated science and technology, it is not an easy task to detect all events in the atmosphere. It was surprising that modern and technologically developed countries were not able to locate the big passenger airplane when it disappeared with its 239 passengers on its route from Kuala Lumpur to Beijing in March 2014. It was neither encouraging to see that the modern and sophisticated technology was not able to locate, or nobody has published the exact origin of the missile that destroyed the passenger airplane in Eastern Ukraine on its route from Amsterdam to Kuala Lumpur in July 2014 killing 295 people. With regard to observations of artificial radioactivity in the atmosphere, the question arises whether we can locate the source of radioactivity by using modern dispersion models and the best available know-how. It might be possible if several dispersion models are run simultaneously for backward, inverse simulations of dispersion of detected radioactivity in the atmosphere. A great number of atmospheric dispersion models are today in operational use in Europe and, if airborne radioactivity is detected somewhere, or in several places in Europe during a short time period, these models can be used to locate the source of the radioactivity. Uncertainties in using one model and one detection are perhaps too big, especially if the source of radioactivity is far away from the detection site, but use of several models simultaneously and/or several detections could yield a sufficiently accurate positioning. This would of course presume fluent cooperation of emergency management organizations in Europe and the NERIS Platform is the suitable forum to create such cooperation. It is important to locate the source of radioactivity in a case when either authorities of the source country or the source facility deny any releases of radioactivity.

1. Introduction

Transparent authorities of nuclear and radiation safety should publish all abnormal observations of radioactivity in the environment. This is a prerequisite for public confidence in the authorities. After publication of such observations there could be immediate questions about the source of the detected radioactivity, and in the modern and open society the public expects that authorities have knowledge about the source. Otherwise there will be suspicions of concealment of information and weakening of the public confidence, especially within the public media. Amounts of detected abnormal radiation or radioactive substances have not remarkable influence on loss of the public confidence. Therefore radiation and nuclear safety society should have methods to identify quickly the sources of abnormal detections of radiation even though the detected levels of radiation would not warrant any health concerns.

If the detected increase in radiation or amounts of radioactive substance are remarkable from radiation protection point of view, need to identify the source is even more important and acute to be able to protect the rescue workers and the population. Authorities having responsibility for implementation of protective actions need to know what has been released, where it was released, where the release is going and how dangerous the release is. If the source is not known by other means, backward or inverse simulations of atmospheric dispersion models could be used to locate the source and estimate its strength. A good review of source estimation methods is provided e.g. by Rao (Rao et al. 2007).

A great number of atmospheric dispersion models are today in operational use in Europe. These models are used to model the atmospheric transport of radioactivity from sources to radiation detectors (forward modelling), but these models can also be used for reverse direction, from the detectors to the upwind sources (backward modelling). This paper deals with possibilities for determining source characteristics with atmospheric dispersion models, and put an open question if there is still room for enhancement of capabilities of European authorities and research organizations to quickly identify unknown sources of radioactivity; do we use all the know-how we have? One of the major problems in quick utilization of backward modelling is availability of fresh radiation monitoring data. The ongoing European PREPARE project is working with improvement of faster exchange of data and information about exceptional radiation situation (http://www.prepare-eu.org/index.php).

2. Problem-setting

In January 2015 there were 185 nuclear power reactors in operation and 17 under construction in Europe (http://www.euronuclear.org/info/encyclopedia/n/nuclear-power-plant-europe.htm). At the same time there were 137 research reactors in operation or under construction in Europe (http://nucleus.iaea.org/RRDB/RR/ReactorSearch.aspx). In addition there are thousands of industrial, medical or educational facilities producing or using radioactive substances in Europe. From time to time there will be smaller or bigger releases of radioactive substances from these facilities due to incidents or accidents, or there might be a malicious use of radioactive substances causing release of radionuclides into the environment. In addition to facilities with known radiation sources also other operations can result in the release of radioactivity into outdoor air. One very potential source is scrap metal smelteries, and accidental meltings of radioactive sources hidden in the scrap have taken place several times. If abnormal radionuclides or radiation are detected in the environment, one of the immediate tasks is to try to identify the source of radioactivity.

A great number of atmospheric dispersion models are in operational use in Europe to simulate the atmospheric transport and dispersion of radioactive substances from a source to downwind. Usually same dispersion models are used both for emergency type purposes like radioactive release and for air quality forecasting (e.g., SILAM in Finland (Sofiev et al. 2006) and MATCH in Sweden (Robertson et al. 1999). This is extremely important practice because daily use and comparison of more common release types give an important feedback of the behaviour of the atmospheric dispersion models. Also the decision support systems developed for management of off-site consequences of nuclear or radiological emergencies in Europe, RODOS (https://resy5.iket.kit.edu/RODOS/) and ARGOS (http://www.pdc-argos.com/), contain dispersion models (MATCH, ATSTEP, RIMPUFF and DIPCOT). The most sophisticated dispersion models are based on either Lagrangian or Eulerian dispersion routines, but still also Gaussian dispersion models are used. The models are developed for either near-range (up to few hundreds kilometres) or long-range (up to thousands of kilometres) dispersion calculations. One aim of these models is to prognosticate dispersion of radioactive substances in the atmosphere and to assess their radiological consequences to the population and the environment.

History of the atmospheric dispersion models began in 1940s when the analytical Gaussian plume models were introduced. These simple models are still useful in short-range dispersion calculations up to a few tens of kilometres from a source. Because they are fast and simple to use, in emergency cases they are a competitive solution compared to the more sophisticated models, when the timescale and distances are pretty short.

The atmosphere is a chaotic system. When the timescales and distances grow, complexity increases. In these cases simple, analytical solutions are not enough. Lagrangian random-walk models compute thousands or even millions of particles' motions in the atmosphere following turbulent eddies. Eulerian dispersion models solve the same problem in a grid. A known amount of pollutants in the grid cell disperses to the neighbouring grid cells following dispersion equations.

In a case of point source, both of these methods are equally good and results do not usually differ very much from each other. More uncertain parts in dispersion calculations are numerical weather prediction (NWP) models, which give the weather information to the atmospheric dispersion models. The NWP models can be very high resolution non-hydrostatic models or more coarse hydrostatic models (e.g., HARMONIE vs. HIRLAM (http://hirlam.org/index.php/documentation/), global or limited area models (e.g., ECMWF, (http://www.ecmwf.int) vs. HIRLAM). Their resolution can be from tens of metres to the couple of kilometres and up to tens of kilometres depending on their purposes.

The finer resolution of the NWP models the more complex events they can present. Non-hydrostatic NWP-models can form single rain showers, while hydrostatic NWP-models present large-scale and convective rain. A trend in the NWP model development is towards finer resolution. Importance of a probabilistic approach in the atmospheric dispersion model increases, when the resolution of the NWP models becomes better and thus a co-operation between different operators all over Europe will be more important.

Atmospheric dispersion models can also be run backwards in trying to determine the source characteristics (source location, source strength, etc.), if abnormal radioactivity is monitored in the environment. This kind of source estimation is, if possible, even more challenging than forward dispersion modelling due to several new factors:

- There might be only one monitoring/detection result available and the source is unknown
- There might be a weak source close to the monitoring/detection site
- There might be a strong source more remote from the monitoring/detection site
- If the source location can be identified, the source strength may remain open
- There might be detection results available at several monitoring sites in the same time
- There might be detection results available at several monitoring sites but in different times
- Several sources or geographically extended source (e.g., forest fire)
- Long sampling times in sampling of airborne radioactivity
- Great uncertainties in the source identification

This paper deals with possibilities to enhance capabilities of European organizations for identification of source characteristics when exceptional radioactivity is detected in the environment. Several organizations have some capabilities for determining source characteristics, but the question is if these capabilities could be improved by combining the efforts, resources and monitoring results of different European organizations.

3. Source estimation

Atmospheric Transport Modelling (ATM) has been utilized for a long time in attempts to identify sources of radioactivity if abnormal radiation or radioactive substances have been detected in the environment. Global efforts in this problem is put by the preparatory Commission for the Comprehensive Nuclear Test-Ban-Treaty Organization (CTBTO) together with the World Meteorological Organization (WMO) (http://www.ctbto.org/publications/information-materials/, Issartel et al. 2003), but also national organizations and the European Commission have developed methods to identify origin of radiation detected in the environment.

The global monitoring network of CTBTO consists of 80 stations which use air samplers to detect radioactive particles released from atmospheric nuclear explosions and those vented from shallow underground or underwater explosions. Half of these stations also monitor radioactive xenon, which can enter the atmosphere after an underground explosion. CTBTO also has a global network of 16 sophisticated laboratories making a more thorough analysis of radioactive particles samples. The radionuclide network is complemented by seismic, infrasound and hydroacoustic monitoring networks covering the whole globe.

For the CTBTO framework, the available observational data is then not necessarily limited to atmospheric radionuclide observation. In case of nuclear test, seismic signal could be detected by the global monitoring network and used for providing location estimate for the observed seismic event. This seismic location data would then need to be combined with radionuclide observations and ATM to provide complete picture. As seismic signal generally provides a more accurate source location, the preferred modelling approach might be to concentrate on forward atmospheric transport calculations in an effort to explain radionuclide detections from the network.

An example of the capabilities of the CTBTO monitoring network and combining different monitoring technologies with ATM is the detection of radioxenon in Canada in 2006 related to an underground nuclear test in the Democratic Peoples Republic of Korea. Following the nuclear test on the Korean peninsula on 9 October 2006 detected by seismic monitoring networks, a Canadian CTBTO monitoring station detected elevated levels of Xe-133 between 21-25 October. Backward ATM calculations confirmed the sensitivity of the Canadian station to an emission originating from the Korea Peninsula. Forward ATM calculations using the event coordinates obtained from seismic signals further revealed how the hypothetical release from the site spread across the Pacific Ocean and Canada before reaching the CTBTO monitoring station. ATM modelling was also used to rule out contribution from an alternative source (Saey et al. 2007).

The European PREPARE project is developing source estimation methods through data assimilation of gamma dose rate measurements and atmospheric dispersion models (Kovalets et al. 2014). Applied methods for determining source characteristics for emergency response applications are described in relevant scientific literature (Wotawa et al. 2003, Rao et al. 2007, Rudd et al. 2012, Flesch et al. 1994, Tsiouri et al. 2010, Yee et al. 2008, Yao et. al. 2011, Winiarek et al., 2011).

Dispersion models were also applied in another European project (DETECT) aiming at optimization of networks (number and sites of the monitoring stations) for monitoring of environmental radiation (Helle et al. 2014).

The most reliable way to find the source is data-assimilation. The ability of the Finnish SILAM dispersion model to locate the source has been tested in case of ETEX-experiment (Sofiev et al. 2006) and Chernobyl accident (Sofiev et al. 2007). These cases proved that the observations play a key role in tracing the sources. In case of Chernobyl, inverse simulations appeared complicated due to the absence of the information for the first days. SILAM manage to find the real source point only because few stations appear to be under the original plume from the reactor. Also Winiarek et al. (2011) underlined importance of observations.

The data-assimilation methods are computationally heavy and use of them requires high-level know-how, but they also improve model results, when both initial stage and emission rate are adjusted (Vira and Sofiev, 2010). Their properties are at their best when the case is analysed afterwards or it lasts longer. In those cases they can significantly help to estimate the strength of the release. This possibility has been used for volcano eruptions (e.g., Petäjä et al. 2012, Vira et al. 2013) and Fukushima nuclear accident (e.g., Masson et al. 2011, Katata et al. 2012, Schopner et al. 2012, Winiarek et al. 2012).

Faster - but not that accurate - possibility to find sources is footprint (or backward/inverse) simulations when the dispersion is computed just backward in time. This kind of computations does not give an exact point of the release, but rather a probability where the source could locate (e.g. Fig 1a). They are fast and they can be run during the case. In addition of the dispersion, they can also take into account wet and dry depositions. Footprint computations are possible using both Eulerian and Lagrangian approaches.

Eulerian and Lagrangian inverse calculations and backward trajectories have been compared with each other e.g. in cases of long-range transported pollen (Veriankaitė et al. 2010). Many pollen types - like birch, alder and hazel pollen - can transport hundreds and sometimes even thousands of kilometres and cause allergic symptoms before or after local flowering season. Footprint computations can help to understand also this phenomenon. Results of Veriankaitė et al. showed that all the methods (including backward trajectories) gave almost similar picture of the events in most of the cases. In the most complicated cases the use of trajectories is, however, more risky. Backward trajectories are very easy and fast method and also persons, who are not familiar with atmospheric dispersion models, are able to use them. In contrast to the advanced dispersion calculations, the interpretation of the result is more demanding. Trajectories cannot take into account complex dispersion and depositions. For example, users should approximate effect of rain by themselves and do several different runs using a bit different setups to get a proper picture of the sensitivity of the case. However, ensemble trajectories (e.g., Figs 1b and 1c) can help in this work.

One example of combining observations at several locations of a release with a likely single origin and subsequent inverse modelling using various dispersion and weather models was detection of abnormal high concentrations of Cs-137 in Nordic countries in April 2013 (http://www.stuk.fi/julkaisut_maaraykset/tiivistelmat/b_sarja/fi_FI/stuk-b174/, Söderström et al. 2014). In Helsinki and Stockholm, where daily samples are collected, Cs-137 values peaking at about 50µBq/m^3 and 23 µBq/m^3 at samples collected between 11-12 April and 12-13 April respectively, were detected. The normal Cs-137 level is below 5 µBq/m^3 at both locations. The origin of the source was researched using available ATM capabilities. Figure 1 shows comparison of various computational models for Helsinki and Stockholm. The figures 1a – 1c show inverse calculation results whereas in figure 1d, a forward dispersion from suspected source point is provided.

The source of the detected Cs-137 was most likely a smeltery in Elektrostal (55.8°N, 38.5°E) 60 km east from Moscow, where a Cs-137 source was reported to been melted around 8-12 April. Both SILAM and HYSPLIT support the conclusion that Stockholm and Helsinki observations might have a common origin but due to a large potential source area no definite conclusion could be drawn. A forward calculation (figure 1d) confirms that the release would have reached Nordic countries.

Abnormal levels of Cs-137 were detected also in other sampling locations than Helsinki and Stockholm. However, due to longer sampling times, often 1 week, did not provide a good starting point for inverse modelling. The long sampling times are generally dictated by economical and organizational constraints but it should be recognized by the responsible organizations that these sampling arrangements do not generally provide a sufficient starting point for inverse modelling.

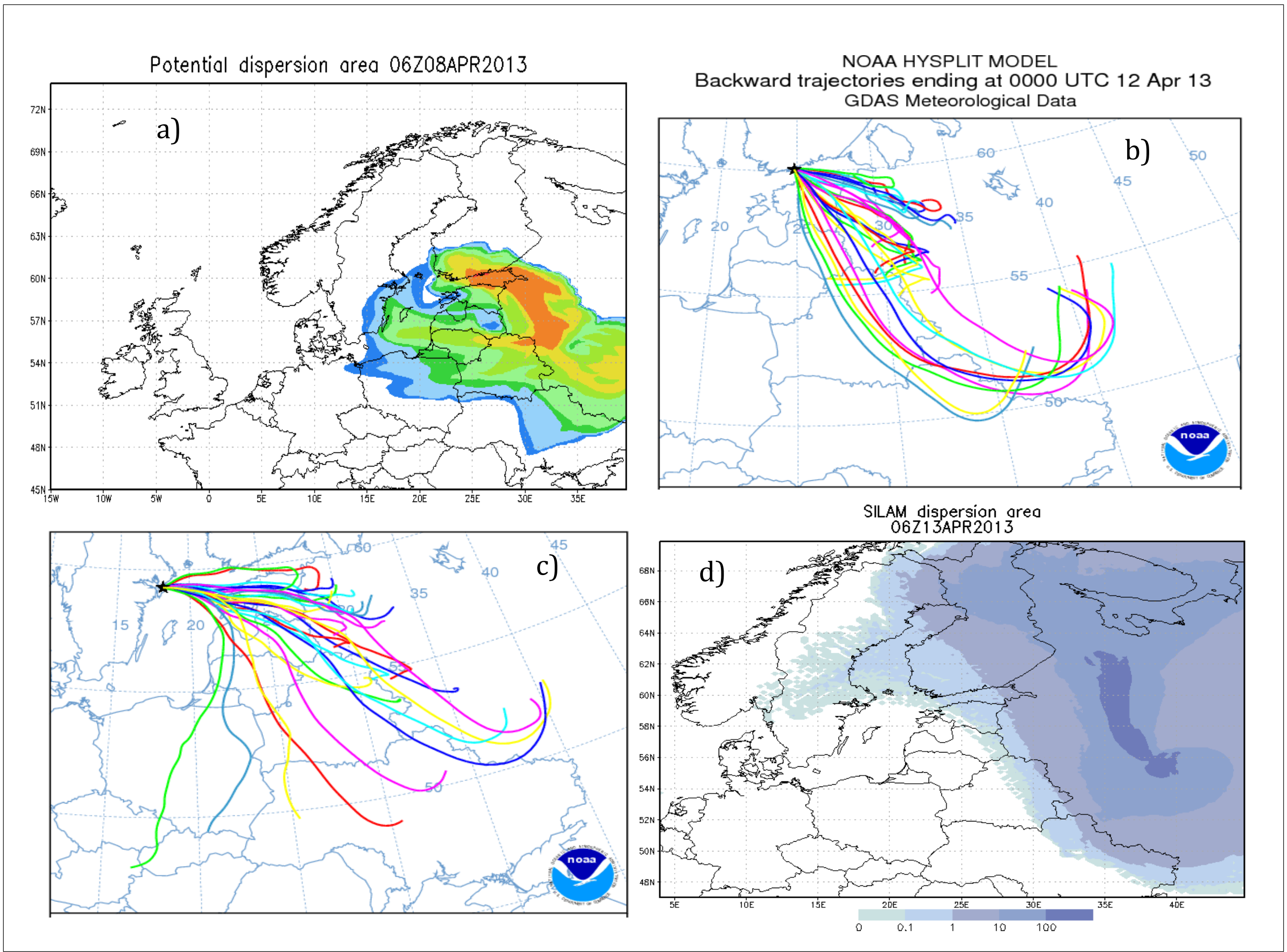

Figure 1. a) SILAM inverse dispersion model for Helsinki. The sample collection period is 12 April 00 UTC – 13 April 00UTC 2013 and particles have been followed backwards for 78h. b) HYSPLIT ensemble trajectories calculated every hour for Helsinki starting 12 April 00UTC and extending 72 hours backwards in time. c) HYSPLIT ensemble trajectories calculated every hour for Stockholm starting 12 April 08UTC and extending 72 hours backwards in time. d) Forward SILAM calculation 5 days ahead from the suspected source.

In February 2013 Br-82 was detected in two subsequent samples collected in Helsinki between 24.2-26.2.2013 and 26.-27.2.2013 (STUK 2014). The detected concentrations were about 5 µBq/m^3 and 15 µBq/m^3 respectively. Br-82 is a relatively short-lived (t½=35.3h) radionuclide used as a tracer in industrial measurement. Br-82 was reported to been used in industrial measurements between 26 – 28 February 2013 in the municipality of Lohja. Lohja is situated about 60km west from Helsinki. Subsequent inverse dispersion calculations using the SILAM model confirmed that the reported test site was a likely source of the observed Br-82 (Fig. 2).

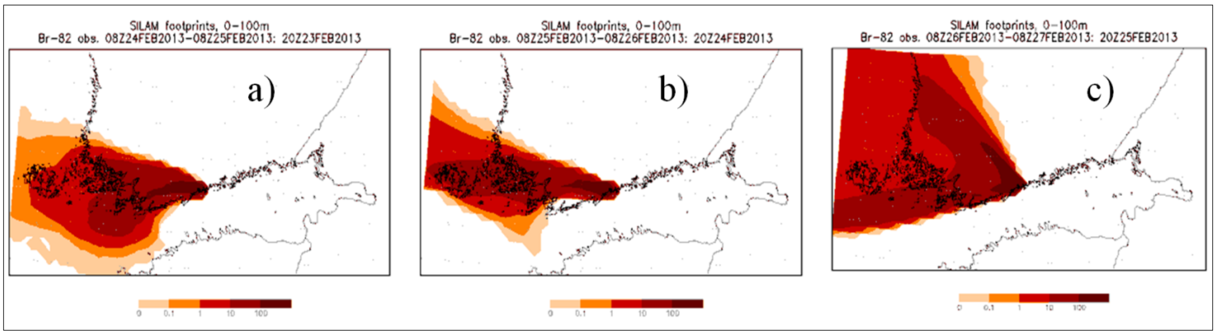

Figure 2. SILAM footprints (12-36 h backward) for identification of source of airborne Br-82 detected in Helsinki in February 2013. Footprints for Br-82 observations on a) Feb 24, b) Feb 25 and c) Feb 26.

Another example of successful backward tracking was the case in Australia when origin of a series of atmospheric radioxenon detections was identified in winter 2008-2009 (Tinker et al. 2010). The detections of airborne radioxenon were done at the CTBT monitoring station in Melbourne. First long range backward trackings showed that the two potential sources of radioxenon in the Southern Hemisphere, one in South Africa and another in Argentina, could not be the sources of radioxenon. Short range backwards trackings, covering a dispersion period of up to 3 days, indicated that the release was initiated at the nuclear facilities of the Australian Nuclear Science and Technology Organisation (ANSTO) producing radiopharmaceutical ^{99}Mo in southern Sydney.

