NERIS

Fifth NERIS Workshop

"Key challenges in the preparedness, response and recovery phase of a nuclear or radiological emergency"

3-5 April 2019, Roskilde, Denmark

PROCEEDINGS

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Edito

The 5th NERIS Workshop, held in Roskilde, Denmark, in April 2019 addressed the key challenges in the preparedness, response and recovery phase of a nuclear or radiological emergency. With a large participation, the Workshop provided a good opportunity to present the recent scientific and methodological developments notably achieved within the European research projects.

An integral part of the mission of NERIS is to identify gaps and needs for further research and development and addressing new and emerging challenges in the field of preparedness for nuclear or radiological emergency response and recovery. In this perspective, the 5th NERIS Workshop contributed significantly to update the NERIS Strategic Research Agenda, published in November 2019, and the NERIS Roadmap, published in May 2020, structured around the three main challenges covered by the Workshop:

1. Radiological impact assessment during all phases of nuclear and radiological events
2. Countermeasures and countermeasure strategies in emergency & recovery, decision support & disaster informatics
3. Setting-up a trans-disciplinary and inclusive framework for preparedness for emergency response and recovery

Due to the current challenge related to the assessment of recent radiological events, a specific topic was also addressed during this Workshop: Challenges in estimating the source term and operational radiological picture (on-site versus off-site).

These proceedings present a series of papers, 18 in total, covering the 4 topical sessions. They present the main achievements related to the management of uncertainties both for the dispersion models and the assessment of protective strategies, notably dealing with decontamination of areas following a nuclear accident. Experiences gained with advanced monitoring are also presented. With regard to decision support system, it is worth to mention the challenging developments dealing with negotiation process for the stakeholders of different backgrounds by constructing agent-based negotiation models with the corresponding computational implementations. Focus is also made on preparedness experiences from different countries and the associated regulatory issues. Finally, the last session provides a series of methodological developments for the estimation of source term, discussing their integration into the decision-support system and learning from the analysis of the Fukushima source term.

Promoting the dissemination of the research works being part of the mission of NERIS, I am pleased to introduce these proceedings and I encourage you to disseminate these papers in the broader community of researchers, experts and stakeholders with interest on emergency and recovery issues.

Thierry Schneider (CEPN), President of the Platform

Radiological impact assessment during all phases of nuclear and radiological events

Uncertainty of Atmospheric Dispersion Prediction

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Introduction

In the early phase of a nuclear power plant accident with possible off-site consequences resulting from e.g. core melt and breach of containment, accurate prediction of the atmospheric dispersion of radionuclides is of utmost importance. However, two large sources of uncertainty exist: one associated with the meteorological data employed for atmospheric dispersion model prediction, and one related to the source term, i.e. the amount of radionuclides released and the temporal evolution of the release.

In recent years, the effects of these inherent uncertainties on prediction of atmospheric dispersion of radionuclides released from nuclear accidents have been studied in a number of Nordic research projects funded by Nordic Nuclear Safety Research (NKS). Corresponding methods have been developed intended for operational use in emergency preparedness and response by national radiation protection authorities.

The methodology is implemented in the ARGOS nuclear decision-support system (DSS) (Hoe *et al.,* 1999; 2002; PDC-ARGOS) and is in operational use by the Danish Emergency Management Agency (DEMA) and the Danish Meteorological Institute (DMI) utilizing the DMI supercomputing facility.

Meteorological Ensemble Prediction

The COMEPS meteorological ensemble prediction system (Yang *et al.,* 2017), which is based on the Harmonie non-hydrostatic numerical weather prediction (NWP) model (Bengtsson *et al.,* 2017), is operational at the DMI. COMEPS includes 25 ensemble members with a horizontal resolution of 0.022°, corresponding to approximately 2.5 km, and vertically the model has 65 layers from the surface up to 10 hPa (approximately 30 km above the sea surface). The ensemble system is nested into ECMWF's global model. The geographical coverage is depicted in Figure 1.

Figure 1. Geographic domain covered by the operational EPS system at DMI.

Meteorological forecast uncertainties arise from uncertainties in the initial and lateral boundary conditions and from model short-comings, particularly short-comings associated with parameterization of physical processes that take place on spatial scales that cannot be represented explicitly by the model (Buizza *et al.,* 1999; Hou *et al.,* 2001).

The Danish Emergency Response Model of the Atmosphere (DERMA)

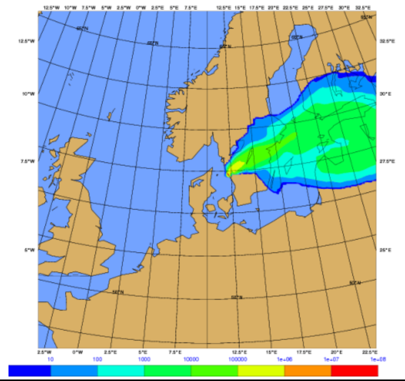
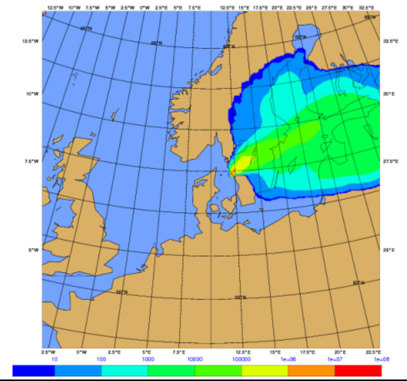
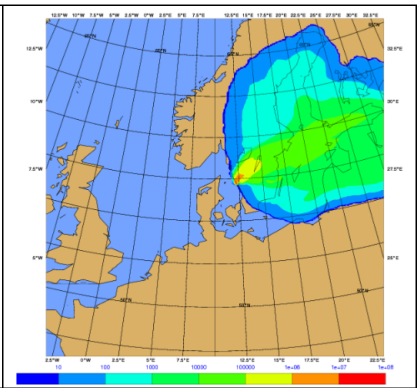
The Danish Emergency Response Model of the Atmosphere (DERMA) (Sørensen *et al.,* 2007; Sørensen, 1998; Baklanov and Sørensen, 2001) is a comprehensive numerical regional and meso-scale atmospheric dispersion model developed at DMI. The model is used operationally for the Danish nuclear and chemical emergency preparedness, for which the Danish Emergency Management Agency (DEMA) is responsible (Hoe *et al.*, 2002). Besides, the model is employed for veterinary emergency preparedness (Sørensen *et al.*, 2000; 2001; Mikkelsen *et al.*, 2003; Gloster *et al.,* 2010a; 2010b), where it is used for assessment of airborne spread of animal diseases, e.g. foot-and-mouth disease. DERMA is also used to simulate atmospheric dispersion of ashes from volcanic eruptions, and dispersion of biological warfare agents, and it has been employed for probabilistic nuclear risk assessment (Lauritzen *et al.,* 2006; 2007; Baklanov *et al.*, 2003; Mahura *et al.*, 2003; 2005).

Meteorological Uncertainty of atmospheric Dispersion model results (MUD)

In the NKS project MUD (Meteorological Uncertainty of atmospheric Dispersion model results), Sørensen *et al.* (2014) developed a methodology to quantify the effects of the inherent uncertainties of the NWP model data used on the atmospheric dispersion prediction.

Having available an NWP ensemble prediction system, dispersion model ensembles can be obtained for a given source term by running the dispersion model for each of the NWP ensemble members. Thereby, a dispersion model ensemble is created from which one can calculate various statistical parameters.

In Figure 2, results are shown for DERMA applied to a scenario with a release from the Ringhals NPP beginning on 2011-05-20 at 18 UTC. The results shown concern time-integrated concentration of I-131 at 54 hours after the start of the release. In the upper row, a low percentile, the median and a large percentile are displayed. Below are shown probabilities for exceeding 10^4, 10^3 and 10^2 Bq h/m^3, respectively.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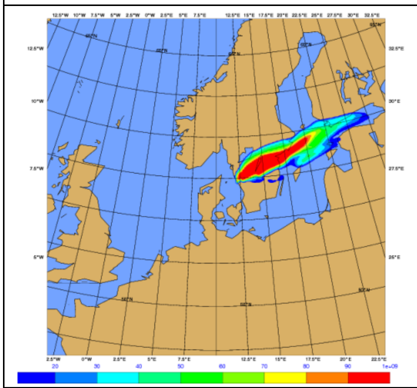
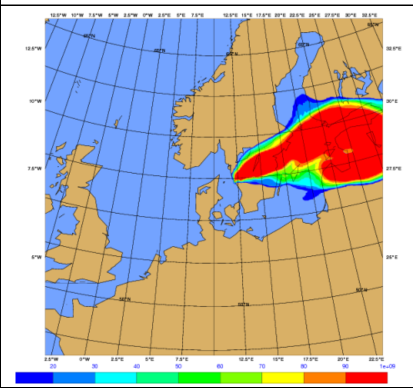
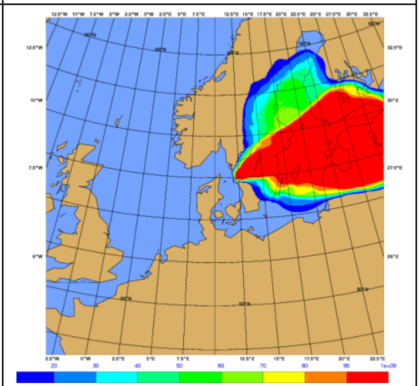
		
Prob. exceeding 10^4 Bq h/m^3	Prob. exceeding 10^3 Bq h/m^3	Prob. exceeding 10^2 Bq h/m^3

Figure 2. Valid time: 2011-05-23. NPP: Ringhals. Field: Time-integrated concentration 54 hours after start of release. Nuclide: I-131.

Fukushima Accident: UNcertainty of Atmospheric dispersion modelling (FAUNA)

In the NKS project FAUNA (Fukushima Accident: UNcertainty of Atmospheric dispersion modelling), Sørensen *et al.* (2016) applied the ensemble-statistical methodology developed in MUD to the Fukushima Daiichi NPP accident. The project addressed real-time forecasting of atmospheric dispersion and deposition of the radionuclides released taking into account the meteorological uncertainties. The source description by Katata *et al.* (2014) was used in the FAUNA project.

The objective of the FAUNA project was to apply the MUD methodology to a realistic setting of the Fukushima accident, and to investigate the implications for the emergency management of the uncertainties on the prediction of the geographical areas affected by radioactivity.

A meteorological ensemble forecasting system was set up and run on DMI's supercomputer for the period of concern and for a geographical domain covering Japan and surroundings. For the full period, two-day meteorological forecasts were generated four times a day, as would be the case for an operational system in real time. Thus, the project imitated real-time emergency management taking into account estimates of the uncertainty of the dispersion model results.

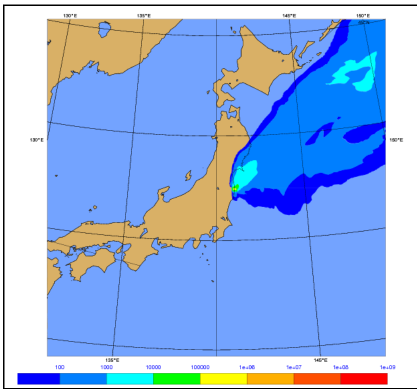
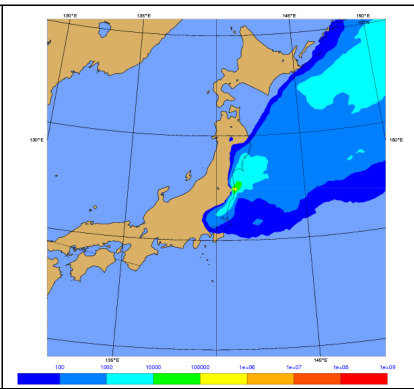
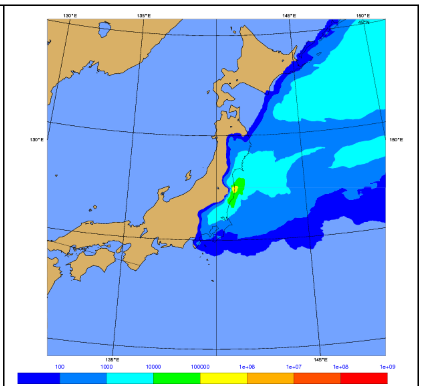
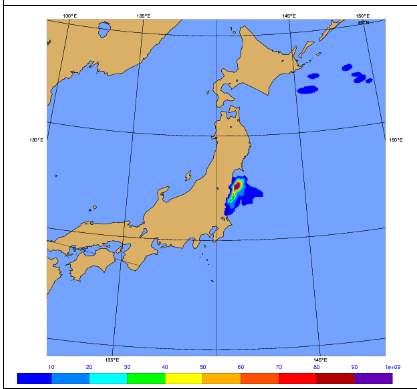
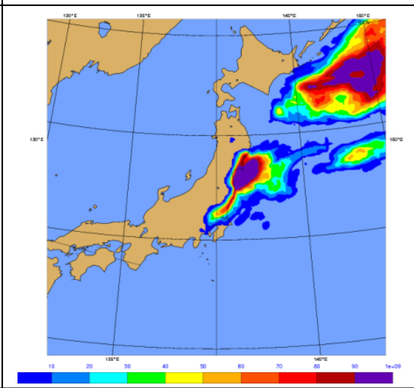
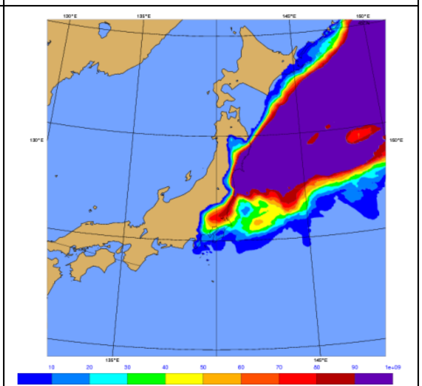
		
10th percentile	50th percentile	90th percentile
		
Prob. exceeding 10^4 Bq/m^2	Prob. exceeding 10^3 Bq/m^2	Prob. exceeding 10^2 Bq/m^2

Figure 3. Plume prediction based on NWP model forecast of 2011-03-13, 00 UTC. Accumulated deposition of Cs-137 at 23 UTC on 14 March, 2011.

One of the scenarios considered is a hypothetical gathering of an expert group at the headquarters of a national radiation protection authority in the morning of 13 March 2011. The group has available the latest DERMA simulations from the 0 UTC run of the ensemble system, cf. Figure 3. Thus, the dispersion calculations are based on the latest full forecast series ranging 48 hours ahead from the meteorological analysis of 0 UTC on 13 March as well as analysed meteorological data and 1, 2, ..., 5 hours forecast data in between the analyses describing the period from 11 March until the latest analysis. During the forecast period, the plume is predominantly over the Pacific Ocean but meanders between north, east and finally south in the direction of Tokyo. In the first row of Figure 3 is shown the 10^{th}, 50^{th} and 90^{th} percentiles of accumulated deposition of Cs-137 valid at the end of the forecast period, i.e. at 23 UTC on 14 March 2011, and in the second row probabilities of exceeding threshold values of 10^4, 10^3 and 10^2 Bq/m^2, respectively. As can be seen, in this case low percentiles do not affect the Tokyo area, whereas larger percentiles do.

MEteorological uncertainty of ShOrt-range dispersion (MESO)

As shown by the MUD and FAUNA projects, the influence of meteorological uncertainties on long-range atmospheric dispersion calculations can be large, up to an order of magnitude or two depending on the weather situation, with significant implications for nuclear emergency preparedness and decision making. In the subsequent MESO (MEteorological uncertainty of ShOrt-range dispersion) project, Sørensen *et al.* (2017) studied to what extent this also applies to short-range dispersion models employed for nuclear emergency preparedness up to about a hundred kilometres from the source. Additionally, the direct use of weather radar data for the simulation of wet deposition of radionuclides was addressed including the uncertainties and potential errors associated with such use of weather radar data. These include the use of a parameterization of the precipitation rate depending on the attenuation of the reflected radar signal, filtering of false radar echoes arising from e.g. clutter or flocks of birds, precipitation from low clouds not being registered by the radar beam, and precipitation evaporating before reaching ground.

In brief, the results of MESO show that there is potentially a substantial influence of NWP model uncertainty on atmospheric dispersion also at short range, even close in at the kilometre scale (the near range). The variability is, however, less than at long range. Expressed as a factor, uncertainties of a factor of two to three can easily be observed at short range. However, in cases with well localised intense rainfalls, which are in general not well predicted by NWP models, one may observe larger effects.

Added Value of uncertainty Estimates of SOurce term and Meteorology (AVESOME)

In the NKS project AVESOME (Value of uncertainty Estimates of SOurce term and Meteorology), Sørensen *et al.* (2019) developed a methodology for quantitative estimation of the variability of atmospheric dispersion modelling resulting from both of the two largest sources of uncertainty, viz. the meteorological data and the source term. With modern super-computing facilities available e.g. at national meteorological services, the proposed methodology is well suited for real-time assessment and implementation in nuclear decision support systems (DSSs).

The methodology developed in AVESOME adapts well to the RApid Source TErm Prediction (RASTEP) system (Knochenhauer *et al.,* 2013), which provides a statistical ensemble of possible source terms and associated probabilities.

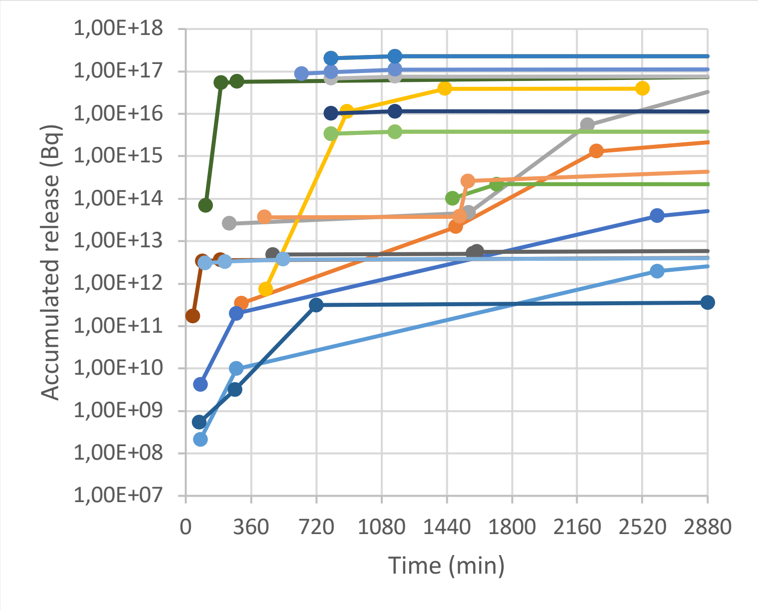


Figure 4. Accumulated release of Cs-137 as function of time since the emergency shutdown of a nuclear reactor (SCRAM) for the source-term ensemble members.

In the MUD, FAUNA and MESO projects, the atmospheric dispersion model ensembles were based on NWP model ensembles with N members. In AVESOME, the ensembles involved can be either a Source Term (ST) ensemble with M members applied to a deterministic NWP model, or an ST ensemble combined with an NWP model ensemble. In the latter case, the overall statistical ensemble is larger including $N \times M$ members. Whereas the meteorological ensemble members are equally likely, this is not the case for the source-term ensemble members, where the severe cases are highly unlikely. Therefore, weighted ensemble statistics should be employed.

A generic BWR source-term ensemble was provided to AVESOME consisting of a list of probabilities and source terms for the different release categories from the full power operation cases of a PSA Level 2, see Figure 4. The ensemble consists of 19 members. With a meteorological ensemble of 25 members, the combined ensemble thus consists of 25×19 = 475 members.

At the early phase of a serious nuclear accident with very limited knowledge on the source term, the difference between the source-term ensemble minimum and maximum is very large. Possibly, the ensemble shown in Figure 4 is too wide to be of practical value. Instead, one may decide to use a scenario-based approach limiting the ensemble members to selected ones. For each such sub-set, the weighting factors should be re-normalized.

Later, when additional information on the plant status is received, the source-term ensemble will become more focused; in the end probably to a fairly well-defined source term or a few. At this point in time, one should probably request new calculations due to the likely appearance of new NWP model forecasts available e.g. each three hours.

Few hours after the start of the event, one will likely know if the containment has been successfully isolated and if (at least one of) the mitigation systems (containment spraying and filtering) are functioning. In such case, the above 19-member source-term ensemble is reduced to 8 members. In Figure 5 are shown percentiles of accumulated deposition of Cs-137, and probabilities for exceeding given threshold values for the mitigation scenario.

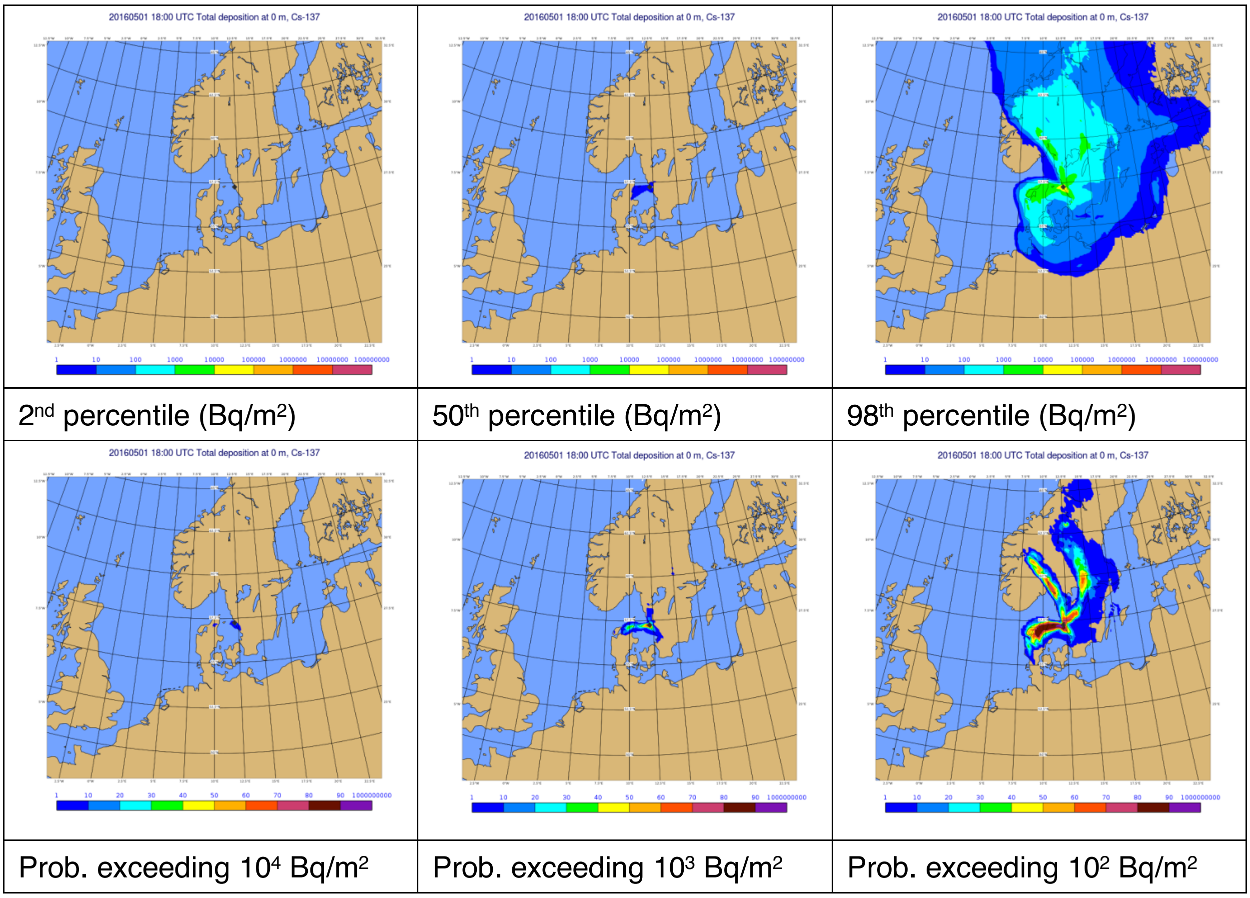


Figure 5. Percentiles of accumulated deposition (Bq/m2) of Cs-137 and probabilities (%) for exceeding threshold values for the mitigation source-term ensemble. Release starts at 2016-04-27, 12 UTC.