4. Do we use all existing know-how in Europe?

Experiences around the world show that there is know-how enough to perform successful backward tracking of abnormal radiation detections in the environment. The major weakness in the present practices is the fact that most of the source estimations are performed afterwards, meaning that our readiness to exploit them in an emergency situation is quite limited. In order to speed up the response opportunities, radiation monitoring data should be near real-time and quickly available to the authorities of the countries whose territory might be affected by the radioactive release. Also other countries should have the same information to be able to advise their citizens in the affected countries.

The Council of the Baltic Sea States (CBSS), the European Commission (EC) and the International Atomic Energy Agency (IAEA) (http://www.cbss.org/, https://eurdep.jrc.ec.europa.eu/Basic/Pages/Public/Home/Default.aspx, http://www-ns.iaea.org/downloads/iec/info-brochures/13-28111-irmis.pdf) have developed official international systems for exchange of information and radiation monitoring data for emergency preparedness purposes. These systems are extremely important tools in management of radiological and nuclear emergencies and in coordination of international protective actions. However, at the moment we do not have any commonly agreed methodologies or procedures to identify the origin of abnormal detections of radiation or radioactivity in the environment in a situation where, for one reason or another, there is no information from the country of origin of an exceptional event. Therefore, it is important that Europe continues to develop the information exchange systems so that authorities and research organizations in different countries could combine their available resources. At expert level such systems have already been developed, but their deployment need official international decisions.

The "Ring of Five" (*Ro5)* was established within the International Union of Radioecology to enhance and speed up exchange of information and monitoring data at expert level. It is an informal club based in Europe with the purpose of exchanging data on occasional concentrations of man-made radionuclides in the atmosphere (http://www.iur-uir.org/en/task-groups/id-22--ring-of-five-task-group). The ongoing PREPARE project within the EURATOM FP7 is working with establishment of the Analytic Platform of European dimension being a focal point for collecting information, analyzing any nuclear or radiological event and providing information about the consequences and its future development. As PREPARE project is also developing source estimation methods by using data assimilation of gamma dose rate measurements and atmospheric dispersion models, the question arises if Ro5 and PREPARE could together focus on development of near real-time methodologies and knowledge data base for estimation of the source characteristics (source location, source strength, etc.). Europe as the array of more than 30 countries with various cultural backgrounds and differences in administrative culture needs a common information and data source where national experts could find information and data and also evaluation results almost in real-time for their own assessments.

NERIS (http://www.eu-neris.net/) as the European platform for improving the current European, national and local preparedness on management of nuclear or radiological emergencies and promoting more coherent approaches in different European countries is an ideal forum to encourage European organizations to join their efforts in development of methodologies and tools for the source estimation. New activities in determining source characteristics should be included in the ongoing European Research Framework Programme (HORIZON 2020), and the developed tools and methods should be implemented in operation use by the EC (DG ENER/D) when they are available. It is self evident that data fusion (combining different calculations) for source location identification and utilization of full potential of European trace networks and national ATM capabilities would bring a real net benefit to the whole Europe.

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The needs for improvement of atmospheric dispersion capabilities for decision support systems

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1. Introduction

After Chernobyl accident a lot of activities have been undertaken in order to develop modern decision support systems (DSS) in case of a nuclear emergency and to increase capabilities of atmospheric dispersion models. Among them one can mention development within the consecutive EU Framework Programmes the RODOS (Real-time On-line DecisiOn Support) [Ehrhardt] system for nuclear emergency, the ENSEMBLE platform [Galmarini1] for the evaluation and analysis of atmospheric dispersion models or development of Danish decision support system for emergency management ARGOS (http://www.pdc-argos.com/). Similarly in the United States a lot of efforts have been devoted for the improvement of ARAC (Atmospheric Release Advisory Capability) tools [Sullivan] and READY (Real-time Environmental Applications and Display sYstem [Rolph]) in NOAA. In Japan SPEEDI/WSPEEDI [Chino] system has been developed by JAERI. The Fukushima accident has shown, however that, there are still some issues regarding emergency planning and support of decision making, for which better solutions should be found. Most current DSSs use atmospheric dispersion models originally developed many years ago, but there is an ongoing process to make them more accurate and reliable. Nevertheless one can identify a number of areas where there is a need for further improvement taking into account both progress in the development of geophysics models as well as fast growth in increasing computing capabilities during recent years, which can be applied in DSSs. It is obvious that in order to improve capabilities of atmospheric dispersion models it is necessary to consider also meteorological models, hence the models for flow simulations are also considered in the paper. In the following sections these issues are discussed basing on many years' experience in using the RODOS system and ENSEMBLE platform as well as exploitation of high performance computing techniques. A number of mentioned above issues was discussed during the Workshop on "Atmospheric dispersion models and Decisions Support systems in the frame of CBRN events" organized by the DG Joint Research Centre, on 16-18 June 2014 in Varese, Italy. Some findings of this workshop relevant to the topics considered here are also included in the paper. Finally some basic concepts for the development of new generation of DSSs are proposed.

2. Key areas for further improvement

During recent years a number of initiatives has been undertaken for the improvement of atmospheric dispersion models for different scales and for various purposes: emergency preparedness and response, air quality and crisis management related to CBRN events. Despite of the various aims it is reasonable to take advantage from all of different experiences related to them. Basing on this one can identify the following areas important for improvement of atmospheric dispersion for decision support systems:

- Multi-scale approach for integration of different modelling scales of atmospheric dispersion models.
- Urban modelling and complex terrain problems.
- Simulations in confined spaces (building, underground systems).
- Use of advanced models like CFD (computational fluid dynamics) or similar class.
- Dirty bombs, blast models, CBRN events.
- Uncertainty modelling, probabilistic weather forecast, sensitivity analysis.
- Data assimilation techniques, coupling with geo-statistical methods.
- Inverse modelling, source term reconstruction techniques based on atmospheric dispersion simulations.
- Model evaluation: needs for field studies, wind tunnel and life experiments, model inter-comparison, numerical experiments, deposition data for model validation.

- Possible application of high performance computing (HPC): adaptive meshes, code parallelization.

Certainly some of these issues are clearly linked to the others, but in our discussion we would like to point out the key aspects of all them.

In general there are six types of atmospheric dispersion models: Gaussian plume, segmented plume, Lagrangian puff, Lagrangian or Monte Carlo particle, Eulerian and CFD. They differ in numerical approach for perfoming simulations and/or in the accurcy of treating environmental processes. In current DSSs typically separate models or modules are used for different scales or specific situations like urban or complex terrain. For short range still Gaussian-type models are often applied due to its short computation time needed for simulation. On the other hand long range models are typically Eulerian or Lagrangian. Some specialized models are used for urban agglomeration. In reality this variety can cause problems in case when there is a need to simulate transport and dispersion in environment which cannot be treated uniformly by one model. In fact not so many attempts have been made towards integration of various modelling scales (spatial and temporal). For example for air quality problems such an approach have been proposed for high-fidelity fine-scale simulation of pollutant concentrations within roadway and building microenvironments as a combination of CMAQ and CFD models [Huber]. In the United States a chain of models (COAMPS - mesoscale, HIGRAD - High-Resolution *Model* for Strong Gradient Applications, FEM3MP – CFD model based on finite element method [Chan]) has been considered to simulate properly the flow in urban environment. The scale of these models is related to the resolution of: 1km, 10-100m and 1-10m grid steps, respectively. In the RODOS system short and long range models can be linked in one simulation although this option is seldom used. However, probably the main problem in multi-scale approach lies in proper transfer of information from one to the other scale. This concerns first of all appropriate configuration of the models for either down- or upscaling to include more detailed description of physical processes in first case or relevant averaging and transferring data in the second case. Secondly, there is always a question about software interfaces which would allow to make integration process easier.

Urban and complex terrain modelling are typical problems which can be related to few elements mentioned in the list above, namely:

- application of CFD models,
- utilization of high performance computing,
- need for validation of the models and therefore need of experimental data of various type (wind tunnel, studies of experiments in cities, numerical experiments),
- uncertainty modelling.

In order to apply urban models in DSS the key point is how fast the model can produce the results. It is quite obvious that even on big computing clusters, in principle, the most accurate CFD models cannot give the results in time enough short to be useful in crisis management. Therefore there is a need for simplified models, but still sufficiently accurate. As an example of work in this direction one can mention QUIC package of Los Alamos National Laboratory [Williams] containing, among others, two basic modules:

- QUIC-URB: fast response mass consistent 3D urban wind model, where wind field is prescribed basing on an incident flow and various flow effects associated with building geometries,
- QUIC-PLUME: the Lagrangian dispersion model that uses the mean wind fields from QUIC-URB and turbulent winds computed internally using the Langevin random walk equations. The lateral and vertical mean motions and horizontal gradients are described in turbulence parameters. Dissipation effects and drift terms are included along with non-local mixing formulation.

In order to validate the models of this type few approaches can be used:

- validation against wind tunnel experiments,
- validation against city experiment (like Joint Urban 2003 Atmospheric Dispersion Study Oklahoma City),
- comparison with refence models, typically CFD or dedicated numerical models for fluid like EULAG (EUlerian/semi-LAGrangian) [Prusa].

A proper balance between simplicity and accuracy in urban and complex terrain modelling is anyway the key factor.

Similar problems also happen in dispersion modelling in confined spaces like building or underground areas. In these cases proper simulation of flow can be a delicate matter as one should take into account forced or natural ventilation and system of channels in complex geometries. Again CFD models can be useful for simulation of fluxes, however setting boundary conditions is not always straightforward. Nevertheless, the results of CFD simulations can be used as reference data in case when there is lack of experimental data. This can be helpful in the development of the fast response models. As an example of such model one can mention QUIC-INDOOR routine from QUIC package. It should be also noted that two situations should be taken into account: when the release is indoor or it comes from outside. In the latter case transfer data from the other atmospheric dispersion model is usually necessary.

We have already mentioned CFD-type modelling several times. In principle one can distinguish between two different types of model classes: general purposed (commercial or not) like Fluent, CFX, STAR-CCM+ or OpenFoam, and dedicated to simulate geophysical flow like FEM3MP, EULAG or QUIC-CFD. The other division comes from different numerical treatment of the Navier-Stokes equations. The most accurate DNS (Direct Navier-Stokes) models can be applied for simple geometries. LES (Large Eddy Simulation) models are probably the most useful for atmospheric flow as RANS (Reynolds Averaged Navier-Stokes) models, which demand additional equations for modelling turbulence to close the system of equations seem to be more adequate for modelling flows in technical installations like pipes, steam generators, etc.. The main purpose of CFD modelling is better understanding of flow characteristics, and eventually generation of datasets that could be useful for verification of simplified atmospheric dispersion models. Direct use of CFD models in DSSs, at present could be of very limited use, however in the future this will be gradually changing along with a progress in high performance computing.

As far as CBRN events are considered several problems should be addressed:

- How the material is dispersed: in this respect there is an obvious need for blast model. On the other hand the dirty bomb can be initially dispersed over quite a big area, which means that the model should able to deal with data scattered practically in random way – hence the Lagrangian or Monte Carlo types of simulations seem to be useful techniques.
- Characterization of source: typically it is not known how big the source term is and very often its location can be somehow only approximated. This means that probably the optimal solution would be to have a stochastic model, either based on stochastic differential equations explicitly or at least with build-in capabilities in dispersion modelling for source term defined in terms of probabilistic density function [Neuman].
- Model validation: there is a general need for experimental data for blast and not only for open areas. Numerical experiments could be also helpful – in this respect CFD models can be applied. There is also general concern on availability of deposition data needed to test models and develop new ones.
- Similarly as for urban modelling there is a need for simplified methodologies, which however should be properly validated. As an example one can mention CERES methodology [Armand] developed by CEA (France), which deals with 4D modelling and simulation of potentially hazardous releases.

The problem of dealing with uncertainty has been already mentioned. There are some issues which need special attention:

- Use of probabilistic weather forecast: ECMWF and NCEP provide ensemble forecast, but these datasets can be hardly applied directly in DSSs simply because it would be time consuming process to perform simulations. It seems that a possible approach can be based on extraction of the most important information from ensemble weather forecast and transferring it to atmospheric dispersion model in terms of stochastic distribution of key meteorological parameters (like wind field, precipitation) or by selection of few representatives of the whole ensemble dataset. In both cases this is strictly related to sensitivity analysis. In order to use efficiently the information from ensemble weather prediction system, in principle atmospheric dispersion models should have built-in features allowing for treatment of stochastic data.
- Uncertainty treatment within atmospheric dispersion models: some models (like Flexpart [Stohl] or Hysplit [Draxler]) allow performing simulation for a set of parameters in one run, thus providing a kind of ensembling. Making interface to ensemble weather forecast would be a step forward for better integration.
- Use of multi-model ensemble systems: this can be an attractive approach as many simulations can be performed simultaneously. Nevertheless there are still some problems to be solved like: selection of the models to be included into ensemble or appropriate processing

and analysis of the results. Extensive research has been made in recent years in this direction [Solazzo], but still there is lack of practical procedures for the choice of the models although some techniques have been developed. A series of exercises undertaken on the ENSEMBLE platform [Galmarini2] has shown that it is possible to deliver, useful for decision making, information on uncertainty of the results of atmospheric dispersion models in short time.

Data assimilation techniques have been utilized for many years in numerical weather prediction systems. However application these methods to atmospheric dispersion models to correct the prognosis is very seldom. Some attempts were undertaken with Rimpuff model within the activities related to the development of the RODOS system. Including in models real measurement is not a straightforward task – good understanding of what is really measured and how is a necessary condition to make it. Information on uncertainty of measurement is also important. Sometimes the problem is related to the fact that the measured values are not directly calculated by the models (like gamma dose rates versus activities). The measurements give usually point information only, so it seems that geo-statistical methods allowing for determination of spatial distribution of measured quantity could be used to combine with the spatial distribution of model predicted values. This however, needs more sophisticated methods than using point data only. It should be also mentioned that new kind of measurement devices (for example based on infrared spectrometry) enable to provide more accurate data and sometimes their spatial distribution.

It has been already mentioned that one of the main sources of uncertainty is source term characterization. The reconstruction of basic source term parameters can be supported by inverse modelling, which is an iterative process. Starting with some source term parameters atmospheric dispersion simulations are performed and the results are compared with the measured data. The other technique is to run dispersion model in backward mode. Whatever approach is used the basic problem comes from the fact that, mathematically speaking, the inverse problem is ill-posed, which means that either no unique solution is guaranteed or the solution does not depend continuously on data. Hence, instead of looking for deterministic results one should rather rely on stochastic solutions providing probabilities of possible values of the parameters characterizing the source term.

The need for model evaluation and validation have been already mentioned. In this respect one should consider a wide range of various field studies undertaken in different meteorological conditions and environment (for example in urban agglomeration) or wind tunnel experiments. It is commonly agreed that there is also a need for deposition data, not only air activities. Numerical experiment, for example the results of high fidelity CFD simulation, could be used as reference data for the improvement of existing models and development of new ones. Then the appropriate platform for model inter-comparison and analysis, like ENSEMBLE, can be a helpful tool for model developers.

High performance computing can be regarded as a basic platform for performing advanced calculations like CFD simulations or supporting other time consuming time tasks, for example sensitivity analysis or uncertainty modelling. In most cases HPC will not be directly applied in DSS, however there should be a possibility to transfer complex DSS tasks to HPC. This can be organized either in the form of dedicated services (a kind of service on demand) and/or cloud computing. A lot of work can be also done in model development and implementation process – this concerns:

- code parallelization and optimization,
- application of effective numerical libraries and some standardized interfaces,
- preparation of meshes for specific regions (like urban areas) – two techniques can be applied:
    - the grid is structured and voxelization is needed for mapping the spatial objects (like buildings) into the mesh to be tailored to grid boundaries,
    - adaptive meshes are used, hence non-structured grid is applied in simulation.

It is truism to say that the role of HPC is constantly growing and, more and more complex models will be used in the future. The question however, is that without appropriate program for continuous expanding of usage of HPC in DSS, application of advanced models is becoming difficult and will be delayed. This is caused by the fact that in order to use efficiently HPC in DSS many efforts have to be made as this is time consuming task.

Conclusions

In a new generation of DSSs more advanced atmospheric dispersion models should be included with a possibility of using high performance computer clusters. One can expect that a number of dedicated models will be coupled via well defined interfaces, so the user will be able to define a chain of the models operating in different spatial or temporal scales in order to perform efficient simulations for the situation under consideration. Real time on-line monitoring data will be used, firstly for better estimation of source term, and secondly for data assimilation to make the diagnosis and prognosis of radiological situation more accurate. Uncertainty of data and models will be provided and taken into account in simulations. In order to develop such DSS a number of activities should be undertaken:

- various sets of experimental data are needed to improve and validate current atmospheric dispersion models or develop new ones;
- research related to modelling processes at different scales in atmosphere is needed and should be supported by availability to high performance computing tools, which enable performing complex simulations;
- development of software techniques enabling for better integration, code parallelisation and building complex systems is needed.

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The impact of different types of atmospheric dispersion model on the extent of estimated countermeasures

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Abstract

Estimations of countermeasure extents are required in both emergency planning and emergency response assessments. Consideration of the local practical and geographical issues is required when determining the region where countermeasures are to be implemented, but for the purposes of this study only estimates of effective and thyroid dose are considered when estimating countermeasures extents.

Determining countermeasure extents on the basis of a technical study assessing accident scenarios requires the consideration of atmospheric dispersion processes. This study considers the theoretical application of two different types of atmospheric dispersion model, one based on a Gaussian plume approach and the other based on a Lagrangian Particle Model (the UK Met Office's NAME model) in a probabilistic framework.

Assuming sheltering, evacuation and the administration of stable iodine are all implemented on the basis of the UK's ERLs, the study presented here estimates numbers of people and geographical areas affected for three different hypothetical source terms and four different hypothetical coastal sites. These sites bear no relation to existing or proposed UK nuclear sites, and neither do the source terms assumed bear relation to potential source terms from current or proposed UK nuclear sites; the assumptions are for illustrative purposes only. The aim of the study is to identify if the consideration of different types of atmospheric dispersion model is likely to impact on the extent of the estimated countermeasures.

1. Introduction

Estimations of countermeasure extents are required in both emergency planning and emergency response assessments. Determining countermeasure extents on the basis of a technical study assessing accident scenarios requires the consideration of atmospheric dispersion processes. The aim of the study is to identify if the consideration of different types of atmospheric dispersion model is likely to impact on the extent of the estimated countermeasures.

2. Model descriptions

PACE (Charnock *et al.*, 2014) is a probabilistic accident consequence assessment tool developed by PHE, within a geographic information system (ESRI ArcGIS [TM]). There are two atmospheric dispersion modelling approaches implemented within PACE and both are considered in this study. The first is NAME, a Lagrangian particle dispersion model developed by the UK Met Office (Jones *et al.*, 2007). The second is Adept, an implementation of the Gaussian plume approach proposed by Clarke (1979).

3. Methodology

Four release locations were selected at random at coastal sites around England (denoted NW, NE, SW and SE for the remainder of this paper).

Two source terms were considered in this study, scoping the potential releases considered in the assessment of the radiological consequences for a proposed (in the 1980's) pressurised water reactor (Jones and Williams, 1988b; Jones and Williams, 1988c; Jones and Williams, 1988a). The scenarios considered include a relatively large source term and 1 hour release duration (denoted by 'ST1'), and a moderately sized source term and 10 hour release duration (denoted by 'ST2'). A relatively small source term and 1 hour release duration was also evaluated but all respective model endpoints were zero and therefore this source term is not considered further in this paper. A release height of 10 metres was assumed in all cases. Source terms ST1 and ST2 are illustrative and do not necessarily bear relation to potential source terms from current or proposed UK nuclear sites.

Four dimensional meteorological gridded fields (on a 12 km x 12 km horizontal grid, a vertical grid split into a total of 31 levels to a maximum height of 19 km above sea level and an hourly temporal grid) from the UK Met Office's Unified Model were applied in NAME. Single site meteorological data was extracted from the respective 4D gridded met data at the location of the release and applied in Adept.

The dispersion scenarios considered in this study were derived using three years of 4D met data (2004, 2006 and 2008) and for each year 188 different meteorological sequences were sampled (using a cyclic sampling method), ensuring the diurnal and annual variability was suitably accounted for. For each meteorological sequence the maximum number of people and geographical area affected by the implementation of evacuation, sheltering, stable iodine prophylaxis countermeasures were estimated. It was assumed that such countermeasures are implemented where the UK's Emergency Reference Levels (ERLs) are exceeded (National Radiological Protection Board, 1990).

4. Results and Discussion

A statistical analysis of the results across all 188 meteorological sequences has been carried out to determine mean, maximum, 50th and 95th percentiles for each year (i.e. the mean of the 188 maximums, the maximum of the 188 maximums, the median of the 188 maximums and the 95th percentile of the 188 maximums).

For approximately two thirds of the scenarios assuming a relatively low dose threshold (i.e. 3 mSv for effective dose and 30 mSv for thyroid dose) the numbers of people and areas affected estimated using NAME was greater than when using Adept for the largest source term, ST1. In contrast (for the same ST1 source term) the numbers of people and areas affected derived using Adept was greater than when using NAME for 70-80% of scenarios considered where the dose threshold was relatively high (i.e. 30 mSv and 300 mSv for effective dose and 300 mSv for thyroid dose). For the moderate source term, ST2, the majority of countermeasure extents were zero (62% of statistical endpoints across all scenarios where both Adept and NAME derived results were zero and 35% where NAME derived results were zero but Adept derived results were non zero), with only 3% of scenarios where both NAME and Adept estimated non zero values.