Conclusions

Implications of the largest sources of uncertainty on atmospheric dispersion of radioactivity from accidental releases have been addressed. These uncertainties involve both the source term, i.e. the amounts of radionuclides released and the temporal evolution of the release, and the meteorological data used. Impacts of the combined uncertainties on real-time emergency preparedness and management are further examined.

The methods developed allow for efficient real-time calculations by making use of scaling properties in the equations governing the release and the atmospheric dispersion of radionuclides. Accordingly, the computer-resource demanding calculations should be carried out at HPC facilities available e.g. at national meteorological services, whereas less demanding post-processing can be carried out at the computer hosting the DSS. The former tasks include atmospheric dispersion model calculations; the latter include interactive communication with the supercomputer as well as presentation of final results in the form of distributions of radionuclide concentrations, depositions and human doses.

The ARGOS nuclear DSS has been extended with a facility to handle multiple results from a single request for long-range prediction, including a set of statistical results from an ensemble run from either a meteorological ensemble or a source-term ensemble, or the two combined.

The facility is in operational use by the Danish Emergency Management Agency (DEMA) and the Danish Meteorological Institute (DMI) utilizing the DMI supercomputing facility.

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Improving European decision support reliability and robustness to manage scenarios involving contamination of inhabited areas

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Introduction:

In recent years, various efforts have been made to enable the European standard decision support systems for management of contaminated areas to address uncertainties in different parts of the dose estimation framework, in order to provide more robust prognoses. Under the European research project CONFIDENCE (COping with uNcertainties For Improved modelling and DEcision making in Nuclear emergenCiEs), the ERMIN model for external dose estimation in contaminated inhabited areas was revisited in this context. Although rough indications of parametric uncertainties associated with some ERMIN parameters have previously been indicated, it was clear that an effort was needed to systematically improve on the quality of these parameter uncertainty indications, taking the latest information into account and considering a wider range of case specific parametric options, thus reducing the overall prognostic uncertainty.

Methods / results:

In estimating external dose in a contaminated area, a number of calculation steps need to be carried out. For instance in the early phase of an accident, where contamination levels have not yet been measured, as well as for the purpose of exercises, drills and training, contamination levels must be estimated by multiplying a time-integrated contaminant air concentration typically from an atmospheric dispersion model by the relevant deposition velocity to the surface in question in the inhabited environment. Whether they were modelled or measured, contamination levels on the different types of surface can then be multiplied by conversion factors from contamination level to an average dose rate to a person living in a given type of environment, as well as time-integrated taking into account functions describing the decline in contamination level over time. The product will be a time-integrated dose - e.g., a dose projected into the future, which can be used to get an overview of the severity of the situation, and, taking into account the effect of potentially implemented countermeasures, residual doses can be estimated, which constitute important information in connection with justification and optimization of intervention. This paper describes work carried out to improve the ERMIN dose calculation parameterization and provide parametric uncertainties that can be applied in estimating endpoint uncertainties. The focus is here on the deposition process and the decline in dose rate with time.

Deposition

The deposition is greatly dependent on the physicochemical properties of the contaminants and the types and orientations of the surfaces in the inhabited area to which the deposition occurs (Andersson, 2009). It should thus first be considered which physicochemical forms the various likely contaminants from a major NPP (nuclear power plant) accident could be expected to have. One of the most volatile contaminants (except noble gases) is iodine, which may be released in its elemental gas form (which has a very high deposition velocity to surfaces), in organic gas forms (where the deposition velocity is comparatively insignificant and thus in practice unimportant), and as condensed vapour on ambient aerosols, typically resulting in an AMAD (activity median aerodynamic diameter) in the range of 0.5-1 μm, which would have an intermediate deposition velocity (Andersson, 2009).

Chernobyl contaminants of certain elements were only released to the atmosphere in the form of comparatively large low solubility fuel particles, indicating that these would in general be expected to be highly refractory (undepleted from the fuel). These elements comprised ^{95}Zr, ^{95}Nb, ^{140}Ba, ^{140}La, $^{141/144}$Ce, $^{237/239}$Np, $^{238-242}$Pu, $^{241/243}$Am and $^{242/244}$Cm (Hinrichsen & Andersson, 2019).

Contrary to this, contaminants of the elements Cs, Te and Rb (and to some extent Sb and Mo) would on the basis of the Fukushima and Chernobyl accidents be expected to a great extent to be volatilised from the fuel, forming submicroneous condensation particles in the range of 0.5-1 μm. However, in connection with the Chernobyl accident, even at distances up to about 50-60 km in some directions from the power plant, most of the deposited caesium was found to be in the form of large low solubility fuel particles.

Ruthenium is different because it has a very high elemental boiling point (2700°C), which would in practically any thinkable incident scenario prevent it from being volatilised and depleted from fuel material. However, in the presence of oxygen, it may be oxidised to a tetraoxide form, which is highly volatile (Hinrichsen & Andersson, 2019). Ruthenium may thus be associated with both large low solubility fuel fragment particles and small soluble condensation particles as observed after the Chernobyl accident.

Deposition relations on the different surfaces in the inhabited environment for particles of different sizes in the relevant range were derived from the current literature for different weather categories involving dry periods, periods of light rain and periods of strong rain. An effort was made to also derive uncertainty estimates. The results and the modelling background are reported in detail in Hinrichsen & Andersson (2019). An example (for dry deposition) is shown in Table 1.

Table 1. Values for deposition to different surfaces relative to that on the grassed reference surface, for situations when dry deposition dominates. The term 'sd' denotes one standard deviation. All distributions are assumed to be normal. Values are given for elemental iodine gas and for particles with AMAD < 2 μm, 2-5 μm, 5-10 μm and 10-20 μm.

Surface	Elemental iodine		AMAD < 2 µm		AMAD 2-5 µm		AMAD 5-10 µm		AMAD 10-20 µm	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Short grass*	1.0	Ref. surf.	1.0	Ref. surf.	1.0	Ref. surf.	1.0	Ref. surf.	1.0	Ref. surf.
Bare soil	0.6	0.4	0.3	0.15	0.3	0.15	0.17	0.10	0.23	0.12
Soil and short grass*	1.0	-	1.0	-	1.0	-	1.0	-	1.0	-
Small plants*	0.8	0.5	1.4	0.7	1.6	0.8	1.0	0.5	1.2	0.7
Trees and shrubs*	0.4	0.25	2.5	1.2	4.3	2.5	1.7	1.2	1.5	1.1
Paved area	0.2	0.1	0.25	0.15	0.75	0.35	0.3	0.15	0.3	0.25
Clay tile roof	1.5	0.3	0.8	0.1	3.0	0.8	1.9	0.5	1.5	0.4
Concrete tile roof	1.8	0.4	1.0	0.2	4.0	1.0	2.2	0.6	1.6	0.4
Fibre cement roof	1.6	0.3	0.9	0.1	3.6	0.9	2.1	0.5	1.6	0.4
Silicon covered fibre cement roof	1.0	0.2	0.7	0.1	2.5	0.6	1.7	0.4	1.4	0.4

Surface	Elemental iodine		AMAD < 2 µm		AMAD 2-5 µm		AMAD 5-10 µm		AMAD 10-20 µm	
	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Glass roof	0.5	0.1	0.4	0.1	1.4	0.4	1.5	0.4	1.3	0.3
Smooth metal roof	0.7	0.1	0.5	0.1	1.6	0.4	1.6	0.4	1.3	0.3
External walls	0.15	0.1	0.03	0.02	0.07	0.04	0.1	0.07	0.05	0.03

*Values given per area of ground covered by the vegetation.
Note: typical dry deposition velocities to ref. surface (unit: 10^{-4} m/s) are respectively (left to right): 20, 4, 7, 30 and 130.

Contaminant mobility

A series of formulas describing the decline in contamination on and/or dose rate from different types of surface in an inhabited area, including parametric uncertainties, are reported in Hinrichsen & Andersson (2019a) on the basis of the work carried out in the CONFIDENCE project. In this paper, only a few examples of this work are mentioned. As demonstrated by Hinrichsen & Andersson (2019a), at least in some types of scenarios, the dose contributions from contaminated soil and roofs of dwellings would be of major importance, and these are therefore in focus in this paper.

ROOFS: Measurements made in Denmark over almost 15 years following the Chernobyl accident of the radiocaesium contamination level on different common roof materials (concrete, slate, clay tile) revealed that whereas the initial retention on the roof of contaminants after a wet deposition process varies considerably between these roofing materials, the following long-term weathering rates were in the Chernobyl case recorded to vary rather little between the examined range of materials (Andersson, 2009). Other, shorter time-series of measurements made elsewhere in Europe support the general validity of these findings. A common feature of these materials is that they generally contain minerals, which selectively and strongly fix and retain caesium cations. Other radionuclide ions would be expected to be less strongly held (Hinrichsen & Andersson, 2019a). ERMIN uses weathering data based on the Chernobyl time series caesium measurements (Andersson, 2009) for all radionuclides in ionic form for these types of roof materials. This may lead to conservative estimates of long term doses for other radionuclides, which are in reality weathered off faster. However, the physical half-lives of other radionuclides that would on the basis of past experience be expected to be potentially released in relatively large amounts and could impinge on external dose are considerably shorter than that of ^{137}Cs, and caesium is among the more volatile elements with generally comparatively high release probability.

The empirical formula thus applied in ERMIN for all contaminant ions deposited in more or less readily soluble form on many types of roofs (clay, concrete, slate) is:

$$C(t) = C_0 \cdot \exp(-Ln2 \cdot t / T_{½}) \cdot (f1 \cdot \exp(-Ln2 \cdot t / T_{w1}) + f2 \cdot \exp(-Ln2 \cdot t / T_{w2})),$$

where C(t) is the contaminant concentration at time t, C_0 is the initial contaminant concentration after the deposition process, $T_{½}$ is the physical half-life of the radionuclide, f1 is the fraction (on average ca. 0.5 on these roof types; estimated standard deviation 0.1) of the contamination removed with a short half-life of T_{w1} (ca. 730 days; estimated standard deviation 85 days), and f2 is the fraction (1- f1) of the contamination removed with a longer half-life of T_{w2} (on average ca. 35 years; estimated standard deviation 7 years). Also sandstone roof tiles contain intact micaceous substances (Hinrichsen & Andersson, 2019a), and would be expected to retain caesium in the same way.

The exception regarding radionuclide ions concerns very smooth (non-porous) surfaces, where experimentation suggests that the weathering of cationic caesium (and very likely also other ions) on a glass roof would occur with a half-life of the order of 95 days, and investigations from the European ECP-4 project suggest a similar value for smooth (uncorroded) metal roof covers (Hinrichsen & Andersson, 2019a).