Table 1. Analysis of the agreement and disparity between NAME and Adept derived numbers of people and areas affected resulting from the implementation of evacuation, sheltering, stable iodine prophylaxis countermeasures

	Percentage (%) of all scenarios where:							
	A&N=0	R<2	R<3	R<10	R not less than 10	A_{10}>N & (N≠0)	N_{10}>A & (A≠0)	(A≠0) & N=0
Mean	25	55	65	75	25.4	2.5	0.0	22.9
Maximum	25	54	60	73	27.5	4.6	0.0	22.9
50th percentile	50	77	84	92	8.3	0.0	8.3	0.0
95th percentile	31	58	68	81	18.8	0.0	0.0	18.8

Note:

R is the ratio of Adept versus NAME for a particular endpoint, where A refers to Adept and N refers to NAME. A_{10}>N refers to instances where countermeasure extents derived by Adept are a factor of 10 (or more) greater than the respective values derived by NAME and N_{10}>A refers to instances where countermeasure extents derived by NAME are a factor of 10 (or more) greater than the respective values derived by Adept. Also note that 'A&N=0' represents instances where NAME and Adept results are both zero and '(A≠0) & N=0' represents instances where Adept results are non-zero, whilst the respective NAME results are zero.

There exists relatively good agreement in the extent of emergency countermeasures using both NAME and Adept in PACE for ratios within a factor of 2 (Table 1), especially for the median statistical endpoint (however this is primarily because of the large percentage of instances whereby the results derived using Adept and the respective results derived using NAME are both equal to zero), but relatively poor agreement for ratios within a factor of 10 (however this is principally because of the large percentage of instances whereby the Adept result is non zero whilst the respective NAME result is zero).

For countermeasure extents based on an effective dose greater than 300 mSv nearly 10% of NAME versus Adept comparisons resulted in differences of a factor of 10 (or more), all transpiring for the maximum statistical endpoint and ST1 source term, the largest difference occurring at the NW site and no differences of a factor of 10 (or more) occurring at the NE site, with five out of nine occurring in a single year (2004), and encompassing the only scenario in 2006 which resulted in differences of a factor of 10 (or more) (Table 2). In contrast, differences of a factor of 10 (or more) when comparing NAME and Adept derived countermeasure extents based on a thyroid dose greater than 30 mSv, transpired for only mean and median statistical endpoints (of which the former always corresponded to the ST2 source term and the latter always corresponded to the NE site and 2008), but not at the NW site and not in 2006. The magnitude of the largest differences in countermeasure extents derived using Adept and NAME were typically factors of 10 to 100, but up to 170 was observed (for thyroid dose at 30 mSv).

On analysis of Table 2 it is evident that for the 95th percentile statistical endpoints no differences of a factor of 10 (or more) in the countermeasure extents derived by Adept and NAME were identified for any of the scenarios considered in this study.

Table 2. Matrix of the 35 model scenarios and dose thresholds which resulted in differences of a factor of 10 (or more) between the model endpoints as derived by Adept and NAME

	Source Term		Site				Year			Statistical Endpoint				Model Endpoint									
Scenarios (numbered)	ST1	ST2	NE	NW	SW	SE	2004	2006	2008	Max	Mean	95^{th} %ile	50^{th} %ile	No 3mSv Eff	Area 3mSv Eff	No 30mSv Eff	Area 30mSv Eff	No 300mSv Eff	Area 300mSv Eff	No 30mSv Thy	Area 30mSv Thy	No 300mSv Thy	Area 300mSv Thy
1	●					●	●			●								●					
2	●					●		●		●								●					
3		●				●			●		●									●			
4		●				●			●		●										●		
5	●			●			●			●						●							
6	●			●			●			●								●					
7	●			●			●			●									●				
8	●			●					●	●						●							
9	●			●					●	●								●					
10	●			●					●	●									●				
11	●				●		●			●								●					
12	●				●		●			●									●				
13		●			●		●				●									●			
14		●			●		●				●										●		
15	●				●				●	●									●				
16	●		●				●						●			●							
17	●		●				●						●				●						
18	●		●				●						●									●	
19	●		●				●						●										●
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21	●		●						●				●		●								
22	●		●						●				●			●							
23	●		●						●				●				●						
24	●		●						●				●							●			
25	●		●						●				●								●		
26	●		●						●				●									●	
27	●		●						●				●										●
28	●		●						●				●	●									
29	●		●						●				●		●								
30	●		●						●				●			●							
31	●		●						●				●				●						
32	●		●						●				●							●			
33	●		●						●				●								●		
34	●		●						●				●									●	
35	●		●						●				●										●

Notes:
"No" = numbers of people affected, "Area" = area affected, "Eff" = effective dose, "Thy" = thyroid dose.

It is evident that the broader atmospheric conditions (eg boundary layer depth, atmospheric stability, precipitation and wind speed) are significant in the determination of the maximum extent of the countermeasures when derived using NAME, but much less so when applying Adept. In contrast the wind direction and the close proximity of the estimated model endpoint (from the release location) appear to be key factors in determining the maximum extent of the countermeasures when derived using Adept. Bedwell *et al*., 2011 demonstrates that estimates of time integrated activity concentrations in air of the order of one kilometre downwind from the release location are greater when derived by the R91 (Clarke, 1979) Gaussian plume method (akin to the method applied in

Adept) compared to NAME. Furthermore, air concentrations derived on the basis of R91 are described by a narrower cross-wind plume profile, whereby concentrations decrease more rapidly with distance (perpendicular to the direction of travel of the plume) from the nominal 'plume centre line'. Further still, air concentrations decrease more rapidly with distance from the release location when using R91. It was often observed that the maximum number of people or area affected when applying Adept occurred where the wind direction was such that it advected the plume directly towards the closest land based receptor point (i.e. the centre point of the nearest grid square). Repeatedly the Pasquill Stability Category (PSC) associated with the maximum countermeasure extents was simply that which happens to occur in conjunction with the critical wind direction (frequently PSC D). In contrast, air concentrations decrease more gradually with distance (i.e. of the order of a few kilometres) from the release in NAME than in Adept (Bedwell *et al*., 2011), in part because NAME applies a box averaging approach and thus estimates are averaged over a volume (rather than at a specific point), resulting in greater scope for the meteorological conditions (rather than the modelling approach) to influence the magnitude of model endpoints derived.

Only four mean statistical endpoints where differences of a factor of 10 (or greater) in estimated countermeasure extents derived by NAME and Adept were evident and all four correspond to the only four ST2 source term scenarios where differences of a factor of 10 (or greater) were observed between NAME and Adept. This is due to the heavy bias towards zero model endpoints estimated (over the 188 met sequences sampled) when running NAME. An example is the number of people affected by thyroid doses greater than 30 mSv following a release of the ST2 source term from the SE site in 2008 (Table 3). Adept assumes that for each hour of release the meteorological conditions remain constant (for the rest of the life of that element of the release), supporting a relatively narrow but concentrated plume and deposition footprint. NAME accounts for changes in meteorology as a function of space and time, including changes in the wind direction, which tends to result in the plume becoming more disperse. This effect is likely to be amplified for a protracted release duration (as considered for ST2) where the variability in the meteorology considered alongside NAME will be magnified, and thus the NAME derived plumes further dispersed.

As previously mentioned, when running Adept in PACE the maximum air concentration over the 188 met sequences considered will tend to occur at the closest land based receptor point to the release location and for a wind direction blowing from the release location directly towards the centre point of the respective grid square. In contrast, when running NAME in PACE the maximum air concentration tends to be more closely tied to the meteorological conditions, notably stable atmospheric conditions alongside a relatively low boundary layer depth and low wind speed. It is thought that for a coastal site where the prevailing wind advects the plume inland, a higher frequency of the former conditions over the course of a year are likely to prevail, relative to the combined latter conditions (a hypothesis supported by the results detailed in Table 2).

NAME estimates which are a factor of 10 (or more) greater than Adept typically occur for 50th percentile results for sheltering, evacuation and the administration of stable iodine (across 8.3% of all scenarios for median endpoints). It is evident from Table 2 that all median anomalies occur at a single east coast site (and an example is detailed in Table 3). It is thought that this is due to a combination of the prevailing wind direction in the UK (from the south-west), the magnitude of the source term and the difference in NAME and Adept's handling of meteorological data. As a result of this site being located on the east coast, releases of radioactivity are most likely to travel out to sea. Adept's handling of meteorological data results in the majority of radioactive plumes being advected out to sea and result in relatively minimal impact on the UK population. Likewise, a large proportion of radioactive plumes modelled in NAME will initially be advected out to sea, however, because NAME is able to account for meteorological conditions changing as a function of space and time, some of the plumes advected out to sea are likely to circulate and be blown back onto the mainland. Thus when running NAME there is the likelihood of a greater proportion of relatively 'moderate' impacts on the UK population and therefore typically larger 50th percentile values. The resolution of the grid squares and their position relative to the release location and the wind direction is also important. As previously highlighted, the Adept model results are based on a value at the centre of each grid square whilst NAME averages model particles over a grid box. Therefore if the main body of the plume slightly intersects a grid box, NAME will account for the contribution from the main body of the plume but Adept will not, thus fostering relatively 'moderate' impacts on the UK population and therefore typically larger 50th percentile values for NAME model runs.

Table 3. Ratios of estimates of the numbers of people affected derived using Adept and NAME, for a range of dose thresholds and model scenarios

	Mean	Maximum	50th Percentile	95th Percentile
Ratios of the numbers of people affected by effective doses greater than 3 mSv following a release of the ST2 source term from the SE site in 2004	N/A[1]	N/A[1]	N/A[2]	N/A[1]
Ratios of the numbers of people affected by effective doses greater than 30 mSv following a release of the ST1 source term from the NW site in 2004	4.5	19	2.4	4.0
Ratios of the numbers of people affected by thyroid doses greater than 30 mSv following a release of the ST2 source term from the SE site in 2008	22	1.2	N/A[2]	N/A[1]
Ratios of the numbers of people affected by thyroid doses greater than 300 mSv following a release of the ST1 source term from the NE site in 2006	0.12	0.24	0.014	0.29

Notes:

Note that 'Ratio' is the value derived by Adept divided by the respective value derived by NAME. The ratios labelled 'N/A[1]' apply to instances where the NAME derived value is zero and the Adept derived value is non-zero. The ratios labelled 'N/A[2]' apply to instances where the NAME and Adept derived values are both zero.

It is evident that median estimates of countermeasure extent tend to be greater when modelled by NAME but the maximum is greater when modelled by Adept. Two endpoints are considered in this study, the geographical area (affected by the implementation of countermeasures) which, barring the potential influence of the sea, is uniform, and the number of people (affected by the implementation of countermeasures), which is significantly influenced by demographics which are non-uniform. Thus estimates of numbers of people (affected by the implementation of countermeasures) can be associated with significant step changes whereby the region within a pre-defined threshold dose encompasses a significant population centre (eg a village or a town) when applying one model but not the other. Under such circumstances it is feasible for the Adept and NAME results to flip from zero to a large positive value over a relatively small percentile range but at different percentiles. Above this small percentile range the derived values are relatively large and in good agreement and below this percentile range the derived values are both zero. The magnitude of the source term, combined with the percentile being considered is very relevant to whether or not significant differences between Adept and NAME derived countermeasure extents are present. In addition the wind direction and the location of the large population centres (relative to the release location) play a significant role in determining the location (and therefore the magnitude) of the maximum number of people affected by doses above a specified threshold.

It is worth noting that in this study hypothetical nuclear sites are considered alongside representative population data. As a consequence members of the public reside uncharacteristically close to a nuclear site. Furthermore it is recognised that at distances less than a few kilometres downwind R91 based approaches should be applied with great caution and with the understanding that larger uncertainties are typically associated with such estimates.

5. Conclusions

In the majority of scenarios the type of atmospheric dispersion model does not significantly impact on the extent of the estimated countermeasures. However for a small but significant percentage of scenarios the consideration of different types of atmospheric dispersion model does significantly impact on the extent of the estimated countermeasures. Neither atmospheric dispersion modelling approach considered here is found to be consistently conservative, so this could not be used as the basis for informing model use. Countermeasure areas which are unnecessarily large will not only be costly in terms of resources to implement, but are also linked with negative health and socio-economic effects, especially for evacuation, which may outweigh the health benefit from the intended dose saving. Because a clear pattern of applicability of model types to different types of scenarios was not defined, the recommendation would be to utilise a more representative modelling approach and data where possible and where time permits. However, for the 95th percentile statistical endpoints no differences of a factor of 10 (or more) in the countermeasure extents derived by Adept and NAME were identified for any of the scenarios considered in this study. It would be of value to explore this further in an effort to identify if this is a universal trend or specific to this study.

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Real-time simulation of the near-range atmospheric dispersion using Computational Fluid Dynamics

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1. Abstract

Nuclear and radiological accidents from the past have demonstrated the detrimental impact radiotoxic clouds can have on the environment (see, e.g., Mahoney et al., 2004, or Ten Hoeve and Jacobson, 2012). In order to optimize the protection strategy after an accident in case of nuclear accidents, on-line risk management tools such as JRODOS are being developed (Landman et al., 2014). To this end, a fast and accurate prediction of the atmospheric dispersion of the radioactive nuclides released is crucial. Dispersion models based on segmented bi-Gaussian models, puff-models and particle models are usually applied in order to obtain a dose rate estimate in a short period of time. Yet all of them show fundamental shortcomings at the near-range i.e. within the first few hundred meters around the nuclear installation. Especially the limited ability to include buildings, vegetation and other large structures in the present models is known to hamper the accurate prediction of the dispersion near the accident. As releases are observed the fastest and the most accurately by the sensors closest to the nuclear installation, usually placed within a few hundred meters from an installation, this is particularly unfavorable for rapid source term estimation after an accident. In addition, the near-range can be specifically interesting to determine the location and the magnitude of the maximal impact of potential releases which is often found close to the release point. Moreover, also the planning of evacuation routes, the impact assessment on the operators mitigating an incident, the optimization of the monitoring equipment locations around the site, and the estimation of the release rate based on data assimilation can be addressed by an effective near-range dispersion model.

An alternative for the existing models is the use of computational fluid dynamics (CFD). Among many other applications, CFD allows to perform accurate air flow and corresponding pollutant dispersion simulations by numerically solving the Navier-Stokes equations and the advection-diffusion equation. The main advantage of this approach is that the air flow and the pollutant dispersion can be solved for very complex domains. Consequently, CFD has the potential of predicting the dispersion of pollutants accurately in an environment with many obstacles, like buildings and vegetation. By subsequently applying dose rate models, a dose assessment can be performed as a post-processing step (Vervecken et al., 2015). The aim of this work is twofold, i.e. illustrating how current state of the art CFD techniques can be used to set-up an accurate real-time simulation system and pinpointing additional research challenges.

2. Method

We use an Eulerian approach to simulate the pollutant dispersion from a stack release over an open field under neutral atmospheric stratification. The evolution of the concentration is formulated as a transient three-dimensional convection-diffusion problem:

$$\frac{\partial c}{\partial t} + \nabla \cdot (\boldsymbol{u}c) = \nabla \cdot D_t \nabla c - \lambda c + S \tag{1}$$

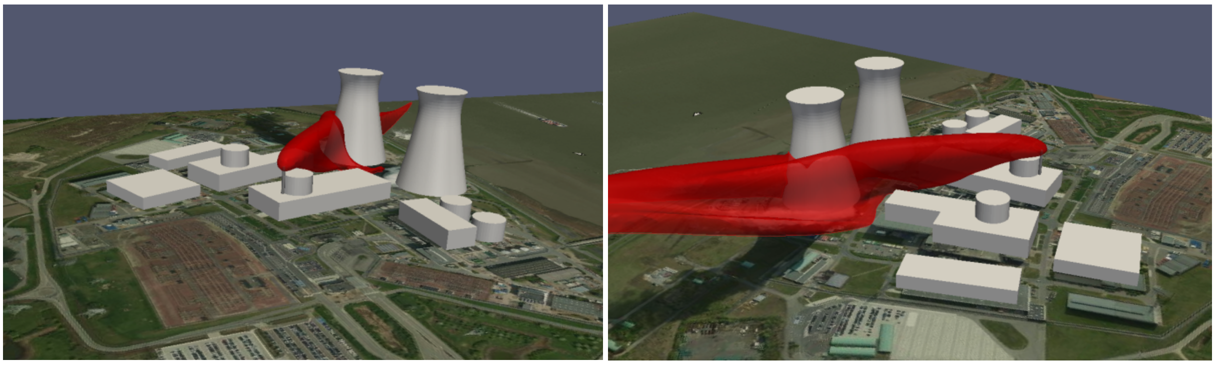

Figure 1: Isosurface of the concentration for a steady pollutant release at the Doel Nuclear Power Station from two different points of view.

where c is the pollutant concentration, $\boldsymbol{u}$ is the wind field, D_t is the turbulent diffusion coefficient, λ is the radioactive decay constant, and S is the pollutant source. The wind field can be computed by solving the Navier-Stokes equations using either time-dependent Large-Eddy Simulations (LES) (Nakayama and Nagai, 2009; Vervecken et al., 2015) or steady-state Reynolds-Averaged Navier-Stokes (RANS) simulations (Blocken et al., 2008; Vervecken et al., 2013). The main advantage of using a transient velocity field is the additional information on the expected fluctuations in dose rate due to turbulence that it provides.

The resulting dose rate can be directly derived from the computed pollutant distribution. The gamma dose rate at location $\boldsymbol{x}_0$ is computed from the gamma fluence rate. Using the point-kernel method with buildup factors, the latter can be evaluated as

$$\phi_{\boldsymbol{x_0}} = \iiint_V \frac{B(\mu,r)}{4\pi r^2} e^{-\mu r} \lambda c dx' dy' dz' \tag{2}$$

where $r^2 = (x_0 - x')^2 + (y_0 - y')^2 + (z_0 - z)^2$, V is the domain volume, μ is the linear attenuation coefficient in air and B is the dose build-up factor. Conversion of the local fluence rate into the local dose rate to a material can subsequently be achieved as

$$d_{\gamma,x_0} = \frac{E_\gamma \mu_{en}}{\rho} \phi_{x_0} \tag{3}$$

With E_γ the gamma energy released per disintegration, μ_{en} the energy absorption coefficient and ρ the density of the receptor. Hence, the resulting gamma dose rate is directly proportional to the gamma fluence rate.

Because of the compute-intensive nature of CFD however, it is unfeasible to use the coupled CFD-dose rate model as a real-time simulation system in a straightforward manner. Therefore, we derive a Reduced Order Model (ROM) from an accurate CFD model, thereby greatly reducing the computational time. It remains however very expensive and complex to construct a ROM which includes a transient velocity field. Therefore, we focus on the construction of a ROM for the time-dependent dispersion of a radioactive pollutant on the mean velocity background. We apply projection-based model reduction techniques to obtain the ROM. The basic principle of this method is the projection of the high order space, i.e. the discrete representation of Eq. (1) onto a Krylov subspace by means of the one-sided Arnoldi algorithm. In this way, the pollutant dispersion simulation can be reconstructed at a much reduced computational cost with respect to the full CFD model.

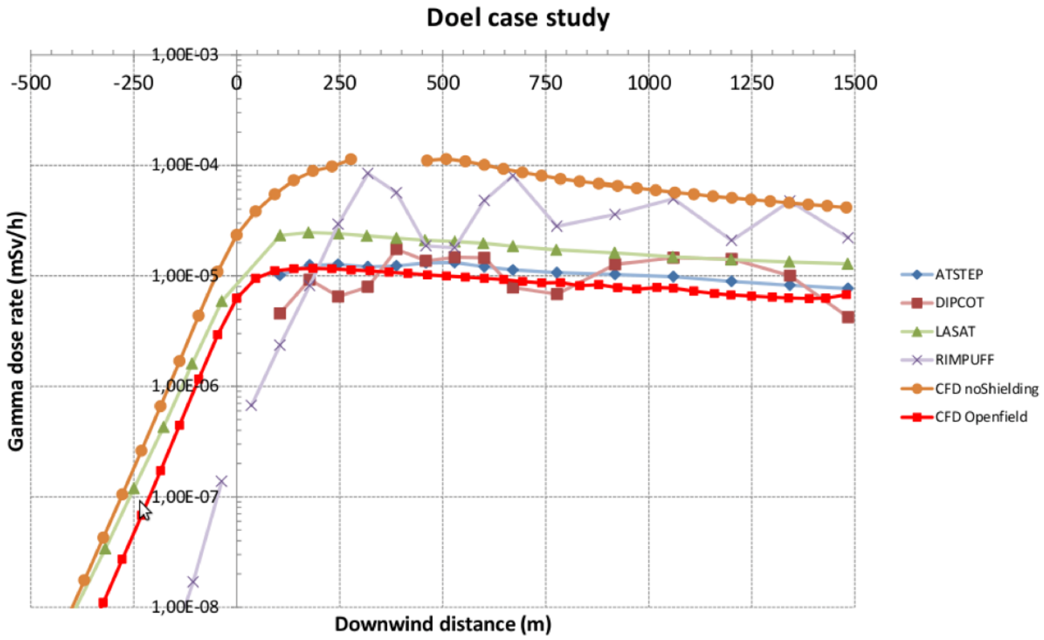

Figure 2: Comparison between four classical dose-assessment models and the coupled CFD-dose rate model applied to the dispersion of Xenon-133, released from Doel 3.

3. Results

We simulate the dispersion of a stack release of Xenon-133 from Doel 3 at the Doel Nuclear Power Station, located to the north of Antwerp (Belgium). Four cylindrical reactor buildings, two hyperbolic cooling towers and a number of cuboid auxiliary buildings are included in the simulation. The wind is set to come from the southwest, which is the prevailing wind direction for this location, and the wind speed is set to 20 km h^{-1} at stack height (74 m). The geometry of the case and the pollutant isosurface from a steady pollutant release is shown in Fig 1. A comparison of the resulting dose from a steady release, releasing Xenon-133 at a rate of 3.6 TBq h^{-1} with widespread used dispersion models implemented in JRODOS is found in Fig. 2. This graph clearly demonstrates the added value of the CFD approach. For sake of reference, also the dose rate from the dispersion in an open field computed using the coupled CFD-dose rate model is added to this graph. While the gamma dose rate in an open field is comparable to the existing models, a non-negligible increase in dose rate at the near-range is found in case of the Doel site. In particular within the first few hundreds of meters to the source, this difference runs up to more than an order of magnitude. The effect of this difference is twofold. First, if the source term is estimated using classical models based on near-range measurements, it is likely to get significantly overestimated. When the estimated source term is subsequently applied to long-range models, overly conservative countermeasures might be taken at longer distance. Second, when the effective dose to the employers on site is estimated based on near-range measurements, classical models are likely to result in a significant underprediction.

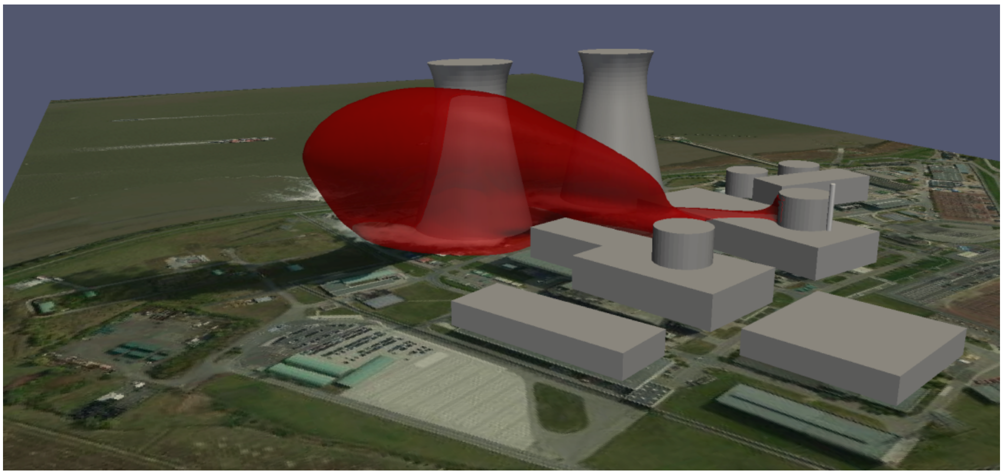

Figure 3: Isosurface for the instantaneous concentration for a time-dependent release of Xenon-133 from Doel 3.

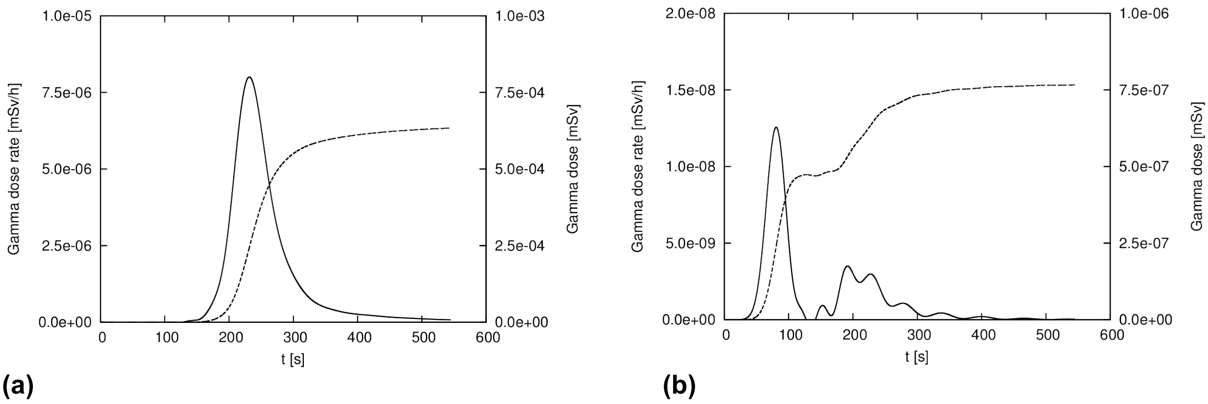

Figure 4: Time-evolution of the gamma dose rate (-) and the gamma dose (- -) at ground level at (a) 740 m along stream-wise direction, and (b) 222 m in stream-wise and 296 m in span-wise direction.

By applying projection-based model reduction techniques to the coupled CFD-dose rate model, a reduced order model is obtained which allows to simulate the dispersion of a pollutant in the built environment and subsequently perform the dose assessment faster than real-time. More precisely, with a minimal loss in accuracy, the computational time is reduced by a factor of 2500, running 25 times faster than real-time.

The run time of the ROM is of the same order of magnitude as classical Gaussian-based models. In order to illustrate the effectiveness of the model, we simulate a time-dependent release of Xenon-133 from Doel 3. The emission rate is modeled as a Gaussian function in time, releasing 3.6 TBq in total. The isosurface for the instantaneous concentration at 132 s after the onset of release is shown in Fig. 3. The time evolution of the dose rate and the total dose received at ground level at distance of 740 m from the point of release along stream-wise direction are shown in Fig. 4. The dose rate increases monotonically up to $t = 230$ s and monotonically decreases afterwards. This profile is significantly different from the observation at 222 m in stream-wise and 296 m in span-wise direction, shown in Fig. 4b. The influence of the buildings, including shielding, results in a strongly distorted profile with multiple peaks. It is clear that the ROM enables for fast dose assessment after the emission of a radioactive gas. Furthermore, it can also be applied in an inverse modeling context which enables for direct source term estimation from measurements.

4. Conclusions and additional research challenges

In this work, we illustrated how current state of the art CFD techniques can be used for the real-time simulation of the atmospheric dispersion of radioactive gases. First, the coupled CFD-dose rate model is applied to the dispersion of a steady release from the Doel Nuclear Power Station. With the coupled model, a non-negligible increase in dose rate at the near-range is found while the gamma dose rate in an open field is comparable to the existing models. In particular within the first few hundreds of meters to the source, this difference runs up to more than an order of magnitude. Therefore, when measurements are interpreted using classical models, this might result in overly conservative countermeasures at longer distance for a significant underprediction of the effective dose to the employers on site. By applying projection-based model reduction techniques to the coupled CFD-dose rate model, a reduced order model is obtained which allows to perform the dose assessment 25 times faster than real-time without a significant loss in accuracy. This is similar to the speed of existing models. Furthermore, it can also be applied in an inverse modeling context for direct source term estimation from measurements.

The reduced order modeling of the radioactive pollutant dispersion at the near-range opens whole doors for research and applications in the preparedness and response phases of nuclear emergencies. Before an on-line monitoring system can be set up however, a number of research topics need to be addressed. A non-zero pollutant emission velocity and the inclusion of buoyancy effects due to a temperature difference between the ambient air and the gas emitted have a non-negligible effect on the pollutant dispersion and should therefore be included in the model. This can be addressed by estimating an effective emission height using plume rise models but a direct handling in the CFD model is preferred. In addition, also thermal stratification of the atmospheric boundary layer can have an important influence on the dispersion. Hence, this should also be accounted for. For taking into account changing wind directions, parametric model order reduction might be considered. Finally, the experimental validation of the model will be key to convince the CFD and nuclear community of the proper operation of the model. To this end, the releases of small but measurable quantities of radionuclides from existing nuclear installations can be used to collect a high quality dataset.

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Challenges in aquatic modeling in case of accidental radioactive discharges in the marine environment

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Assessing the impact of radioactive discharges in the marine environment requires both measurements and modeling. In situ concentration data provide robust information at the time and locations of sampling and, if evenly distributed on a suitable geographical area, they provide a snap shot of the contamination picture. If depths are known, inventories and balances with industrial releases can be calculated. However, they are costly, time-consuming, seldom synchronous and they leave questions pending about how much is there between the sampling locations or before/after the measurements were performed. This is where modeling comes into play to complete the assessment and, if reliable enough, to carry out hindcasts and forecasts under several assumptions. Modeling contaminant dispersion in the marine environment usually involves 3 major compartments, seawater, the sediment, and biota. Marine modeling consists in 2 steps, the hydrodynamic dispersion of known source terms (from the accident) and the transfer between seawater and the sediment and biota compartments.

Ocean dynamics are known over the whole planet and hydrodynamic models are potentially available worldwide. They can operate in 3D (or in 2D in shallow waters), with variable time/space resolution. But to reliably calculate soluble substances dispersion, several prerequisites should be met: an accurate knowledge of local bathymetry; open boundary forcings; the source term and a previous validation of the model with the proper resolution and frame size. In case of an accidental radioactive discharge, the source term is usually unknown, apart from estimates by the operator (total amount in the leaking tank or fuel in the reactor). Another alternative is to use environment measurements at many points after the start of the accidental release and to attempt to build an inventory of the observed increase in the marine area. The recent case of Fukushima accident illustrates this strategy. Once the source term agreed, hydrodynamic can be run to simulate the dispersion of this release and match the results with observed data. In marine areas where hydrodynamics are very sensitive, hydrodynamic model heavily depend on basic hypothesis including mixing layer depth, tide, wind forcing, etc… This is the case off Japan east coast for example, where depth stratification requires 3D calculations and strong surface currents merge, producing powerful eddies. The recent comparison of 9 hydrodynamic models by the Science Council of Japan demonstrated divergences after only 3 months of dispersion. None of the available models had been validated prior to the accident. An example will be presented to illustrate how much an investment it is to validate a hydrodynamic model for use in case of radioactive release. Having a reliable hydrodynamic model is the key to marine assessment modeling because transfer to sediment and biota primarily depends on seawater concentration.

Radionuclide transfer to sediment involves interactions between dissolved radionuclides (filter < 0.45 μm) in seawater with the suspended and deposited particulate matter. Thus, the challenges in transfer to sediment modeling include the interaction of radionuclides with particles and the behavior of these particles down to the bottom, but also once they have reached the seabed. The size of particles is critical since the amount of radionuclides associated with a particle is inversely related to its size. The grain-size distribution of suspended matter (SM) and sediment is thus a critical issue because it varies widely between samples. A first challenge is to quantify the interaction of dissolved radionuclides with the seabed and with SM. Knowledge of the SM concentration and size/nature is obviously essential during an accidental release because these parameters may vary widely depending on the season, for example (phytoplankton bloom). The interactions of radionuclides with SM/seabed take time to reach a steady state, this is critical in the case of an accidental situation when high concentrations in seawater are only transient due to hydrodynamic dilution. Here lies a second challenge because parameters used to quantify radionuclide transfer to sediment (Kd) actually do not take into account the kinetics, nor the size/nature of particles. Furthermore, once SM has settled down on the seabed, transport of sediment particles still occur. Modelling multiclass size sediment transport is a third challenge.

Finally, in the case of an accidental release, after radionuclide concentrations returned close to background level in seawater because of dilution, radionuclides trapped in sediment remain locally. The inventory of this pool of radionuclides and the consequences of their presence in the seabed for a long time is a last challenge because contaminated sediments thus become a potential source of radionuclides towards the water column (and biota).

The biota compartment involves seafood, an obvious priority as regards human radioprotection. Radionuclide transfer to biota potentially includes two major routes, the direct interaction with seawater and the ingestion of contaminated food. Influence of sediment was usually considered as minor. However, though the reason need to be confirmed, observations in the marine fauna after Fukushima accident showed that contamination of bottom-dwelling species remains higher than in pelagic species. The question is how many compartments should best represent a species when attempting to model radionuclide transfer from seawater concentration? This includes the species itself, which may be represented by one or more compartments, with different transfer kinetics. This also includes its food, which is also a biota itself, so a recursive problem. For upper levels of the trophic web, the number of compartments becomes prohibitive. Besides, the transfer parameters between each interacting compartments must be determined. This may be not compatible with an operational model to be used in an emergency situation. An alternative option is to consider one compartment depending on seawater concentration with only two transfer parameters, a concentration factor in steady state (CFs) and a half-time (t1/2). CFs is the ratio between the concentration in the species and that in seawater in steady state (constant seawater concentration) and t1/2 characterizes the kinetics of the transfer process (including the radioactive decay). Adding an extra compartment to account for the trophic route is probably a good idea for upper levels of the food chain. Nevertheless, whatever the option taken, seafood includes highly mobile species (like fish). Their capture location is poorly indicative of the seawater concentration they have been exposed to, as well as for they preys. The consequence is a very high uncertainty when modelling the transfer to those species. An interesting question is to determine where is the greatest source of uncertainty? Does it lie in the oversimplification of the transfer modeling to biota (only one compartment depending on seawater level) or in the uncertainty on the seawater concentration itself (dispersion in seawater simulated by not validated hydrodynamic model, mobility of species)?

SESSION 2 – IMPROVEMENT OF EXISTING DECISION SUPPORT SYSTEMS

Implementation of a method for source term estimation based on measurements and atmospheric dispersion modelling for use in decision support systems

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Abstract

This paper presents the activities performed in the frame of the PREPARE Project towards developing and implementing in JRODOS an advanced computational technique for source term estimation based on measurements outside the nuclear facility and atmospheric dispersion modelling. The method is based on the variational approach. A cost function is formulated from the differences between (a) model predictions and measurements and (b) "first-guess" and estimated source term. For the model predictions, source-receptor matrices are employed based on the linear dependence of concentrations and gamma dose rates from the radionuclides emission rates. Currently the source-receptor matrices have been calculated by a Lagrangian dispersion model. The cost function is minimized with respect to the emission rates and the following quantities are assessed: (a) released activity and isotopic composition of release, (b) emission rate as a function of time, and (c) release height or vertical distribution of the release. The methodology is able to assimilate measurements of gamma dose rates, air concentrations and ground depositions. Important items that are addressed in the context of the methodology are the calculation of multiple-nuclides releases, the estimation of uncertainties in model predictions and measurements, the estimation of uncertainties in the first-guess source term and the calculation of the release height. The paper discusses the approaches that have been adopted to resolve the above items. The paper presents also the software implementation and the operation of the computational method in the frame of the Decision Support System JRODOS. Preliminary results for test cases are also presented and evaluated.

1. Introduction

The work presented in this paper has been performed in the framework of the collaborative project entitled "Innovative integrative tools and platforms to be prepared for radiological emergencies and post-accident response in Europe" – PREPARE, which is co-funded by the European Commission, under Grant Agreement n° 323287 and under FP7 theme "Fission-2012-3.3.1: Update of emergency management and rehabilitation strategies and expertise in Europe".

The basic features of the activity can be summarised as follows:

- The aim was to develop a technique for source-term estimation that could combine measurements taken at farther distances from the nuclear power plant with computations by advanced atmospheric dispersion models.
- The algorithm would be a "top-down" or "source inversion" algorithm, since source term is estimated by combining the solution of the atmospheric dispersion model with measurements, i.e., with information outside the nuclear power plant.
- In the cases of interest in this project, the source location is known – it is the location of the nuclear installation. Therefore, by "source term" it is meant that the following radionuclide emission characteristics are to be calculated: (a) released inventory and isotopic composition of release, (b) emission rate and its time-variation for each radionuclide, (c) release height or vertical distribution of the release
- In summary, the algorithm works by adjusting the emission characteristics (as modelled according to the dispersion model in use) so that results of the atmospheric dispersion model best match the available measurements (at the locations and times that the latter have been taken).

In the following section the developed methodology and the important issues that have been addressed will be described before its implementation in the Decision Support System JRODOS. For evaluation purposes, preliminary results from some test cases are also presented.

2. Description of the methodology

A variational methodology has been selected to solve the inverse modelling problem. This methodology is based on the minimization of a "cost" function and the use of "source receptor functions" (SRF). The cost function has been formulated on differences between: (a) model predictions and measurements, and (b) "first-guess" and estimated source term (Kovalets et al., 2013):

$$J(\mathbf{x}) = (\mathbf{y} - g(\mathbf{x}))^T \mathbf{R}^{-1} (\mathbf{y} - g(\mathbf{x})) + (\mathbf{x} - \mathbf{x}^B)^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x}^B) = J_1 + J_2$$

In the above relation, vector $\bar{x}$ is the source term (control vector) that consists of the different nuclides release rates at different time steps, vector $\mathbf{y}$ $\bar{y}$ contains the observations (measurements), $g(\cdot)$ $g(.)$ is the model operator – that calculates the model predictions at the locations and times of the observations, as function of the source term information – and $\mathbf{x}^B$ $\bar{x}^B$ is the "background" or first-guess estimate of the source term. The background source term must be estimated prior to using the source term estimation algorithm and can be based on accident analysis and expert judgement. $\mathbf{R}$ $\underline{R}$ and $\mathbf{B}$ are the error covariance matrices, which are assumed to be diagonal, i.e., errors are assumed to be uncorrelated, and represent combined model and measurement errors and first guess errors respectively. The model error can be estimated through statistics of ensemble model calculations, by analysis of effects of errors of the model input parameters, or by model calculations at a number of points around the point of interest. Observation errors are usually set proportional to the measured value, plus a "background" threshold, depending on the measurement device. The estimation of the uncertainties in the first-guess source term is a matter of expert judgement. The so-called "robust" simplification is possible, where the magnitude of the error is taken equal to the maximum value of the prior estimation. The regularization term (J_2 J_2) in the expression of the cost function $J(\mathbf{x})$ $J(\bar{x})$ assures convexity of the function and uniqueness of the minimization problem solution.

For the minimization procedure, Source-Receptor Functions (SRF) are used, which describe the sensitivity of the model calculations at a certain location (receptor) on the source term. For a Lagrangian puff or particle dispersion model—such as DIPCOT that is used in JRODOS—the model operator $g(\cdot)$ is linear:

$$g(\mathbf{x}) = \mathbf{G} \cdot \mathbf{x}$$

The linearity is valid both for concentration in air and for the gamma radiation dose rate. The calculation of the Source-Receptor Matrix (SRM) $\mathbf{G}$ can be performed both by forward or backward model runs, depending on the number of existing observation locations. In the present paper it is performed by forward model runs and its mathematical formulation is straightforward from the relationships used in the Lagrangian model (Tsiouri et al., 2011). Therefore the minimization of the cost function *J* is a linear regression problem with the additional constraint $\mathbf{x} \geq \mathbf{0}$.

3. Releases of multiple nuclides and unknown height

Atmospheric releases resulting from severe accidents in nuclear power plants are composed of a large number of nuclides in different forms (gases and particles). Therefore, inverse modelling methodologies for estimation of the "source term" need to cope with this and be able to calculate the release rate of several nuclides. This is a challenging issue, especially for models that intend to be used for emergency response in the frame of decision-support systems.

The computational methodologies for source term estimation depend on the available types of measurements. In the event of a nuclear accident, measurements of the following quantities are performed: (a) atmospheric activity concentrations, (b) surface activities (accumulated deposition) and (c) gamma radiation dose rates. Atmospheric activity concentrations and deposition data are nuclide specific. Therefore they can be directly used in the inverse modelling method to calculate the source term of the specific nuclide. Their drawbacks are that these measurements are usually available with some considerable time delay, which can be a problem for their use in real-time decision support systems, and that they represent time averages of rather long periods (some hours to 1 day). On the other hand, measurements of gamma radiation dose rates are available in real-time from automatic monitoring networks which are – even though in variable density – available everywhere. Therefore, they constitute the main body of observational data of the plume and radioactive deposition. However, such measurements have also a drawback: the dose rate signal does not provide direct information on the nuclide composition.

One method to overcome the difficulty of using gamma dose rate measurements to estimate release rates of multiple nuclides is to use fixed ratios between release rates of the different nuclides with corresponding standard deviations (Kovalets et al., 2014). The relationships between the release rates of the different nuclides enter the minimization problem as additional linear equations.

Although the geographical coordinates of the nuclear power plant where the accident happened are (or should be) known – also because of international agreements – the effective height of the release (or the vertical distribution of release rates) often is not. This is true in cases of uncontrolled releases through buildings openings and especially for hot effluents and cases of fires and explosions that cause buoyant plumes. The release height affects the atmospheric dispersion of the plume and the ground-level impact; therefore inverse modelling methods need to be able to estimate it. To calculate the vertical distribution of release rates for a vertically distributed source, a number of discrete point sources can be assumed in the Lagrangian dispersion model and source-receptor-sensitivities of measurements to releases at different heights are calculated. If the inverse problem is well conditioned, release heights best fitting the measurements will be identified and assigned appropriate (non-zero) emissions through the minimization of the cost function for each of the vertically distributed sources. The overall solution is then two-dimensional, being a function of height and time for each nuclide (Kovalets et al., 2014).

4. Application example and evaluation

The settings of the European Tracer Experiment – ETEX (Van Dop and Nodop, 1998) have been selected as a test case, regarding the geographical domain, the meteorology, the topology of the sensors and the source location (Figure 1), because it is a medium- to large-scale dispersion experiment, well documented and for which data are available.