Regarding low solubility particle contamination, these types of surfaces would not constitute an environment that could over a reasonable time (compared with weathering half-lives) lead to very much fuel particle dissolution (Hinrichsen & Andersson, 2019a). For the parameterisation time series data exists for Chernobyl lanthanum and barium, associated with 2-5 μm particles, as measured on roof pavings (concrete, slate, clay tile) in Denmark. These contaminants were found to be weathered off the surface much more rapidly than caesium (Hinrichsen & Andersson, 2019a). A reasonable weathering half-life, T_{w3}, would on the basis of that data seem to be of the order of 100 days. A probably dose conservative estimate of the weathering half-life for 5-10 μm (and larger) particles would judging from the data for paved horizontal surfaces be expected to be of the order of 60 days. The general formula for contaminants deposited in fuel particle form becomes:

$$C(t) = C0 \cdot \exp(-Ln2 \cdot t/T_{½}) \cdot \exp(-Ln2 \cdot t/T_{w3})$$

SOIL: The concentration of contaminants in soil is described in ERMIN as a function of time and vertical soil depth by a convection-dispersion model (Hinrichsen & Andersson, 2019a):

$$C(x,t) = C_0 \exp(-\ln(2)\, t/T_{½}) \left(\frac{1}{\sqrt{\pi D_s t}} \exp\left(-\frac{(x - v_s t)^2}{4\, D_s t}\right) - \frac{v_s}{2\, D_s} \exp\left(\frac{v_s}{D_s} x\right) \operatorname{erfc}\left(\frac{x + v_s t}{2\sqrt{D_s t}}\right)\right)$$

Here $T_{½}$ is again the physical half-life, Ds is the effective dispersion coefficient, and vs is the convective velocity, defined respectively as

$$D_s = \frac{D}{1 + K_d \frac{\rho}{\varepsilon}} \qquad v_s = \frac{v_w}{1 + K_d \frac{\rho}{\varepsilon}}$$

where D is the dispersion coefficient, v_w is the mean pore water velocity, K_d is the distribution coefficient of the contaminant in the soil, ρ is the bulk soil density, and ε is the soil porosity (all these parameters vary with soil type).

Before the CONFIDENCE project, only one 'standard' soil type was considered in the ERMIN model, which obviously meant that the results would be associated with huge uncertainties. A review has now been made of D_s, v_s, ρ and ε by soil type on the basis of numerous assessments over different parts of Europe (Hinrichsen & Andersson, 2019a). For radiocaesium from Chernobyl, the values of D_s and v_s were found to be as shown in Table 2. Certain soil clay minerals bind cationic caesium strongly and selectively. The soil classified here as 'sand' may in reality contain some clay minerals; no texture analysis was reported for the soils – only a broad classification.

It should be noted that the values of D_s and v_s for e.g. ruthenium and iodine contaminants generally differ from those for caesium by orders of magnitude. In the past, values representing caesium have been applied in ERMIN for all contaminants.

Naturally, the downward migration of contaminants associated with fuel particles is governed by completely different physicochemical processes, and much lower effective diffusion coefficients have been recorded for contaminants contained in dispersed fuel particles deposited on soil (Hinrichsen & Andersson, 2019a). For sandy, loamy and peaty soils, these were all found to be of the order of 0.015 cm^2 per year. This needs to be built into ERMIN. Based on these results, the downward migration of fuel particles is seen to be exceedingly slow, and it could only lead to limited conservatism in external dose estimates to assume that the particles remain in the very top of the soil until they dissolve over months or years.

However, once the radionuclides are released from the fuel particles, other relevant contaminants can generally be expected to migrate much faster than caesium (Hinrichsen & Andersson, 2019a). The dissolution of fuel particles in soil has in the Chernobyl case been reported to take place according to the formulae below:

If the material was initially oxidised, the dissolution rate constant after deposition in soil will be: k ($years^{-1}$) = $0.6 * 10^{(-0.15*pH)}$ at pH < 7.0, and k = 0.05 at pH > 7.0

If the material was NOT initially oxidised, the dissolution rate constant after deposition in soil will be: k ($years^{-1}$) = $40 * 10^{(-0.45*pH)}$ at pH < 6.5, and k = 0.05 at pH > 6.5

Table 2. Results of a review of values of Ds and vs by soil type in different types of soil, based on Chernobyl soluble caesium contamination assessments.

Soil group	GM	GSD	AM	SD	Min	Max
Parameter: D_s (cm^2 per year)						
All soils	0.22	3.1	0.37	0.4	0.02	1.9
Clay/Loam	0.20	4.6	0.36	0.3	0.02	0.8
Sand	0.11	2.3	0.16	0.2	0.03	0.6
Organic	0.94	1.8	1.07	0.7	0.63	1.9
Unspecified	0.27	2.6	0.37	0.3	0.04	0.8
Parameter: v_s (cm per year)						
All soils	0.18	3.3	0.27	0.2	0.00	0.9
Clay/Loam	0.06	17.5	0.24	0.3	0.00	0.6
Sand	0.15	1.7	0.17	0.1	0.07	0.6
Organic	0.69	1.6	0.73	0.3	0.40	0.9
Unspecified	0.22	1.6	0.24	0.1	0.09	0.5

GM: geometric mean; GSD: geometric standard deviation; AM: arithmetic mean; SD: arithmetic standard deviation.

Discussion / Conclusion:

The paper reports on results from the CONFIDENCE project carried out to improve on the reliability and robustness of dose calculation methodologies/data for use in the ERMIN inhabited areas external dose model, which is an integral part of the decision support systems RODOS and ARGOS. The work is aimed at providing generic model improvement by considering relevant contaminant physicochemical forms and environmental surface types. For instance for roof pavings, it is clear that the difference in terms of long-term projected dose between a weathering half-life of less than 100 days (for glass/metal surfaces) and a weathering half-life of 35 years (for e.g. clay tiles) is huge. As demonstrated by Hinrichsen & Andersson (2019a), dose contributions from contaminated roof pavings would be dominant in some plausible NPP accident contamination scenarios. Uncertainties are reported on all relevant input parameters.

In the CONFIDENCE project the new data was used to predict total doses (including uncertainty bands) of a predefined unoptimised recovery strategy (Charnock, 2019), for stakeholder discussions. Such calculations might give the impression that uncertainties on some dose contributions are unimportant if the dose contribution from the given surface is limited relative to those from other types of surface. An essential thing to ascertain is of course that the recovery strategy can be expected to solve the radiation problem in a satisfactory way (i.e. that the residual dose will be lower than an agreed threshold value). However, as demonstrated above, the variation in dose contribution from a specific surface may be extremely large depending on contaminant and surface characteristics. According to ICRP recommendations, not only the most effective countermeasure should be applied. Also other countermeasures may contribute to reaching the required dose reduction and should be carried out if they are cost-effective. It is therefore always important to know how much treatment of any given surface type would reduce dose. The cost elements need to be remembered in recovery strategy optimization.

It is a frequent misunderstanding that there will be lots of time to plan a recovery strategy before its implementation, taking lots of samples and measurements and having lengthy stakeholder discussions to be certain to agree on everything. Since contamination will migrate in the environment and become increasingly strongly fixed, the most advantageous countermeasures will only be effective over limited time periods. For instance, if the contamination occurs to a grass cover, simply cutting and removing the grass can greatly reduce the contamination level, but this must be done before the contaminants are transferred to the ground (usually over a period of days to weeks). Otherwise there will be a much more severe problem of soil contamination. Essentially everyone who has a lawn also has a lawn mower, and can readily contribute to the task as a self-help measure.

Also, large amounts of equipment, skilled equipment operators, means for transportation of equipment/consumables and waste etc. will for many countermeasures need to be acquired and brought to the area. Planning for how to achieve this in practice is crucial in advance of any accident. A tool like ERMIN is thus of great value both in constructing an operational preparedness that can respond effectively and cover to the expected extent, and to secure justification and optimization of recovery strategies within the relevant time frame.

Also measurement strategies to guide effective practical implementation of recovery strategies are highly important to have in place, as illustrated by the poor results of the 'hit-and-miss' efforts made after both the Chernobyl and Fukushima accident with essentially sound (in theory) countermeasures. The mere fact that we have tools in Europe to facilitate selection of potentially efficient recovery strategies does not mean that we would be able to implement the strategies properly in practice.

As mentioned above, ERMIN also needs proper conversion factors from contamination level to dose rate for a range of representative environment types. Currently, this type of data is only available for very few environment types, which all consist of at least 30 % grassed ground surface. These scenarios must thus in general be characterized as suburban. Recent work by Hinrichsen & Andersson (2019b) has produced dose conversion factors for modern urban building environments with much glass construction. However, the current range of environment types is still very limited.

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Radiological impact assessment in preparedness and response phase for nuclear emergency management in Greece

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Introduction

The new European BSS Directive (Directive 59/2013/Euratom) brought important changes in the system of radiological safety, including in emergency preparedness and response system. As part of the transposition and implementation of the new BSS Directive, Greece undertook a new National Hazard Assessment (NHA) of the potential radiological or nuclear emergencies that can potentially affect the country. As Greece is a non-nuclear country, nuclear emergencies are relevant with regard to an accident in a nuclear vessel, visiting the country, or a major accident in a nuclear power plant abroad. Both are considered in the NHA. This work deals with the latter case.

The possibility of a significant release from a nuclear reactor, as a result of an accident in Europe, whereas very small, it cannot be eliminated, and so it should be considered in the emergency preparedness system. In Europe, unlike Fukushima, such an accident might potentially have a significant transboundary impact, because of the higher population density and the number of reactors close to national borders. Moreover, even in the case of a low actual radiological impact, public radiological risk perception might create fear and/or stigma with considerable social or economic detriment. The importance of ensuring a consistent transboundary response among the affected countries in case of a hypothetical nuclear accident has been recognized and highlighted in Europe, in particular after the Fukushima accident (e.g. [1], [2]).

In the followings, we present basic elements of the national assessment for a nuclear emergency from a hypothetical nuclear accident abroad. The assessment is based on two sets of scenarios and calculations, using different atmospheric dispersion models. Some of the pertinent difficulties and uncertainties in assessing the situation and decision making during the course of such a hypothetical event, are indicated, in particular for distances out of those typically covered by the emergency planning of the installations.

Hypothetical scenarios

No part of Greece belongs to the emergency distances of a neighboring country nuclear power plant. According to latest IAEA standards ([3]), such a hypothetical nuclear accident outside the national borders can be categorized as a category IV emergency and considered relevant to all jurisdictions across the country.

The assessment is based on two different sets of calculations. In both sets we looked mainly at the potential impact on relatively long distances, representative of the distances of the closest in our borders nuclear power plant abroad, i.e. distances in the order or longer than 300km. The first set was undertaken in 2015-2016 using US NOAA Hysplit ([6]) model and is presented in detail in [4].The second one was performed recently, in 2018. In this case JRODOS ([5]) was used for atmospheric dispersion and dose calculations. JRODOS and

Hysplit are used in EEAE, as the operational tools for emergency response with forecast meteorological data from ECMWF, available through the Hellenic National Meteorological Service. Radiological impact is estimated taking into account the following exposure pathways: external exposure from cloud shine and internal exposure from inhalation during the plume passage and external exposure from ground shine emanating from the deposited radioactivity on the ground.

In the first set of calculations, source term is based on the Fukushima accident releases. More specifically, a 10-day release is assumed following the estimated amount and time sequence of the Fukushima accident source term. Release of ^{131}I, ^{134}Cs, ^{137}Cs and ^{132}Te is assumed, because of the high abundance and health significance of these radioisotopes in nuclear accidents. More information on the source term can be found in [4]. Meteorological data from ERA-INTERIM re-analysis database of the ECMWF are used, downloaded in grib1 format and converted to the format suitable for Hysplit. The ECMWF meteorological data are interpolated on a 0.25^{o} resolution grid covering Europe, with a 6 h time step and on 11 vertical pressure levels. Doses are calculated with Hysplit pre-processing tool, modified for the purposes of EEAE emergency needs.