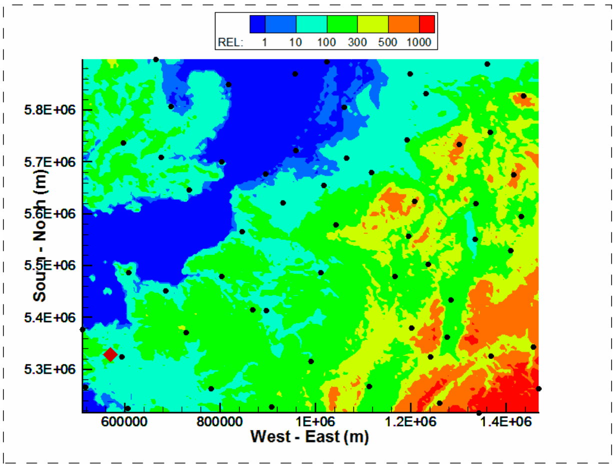

Figure 1: Test case: geographical domain, topography, location of source (red rhombus), locations of sensors (black circles)

Since in the actual experiment one non-radioactive tracer was released, for the purposes of this study a hypothetical release of 21 nuclides has been assumed. The release consisted of 2 release phases of 0.5 and 4h, separated by 2h of no release (source term Muehleberg-1 from flexRISK, http://flexrisk.boku.ac.at/). The release rates of the different nuclides varied from 0 to 10^{12} Bq/s. In addition the release was assumed to be vertically distributed, described by 10 vertical levels with Gaussian profile, between 0–100m above ground and a mode at 50m above ground (Hofman et al., 2015).

Since no real measurements of gamma dose rates exist, synthetic measurements have been produced by running the Lagrangian puff dispersion model DIPCOT with “true” source term, giving 10-min gamma dose rate “measurements” from 59 stations. For the source term procedure, 4 time-phases for the description of the release were assumed: 2h before 1st release, 1st release, 2nd release and 2h after 2nd release. The SRFs have been calculated by DIPCOT with a time step of 0.5 h and then were exported to the minimization module as binary arrays. The pre-defined ratios of nuclide release rates enter the mathematical problem as additional linear equations. The corresponding error variances allow controlling the level of enforcement of prescribed values.

Two computational experiments are presented here, aiming to assess the influence of time resolution that is used in the model for the description of the release: (a) 1st experiment: the release rate of each nuclide was taken as constant in each of the 4 phases, (b) 2nd experiment: the release rate of each nuclide varied in each of the 4 phases with a time step of 0.5h.

The results of the 1st experiment concerning emission rates are shown in Figure 2. The results are acceptable and resolve the most important features of the release (timing and magnitude of higher emissions). The observed differences—underestimations—in the lower emissions can be attributed to differences in emission between the different vertical sources even in the same phase. Results of the 1st experiment concerning estimated vertical distribution of release rates for the iodine are shown in Figure 3. Although there is an underestimation of the magnitude, the height of the maximum is well predicted.

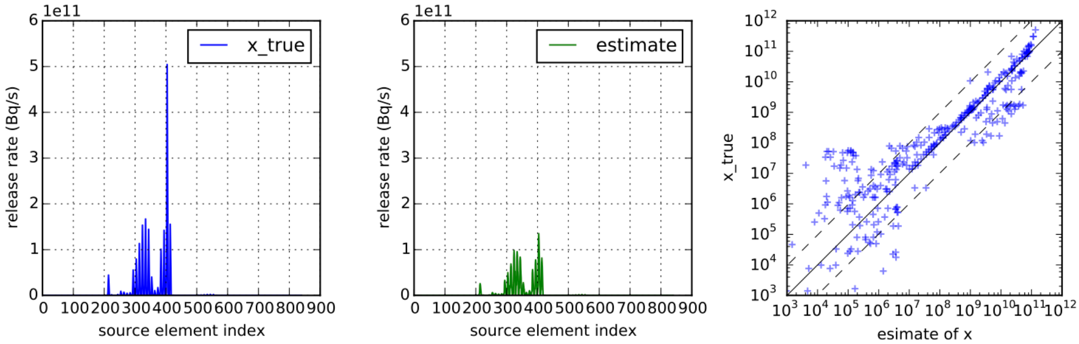

Figure 2: Evaluation of estimated source term with assumption of four phases and constant release rates of nuclides in each phase.

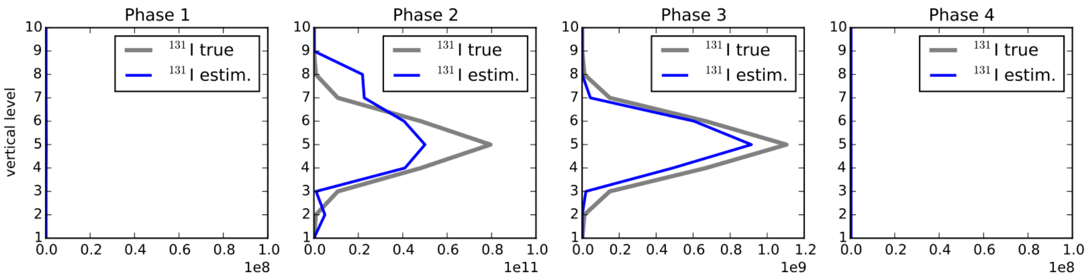

Figure 3: Comparisons of calculated and "true" vertical profiles of the iodine releases

The results of the 2nd experiment (where more elements exist in the source matrix to be calculated) concerning emission rates are shown in Figure 4. It can be seen that the timing of releases was estimated correctly and the periods with no releases were more or less preserved. Also here a better agreement is achieved for higher releases.

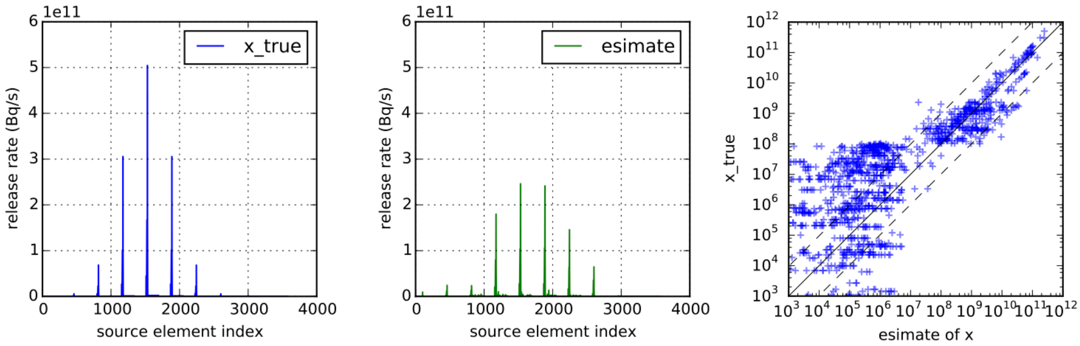

Figure 4: Evaluation of estimated source term with assumption of four phases and variable release rates of nuclides within each phase.

5. Conclusions

An advanced method for source term estimation based on measurements and a Lagrangian puff atmospheric dispersion model is well under development. The critical issues of handling multiple nuclides releases and vertically distributed releases have been successfully addressed. The method will be shortly integrated in JRODOS in the framework of PREPARE Project. The first test results for realistic emission scenarios with multiple nuclides and vertically distributed releases are very encouraging.

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Improving the decision support system JRodos with respect to user requirements

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1. Introduction

The first stage in the development of the decision support system RODOS (Real-time on-line decision support, Raskob and Ehrhardt, 2000) for nuclear and radiological emergency management in Europe was determined by the endeavor to design and produce an operationally applicable computer-based system that was to include the most advanced physical models available at the time. The second stage consisted in a re-design of the system while keeping the models as they were, mainly with the aim to improve the operational applicability (Ievdin et al, 2010). As result, the first version of the Java-based system JRodos was issued and became the basis for all further developments. Later, the applicability range was extended to long-term rehabilitation of contaminated areas (Charnock, 2010; Gering et al, 2010), strategy development with respect to the new ICR-103 recommendations (ICRP screening tool, Landman et al, 2014), and from the European to the global scale (World-Wide Accident Scenarios, Landman et al, 2014).

The JRodos users now range from operational customers in national emergency centers to user groups or organizations supported by the EU and self-organized users on a local scale. For all of them, the stability of the system is always the top priority. Also, the users are generally interested in an easy interaction with the system, and some even demand that non-specialists should be able to use it to some degree. Operational users, on the other hand, have to serve national practices or regulations, which often leads to requests for improving existing or including new features. In parallel, advances in computer hardware and in freely available tools and libraries over the last years enabled developments that were previously beyond the scope of an operationally employed decision support system. Increasing complexity makes it more demanding to control and guarantee the stability of the product, so the quality assurance aspects become more and more important and require growing investment to assure the stability of the system as well as the continuity of model results.

In the recent years, significant system and model developments were initiated on behalf of application-oriented needs of operational users. It is worth noting that within the JRodos User Group all resulting improvements or new features become available for the whole community, even if initiated (or paid for) by the interest of individual users or groups. The paper describes major developments since 2013 and outlines further plans.

2. The LASAT model and the exploitation of multi-core systems

In 2013, a new atmospheric dispersion model, LASAT[1], and an additional grid type were introduced in JRodos per order of one active user who intended to run JRodos operationally using a multi-core machine for the JRodos Server part. LASAT is a three-dimensional Lagrange particle model that can handle multiple sources and different substances and particle sizes. It is highly parallelized by design (OpenMP) and contains the certified cloud gamma dose calculation module LOPGAM. With the new grid, the user can select between one and five distance rings and different configurations for the combination of calculation radius and inner grid cell size. The number of points in the resulting calculation grid depends on the number of rings and ranges from 36864 points for one ring up to 147456 for five rings. As a consequence of the memory demands to hold the results on the large computational grid, JRodos with LASAT required the transition to 64 bit Operating System for the Server part.

[1] http://janicke.de/en/lasat.html

LASAT is freely applicable for JRodos users via a community license. For the implementation in JRodos, though, LASAT is provided only as binaries (closed source). Consequently, the only targets for speed/memory optimizations are the tasks and data flows that connect LASAT and LOPGAM with JRodos, and the distribution of tasks to the available system cores.

Coping with the time constraints set by the customer required a thorough analysis of the tasks involved and the way how the JRodos system gets and saves the results of the FORTRAN model codes. In a first step, the result processing was re-organized as a separate task that could run in parallel with model calculations. From this optimization all atmospheric dispersion models benefited as the change is not model specific.

Finally, the complete task of running LASAT in JRodos - from the preparation of the input data over the model calculations to saving the results - could be separated into six independent computation blocks: 1. Calculation of the weather input for LASAT; 2. The LASAT step with parallel result dumping; 3. Result averaging when needed; 4. The LOPGAM step; 5. Reading the calculated concentrations and gamma dose rates and repacking them into JRodos containers; and 6. Saving the JRodos step results. The task flow proceeds from the first block to the last, because each lower block needs as input some output from the previous upper one, and the calculations within each block must be performed for one calculation time step after the other in a sequential way. Nevertheless, the computation blocks can be executed in parallel but with data related to a different calculation time step. Figure 1 illustrates the task flow and the calculation time steps for the computation blocks executed in parallel at some "now" time. Here the "now" time is assumed to be after the initial warming-up phase.

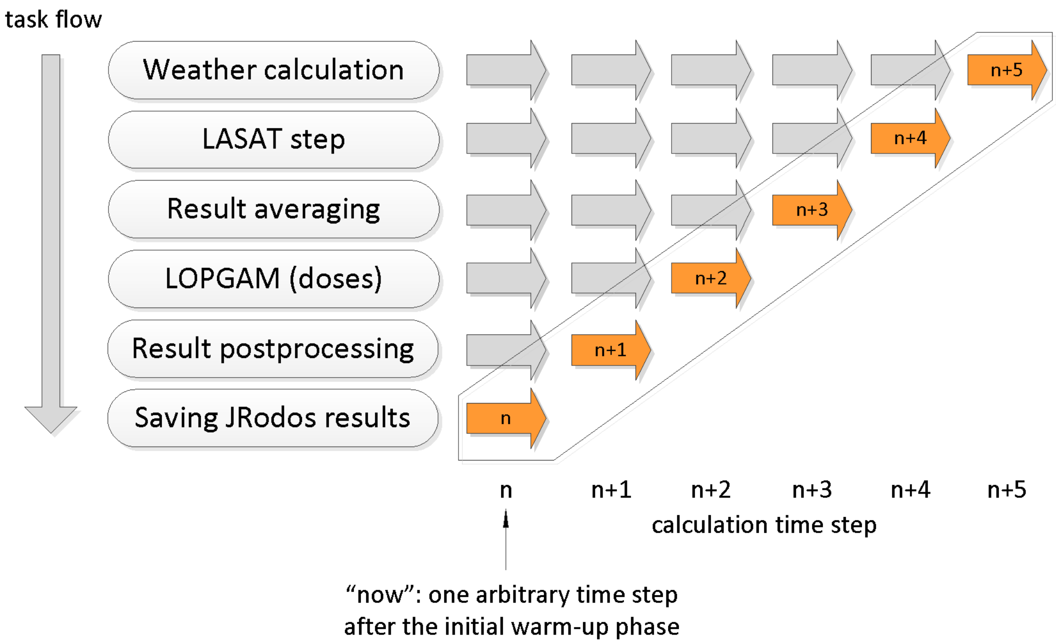

Figure 1: Parallel execution of six calculation blocks of the LASAT implementation in JRodos

The resulting structure enables to distribute the calculation blocks to different cores. By making full use of the customer's multi-core machine the computing time specifications could be met; now, the time width of one complete set of parallel calculations is determined by its slowest component.

3. Risk study applications and the JRodos Statistic Output tool

Several JRodos users have repeatedly expressed their interest to use JRodos as a tool for generating a statistical distribution of results by utilizing different weather sequences for risk study like applications. As the number of runs required for this task can easily be of an order of 1000 it is specifically necessary to be able to perform these computations in a parallel regime for reducing the total computational time.

A new Statistic Output tool has been introduced in the JRodos system by 2013 with further stabilization and improvements in the following year. The approach is to run a predefined customized scenario repeatedly for each day of the study period - usually several years - where the time of the day is selected randomly.

To start such a batch of calculations a JRodos user has to have 1. consecutive meteorological data covering the area of interest and the study period, 2. a customized scenario with definition of the release location, source term, JRodos meteorological provider, grid type and extent - this remains fixed for the whole batch, 3. the list of results for generating output in the form of "Cell Value" text files. The generated files can then be post-processed with statistics software; that step and the tools used (for example "Matlab") is in the responsibility of the user.

Because each calculation from the batch is defined independently, several model runs are naturally performed in parallel. The number of allowed parallel runs is set by the user; a common setting is "the number of cores on the JRodos Server machine - 1". This allows a beneficial and efficient usage of multi-core machines.

4. Storage of results and system stability

Until 2015, calculated model results were stored in the JRodos Project Data Base (PDB) together with input data and messages of the generating project. In the meantime, new features had been introduced such as the new grid type with up to 147 000 points or the possibility to launch multiple calculations by a script. This allowed applying the system in ways which could lead to heavy database loads. In some extreme use cases the database could grow up to 150 GB, with severe impairment of the operational stability when saving projects to or loading or deleting projects from the PDB.

To overcome such problems, only the metadata and relations of model results are by default stored in the PDB, while heavy data arrays of results are saved as files in a dedicated folder. This reduces the data base load and thus enables stable operation on all scales, from occasional light single-user applications up to heavy load single or parallel multi-user deployment.

5. Access to results from a third party GIS software

For many institutions, getting access to geo-referenced model results from an external Geographical Information System (GIS) is an important feature, for example to visualize a result layer in a custom Web-based GIS. The hitherto offered method consisted in the possibility to export user-selectable map-type results to a Model Results GeoDB open for external access. This process did not work reliably in all installation environments and could also quickly bloat the GeoDB size.

Now, a new approach has been implemented where map-type result fields can be accessed by the JRodos Web Processing Service (WPS) extension of the Geoserver web software[2]. The WPS request builder included in the package can then be used to formulate the request; no running JRodos Server or Client is required for accessing model results. In a WPS request a user specifies the project and the result name that are to be accessed, and selects among the offered types of geo-containers the one to be used for the result representation, e.g. zipped shapefile format container. The JRodos WPS request can be saved as an XML file for later use as a template. In this way, the export / publish process can be automated by using the cUrl script approach and RESTful Geoserver functionality for automated processing/publishing/deleting layers[3]. It is worth mentioning that the recently introduced file storage of result data achieves much better response times of the WPS request processing as there is no need to download heavy data blobs from the PDB to a cache storage on the disk.

A simple Geoserver publishing automation could consist in creating a WPS chaining process where the output of one WPS is an input of another WPS. A command line tool[4] for controlling the Geoserver data is another useful application.

[2] http://geoserver.org
[3] http://docs.geoserver.org/2.6.x/en/user/rest/examples/curl.html
[4] https://github.com/jericks/geoserver-shell

6. Quality assurance aspects

Since 2013 the complexity of the JRodos system has increased significantly, leading to considerable demands on stuff and methods to maintain continuity and trust after new releases and system / model updates.

As one consequence, test cases were developed for individual system features and for system / model bugs reported via the Bugzilla system[5]. In parallel, operational users have started providing use cases for special requirements of their JRodos installation. With respect to the JRodos Emergency chain models, base tests were developed for studying the effects of basic input quantities on basic results of atmospheric transport and deposition model (ADM) calculations; significant deviations to previous tests have to be recorded and explained.

In particular the base tests can require many calculation runs. For example, the new grid type with the possibility to select between one and five distance rings in addition to the existing grid with a fix numbed of five rings required stability and result continuity checks with selected grid settings with each of the DIPCOT[6], RIMPUFF[7] and ATSTEP[8] ADM, and for all possible settings for the LASAT model due to its grid nesting possibility. One JRodos feature that supports bulk processing is the possibility to start calculations without user interaction via an incoming xml file (triggered mode), with the additional benefit that the xml-files containing the input specifications can be stored for re-use in future tests. Currently, the tests are analyzed by hand. A recently introduced feature allows generating text file output via the triggered mode; this could be helpful in future for a further automation of model testing tasks.

Test material involving sensitive data or procedures is transmitted internally between the JRodos Team and the respective user. Currently under construction is the "JRodos Internet Websites for Testing" which will contain test material open for all (test or use cases, ‚appropriate screen dumps of RodosLite pages, test outcomes). Where possible, test material like the associated xml-file and meteorological data will be made available for downloading, giving JRodos users the opportunity to re-play the tests at their own JRodos installation.

7. Current developments and future plans

The JRodos dose factor data bases for external and internal exposure are outdated; their replacement is under way. As part of this revision, the nuclide list will be extended from 77 to 142 radionuclides.

As DIPCOT is a model where the developer is part of the JRodos community, in contrast to LASAT, the adaptation to possible new user requests can be managed more easily. In 2015 the DIPCOT model will be upgraded so that it can be applied to the same tasks as LASAT. Among others, radioactive decay chains and multiple release points can then also be considered.

With the active development of Web and mobile technologies there have already been several demands from the JRodos user community for an implementation of a JRodos Web Client and optionally a JRodos Mobile Client. At the moment the development efforts are directed towards creating a powerful Web Client for desktop browsers. As a next step, a separate User Interface implementation for mobile browsers and/or a complete development of a JRodos Client mobile app is envisaged.

[5] https://resy5.iket.kit.edu/bugzilla/
[6] http://milos.ipta.demokritos.gr/DIPCOT.htm
[7] http://en.wikipedia.org/wiki/RIMPUFF
[8] http://en.wikipedia.org/wiki/ATSTEP

8. Conclusions

The JRodos system is applied by its users as a support and training tool for radiation protection, emergency management, long-term rehabilitation and pre-planning, thus contributing to the improvement of radiation protection capabilities in all areas.

In the last years, application-oriented needs of operational users had a significant impact on the development. That has led to the creation of system and model extensions allowing new forms of applications. The increasing system complexity and the growing computation and data base loads in heavy duty applications required additional investment in the quality assurance and system design. The latter has improved the continuity and operational stability of the system.

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How to use decision support systems in a nuclear emergency?

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Abstract

In the early phase, emergency management involves decisions on measures of disaster response, such as evacuation, sheltering or distribution of stable iodine tablets. Decisions on whether or not to implement such measures depend to a great extent on the spread of the radioactive plume and the estimated contamination levels. In the longer term, more complex decisions on decontamination and remediation strategies, restricted access measures (e.g. relocation) and agricultural countermeasures are required.

In the early phase, decision making is crucial before a release starts as precautionary evacuation minimises the dose to the public. The uncertainty, however, is also highest at this stage, in particular about the source term and the weather. To deal with these uncertainties, tools to estimate the source term based on in-plant data have been developed, however their usage is very limited. In addition, developments are ongoing to estimate the source term based on external information such as measurements from gamma dose rate monitors together with atmospheric dispersion models. Models will be implemented in decision support systems as part of the PREPARE project, however, such an approach is only applicable when the release has started. Approaches to use ensembles of numerical weather prognosis data are also under investigation.

To deal with the remediation phase, several European simulation models for inhabited areas and food production systems have been developed and implemented in the two DSS ARGOS and RODOS. However, these models are complex and according to the bug statistics of RODOS not really used/trained by the emergency management organisations.

This paper discusses the usage of decision support systems in all phases of an emergency, the need for a better uncertainty handling and how to further develop late phase tools to improve their operability and acceptability.

1. Introduction

In the last 20 years, emergency management and rehabilitation preparedness has made significant progress. In particular in the last years, the multi-national project EURANOS (Raskob 2010), funded by the European Commission and 23 European Member States, has integrated 17 national emergency management organisations with 33 research institutes and brought together best practice, knowledge and technology to enhance the preparedness for Europe's response to any radiation emergency and long term contamination. Key objectives of the EURANOS project were to collate information on the likely effectiveness and applicability of a wide range of countermeasures, to provide guidance to emergency management organisations and decision makers on the establishment of an appropriate response strategy and to further enhance advanced decision support systems (DSS), in particular, RODOS (Ehrhardt 2000) but also ARGOS (Hoe 2002) and MOIRA (Monte 2009), through feedback from their operational use. This included also first attempts to deal with uncertain information.

In 2011, the collaborative project NERIS-TP (http://www.eu-neris.net/) with 19 partners was established. It had two points of focus: the first is on topics that were not addressed within EURANOS; and the second was on the operation of a Platform on emergency management and rehabilitation preparedness that became self-sustainable from 2014 onwards. This platform is where the scientific and operational community can exchange and discuss research needs to further improve radiological and nuclear emergency management and rehabilitation in Europe.

In 2013, the project PREPARE started, aiming to close gaps identified when evaluating the response to the Fukushima accident in 2011 (Raskob 2014a). This comprises among others the estimation of a potential source term, improvement of decision support systems as well as issues such as food safety and monitoring of gods in general. In addition, the trustworthiness of information is under investigation.

2. The problem definition

Any emergency can be subdivided into different phases and a typical distinction can be seen in Figure 1. In the early phase, decisions on evacuation, iodine thyroid blocking, and sheltering (and some few more in the pre-deposition phase) have to be made. In the post-accident phase, many more countermeasures are available and thus decisions have to be based not only on the radiological situation but also taking into account social and political issues (see e.g. Nisbet 2009).

Decisions on early phase countermeasures are best taken before the release starts as the efficiency of the measure is highest. However, the uncertainty on the start and the severity f the release is highest.

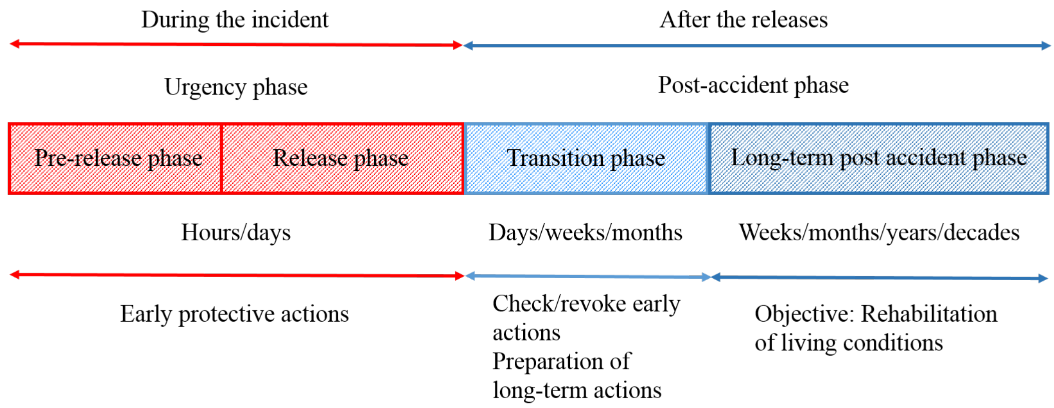

Figure 1: Phases of a nuclear accident (SSK 2014, p.12)

The two major nuclear accidents for nuclear power reactors, Chernobyl 1986 and Fukushima 2011, demonstrated that the releases lasted longer than one week and that the first source tem estimation was not available at the beginning of the release. In the case of Fukushima, the first source term was published after more than one week by ZAMG in Austria and IRSN in France (Stohl 2012). Internal estimations might have been available long before; however, there was no commonly agreed source term that could be used by emergency centres to define necessary countermeasures.

Both accidents are demonstrate that the post-accident phase lasts for years and decades and that decisions to be taken are complex, requiring expert knowledge but also comprehensive tools. In addition, exchange with stakeholders is a key for success, however will be not further discussed in this paper.

In the following section, the potential of decision support systems in supporting the decision making team will be discussed, together with still existing shortcomings and thus the need to further tackle either research questions or possibly operational procedures.

3. Support provided by a DSS in the various phases of an emergency

3.1. Urgency phase

Developing strategies

In the frame of the NERIS-TP project, a so called ICRP-103 screening model was developed that supports the implementation of the ICRP recommendations issued in 2007 (Landman 2013). Within these recommendations, decision on countermeasures should consider all exposure pathways. Such an approach was so far not realised in existing simulation models (ICRP 2007).

The screening model now takes into account all terrestrial exposure pathways, including ingestion, and considers sheltering, evacuation, relocation, food restrictions, and the use of iodine tablets for thyroid blocking, for reducing or avoiding doses. The screening goal is the identification of action strategies that limit the total effective equivalent dose, received from all pathways over a given time period, the "criterion dose", below a given reference revel.

Having realised and demonstrated the added value of this model in workshops and meetings of the NERIS-TP project, the usage of the model seems to be limited. As a consequence, better dissemination strategies and an even closer cooperation with the potential end users might be necessary.

Within the aftermath of the Fukushima accident, the German Environmental Ministry asked the German Commission on Radiological Protection to analyse the current procedures and tools for emergency management used in Germany. As a consequence, the planning areas around nuclear installations have been revised (SSK 2014). To derive these areas, several thousands of calculations for three different source term classes (INES 5, 6 and 7), sites (three sites) and weather conditions (365) were performed with the RODOS system.

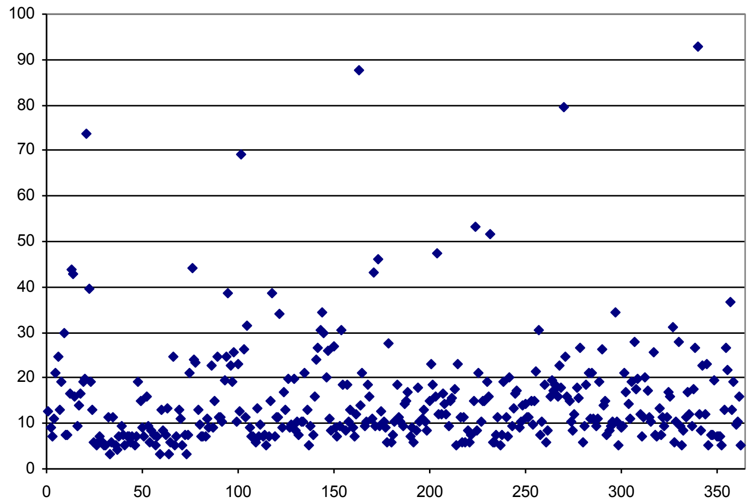

Figure 2: Maximum distance in which dose reference level for evacuation was exceeded for INES 7 source term and NPP Unterweser (Gering 2014, personal communication))

This unique dataset was used to derive the new planning areas, however, it could have been used also for setting up more dedicated strategies for evacuation knowing the source term, the NPP and the weather. As indicated by Figure 2, distances can vary from some 10 to up to 100 kilometres. Such information is extremely important in a real event. As a consequence, all calculations could have been stored in a knowledge database and so could be re-used in an emergency providing a first indication about the evacuation distance based on information on weather and potential source term. Such a query can be performed nearly instantaneous as demonstrated within the PREPARE project. There, a knowledge database is under development that contains historic events (Chernobyl and Fukushima) and scenario calculations to support decision making in all phases of an emergency (Raskob 2014b).

Source term estimation

As discussed before, the source term is the most critical and most uncertain parameter in performing dose assessments aiming to protect the public in the best possible way. Evacuating the people close to the site is not always an option as any action has to be justified (e.g. ICRP 2007). To estimate the source term, tools have been developed to assess the possible release based on in-plant information. A system that is operational and installed in several NPPs is the system Q-PRO developed by GRS based on results from European research projects (Löffler 2009).

On the other hand, attempts were made in various European research programmes and beyond to use atmospheric dispersion models and dose rate monitoring stations to assess the source term (e.g. Rojas-Palma 2003 and Tsiouri 2012). However, so far these approaches were not implemented in a DSS as their results were not always convincing. A new approach is under development in the frame of the PREPARE project which will be implemented in the RODOS system.

As both research lines so fare are fully independent and having in mind the high importance of the source term estimation, the question might be raised why not to combine both approaches to obtain added value in a feedback loop for example?

3.2. Post-accident phase

Within the EURANOS project two models, ERMIN ("EuRopean Model for INhabited Areas") for inhabited areas and AGRICP ("AGRIcultural Countermeasure Program") for agricultural areas, have been developed (see Charnock 2010 and Gering 2010). Both models contain dynamic activity transport models as an integral part, thereby differing significantly from previous methodologies that employ pre-calculated - hence static - datasets. Embedding dynamic transport models into the simulation codes enables dynamical calculations and thus are consistent with the environmental processes. Results are among other the consequences of countermeasures or countermeasure strategies in terms of contamination and dose levels and the associated waste and costs.

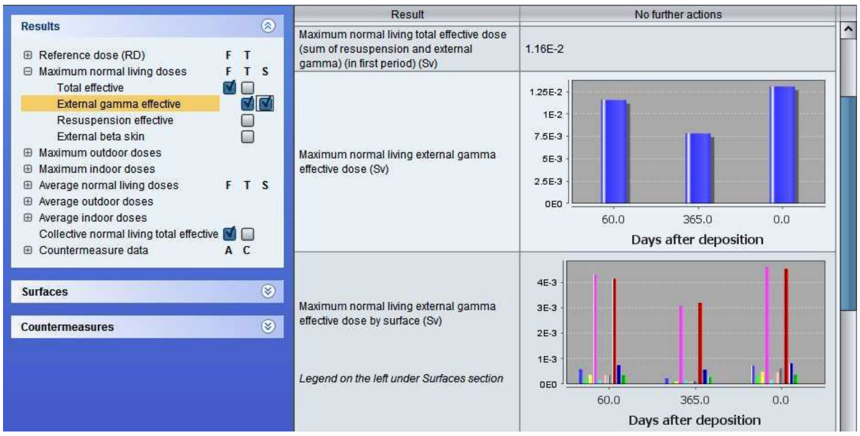

Figure 3: The RODOS ERMIN tabular interface, showing the drill-down system and use of graphical elements.

As part of the development, end user consultation was a key aspect of the work. As one result, a wizard was created for the ERMIN model guiding the user in developing a sensible countermeasure strategy (see Figure 3). In this respect, also complex models become more and more user friendly.

To evaluate countermeasures, RODOS is linked to an evaluation system using multi-criteria decision analysis capabilities (Hiete 2010). This module allows ranking countermeasures or countermeasure strategies based on preferences of the decision makers and can consider also soft factors such as acceptability by the affected stakeholders as well as ethical or political aspects.

Having in mind the positive reaction by the end users when presenting the models at the end of EURANOS and the revised ERMIN at the end of the NERIS-TP project, one might conclude, that decision support systems are well prepared for their usage in the post-accident phase. However, looking at the RODOS Bugzilla system that collects bugs and wishes from end users, the positive impression might be wrong. The Bugzilla is dominated by early phase issues and late phase models play a very minor role. This indicates that these models are not much used as complex simulation software in hardly bug free.

4. Summary and conclusions

This papers demonstrated capabilities of a DSS in supporting the decision maker in all phases of a nuclear emergency. It also showed that there are areas, in particular related to the source term estimation where gaps might still exist. As a conclusion – which is surely a personal one – one can identify three topics that may require further attention

- Research needs in source term estimation in real-time by using both, the in-plant information as well as external sources from atmospheric dispersion estimations up to dose monitoring,
- Operational improvements by applying the DSS in preparedness phase to develop strategies and databases that can be applied in an emergency using pre-defined trigger values of different nature (e.g. status of NPP, weather conditions, season of the year etc.), and
- Methodological improvements by attracting the end user in the application and operationalisation of late phase models including the evaluation of countermeasures together with the effected stakeholders.

In particular the last item has been recognised as important in the frame of various European research projects; however, the methodological basis on the usage of a DSS together with stakeholder consultations is still week.

A final point that can be raised is the question how a DSS is at the moment used and how it might be best used in the decision making process and what are the operational functionalities necessary in such an “optimal” context. Such an investigation might also result in a reduction of complexity which is crucial to assure operability of the DSS.

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SESSION 3 – IMPROVEMENT OF THE DECISION-MAKING-PROCESSES AND THE IMPLENTATION OF THE BASIC SAFERY STANDARDS

Assessing Personal Doses from External Radiation Using Personal Dosimeters with GPS and GIS technologies in Fukushima

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1. Introduction

The accident at the Tokyo Electric Power Company's (TEPCO) Fukushima Dai-ichi Nuclear Power Plant (F1NPP) in March 2011 discharged radionuclides into the environment and contaminated large areas of land in Japan. On April 22, 2011, the Japanese government designated the evacuation zones that include a restricted area and a deliberate evacuation area. The restricted area is the area within a 20-km radius of the F1NPP, while the deliberate evacuation area is the area where the cumulative dose of radiation was predicted to exceed 20 mSv/y. Approximately 85,000 people from 11 municipalities were evacuated from these areas, which cover approximately 1,170 km^2. As of January 2015, the evacuation advisory has been lifted only the limited area, but most of the areas are still not permitted to live. In addition, not only the residents from the evacuation zone, but also many residents from outside the evacuation zone had fled their original homes voluntarily because of, in part, anxiety of radiation. To lessen the anxiety of radiation for the local residents and to make decision on returning the restricted areas, it is important to correctly understand and assess realistic personal doses in the affected areas in Fukushima. For adopting appropriate countermeasures, it is important to identify when, where, and how much external exposure occurs and to quantitatively relate personal dose and air dose to different activity patterns of individuals living in Japanese-style homes. The primary goal is to establish a sound and pragmatic approach to assess and manage the external exposure of individuals in the affected areas in Fukushima. In the study presented here, we use a new personal dosimeter (D-shuttle) along with a global positioning system (GPS) and geographical information system (GIS) to relate personal doses with activity patterns and air doses (airborne and car-borne monitoring surveys). From the planning stage of this study, we have been engaging and communicating with diverse stakeholders (e.g., local residents and municipality) and the support of local residents has been essential, especially in the personal dose measurement (Fig. 1).

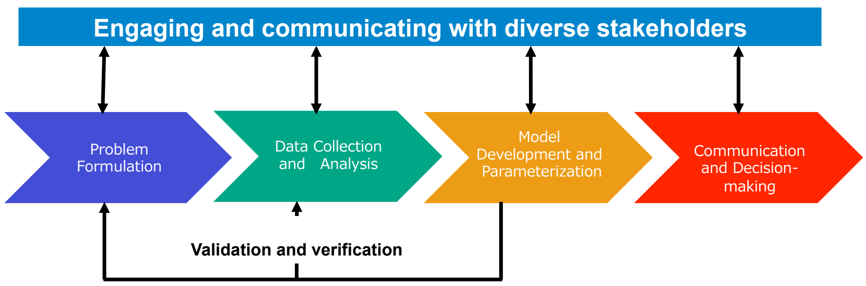

Figure 1 Flow and Elements of the individual dose assessment study

2. Materials and methods

As of March 2015, more than 150 local residents of Fukushima Prefecture volunteered for participation in our study. The study was conducted over approximately 7–14 days. Personal dosimeters, GPS receivers with time-activity diaries, and a GIS were used to determine when, where, and how much external exposure occurred. The D-Shuttle (Chiyoda Technol Inc., Tokyo and AIST, Tsukuba) was used to determine hourly and total personal doses. The D-Shuttle consists of a silicon semiconductor and can measure total dose ranges of 0.1 μSv to 99.9999 mSv. D-Shuttle is recognized as a good communication tool to understand dose from external irradiation in the affected areas. The i-gotU (GT-600, MobileAction Technology Inc. Taiwan), a commercial GPS receiver with data logger, was used to determine time and location of study volunteers. In addition to GPS, self-reported time-activity and location diary data were used to fill any gaps in the GPS data, and determine indoor and outdoor positions. The GPS and time–activity diary data were used to determine location and activity of subjects. The airborne and the car-borne monitoring surveys were used to determine the air dose rate. Data from the D-Shuttle, GPS receiver with time-activity diaries, and air dose rates were collated into a database by matching the associated timestamps from each device, thereby integrating the data into a common array. The collated data was then available for post processing and analysis.

3. Results and discussions

Figure 2 shows the examples of the comparisons between personal dose rate obtained by D-shuttle and air dose rate based on the air-borne and the car-borne monitoring survey. As seen from the figure, personal dose rates vary depending on activity patterns and locations of individuals even though the air dose rates exhibit similar levels. Marked differences were observed for orchard worker (A) who worked orchard field during daytime and stayed indoor at home during nighttime. Such examples suggest that D-shuttle provides reliable information for residents to understand the radiation situation in their daily life and the integration with GPS/GIS technologies allowed for identification of peak exposure locations/times.

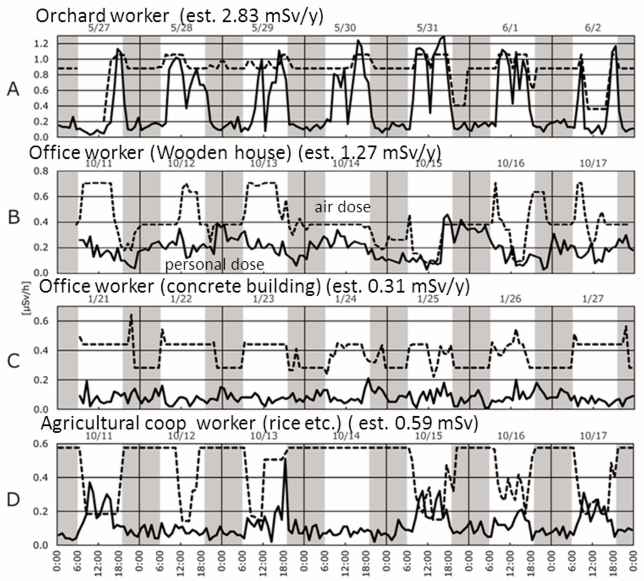

Figure 2 Examples of the comparisons between personal dose rate obtained by D-shuttle and air dose rate based on the air-borne and the car-borne monitoring surveys. The solid line represents the personal dose rate and the dotted line represents the air dose rate.

For examining effective personal dose reduction measures, it is important to identify source contributions to the cumulative external doses. Examples of the relative source contributions to the cumulative personal dose are shown in Figure 3. The working at orchard field contributed more than 70% of the cumulative personal dose of individual A, while other examples (B, C, D) indicate staying home contributed significantly to their cumulative personal dose.

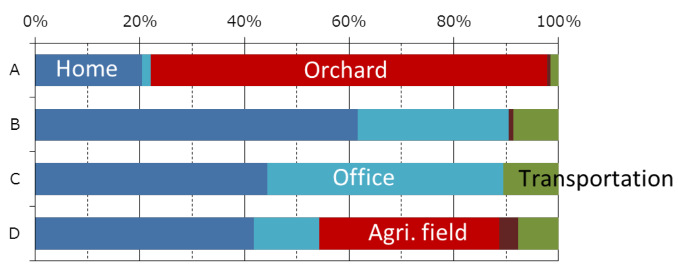

Figure 3 Examples of the relative source contributions to the cumulative personal dose over the study period. A: orchard worker, B: office worker, C: Office worker, D: Agricultural coop. Worker

Relationship between additional personal doses and corresponding air doses for individuals are shown in Figure 4. The values are expressed as hourly dose on average of entire study period. This result indicate that additional personal doses obtained by D-shuttle were 22% on average of the corresponding cumulative air dose based on the airborne and car-borne monitoring surveys. This result support the findings of the previous studies (e.g., Naito et al. 2015) and the report by Date-City(2013), Fukushima, which compared the individual dose values obtained by glass badge with the calculated external doses based on the ambient dose values for the entire population of the city. The effects of shielding such as human body and the dwellings mainly explain the observed differences between personal doses and air doses.

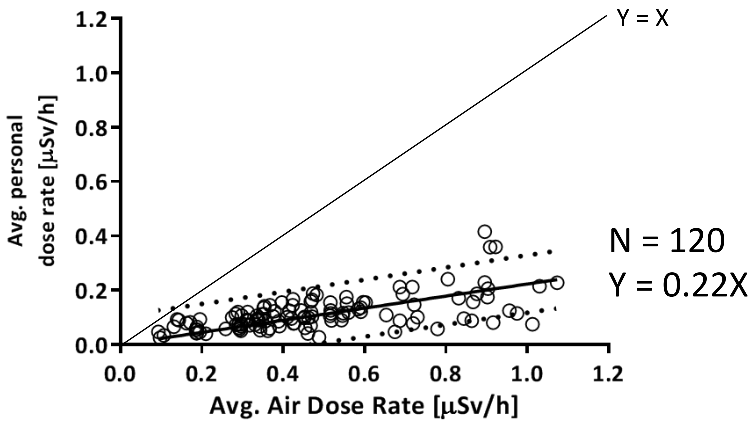

Figure 4 Relationship between additional personal doses and corresponding air doses for individuals. When calculating additional personal dose, the background personal dose of 0.052 μSv/h was considered. Data obtained by December 2014 were used for this analysis

4. Conclusions

In this study, engaging and communicating with various stakeholders from the planning stage of the study, we have illustrated the use of D-shuttle along with GPS and GIS technologies for providing valuable information to improve the understanding of the external radiation situation in their daily life in the affected areas in Fukushima. Personal doses obtained by D-shuttle were approximately 22% on average of the corresponding cumulative air dose based on the airborne and car-borne monitoring surveys.