Using meteorological data covering the whole year 2013, we assessed, through a series of about 11000 trajectories calculations, that the plume from a location representative of the nearest nuclear power plants reaches Greece with a frequency of the order of a few present in a year. Among these dates, several were found with adverse weather conditions, namely, the plume heads directly towards the country, over which rain events occur leading to increased ground contamination.

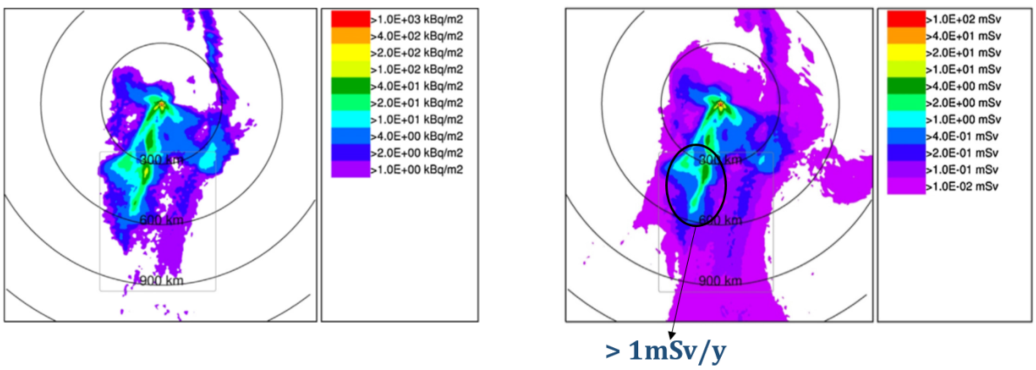

Figure 1. ^{137}Cs deposition (left) and 1st year dose (right), as calculated in the first assessment, for a Fukushima-like release in summer 2013. ECMWF re-analysis meteorological data are used.

In the latter set of calculations performed with JRODOS, NOMADS re-analysis meteorological data were used. Release dates were selected among a series of dates with adverse radiological conditions for Greece, which had been previously specified with the help of colleagues from CIEMAT (Spain) for the purposes of WP4 of European Project CONFIDENCE. Final release dates in summer on 2017 were selected, favoring increased contamination in the country. In this case, the release characteristics proposed by IAEA ([7]) for emergency preparedness are assumed. More specifically, it is assumed that 10% of the core inventory is released within a short period equal to 10 hours. The inventory is estimated according to IAEA values for a $3GW_{th}$ reactor ([8]), which is representative of the plants sizes in the vicinity of

Greece. These calculations were also used in the last exercise regarding a nuclear emergency abroad.

In Figure 1, the effective dose for the 1st year and ^{137}Cs deposition are shown, as calculated in the first assessment. Although the dose in the first year remains below the lower limit (20mSv) of the reference levels band, yet it exceeds 1mSv in a considerable area out of the distance of 300km (maximum values around 9mSv), so representing an exposure which can be considered as radiologically significant. ^{137}Cs deposition also depicts a considerable area with radiologically significant values, exceeding 37kBq/m^2, the threshold value adopted by IAEA in characterizing contaminated areas after the Chernobyl accident. Distribution of the contamination in the different areas is shown in Figure 2, where the calculated ^{137}Cs deposition is presented in each administrative department. It is worth noting that more that 7% of the total ^{137}Cs quantity released it is calculated that is deposited in the country at distances of the order or greater than 300km from the release point.

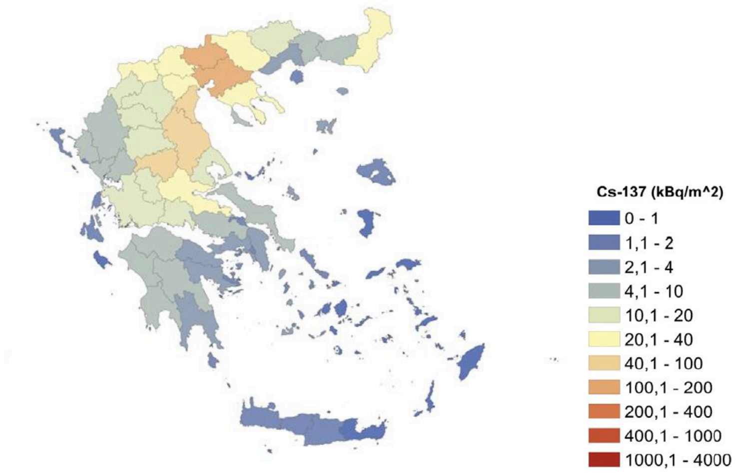

Figure 2. Maximum ^{137}Cs deposition in each administrative department, as calculated in the first assessment calculations.

The second set of calculations provides similar results. As it is obtained from Figure 3, where ground dose rate and ^{137}Cs deposition are shown, the impact, even at long distances, can be also considered as radiologically significant. In particular, there are areas where deposition is greater than the threshold value of 37Kb/m^2, and also areas where ground dose rate depicts values greater than 1μSv/h. The latter value corresponds to OIL_3 of IAEA (e.g. [8]), above which it is suggested that measures for the protection from ingestion should be taken. Both sets of calculations, although with different models, different source terms and different dates with different weather data, and, albeit their significant conservatism, provide important evidence that we cannot eliminate completely the possibility a nuclear accident abroad, with significant radiological impact, irrespectively if Greece belongs to the emergency zone of the plant or not. Therefore, a level of preparedness is warranted, so that we will be able to apply effectively a strategy for the protection of the public, the food chain, the economy and also to maintain the public trust. The protection strategy could contain actions, such as food and agricultural production restrictions, as well as softer suggestions and advise to the public, especially children, to limit contact with environment.

Response Strategy

During the course of the emergency, maps providing the picture of the actual radiological contamination across the country are not expected to be available for long after the accident. This complicates the process of assessing the radiological impact and preparing for decision making, in particular with regard to extended areas, distant from the release point. Moreover, besides the radiological impact itself, it is well recognized that other non-radiological factors might also play a very important role in the effectiveness and the overall cost and benefit of the protection strategy. The time, for instance, of ordering food protection and agricultural measures might affect significantly the efforts to sustain public trust or the image of the agricultural production and tourism industry in the country, causing potentially more harm than good.

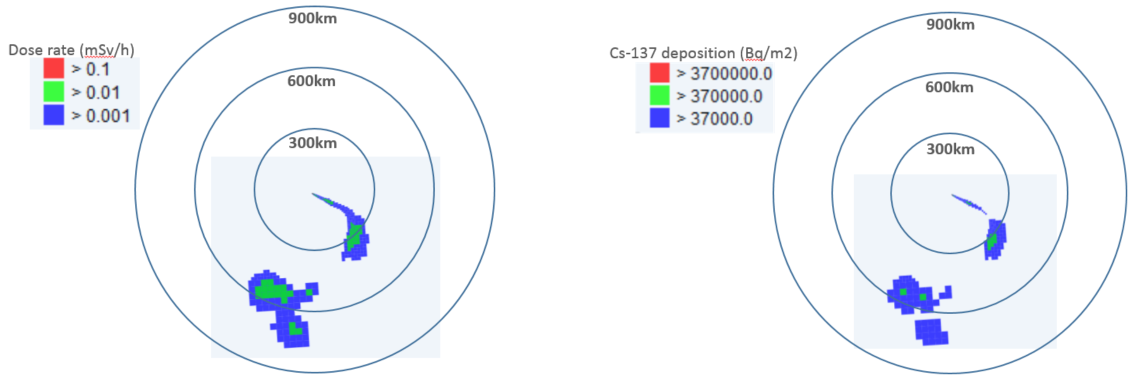

Figure 3. Dose rate (left) and ^{137}Cs deposition (right), as calculated in the second assessment, assuming that 10% of the inventory is released in 10 hours ([7]). Release starts in summer 2017. NOMADS meteorological data are used.

Considering the quite large uncertainties in source term estimation and atmospheric modelling, along with the fact that adequate measurements of the contamination will not probably be available timely, we anticipate that it would be very difficult to specify, in particular in the first days of the response, when and where measures should be taken. Given the relatively low level of the doses - even in extreme cases - compared to the emergency dose criteria, it could be argued, for instance, that no urgent measures are necessary in the first days. Rather, the measures (e.g. agricultural, food restriction) should be taken only after definite radioactivity measurements warrant this. Although, this seems reasonable on a radiological basis, nonetheless, it has the potential to cause confusion to the public and stakeholders, if at a later stage, restrictions are being introduced gradually on products that initially were allowed to be consumed. All this would, in turn, make the aim of maintaining public trust quite challenging and alter significantly the pressure on the authorities and decision makers. To cope with the uncertainties and overcome these difficulties, a simplification of the response is being considered, by following a precautionary-like approach.

Using the terminology of IAEA, a response phase can be defined followed by the transition phase. The response phase, within which the measures and actions for the protection of the public are assumed that have been completed, could last from days to weeks. As already stressed previously, the assessment of the actual radiological impact early in the response phase would be very uncertain. During the first days of the response, precautionary food restrictions and instructions to the public could be decided for a large area of the country. The decision about these measures would be based on the prevailing meteorology, as it reflected in the dispersion modelling, together with any available evaluation of the accident evolution and data about the releases. During the later stage of the response phase (weeks), the measures and their spatial distribution would be progressively refined based on the estimation of the ground contamination from ground dose rate measurements, with the help of OIL_3 ([7]). Further gradual refinement and final adjustment of the measures is expected in the first months, as the radioactivity measurement campaign is progressing and data about the actual contamination of soil and/or food samples are becoming available.

It should be noted that the capacity to perform dose rate measurements, surveying relatively quickly a large part of the country, is a very important part of the overall preparedness and response. The fixed radioactivity monitoring network across the country would contribute to this aim, yet a fast dose rate mapping of the radioactivity deposition is also judged very important, as it would offer an adequate first step basis for evaluating the actual course of the plume and its deposition. This mapping would allow us to revisit the initial restrictions and adjust, maintain or withdraw the measures in large parts of the country, so, limiting the economic cost of measures taken on areas where they were not radiologically warranted. It is recognized that such an approach could be considered as exceedingly conservative. It is, nonetheless, under consideration as the predominating one because it seems prudent. It is expected that, keeping the production and distribution of products and the contamination under continuous control would help in alleviating public concerns and maintaining trust to the agricultural production and other potentially impacted economic sectors (e.g. tourism), particularly in the longer term. Apparently, a consistent approach in response and public information and communication, among involved countries and in European level, would have a significant impact to this aim.

Conclusions

In this work, elements of preparedness and response to a hypothetical nuclear accident abroad, from the perspective of a non-nuclear country, relatively distant, are discussed. Several difficulties are expected, related primarily to the uncertainties of the actual contamination of the territory. Non-radiological parameters should also be considered, particularly because the radiological impact itself would not reach levels, high enough, so that it would be the main decisive factor in decision making. Non-radiological factors are also characterized by large inherent uncertainties. In this context, a conservative, “precautionary-like approach” is being considered as a first response, according to which, extensive food restrictions are initially suggested in a large part of the country. These measures can then be progressively refined, based on dose rate measurement firstly, and then according to more detailed sampling result. Such an approach, seems prudent, as it is able to help in sustaining public trust and safeguarding the image of the products and other sectors of the economy, such as tourism. Nonetheless, the capacity for implementing, in all phase, the required radioactivity measurements campaign, able to achieve an adequate picture of the radiological contamination as quick as possible, remains a critical constituent of the overall response strategy.

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Lessons learnt from the gamma-based monitoring stations of RARE (Radiological Alert network of Extremadura, SW Spain): development and real-time performance

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Abstract

The ambient dose rate has been adopted by the International Commission on Radiological Protection (ICRP) as a fundamental parameter in the field of dosimetry (Council Directive 1996/29/EUROATOM). The above mentioned parameter is usually continuously monitored, using Geiger-Müller or ionization chamber detectors, by early warning radiological networks around the world. They have several advantageous capabilities owe to their sensitive and fast response, easy operation, relatively low cost and robustness. However, their main drawback is based on the impossibility to individually identify and quantify each of the natural and/or man-made radioisotopes that produce alterations of the natural background. In fact, in the case of a nuclear accident, to know the radioisotopes released to the environment (atmospheric and/or aquatic media) and their activities is a crucial support to take decisions about the protection not only of civilian population but also of emergency teams. In this communication, the homemade gamma-based atmospheric and water monitoring systems currently working in the Radiological Alert Network of Extremadura (RARE, SW Spain) which is composed by 17 monitoring stations, a mobile laboratory and a drone are briefly presented. They are based on $LaBr_3$(Ce) and NaI(Tl) detectors, and their constructions have required important mechanical, electronic and communications developments. Moreover, in order to accomplish with their early warning function, new software tools have been required, including an intelligent system to issue the necessary warnings when radiological anomalies or technical problems are identified in the monitoring stations. After about five years of operation, the capabilities of the gamma-based RARE monitoring stations are considered highly satisfactory, although some shortcomings have emerged and the approaches to deal with them are also presented.

Introduction

In 1990, the University of Extremadura initiated the design, construction and management of the Radiation Alert Network of Extremadura (RARE in Spanish) [1]. This was designed to acquire reliable near-real-time information on the environmental radiological status in the vicinity of the Almaraz Nuclear Power Plant (ANPP) by measuring the radioactivity levels of the air and water at different points around the plant. The phased development of this network has been in two ways. On the one hand, there has been an increase in the number of stations comprising the network, including some beyond the environment of the ANPP. On the other hand, there has been an increase in the number of monitored parameters, not only radiological but also meteorological and operational ones. In this paper, a description of the RARE network along with a brief description of our experience using Geiger-Müller probes in the last 30 years is carried out. Also, our commitment to gamma spectrometry-based monitoring stations, both in airborne and water, is presented.

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Material and methods

RARE's monitoring stations

The network's design is based on the principles of reliability (in order to allow the gathering of data even under adverse operating conditions) and versatility (to facilitate the substitution of components and the implementation of future stations). There are 17 dose rate monitoring stations, 9 of them situated around the ANPP and 3 situated in Portugal close to the Spanish border. Also, the RARE's network is composed by 5 airborne monitoring stations and 3 water monitoring stations. Moreover, the network stations also register and report values of non-radiological parameters (meteorological and operational data). For data acquisition and communication management, each station has a computer, a radiofrequency broadcasting station and internet connection. To ensure maximum reliability of the network even under extreme conditions such as the interruption of the main electrical power supply, each station operates its own 1000 VA uninterrupted power supply (UPS) which delivers about 24h autonomy. There are also high-voltage suppressing filters installed at the inputs of the UPS to avoid voltage peaks that could damage the equipment. Due to the distance, more than 70 km, between stations in the surroundings of the ANPP and the RARE headquarters located in Cáceres, the network incorporates a radio frequency repeater situated at 840 metres above sea level.

Each dose rate monitoring station includes a Geiger-Muller probe that covering a broad gamma radiation dosimetric range from 10 nSv/h to 10 Sv/h and energies from 0.045 to 2.0 MeV (manufacturers specifications [2])

Related to the airborne monitoring stations, they are based on a modified BAI 9100D Berthold Technologies module [3]. The main detection system is a 2"x2" $LaBr_3$(Ce) scintillator detector which is placed to face the exposed filter. For the determination of the gaseous fraction of radioiodine a 2"x2" NaI(Tl) gamma detector is used. Gaseous fraction of radioiodine is retained in active charcoal cartridges which are situated in front of the gamma detector. A sophisticated mechanical device designed to be controlled remotely changes each exposed cartridges by a new one. Both scintillation detectors are assembled inside a lead shield in order to reduce the gamma contribution of the cosmic and terrestrial background.

On the other hand, related to the water monitoring stations, they are Berthold BAI-9125 modified systems [4]. This equipment consists of a (i) NaI(Tl) or $LaBr_3$(Ce) gamma spectrometer with a 2" × 2" crystal coupled to a compact digital multichannel analyser, (ii) a 25 L capacity stainless steel vessel. The vessel is surrounded by 5 cm thick lead shielding in order to attenuate the background radiation from the surroundings. A complex pipe system that includes remotely controlled water pumps and electronic valves allows to monitoring the water flow intake inside the 25 L vessel. Additionally, in the case of anomalous activity concentration detection, the system controller is designed to take a sample of water in order to be analysed later in a low background laboratory.

Results and discussion

Our experience over the last 30 years using G-M probes and why do we opt for gamma spectrometry combination?

The ambient equivalent dose rate is the essential parameter in radioprotection field as a council directive 1996/29/EURATOM establishes. It is usually measured by a Geiger-Müller counter that is a sensitive (over an extended operational range of dose), robust, cheap and easy to use instrument. Therefore, dense networks are available. It can be considered as a global parameter since most of early warning networks in Europe and world-wide comprise automatic measurement stations equipped with GM tubes [5]. Despite the solidly proven capabilities of Geiger-Müller counters, an inherent limitation of these devices is that the external dose rate, while relevant, is just an overall measurement. For this reason, if a radiological anomaly occurs it will be impossible, with these detectors, to distinguish whether the cause is natural, anthropogenic, or both.

The increment ambient equivalent dose rate due to the scavenging of the airborne naturally occurring radionuclides during precipitation events is a well-known phenomenon [6]. However, could a simultaneous weak man-made radiological anomaly have been overlooked during those rainy events? (Figure 1a and 1b). To solve this problem, it is necessary to carry out indirect analysis. For example, the determination of the average experimental half-life from the ambient dose rate values measured after the dose rate monitors had recorded a maximum H*(10) value during a rainfall event allows to infer what radionuclides are involved dose rate increases. Moreover, some spurious dose rate increments are linked to electronic noise in the Geiger Müller probe (Figure 1d), but an abrupt increment can be also due to a short time exposure to a radioactive source (Figure 1c).

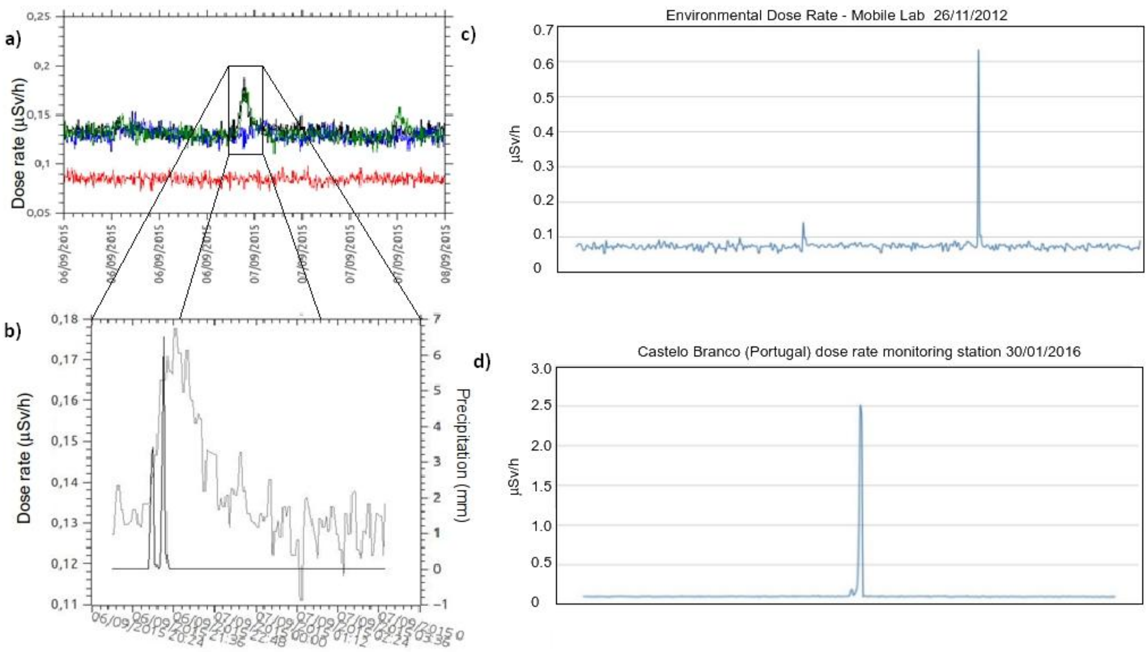

Figure 1. Left: a) and b) Behaviour of environmental dose rate in four monitoring during a precipitation events. Right: Two examples of spurious increment of dose rate. c) electronic noise due to a strong storm d) Mobile lab during an exercise detected the dose rate increase of a lorry which carried a radioactive container.

It is a fact, that the information provided by G-M probes must be complemented by other monitoring system. Gross alpha and beta measures with Rn-222 compensation are one of the most extended methods for the air particulate fraction monitoring. However, in some situations is very difficult to understand the results that they provide. Therefore, the use of gamma spectrometry systems based on scintillators detector which, at this moment, are robust and compact, is an excellent option to take account in modern early warning networks. In the last 10 years, both, RARE's air and water monitoring station have been modified in order to implement the gamma spectrometry systems. The gamma spectrometry allows us to operate in two different ways: Early warning mode: A gamma spectrum is analysed every 10 minutes. Surveillance mode: In this mode, a gamma spectrum is analysed every 6 h and at last, every 24h we obtain another gamma spectrometry analysis. In the table 1, it is shown the Minimum Detection Activities that the RARE's air monitoring station is able to reach in both performance modes. It is important to emphasize that the MDA of radioactive iodine in the 24h spectra is, more or less, of the order of the maximum activity detected when Fukushima's cloud reach Cáceres [7].

	MDA (Bq/m3)		
	10 min	**6 h**	**24 h**
Ba-140	35	0,18	0,022
I-131 particulate	3	0,018	0,004
Cs-137	5	0,025	0,003
Co-60	6	0,011	0,004
Zn-65	40	1,53	0,38
I-131 gaseous	36	0,18	0,023

Table 1. Minimum Detection Activity (MDA) of the main man-made radionuclides monitored in RARE's airborne monitoring stations. Flow for particulate matter fraction ($LaBr_3$:Ce detector): 25 m^3/h and for gaseous fraction (NaI:Tl detector): 8 m^3/h

The management of information:

The information that is provided by a radiological network requires powerful and reliable software. Considering the number of RARE's monitoring stations and their analytical capabilities to measure radiological, weather and operational parameters, the headquarters in Caceres must be prepared to receive, manage and storage more than 200000 data per day. This huge amount of information is not easy to be processed in quasi real-time in order to be analyzed and supervised by the technical staff. For that reason, it is necessary to develop powerful software to run the required analysis and to facilitate the visualization of the parameters. Figure 2 shows an example of the gamma spectrometry results of one of the RARE's monitoring station. Additionally, there is a software application in order to send message by SMS (Short Message Service) to the analyst in charge when radiological and/or operational anomalies occur.