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Soil vulnerability maps for predictive purposes in decision making processes for post-accident recovery in spain

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1. Introduction

In a nuclear post-emergency situation, large areas of agricultural land may be affected by restrictions, due to the accumulation of radionuclides in soils, causing an impact in the production and the way of life of the affected population. In this phase after the emergency, the assessment of the radiological consequences and the planning and development of recovery strategies must take into account the local specificity for an adequate and realistic optimization of protection.

Following the Fukushima Daiichi accident, this need has being highlighted, as careful mapping of contamination and soil characteristics can help to identify those areas that are most vulnerable to high levels of soil-to-plant transfer and where treatment with agrochemicals or other techniques would be feasible and effective. To do this, information and site specific parameters are needed, including the knowledge on the behavior and fate of radionuclides in soil, land use and agricultural practices and dietary habits of the affected population.

Most of the Spanish soils have been developed under Mediterranean climate, which is characterized by warm to hot, dry summers and mild to cool, wet winters. This climatic regime, whose key element in agricultural areas is the water availability in soils, affects not only the soil formation and its evolution; it influences the land use (intensively for both rain-fed and irrigating cropping), the crop selection (tolerance to summer moisture stress or reduction of the growth cycle) and the behavior of contaminants in soil and their transfer.

Concerning this behavior, after the Chernobyl accident in 1986, many studies were conducted, both in field and in controlled laboratory conditions, taking advantage of the contaminated areas in Europe. The parameter values obtained showed a generic nature, but were not sufficiently representative for potential Spanish contaminated soils and environments. To solve this problem, theoretical studies based on the influence of soil characteristics and agricultural practices were carried out, in order to establish a methodology to assess the behavior of radionuclides in soils and their potentiality to be transferred to the food chain, without the use of experimental radiological data. The results were soil vulnerability maps that allowed the categorization of soils into five classes, according to the potential soil-to-plant transfer.

This way of regionalizing Spanish soils from the rest of Europe, was a first stage in the local specificity to achieve a proper decision making process for post-accident recovery in Spain [1]. These maps have been revised recently, taking advantage of new technologies based on GIS and database management [2]. Considering a National scale (1:1.000.000), the vulnerability maps are considered an optimal way of identifying the priority areas for action. However, for more local scenarios such as the emergency planning zones (EPZ) around the Spanish NPP, a second stage in the local specificity is required. This development would integrate the methodology developed with local data and specific thematic maps of soils, agronomic practices and agricultural production. It is intended that this next outcome could help decision-makers and other stakeholders in the development of recovery plans for post-accident contaminated areas, to be carried out in our country.

This paper shows the methodology designed to assess the radiological vulnerability of Spanish soils and its application for predictive purposes in a specific case study. The framework, in which the second stage in the local specificity will be developed, is shown.

2. Methodology

The potentiality of Spanish soils, according to their specific properties, to transfer ^{137}Cs and ^{90}Sr to the population is defined as radiological vulnerability (RV). The assessment of this potentiality allows the categorization of Spanish soils by means of indexes representing, qualitatively, the maximum to minimum transfer capacity, identifying the areas of most concern.

In general terms, ^{137}Cs and ^{90}Sr have the same physical behavior, entering the soil with water and migrating along the soil profile in the soil solution. However, the physico-chemical behavior differs, and while ^{137}Cs is fixed in an irreversible way when adsorbed in the selective, and small in number, frayed edge sites of micaceous clays (illite) and competes for those sites and for plant nutrition with K, the ^{90}Sr is not fixed, it takes part in exchangeable reactions, the pH conditions its solubility and competes for plant nutrition with Ca.

In soils developed under Mediterranean climate, the availability of water is more influenced by physical than by chemical properties. Soil texture is an important parameter as it affects the water retention of the profile. In terms of soil chemical properties, these soils have generally high values of cation exchange capacity, except on very acid rocks, and with appropriate contents of Ca and K, although the latter depend on the fertilizing programs and crops.

In order to characterize the Spanish soils, to know the values of the soil parameters of influence in the assessment, a literature review of soil profiles has been made collecting 2.177 soil profiles of which 1.657 are complete for assessing purposes. Figure 1 shows the geographical distribution of the latter. After a process to standardize units, coordinates and nomenclatures the data has been compiled in a database.

The reference unit on which the methodology for estimating the RV applies is the soil profile. According to the behavior described, two potential exposure pathways to the population are considered: the external irradiation (EI) due to the retention and accumulation of radionuclides in the soil surface layer and the internal exposure from ingestion of contaminated food, if radionuclides are transferred from soil to crops by root uptake and eventually to humans through the food chain (FC).

The soil processes of influence to be considered, for both exposure pathways, are the infiltration capacity (F), the water retention capacity (H) and the physico-chemical retention capacity (FQ), but in different soil depths. For the EI pathway the depth considered is the top layer thickness and for the FC pathway, a thickness of 60 cm, where the maximum root development is considered to occur and may include, depending on the type of soil, a variable number of layers. For this same pathway, an additional capacity is considered, the nutritional status on K and Ca.

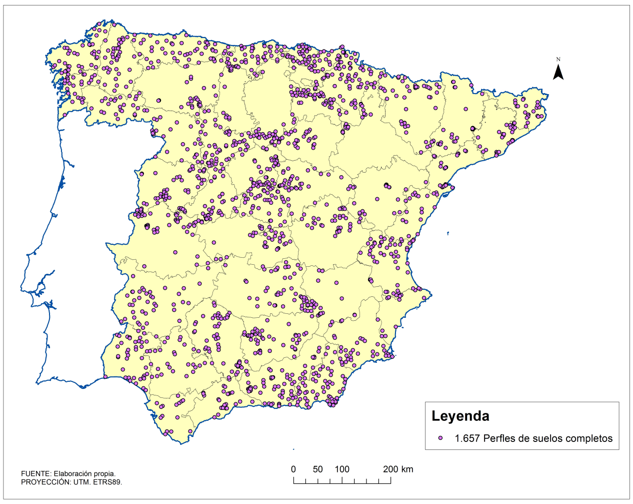

Figure 1.- Geographical distribution of complete soil profiles

Each of these processes, depend on one or several soil properties. Selecting among them a reference soil parameter, five categories have been established for each, defined from minimum to maximum as a function of the range of values assigned. An example of the five categories established for the K nutritional status is shown in Table 1, with the reference parameter selected and the categories and range of values assigned.

According to this table, a soil profile will show a maximum vulnerability index for ^{137}Cs transfer, at minimum K nutrient status in soils. The vulnerability results obtained for each soil profile have been spatially distributed based on the Soil Map Units (SMU) of the Soil Geographical Data Base of Europe: SGDBE v.3 [3], scale 1:1.000.000.

Table 1.- Reference parameter categories and range of values assigned for the K nutrient status.

Vulnerability index for Food chain	IK-FC
Soil processes	K nutrient status
Soil Property of influence	Exchangeable K content
Reference parameter	K (cmol/kg)
Parameter categories and range of values assigned	
Maximum	$K > 1.0$
High	$0.5 < K \leq 1.0$
Medium	$0.25 < K \leq 0.5$
Low	$0.1 < K \leq 0.25$
Minimum	$K \leq 0.1$

An example of these results, in particular the vulnerability map for K nutrient status in soils, is shown in Figure 2. The maximum values correspond to soils developed on the acidic lithologies on the NW and W areas of the Peninsula and on mountainous areas. These soils with coarse textures and low potassium reservoir favor the transfer of ^{137}Cs to crops. High values are probably due to low levels of K fertilization on arable lands. The lowest values of vulnerability are given in soils where the content of potassium is such that it hinders the ^{137}Cs transfer. These soils developed under more calcareous lithologies and have clays that act as reservoirs of K.

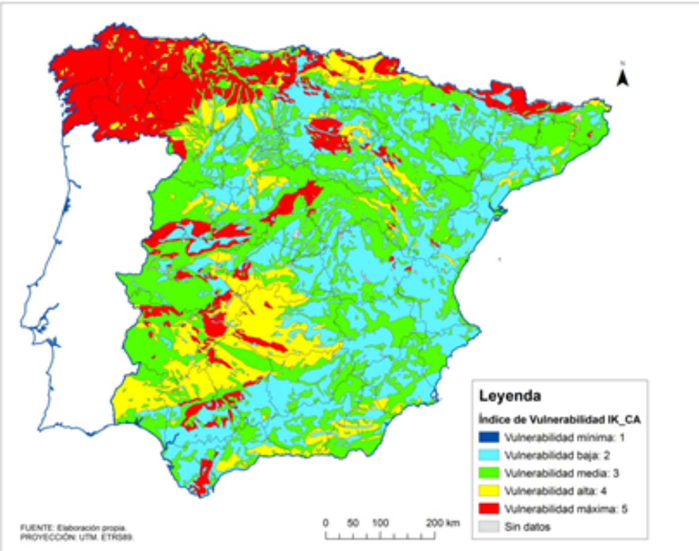

Figure 2.- Vulnerability map for K nutrient status in soils

Once identified those areas were recovery should be a priority, a case study applying K fertilizer to decrease the transfer potentiality of ^{137}Cs, has been developed. The application of K fertilizer has been assessed under two assumptions:

- As a standard agricultural practice: correcting the deficiencies of K in soils.
- As an agricultural countermeasure: applying the quantities of K needed to reduce to minimum values the soil vulnerability.

In both cases only the decrease of the transfer potentiality of ^{137}Cs is taken into account, not considering other factors such as machinery, costs, side effects, etc. The total quantities to be added are estimated without considering their distribution with time. The results of this case study are shown in figure 3, on the left the addition of potassium as a standard agricultural practice and on the right as an agricultural countermeasure.

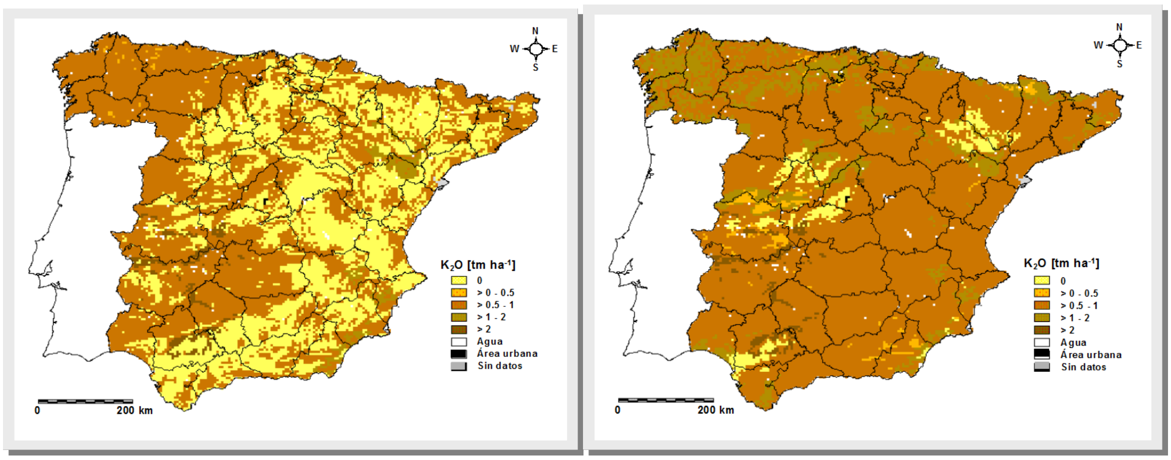

Figure 3.- K addition as: l) standard agricultural practice and r) countermeasure

About 55% of the Spanish soils require, as a standard agricultural practice, a medium level of potassium addition, that is, between 0.5-1.0 Tm ha^{-1} of K_2O. The application of K as an agricultural countermeasure, to obtain a minimum vulnerability index, requires the addition of levels of K_2O, in the same range as before, in around 80% of the soils. Higher additions of K are necessary in those soils with a very low K reservoir due to their coarse textures.

Although these results are, considered at a National scale (1:1.000.000), an optimal way of identifying the recovery priority areas, for more detailed scenarios there is a need to increase the local specificity. Figure 4 shows the location of the Spanish NPP emergency planning zones (EPZ) on the total vulnerability map for nutrient K status in soils. As seen, there are areas where the high values of vulnerability recommend a more detailed and local characterization.

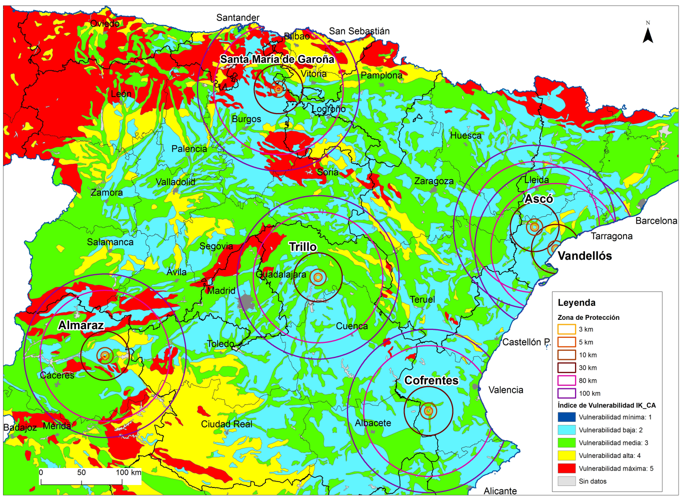

Figure 4.- ***Vulnerability map for K nutrient status in soils and Spanish NPP EPZ***

3. Conclusions

To conclude, several points can be highlighted:

- The methodology developed, estimates the radiological vulnerability of Spanish soils, that is, their potentiality to transfer ^{137}Cs and ^{90}Sr to the exposed population, exclusively according to their specific properties.
- The results, in form of vulnerability maps, show the trends of the behavior of these radionuclides, allowing the prioritization of rehabilitation areas in the decision-making processes.
- A case study regarding the vulnerability due to K nutrient status, allows to plan the K fertilizer applications needed to reduce the vulnerability.

- Increasing the local specificity scale, will require more detailed parameters and information to improve reliability.

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SESSION 4 – STAKEHOLDER ENGAGEMENT AND DIALOGUE

Stakeholder Engagement in Ireland on Radioactive Contamination of Food

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1. Introduction

Ireland does not have any nuclear facilities but there are a large number of nuclear sites across Europe which could result in widespread but low level contamination of the Irish environment if a nuclear accident was to happen at any such site. If this was to happen, the most significant route of potential exposure for members of the Irish public would be from the consumption of food containing increased levels of radioactivity. The concentrations of radioactivity in food would be dependent on the severity of the accident and the quantity of radioactivity reaching Ireland. It would also be dependent on food controls and protective actions implemented during the operation of Ireland's National Emergency Plan for Nuclear Accidents (DECLG, 2005).

Most of the potential dose to the Irish population could be averted by taking protective actions to reduce the transfer of radioactivity to food products and restricting the sale of contaminated food. While these measures have been shown to be very effective in controlling radioactivity levels in foods for sale, and hence radiation doses to people, they do have significant socio-economic implications and costs. These effects could last for months or years depending on the severity of the accident and prevailing weather at the time of the accident.

Experience from severe nuclear accidents such as those at Chernobyl in 1986 and Fukushima in 2011 has also shown that when systems are put in place to manage contaminated produce they do not always take into account stigmatisation or rejection attitudes from consumers or retailers who anticipate the fears of consumers. Depending on the scale and geographic extent of the accident, the consumer consideration is likely to be whether the food is contaminated or not rather than the degree of contamination. Public reassurance can be enhanced by quick, decisive introduction of protective actions in the aftermath of an emergency. Yet, experience elsewhere suggests that the economic consequences from the stigma of food that is contaminated with radioactivity can be considerable.

2. Stakeholder Engagement on the Customisation of the EURANOS Food Handbook

In 2009, a multidisciplinary group was established to customise the EURANOS handbook (EURANOS, 2006) for Irish conditions. This group included experts from the Radiological Protection Institute of Ireland (RPII), the Food Safety Authority of Ireland (FSAI), the Department of Environment, Community and Local Government (DECLG) and the Department of Agriculture, Food and the Marine (DAFM). The resulting document was called the Irish Food Handbook and it continues today to be a living document which is maintained by the DAFM

The Irish Food Handbook specifically addresses potential Irish scenarios and their possible consequences. It provides a framework for managing the impact of nuclear accidents on the agricultural sector, the production of safe food and the disposal of contaminated material in Ireland. It includes provisions for basic pre-emptive protective actions, for providing rapid advice to farmers, food producers, food distributors/retailers and the public, for the possibility that food restrictions may have to be applied, as well as guidance for food waste disposal. The timely application of agricultural protective actions will reduce or eliminate the need to introduce food restrictions, even if the level of contamination is such that food restrictions would otherwise be expected to be necessary.

In November 2013, the RPII brought together a team of representatives from a number of sectors in the DAFM (corporate affairs, food safety, veterinary health, livestock breeding, meat, dairy and crops) to refresh their knowledge and introduce new representatives to the Irish Food Handbook. Following this, RPII organised a table top exercise to test the handbook. This exercise was held in February

2014 and involved staff from both RPII and the DAFM. A number of different scenarios involving radioactive contamination in Ireland during different seasons of the year were tested. Following this, areas in which updates to the Irish Food Handbook were required were identified.

3. Stakeholder Engagement for the PREPARE project

The PREPARE research project is a three year project which started in February 2013 under the European Commission's 7th Framework Programme, EURATOM for Nuclear Research and Training Activities. The main objective of the project is the harmonisation of emergency management and rehabilitation preparedness in Europe. It is divided into seven work packages and Ireland's Environmental Protection Agency (EPA) Office of Radiological Protection (formerly RPII) is participating in work package three (WP3) entitled "Consumer goods". The overall objective of WP3 is to contribute to the development of strategies, guidance and tools for the management of contaminated goods, taking into account the views of producers, processing and retail industries and consumers.

Each country participating in PREPARE WP3 was tasked with setting up a national panel to discuss issues associated with contaminated food or consumer products. Ireland's national panel is focusing on agriculture and food because of their importance to Ireland's economy. The focus of Ireland's national panel is the placement of Irish foodstuffs (meat, dairy and crops) in the marketplace (within and outside Ireland) following contamination from a nuclear accident abroad. In setting up this panel, the first members identified were those from the organisations that customised the EURANOS food handbook. Additional stakeholder groups from the Irish food industry were also identified.

A number of difficulties were encountered in setting up the Irish stakeholder panel. Firstly, care was needed to ensure the topic was presented in such a way as to convince organisations that it was of sufficient importance to warrant their attention, particularly in a non-nuclear country where there are many other competing issues in the agrifood sector. Secondly, while it was relatively straightforward identifying organisations that should be involved in the panel, identifying and securing the most appropriate representatives proved much more difficult. This issue was helped greatly when individuals from the selected organisations were nominated by people who had already agreed to participate on the panel and had experience of working with these organisations.

Information on the PREPARE project and the purpose of the stakeholder panel were sent with invitations to participate in the panel in spring 2014 and thirteen organisations responded positively. At the first panel meeting it was noted that there were no consumer organisations present so invitations were issued to consumer organisations prior to the second panel meeting. The organisations who accepted invitations to participate in the panel are shown in Table 1.

The majority of participants in this stakeholder panel have no background in radiation or radioactive contamination. It was made clear to participants when invitations were sent that there was no pre-requisite for this knowledge. Assurances were also given that, although this is a stakeholder engagement process, individuals would not be singled out to contribute at meetings. All of the participants who were invited to take part in the panel are either involved in emergency preparedness and response or are involved in the food industry in Ireland and have insight into food contamination issues such as the dioxin contamination of Irish pork meat products in 2008.

Prior to the first panel meeting, a briefing note was sent to all members on the sources of radioactivity in the environment, the potential impact of a nuclear accident abroad on Ireland, the National Emergency Plan for Nuclear Accidents, EU maximum permitted levels of radioactive contamination in foodstuffs following a nuclear accident and finally a case study on the Irish experience of dealing with a food dioxin contamination crisis.

Government Departments	• Department of Agriculture, Food & the Marine (DAFM) • Department of the Environment, Community & Local Government (DECLG)
State Agencies	• RPII/ now EPA Office of Radiological Protection • Food Safety Authority of Ireland (FSAI)
Dairy Sector	• Irish Dairy Industries Association (IDIA) • Irish Dairy Board (IDB)
Farming Sector	• Irish Farmers Association (IFA)
Meat Sector	• Meat Industry Ireland (MII)
Crops Sector	• Teagasc • Irish Grain and Feed Association (IGFA)
Seafood Sector	• Sea Fisheries Protection Agency (SFPA)
Retail Sector	• Tesco • Musgrave Group
Consumer Sector	• Consumer Association of Ireland

Table 1 Irish organisations participating in stakeholder engagement for the PREPARE Project

4. Stakeholder meetings

Having secured acceptances to participate in the stakeholder engagement, meetings of the panel were then arranged. The meetings were limited to a half day each to encourage attendance. Since the panel members came from different parts of the country, it was important to hold the meetings in an easily accessible location. The National Emergency Co-ordination Centre (NECC) in Dublin city centre was chosen to facilitate this. The NECC is a strategic response centre where all the relevant Government Departments and Agencies convene when a major emergency occurs and thus, is an attractive venue for people to visit.

The meetings were designed to include introductory presentations followed by panel discussions. Given that the participants came from diverse backgrounds and the amount of time for discussions was limited, it was decided to engage a market research company with expertise in stakeholder engagement to facilitate the meetings. This turned out to be a very valuable decision as the facilitator was viewed by the panel members as being neutral. He was also expert at keeping the discussions on track and to the point and ensuring that no one person dominated discussions and that everyone had an opportunity to contribute if they so desired. The facilitator provided a person to take notes at the meetings and produce summary reports afterwards. Prior to each panel meeting the facilitator was briefed on the content of the agenda and the objectives of the meeting.