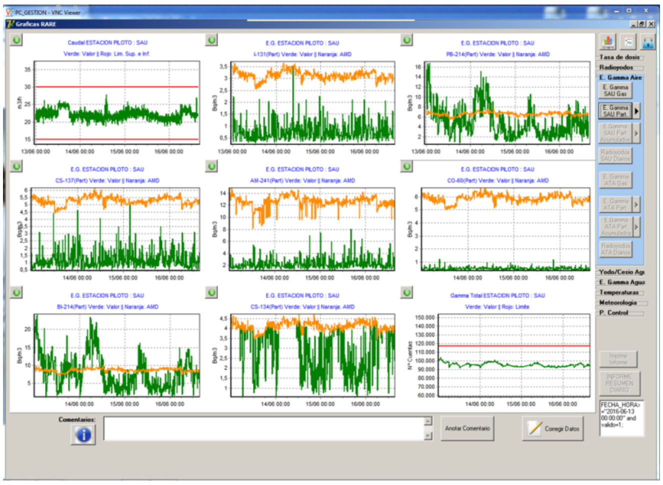

Figure 2. Screen capture of RARE’s software “Gráficas RARE” which shows the radiological information of each monitoring station (activities in green and MDA in orange) to be easily interpreted by the technical staff and flow as an operational parameter (with red lines for the acceptable performance range).

Main gamma spectrometry drawbacks:

One of the main drawbacks using scintillation detectors like NaI(Tl) or $LaBr_3$(Ce) is related to their low resolution which it is important to take into account when some relevant photopeak overlaps. In early mode analysis (every 10 min) due to the poor statistics and the difficulty to analysed gamma multiplets , such as I-131 (364 keV) and Pb-214 (352 keV), the presence of a high number of I-131 false positives can be relevant in a region with high levels of radon. This problem has been solved by the introduction of an algorithm that, on the base of the Pb-214 (295 keV) photopeak, is able to recalculate the Pb-214 (352 keV) area and, then, a more precise I-131 activity. The performance of the algorithm has been successfully tested, by the elimination of 90% of false positive and the detection of I-131 when a source was intentionally placed close to the gamma detectors.The other drawback is related with the integration time and the sensitivity of the gamma detector. An agreement between integration time and sensitivity is needed. In early warning mode a integration time of 600 s have been established. But, if a radiological anomaly is detected our software allows to decrease this integration time remotely.

Conclusion

Its is clear that the only way to identify radioisotopes and quantify activity concentrations in quasi-real-time is to use automatic gamma spectrometry monitoring stations. RARE´s atmospheric monitoring stations are based not only on gamma dose rate determinations by Geiger-Müller counters (passive measurements) but also on sample retention and the gamma spectrometry of its gaseous and the particulate fractions. From our gamma spectrometry system, the accurate energy-efficiency calibrations thanks to the well-known sample geometries can be pointed out. However, the presence of radioactive sources that may occur far to airborne collector could not be detected by our gamma spectrometry system although the Geiger-Müller response is guaranteed for a wider range of situations. Other drawbacks, such as the related to the interference of close photopeaks in the gamma spectra, are easily solved using home-made software applications.

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Passive dosimetry measurements used in the aftermath of a radiological accident in the framework of "PREPAREDNESS" EMPIR project

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Abstract

The measurement of ambient dose equivalent rate using passive dosimetry in the aftermath of a radiological accident was studied to evaluate the current status of application of passive detectors for radiation protection.

This work is carried out in the framework of Preparedness EMPIR Project "Metrology for mobile detection of ionizing radiation following a nuclear or radiological incident" and it focus on the activities of the work package 4 "Passive Dosimetry".

In Europe, about 100 dosimetry services exist from measuring bodies (such as governmental offices, companies, institutions associated with a research facility or a hospital, etc.). They have in common that they use passive area dosemeters (dosemeters without electronic inbuilt) for environmental monitoring. A survey by the European Radiation Dosimetry Group showed that some of these services are neither traceable to primary dosimetric standards nor accredited. Due to the lack of international standards, a variety of different measurement procedures and uncertainty calculation methods are used. The application of passive detectors for radiation protection is not trivial. For nuclear and radiological accidents, the feasibility of follow-up surveillance using passive dosemeters could be of wide interest to confirm the environmental radiological data by active detectors in long-term monitoring after a nuclear accident.

The literature overview showed that there are a very few studies dealing with specific topics on passive dosimetry measurements in the aftermath of a radiological accident.

Some articles are focused on radiation measurements and the dosimetric results with passive dosimetry systems are summarized and not described in deep. A lot of publications studied thermoluminescence property for retrospective dosimetry after an accident and sometimes the results were compared with standard passive dosimetry (environmental or personal TLDs). Most of the papers are dealing with characterization and comparison of the different passive dosimetry methods for the use in environmental monitoring as well as for their application to terrestrial wildlife assessment. Summary works on environmental monitoring with TLD were published for the area next to nuclear sites.

In conclusion if solid state systems are used for long term environmental monitoring, the traceability and harmonization of these systems is needed to obtain reliable data. Currently there is a lack of systematic data, recommendation and protocols for the use and the most appropriate types of passive dosimetry systems in the aftermath of the radiological incident.

Therefore, this EMPIR "Prepardness " Project aims at the implementation of stable and reproducible procedures to measure ambient dose equivalent rates by passive dosimetry and the improvement of the necessary metrological infrastructure in Europe.

Introduction

The EMPIR -16ENV04 "Preparedness" is a project founded within the framework of the European Metrology Programme for Innovation and Research (EMPIR, https://msu.euramet.org/calls.html) by EURAMET and the European Commission [1,2]. The consortium comprises 17 participates at the project from eleven European Countries. One of the main objective of joint research project is the development of reliable instrumentation and methods for radiation and radioactive contaminations caused by nuclear accident or other radiologically relevant events. The Work Package (WP) 4 "Passive Dosimetry" objective is to establish stable and reproducible procedures to measure the ambient dose equivalent H*(10) using passive dosimeters in order to harmonize passive area dosimetry across Europe. Six active partners are involved in the WP4: the Physikaisch-Technische Bundesanstait (PTB; WP leader); Vinca Institute of Nuclear Sciences (VINS), University of Belgrade; Ruđer Bošković Institute (RBI) ; Centralne Laboratoriun Ochrony Radiologicznej (CLOR); Aristotelio Panepistimio Thessalonikis (AUTH); Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) . The tasks of WP4 are reported in the figure 1.

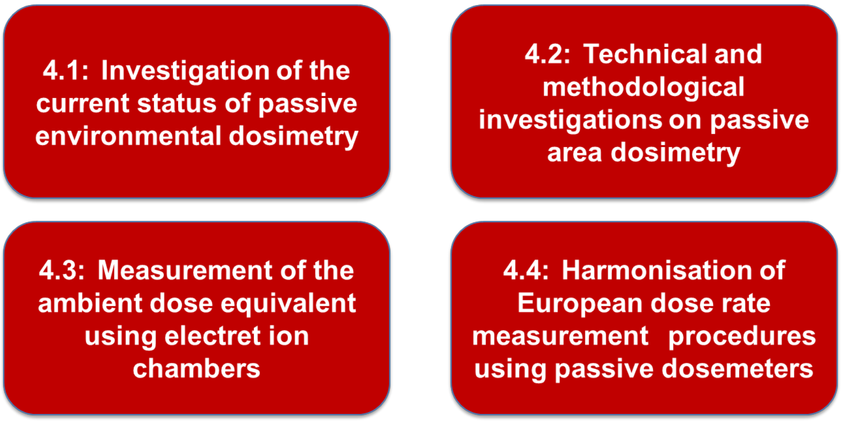

Figure 1. Description of the four task of the WP4 of EMPIR -16ENV04 "Preparedness" project.

The measurement of ambient dose equivalent rate using passive dosimetry in the aftermath of a radiological accident was studied by the Rudjer Boskovic Institute, RBI (Croatia) and the Radiation Protection Institute of ENEA (Italy) to evaluate the current status of application of passive detectors for radiation protection.

Methods

In routine situation many national measuring bodies in Europe and worldwide use passive dosimetry systems to survey nuclear installations at the borders of the restricted territories in order to verify the dose level and to measure increment of dose arising from artificial ionizing radiation, with the respect to allowed dose limit. Otherwise in the early phase of a nuclear/radiological accident, the main focus is to bring the facility/site to a stable condition and to ensure the safety of workers, members of the public. In this condition, the use of passive dosimetry systems for environmental radiation monitoring in the aftermath of a radiological accident (i.e. decommissioning and/or remediation phases) could produce important data for the activities of decommissioning, remediation and for the radiation protection of the public.

For this study, the desk research was used by RBI in collaboration with the Radiation Protection Institute of ENEA. In particular the collection of information was based on journal web sites relevant in the metrological and radiation protection fields. The objective of the work was been to find information about metrological aspects traceability, uncertainty calculation and methodical descriptions.

Results

The study collected information from more than 10 scientific journals (see Table 1) and all articles were been classified in six categories (see Table 2).

Table 1. List of Scientific Journal and number of publications related to passive dosimetry systems related to environmental monitoring and emergency

Name of Scientific Journal	N° of publications
Applied Radiation and Isotopes	2
Environment International	1
Health Physics	1
The International Journal of Applied Radiation and Isotopes	1
Journal of Environmental Radioactivity	4
Journal of Radiation Research and Applied Sciences	1
Nuclear Instruments and Methods in Physics Research Section B	1
Nuclear Tracks Radiation Measurements	1
Radiation Measurements	7
Radiation Safety Management	1
Science of the total Environment	1
Other Publications	6
Total	**27**

Table 2. List of main theme in selected representative publications related to environmental monitoring and emergency

Main theme	N° of publications
Overview on passive dosimetry for environmental monitoring	4
Study of dosimeters for accident and retrospective dosimetry	6
Measurement by dosimeters and retrospective dosimetry after nuclear accident	9
Monitoring of nuclear site and environment	4
Dosimetry measurements on animals	2
No data on passive dosimetry systems	2
Total	**27**

Some articles are focused on radiation measurements and the dosimetric results with passive dosimetry systems are summarized and not described in deep. A lot of publications studied thermoluminescence property for retrospective dosimetry after an accident and sometimes the results were compared with standard passive dosimetry (environmental or personal TLDs). Most of the papers are dealing with characterization and comparison of the different passive dosimetry methods for the use in environmental monitoring as well as for their application to terrestrial wildlife assessment. Summary works on environmental monitoring with TLD were published for the area next to nuclear sites.

The literature overview showed that there are a very few studies dealing with the specific topics on “passive dosimetry in the aftermath of a radiological event”. It is possible to suppose that the use keywords and common search machine is a weakness of this kind literature study and other articles could be identified by a new random search.

Conclusion

In conclusion if solid state systems are used for long term environmental monitoring, the traceability and harmonization of these systems is needed to obtain reliable data. Currently there is a lack of systematic data, recommendation and protocols for the use and the most appropriate types of passive dosimetry systems in the aftermath of the radiological incident. Therefore, this EMPIR “Prepardness “ Project aims at the implementation of stable and reproducible procedures to measure ambient dose equivalent rates by passive dosimetry and the improvement of the necessary metrological infrastructure in Europe.

Currently, all the partners are involved in the technical and methodological investigations on passive area dosimetry using their facilities (see Table 3).

Table 3. Summary of basic properties of dosimeters to investigate under laboratory conditions

ENEA Italian National Agency for New Technologies, Energy and Sustainable Economic Development	**Energy response** (8 X-ray quality, Cs-137, Co-60)
CLOR Centralne Laboratorium Ochrony Radiologicznej	**Natural spectrum** (Ra-226, Cs-137 and Co-60)
Vinca Institute of Nuclear Sciences	**Angular dependence** (0°,30°,60°,90°, 180°)
IRB	**Dose dependence** (from ≈150 μSv to1Sv)

The results of all technical and methodological investigation will be taken in account in the development of recommendations for the harmonization of passive area dosimetry systems.

Acknowledgment

The EMPIR initiative is co-funded by the European Union’s Horizon 2020 research and innovation programme and the EMPIR participating States.