The first panel meeting was held in May 2014 and while 25 individuals accepted the initial invitation to attend this meeting, 19 were present on the day. At the start of the meeting, short presentations were given on how Ireland would respond to a nuclear emergency, the impact of the Chernobyl and Fukushima accidents and an overview of a risk assessment of the potential radiological implications for Ireland of the proposed nuclear power plants in the UK (RPII, 2013). Panel discussions were then held on issues surrounding food contamination, protective actions that could be implemented to reduce radioactivity in food and the impact on trade if food was contaminated following a nuclear accident.

The second panel meeting took place in October 2014. Prior to this meeting, a briefing note was sent to panel members on the main outcomes of the first meeting, outcomes from the other PREPARE panels in Europe and examples of protective actions that could be introduced in Ireland to reduce the activity concentrations in meat, milk and crops intended for sale. The meeting started with a presentation on the main points from the previous meeting and feedback from the other PREPARE panels. An expert from the UK who was one of the authors of the EURANOS handbook gave a presentation on food management options in the UK using the Windscale fire in 1957 as a case study. Discussions were then held on the feasibility of various protective actions that could be introduced in Ireland to prevent or reduce contamination of food intended for sale such as additives to cattle feed or changes in farming practices such as delaying slaughter times in conjunction with clean feeding.

5. Outcomes from Stakeholder Engagement

It is well established that even an accident at the nearest nuclear power plant in the UK will not cause significant radiation exposure to people in Ireland or result in immediate health effects (RPII, 2013). It is the socio-economic rather than the health effects that may have the largest impact on the Irish public. Since agriculture and food exports are very important to the Irish economy, these must both be protected following a nuclear accident abroad. Although the panel of experts which was brought together to discuss this issue were representing their own sector's interests, they had a common objective of protecting the food industry in Ireland and ensuring food products were fit for consumption.

One of the key issues that arose in this stakeholder engagement was communications. Following a nuclear accident it is critical that communication paths are clear to avoid confusion and to ensure the public and industry are not receiving mixed messages. Key stakeholders in the food industry must be notified directly quickly and should not be receiving their information from the media. Communications between industries is also very important e.g. between supplies and processors. Therefore, all the stakeholders in the food industry must be involved in the communications plan. The development of pre-prepared key messages as part of the emergency plan was seen as very beneficial. In addition, careful consideration should be given when selecting the organisations who will deliver the communication as the public are more likely to trust independent health and scientific experts rather than politicians or those with vested interests in the food industry. Also, it was highlighted that the language used should be non-technical and the risks explained by comparison with everyday examples and familiar concepts.

Ireland's National Emergency Plan for Nuclear Accidents (NEPNA) is currently undergoing a review process to update it with lessons learned from key developments in emergency preparedness and response since it was last updated in 2005 including

- Lessons learned from the response to the Fukushima accident in 2011;
- Lessons learned from the operation of the National Coordination Group (NCG) model in dealing with other emergencies such as severe weather, flooding and the ash cloud event;
- Outcomes from the EU review of current off-site nuclear emergency preparedness and response arrangements in EU member states and neighbouring countries (European Commission, 2013);
- Outcomes from two key hazard assessments which considered the risks to Ireland from potential accidents at the Sellafield nuclear reprocessing site and at the eight proposed nuclear power plants in the UK.

The outcomes from this stakeholder engagement process will also feed into this review.

6. Future Stakeholder Engagement

This is the first time in Ireland that so many representatives from key organisations in Government, farming, food production, retail and consumer sectors have come together to discuss the issue of radioactive contamination in food following a nuclear accident. The discussions have been very interesting and illuminating and important issues that need to be addressed to ensure Ireland's preparedness for and adequate response to a nuclear emergency have been identified.

Without doubt, the most difficult element of this stakeholder engagement process was the creation of a panel of suitable representatives who were interested in the topic and had the expertise to contribute to the discussions. Having put the group together the focus now is on keeping the panel together and maintaining interest. Following the first year where two meetings were held, it is now proposed to keep the frequency of meetings to one per year as this will be sufficient to maintain contact without becoming a burden to members.

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The involvement of experts in post-accident management at the service of population: lessons from the Fukushima accident

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In fall 2011, ICRP initiated a dialogue between representatives of the Fukushima Prefecture, local professionals, local communities, and experts in radiation protection from Japan and abroad. The aim of this dialogue is to find ways to respond to the challenges of the long-term rehabilitation of living conditions in the areas affected by the Fukushima nuclear power plant accident. This initiative is organised in cooperation with IRSN, ASN, NRPA and the Committee on Radiation Protection and Public Health of NEA/OECD. Up to now, 10 Dialogue seminars have been organised in the Fukushima Prefecture.

In order to draw the lessons of this initiative for the involvement of radiation protection experts in the post-accidental management, IRSN and CEPN have analysed and discussed the key facets of the post-accident management following the Fukushima accident, as reported during the ICRP Dialogue. This analysis points out the human dimensions of the post-accident situation, the stakeholder engagement process, the co-expertise process and the development of the radiation protection culture.

The human dimension of the post-accident situation

The irruption of radioactivity in the daily life of people is a rupture, creating an unprecedented situation and a profound change in the relationship of each to her/himself, to the other and with her/his environment. Living in a contaminated environment is a complex situation that generates a lot of questions and concerns among the affected population. The technical answer to improve the radiological situation (decontamination, prohibitions, restrictions, control of food ....) has indirect effects that isolate affected people from their day-to-day environment. The accident has a significant emotional and social impact that challenges the lifestyle and leads everyone to find a way to rebuild her/his life.

The human consequences of Fukushima are very close to those observed in Belarus after the Chernobyl accident:

- A loss of confidence in the authorities and experts;
- A strong worry about health and especially of children health;
- A general feeling of discrimination and exclusion;
- A feeling of helplessness and abandonment;
- A loss of control on daily life and apprehension of the future.

Finally, each individual is constantly confronted to the dilemma: to continue to live in the affected areas or to leave them; to return or not at home.

The stakeholder engagement

In Belarus, the stakeholder engagement process was initiated and facilitated by foreign experts of the ETHOS project and the CORE program. National and local authorities allowed to implement projects without the direct involvement of national experts. Local people called for a clear commitment of the foreign experts to improve their living conditions. Gradually a network of volunteers from villages was set up to deal with key issues (internal contamination of children, production of clean food, education of children, management of contaminated ashes...). Progressively, they were joined by local professionals and Belarusian experts.

In Fukushima, local authorities have taken charge of the situation with the help of national experts and the support of local government. Local communities have mobilized themselves to initiate actions with the help of local and national experts. These experts of very different backgrounds are personally committed to serve the affected people. National authorities remained away from these initiatives but are just beginning to take an interest.

The main challenge for experts is the lack of connection of their engagement with the institutional framework. This difficulty was already pointed out in Belarus, and was assigned to the post-Soviet institutional context. In Japan, in a democratic context, the same lack of connection between local initiatives and government programs is observed. Until recently, it seems that there is no national support for the development of local initiatives, neither in terms of expertise nor financially.

This observation raises questions about how national expertise could be deployed locally in a post-accidental situation.

The Japanese experience feedback from colleagues who committed themselves in a personal way in local initiatives highlighted several elements:

- The rapid need for a reliable and accessible information and the important role of social networks in the dissemination of information,
- The need to be consistent with the scientific knowledge by being modest about the uncertainties and limits of knowledge,
- The importance of a clear commitment of the authorities and administrations to serve local communities with a good coordination between the different levels of the decision-making processes,
- The importance of engaging local professionals involved in the management of the situation (medical, teaching staff, administration ...) and establishing mechanisms for sustainable cooperation,
- The importance not to conclude too easily or quickly that the situation is safe and respect the values of each,
- The difficulty of talking about the effects and risks associated with exposure to ionizing radiation,
- The need to promote dialogue based on local resources rather than the expert presentations,
- Radiation protection is unavoidable but can not handle people's lives. Rather, it should be at the service of individuals and the community.

The co-expertise process

The co-expertise process relies on:

- The establishment of places of dialogue allowing experts to listen to and to discuss together with affected people their questions, concerns, challenges, but also expectations;
- A joint evaluation by experts and local stakeholders of the situation and its impact on the daily lives of the people and the community;
- The implementation of projects, with the support of local professionals, experts and authorities to address the issues identified at the individual and community levels;
- The evaluation and dissemination of results.

In Fukushima, it seems that the co-expertise process has been implemented only in a few communities that gradually engaged themselves in the development of concrete initiatives. This process has evolved in a similar way to that of Belarus with few differences:

- The personal engagement of voluntary experts and local professionals at the service of the population,
- The means for measurement to characterize the radiological situation,
- The sharing of information via social media.

Moreover, the Belarusian experience of CORE and ETHOS projects played a key role in the appropriation of the co-expertise process by Japanese stakeholders.

The experience feedback from the Japanese colleagues shows the importance of dialogue and measurement to restore confidence. The only scientific explanations are not enough to create confidence in the experts and it is essential to create a long-term cooperation, returning regularly to interact with people and sharing experiences and feelings with them. Key elements to work with the population are: reaching out to the population, using a common language, being sincere, conducting actions on the long term and producing tangible results for the population. Similarly, the sharing of lessons encourages the development of new initiatives among the communities. It is also important for communities to have a financial support from the administration to generalize the actions and ensure their sustainability.

The development of the practical radiological protection culture

The co-expertise process promote the development of the practical radiological protection culture within the affected communities, gradually allowing everyone:

- To nterpret the results of measurements: ambient levels, internal and external doses, product contamination,
- To build her/his own benchmarks against radioactivity in day-to-day life,
- To make her/his own decisions and protect her/himself and loved ones (i.e. self-help protection).

In this approach, access to measurements by the population, with suitable devices is critical. On the individual and community levels, beyond self-protection, the practical radiological protection culture makes possible to improve living conditions. It allows individuals to regain autonomy, develop solidarity and to look to the future.

In Belarus, the self-help protection measures have gradually complemented the measures implemented by the authorities. In Fukushima, this complementarity is becoming a reality in some communities such as Suetsugi and Hippo. However, the appropriation process of the practical radiological protection culture in Fukushima and Belarus is very similar

Perspectives

Beyond the analysis of the human dimensions and the role of experts at the service of the population in the context of the Fukushima post-accidental management, this analysis aims to identify how to favour the development of co-expertise processes in post-accidental situations. In this perspective, on the basis of the feedback from Fukushima and its follow-up, further developments seems to be needed such as:

- analysis of case studies and/or preparation of guidelines for developing places of dialogue and tools to allow the involvement of public experts at the service of the affected population,
- reflection on the mechanisms to put in place to ensure the coordination and sustainability of protection measures adopted by the affected people with the support of experts,
- reflection on the possible organisation of the scientific and technical work to answer questions from the affected population related to radiation protection,
- reflection on the organisation of the decision-aiding processes relying on the cooperation with local, regional and national professionals from health care, education, administration in charge of environment…

It has also been noticed the need for further investigating the dynamics associated with the issue of the return of populations in areas evacuated following the Fukushima accident. Of particular interest is the analysis of the conditions and means for the return of the population, including the legal and administrative framework, the characterisation of the radiological situation, the human and social dimensions, the constraints on the economic and agricultural activities…

Among the key concerns of the people affected by the accident, is the health issue. Analysing the surveillance programmes put in place and challenging their strengths and weaknesses would also contribute to identify the possible framework for developing a global approach for health surveillance in the perspective of the well-being of the population and assessing the health statute of the population, producing scientific knowledge on the potential effects of chronic exposures, and providing the means for affected people to improve their daily life.

Stakeholder involvement and local preparedness and communication strategies – views and experiences from Portugal (a non-nuclear country)

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Abstract

The decision about not to follow the nuclear energy option for the production of electricity was taken in Portugal in the mid-seventies and is in force since then, despite recurrent discussions about the subject driven by the international context (e.g. nuclear energy *renaissance*) or by specific national economic and political contexts.

The non-existence in national territory of nuclear reactors or any installations (besides a research reactor),, industries and economic activity (including mining) associated to the nuclear fuel cycle has impact at different levels including education and training (scarce curricula offered by the national universities in areas associated to nuclear energy and technology, absence of degrees in Nuclear Engineering, Nuclear Technology, etc.) and also in the perception by the national stakeholders, ranging from the public to the decision makers, including also journalists and institutional or non-institutional experts, about the associated scientific, technical, socio-economic, ethical and legal topics and issues.

However, the park of nuclear reactors in neighbouring countries, namely Spain, and the geographical and environmental factors raise concerns that are often addressed in media, especially due to the consideration of potential nuclear accidents and their radiological consequences due to the release of radioactivity and the resulting environmental contamination. Major concerns are related to the potential contamination of foodstuffs, feedstuffs and consumer goods and the associated consequences to human health.

The Fukushima accident and its characteristics, namely the long duration of the radioactive releases, have triggered nationwide concerns about the preparedness of the country and the existing established structures and expertise to address nuclear or radiological (RN) emergencies. Questions about emergency preparedness and response at the national level but also in coordination and cooperation with neighbouring countries and international organizations were raised and there was a need to provide, both to media and to decision makers specific answers to address and respond to public concerns.

In the framework of the FP7-EURATOM funded project PREPARE, i) panels were organized with experts covering a wide range of national stakeholders and ii) interviews were conducted to institutional and non-institutional experts involved in the follow-up of the Fukushima accident.
In this work, the main conclusions of these panels, together with the results of the interviews are presented. The positive interplay between the two methodologies (national panels and interviews) in building up and raising awareness amongst experts on the need to further develop, consolidate and strengthen cooperative actions and dialog in emergency preparedness are shown. The priority actions that emerged from the analysis of the results obtained using both methodologies are identified.

Overall, it is felt by the authors of this work, that views and experiences from non-nuclear countries such as Portugal, presumably carrying more resilient views and perspectives *vis a vis* the benefits of nuclear energy and the associated risks, can provide innovative contributions to improve the effectiveness of risk communication methodologies, procedures and strategies.

1. Introduction

Portugal does not have any nuclear installation for the production of electricity. However, there are several nuclear power plants in neighboring countries, namely Spain, which has raised some concerns regarding the occurrence of potential nuclear accidents and their radiological consequences. The major preoccupations expressed by public, decision makers and radiological protection (RP) experts are related to environmental contamination, the potential contamination of foodstuff, feedstuff and consumer goods and the associated consequences to human health.

With Fukushima nuclear accident, a nationwide debate was triggered about the preparedness of the country to face RN emergencies and the involvement of the national stakeholders in post-accident management. Questions related to emergency response at national level but also in coordination with neighbouring countries and international organizations were raised and there was a need to provide specific answers to respond to public concerns.

Furthermore, at European level, some gaps have been identified in nuclear and radiological preparedness, following Fukushima accident. The project PREPARE (FP7-FISSON-2012-3.3.1) appears in this context as a collaborative project of the 7th framework Programme EURATOM, for Nuclear Research and Training Activities, of the European Union. The PREPARE project consortium team aims to review operational procedures for dealing with long lasting releases and for monitoring foodstuffs, feedstuffs and consumer goods across the borders and to update emergency management procedures, through the development of missing functionalities in decision support systems (KIT, 2012).

One of the main activities carried out in PREPARE WP3 ("Consumer Goods") comprises the development of strategies and safety criteria for the management of contaminated foodstuff and feedstuff, given the different opinions of the relevant stakeholders, such as national and regional authorities, producers, food industries and consumer associations (Description of Work: "PREPARE - Innovative integrative tools and platforms to be prepared for radiological emergencies and post-accident response in Europe", 2012). Another important aspect during a RN emergency, as well as in a post-emergency phase, is the relevant, reliable and trustworthy information that is available to the members of the public at the appropriate time and according to its needs. This issue is addressed in PREPARE WP6 ("Information and participation of the public"), where one of main objective is to analyze the emergency and post-emergency network interactions between various categories of experts, in the context of Fukushima accident (Description of Work: "PREPARE - Innovative integrative tools and platforms to be prepared for radiological emergencies and post-accident response in Europe", 2012).

For this work, in the framework of WP3, a national panel was organized with experts covering a wide range of national stakeholders, whereas for WP6, interviews were conducted to institutional and non-institutional experts involved in the follow-up of the Fukushima disaster.

2. Panel Methodology and Interview Process in Portugal

In context of PREPARE WP3, the first national panel organized was about "*Management of contaminated foodstuff and feedstuff after a radiological or nuclear accident*". The main objective of this panel was to bring several national stakeholders to discuss issues that should be address in a RN emergency, such as management practices, regulatory issues, risk perception and risk communication. Additionally, we tried to understand the stakeholder's concerns regarding the radioactivity monitoring and control of goods and we promoted the exchange of experiences in previous emergencies situations with different RP experts.

A total of 35 participants from 16 different institutions (10 governmental institutions and 6 non-governmental organizations) attended the meeting. The participants in the panel included national and regional authorities, regulators, agro food companies, food industries associations and consumers associations. For the discussion between the different stakeholders, the Chatham House Rule was adopted in order to increase the openness of the discussion, since the information from the debate may be used, but the person who made the comment cannot be revealed.

Concerning the methodology adopted for the interviews, it was assumed that an institutional expert is a scientifically and technically recognized expert in a specific area that convenes the opinions of the institutions he represents, while a non-institutional expert is a scientifically and technically recognized expert in a specific field that convenes his own opinions and shows a distance from the "official" channels. Taking into account this observation, a total of 7 specialists from 7 different institutions were contacted: non institutional experts - Press (1) and University (1); Institutional experts - Regulator's (2), Civil Protection (2) and State Labs (1).

Some of the experts contacted were identified as being involved in the Fukushima Working Group (WG) established by CNER (National Commission for Radiological Emergencies), to perform the follow-up on the radiological situation resulting from the event. The interviews were developed accordingly to the functions and roles of the responders during the Fukushima crisis, and were conducted face-to-face, taking an average of 2-3h time, or by email. The answers received are an exclusive responsibility of the interviewee and are not necessarily the views of the organizations they represent.

3. Discussion and Conclusions

i) WP3: Consumer Goods - 1st National Panel

One of the most important challenges identified during the overall discussion of the national panel were the similar or overlapping competences between different entities in an emergency situation. The stakeholders blamed the unclear legislation, which may lead to an inefficient articulation between institutions and to an incomplete knowledge of the different organization's skills.

When questioned about the protocols related to the management of radioactive contaminated foodstuff/feedstuff, some competent authorities and public institutions related to the food products issues were not fully sure about the specific procedures. Nevertheless, the industrial stakeholders did recognize the importance of their social role during and after the emergency phases by showing availability in investing in monitoring equipment for the control of their products.

It was verified that the stakeholders are, in general, aware of the European regulations regarding the maximum permitted levels of radioactive contamination of foodstuff and feedstuff following a RN emergency. However, concerns were raised about the implementation of harmonized reference levels in EU, since different countries have distinct consumption patterns.

There was no receptivity of the public to consume contaminated products regardless compliance with legal radionuclide established reference levels, but lowering the costs of the foodstuff and the absence of direct health effects may change this behavior. Though, when questioned about the health effects related to the ingestion of contaminated foodstuff, the majority of the participants admitted complete lack of knowledge.

The effects of possible contamination in foodstuff/feedstuff on the regional and national economy were also discussed. The costs of the production would decrease very quickly with negative impacts on the overall economy. Moreover, the stakeholders pointed out that a bilateral cooperation between the EU and IAEA members in emergency situations are a good mechanism of rescuing and helping a country that may face these disasters.

The general perception is that the public is sensitive to issues related with radioactive contamination and its perception depends on the way the subject is communicated. Non-reliable sources of communication and information may cause public mistrust regarding the information transmitted by the competent authorities. This distrust is also emphasized by the contradictory information given by different institutions, which gives a wrong image about the competences of the management emergency and post-emergency crisis. In order to efficiently communicate scientific and technical issues, the experts, including media, should be trained in communicating clear concepts using simple and transparent information based on straightforward language.

Additionally, education and training needs related to emergency and post emergency situations were regarded as fundamental for technical, scientific, *media* and general public as well as for other stakeholders' awareness.

ii) WP6: Information and participation of the public – Expert's Interviews:

The overall analysis of the interviews performed suggest the importance in implementing harmonized measurements at EU level in terms of regulations and procedures in RN emergencies. The establishment of reference levels will also contribute to show to the public that, even in the absence of harmonization of values, there is an implemented protection level.

All interviewees agreed that having links to other organizations including the non-governmental ones is important and the link to an independent regulatory body is fundamental. However, the fully implementation of an independent regulatory body and the clear allocation of its responsibilities, its scope for action and its role to managing radiological emergencies is not yet fully accomplished.

When asked if an emergency occurs close to Portugal, some challenges were identified: insufficient trained human resources that could assure rotation in acquiring and analyzing information; inexistence of enough monitoring equipment; generalized lack of emergency procedures.

The respondents were assertive in considering that the public trusts in the information received from the official authorities in Portugal, namely during Fukushima event. The credibility of the information is a fundamental step to achieve public confidence in the authorities' decisions. However, they stated that the relations between media and institutional experts need to be promoted by having more contacts between them, with the arrangement of working meetings and the presence of the *media* in planned national and international emergency exercises. Moreover, the training of the institutional experts and *media*, in terms of briefing adequately and clearly about RN emergencies, should be implemented.

The overall analysis of the interviews also shows that the information dissemination needs a better coordination, which requires a more continuous dialogue between all involved actors in the management emergency and post-emergency crisis. Regarding education and training schemes, it was suggested that these should be expanded to a wider professional audience at national level.

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