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Countermeasures and countermeasure strategies in emergency & recovery, decision support & disaster informatics

Simulations of decontamination scenarios using the system dynamics approach

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1. Introduction

This paper is dedicated to creation of a complex mathematical model connecting dose assessments and economical estimations for decision-making purposes in case of a radiation or nuclear accident. In order to create the model allowing to simulate and compare decontamination scenarios and assess the costs and benefits of each proposed scenario, the system dynamics methods were used. This work was carried out in collaboration between the National Radiation Protection Institute (SÚRO) and the Czech University of Life Sciences within the Project of the Ministry of the Interior of the Czech Republic, VH172020015 – Recovery Management Strategy for Affected Areas after Radiation Emergency.

2. Material and methods

2.1 System dynamics

System dynamics is focused on complex systems with non-linear dynamic behavior containing many variables and parameters and more importantly the interconnections between them. A system structure could be represented graphically using e.g. stock and flow diagrams [1]. In order to create a mathematical model of decontamination scenarios and to simulate them, the Vensim PLE software was used [2].

2.2 Grassed meadow

Proposed scenarios were related to a real object1 – a large recreation meadow with an area of roughly 60 000 m2 (Figure 1). Simulated decontamination scenarios were applied to a grassed area only. Therefore, a clean-up of streetlamps, trees, information boards, benches or paved roads around the meadow was excluded. However, the meadow in the created

[1] The meadow is neither contaminated, nor located in an emergency planning zone. The object was used in simulations for demonstration purposes only.

mathematical model could be transformed into another object if needed, e.g. an agricultural land or a playing field.

2.3 Population

In order to assess collective effective doses and benefits of each scenario, a group of the most irradiated persons living in houses near the meadow was estimated. The estimation was based on data from the Czech Statistical Office (CZSO), e.g. average numbers of persons per house/apartment [3, 4]. Numbers of houses/apartments were known. The estimated group contained 631 adult persons.

Figure 1. Area of the selected meadow [5]

2.4 Dose assessment

The mathematical model considered a large-scale ground contamination with ^{137}Cs and ^{134}Cs only and a total surface activity of 2 MBq m^{-2}. Initial surface activities were set 1 MBq m^{-2}, resp. 0.93 MBq m^{-2} for ^{137}Cs, resp. ^{134}Cs. Short-lived radionuclides, e.g. ^{131}I or ^{132}Te, were excluded due to short half-lives. Anticipated activities of both cesium isotopes were converted to annual effective doses using the modified formula [6]:

$$E = DF \cdot \frac{1}{\lambda_r + \lambda_w + \lambda_d} \cdot A_0 \cdot \left(1 - e^{-(\lambda_r + \lambda_w + \lambda_d) \cdot t_1}\right) \cdot \left(\Delta_{outdoor} + \Delta_{indoor} \cdot SF\right), \qquad (1)$$

where *DF* is the dose conversion factor for ground contamination, $\Delta_{outdoor}$ is the correction for time spent outdoor, Δ_{indoor} is the correction for time spent indoor, *SF* is the shielding factor of buildings, λ_r is the decay constant, λ_w is the natural dispersion rate, λ_d is the estimated decontamination rate (dependent on values of dose rate reduction, the meadow area and anticipated decontamination speeds). Dose conversion factors *DF* were adopted from [7] and set 1.8E-05 (mSv year^{-1})/(Bq m^{-2}), or 4.9E-05 (mSv year^{-1})/(Bq m^{-2}) for ^{137}Cs, resp. ^{134}Cs. Owing to a major type of buildings around the meadow, the shielding factor *SF* was set 0.2. The natural dispersion rate λ_w was set equal to 0.05 year^{-1} [7]. According to a recommended value in the Czech legislation [8], the correction for time spent indoor supposed 7 000 hours per year. A total effective dose in each scenario was a sum of annual effective doses from ^{137}Cs and ^{134}Cs. Afterwards, collective effective doses were estimated using total effective doses and the number of the most irradiated persons (631 persons).

2.5 Benefit calculation

Benefits could be calculated as averted doses for the selected population, multiplied by a financial coefficient for accidents, equal to 2.5 million CZK Sv-1 [8]. In the model, due to simpler implementation, the benefit calculation was based on an estimation of health detriment costs for all considered scenarios. The health detriment cost was calculated as a collective effective dose multiplied by the relevant financial coefficient. Therefore, benefits were estimated as a difference between the reference health detriment cost (corresponded to 20 mSv per year) and the health detriment cost of each decontamination scenario.

2.6 Implemented scenarios

Owing to the expected surface activities and higher soil specific activity, only two decontamination scenarios (with the removal of a turf or upper soil layer) and one reference scenario (without any decontamination) were implemented in the model. The reference scenario considered the meadow demarcation only. The second scenario employed turf stripping. Soil stripping was used in the third scenario. All designed scenarios included the meadow demarcation with fences, warning tapes and warning boards. Decontamination (using showers) of workers and vehicles were also taken into consideration. Scenario simulations were implemented using switches, Boolean operators AND/OR and conditional expressions IF THEN ELSE. Changing specified values of switches (1 or 0), the model simulated the relevant scenario.

2.7 Decontamination costs

Total costs always included labor costs, costs of personal protective equipment and personal electronic dosimeters, costs of fences, tapes and boards, estimated costs of fuel and water consumption. Turf and soil stripping scenarios moreover anticipated grass removal and a manual collection of waste residues using shovels, brooms and garden carts. Therefore, costs of these scenarios also included waste bags costs, waste transportation costs, costs of auxiliary equipment (e.g. brooms and shovels), consumption of fixed capital (e.g. tractors with mowers, sod harvesters, excavators) and correction for inflation.

3. Results and discussion

3.1 Mathematical model

The created mathematical model contains 13 working layers. The model provides both dosimetry and economical calculations, e.g. the activity decrease, the dose estimation (for the population and workers in each stage of decontamination), an estimated length of decontamination, total costs of each decontamination scenario, decontamination costs related to 1 m² of the decontaminated area and others. The layer with the dose assessment is represented in Figure 2. The model also includes a summary page (an auxiliary layer) with links to the most important results, outputs and scenario switches.

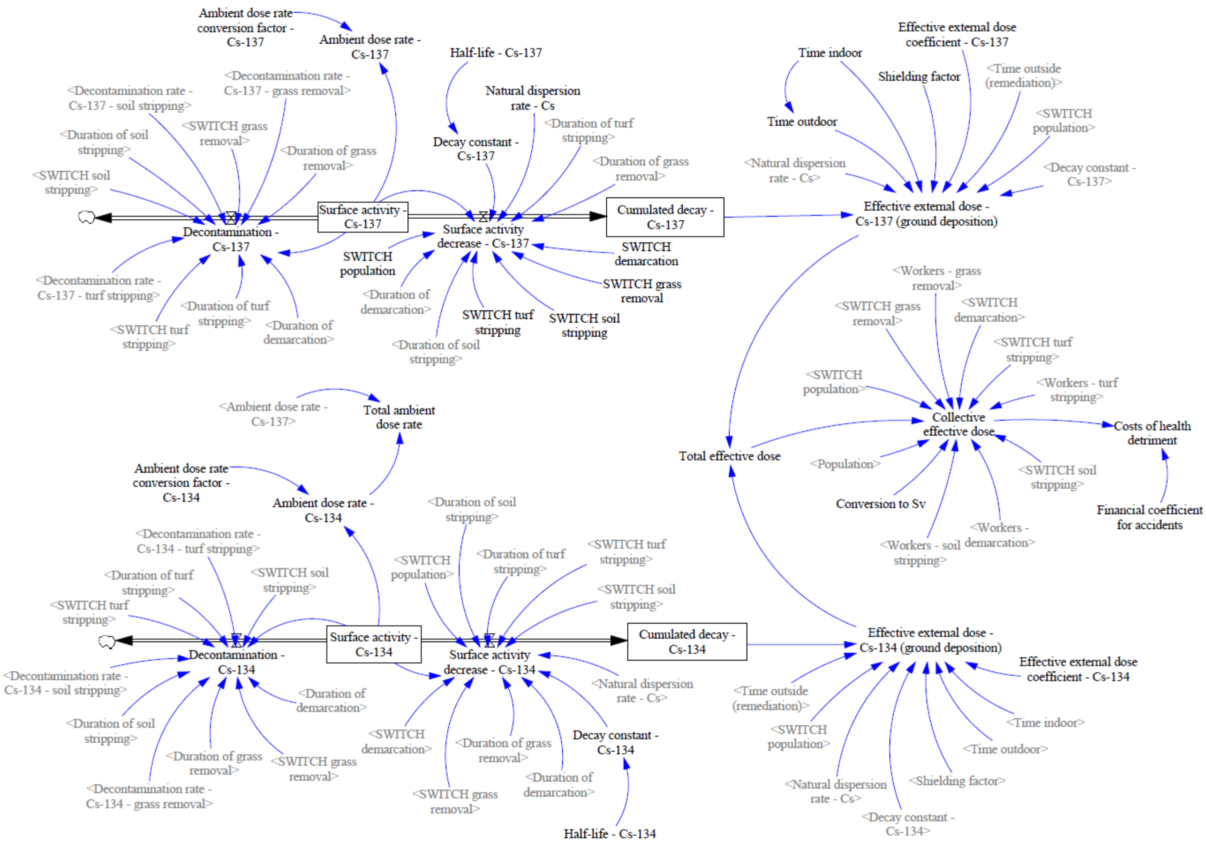

Figure 2. Stock and flow diagram: dose assessment

3.2 Model validation

In order to check the model, two tests were performed. The first test, the *Units check*, was provided by the Vensim PLE software. This test checks the model dimensional consistency, since complex models often handle with a number of parameters from various fields with different units. The model passed the *Units check*, therefore, the units consistency was validated.

The second test was focused on the dose calculation. In the test, the shielding factor of 0.4, known activities of ^{137}Cs (1 MBq m^{-2}) and ^{134}Cs (0.5 MBq m^{-2}) were used. According to [6], these parameters corresponded to an annual effective dose of 20 mSv. Contrary to this reference calculation, the model employed different corrections for time spent indoor/outdoor, 80 %, resp. 20 %, while the reference calculation supposed 67 % of time spent indoor, resp. 33 % of time spent outdoor. Moreover, effective doses in the model were calculated using numerical integrations with different dose conversion factors adopted from [7], whereas the reference estimation was based on a simple multiplication of known surface activities and selected parameters. The annual effective dose obtained from the simulation was equal to 19.6 mSv. Then, the difference between the literature source [6] and the model was low, almost 2 %, therefore, the model was accepted for the following scenario simulations.

3.3 No decontamination scenario

The reference scenario assumed the meadow demarcation only. Total costs of the demarcation were estimated equal to 0.4 million CZK, or roughly 16 000 EUR. Costs per 1 m^2 of the decontaminated area were 7 CZK m^{-2} or 0.3 EUR m^{-2}. The model supposed 1 day of work of two persons. Using the parameters from chapter 2.4, the calculated annual effective dose was 20 mSv (for the most irradiated person living near the meadow). Supposing this scenario as the reference scenario, neither averted doses nor benefits were calculated.

3.4 Turf stripping scenario

Total costs of the turf stripping scenario arisen from the simulation were equal to approximately 6 million CZK, or 240 000 EUR (neglecting rounding errors). Decontamination costs per 1 m^2 were 99 CZK m^{-2} or 4 EUR m^{-2}. Assuming two workers operated two sod harvesters, the duration of the whole turf stripping scenario (including the meadow demarcation and grass removal) was estimated 15 days. The annual effective dose was calculated to equal 10 mSv. Afterwards, the averted dose for one person from the most exposed group was 10 mSv. Estimated benefits for this scenario were roughly 16 million CZK or 0.6 million EUR.

3.5 Soil stripping scenario

Simulated costs of the soil stripping scenario were 7 million CZK or approximately 280 000 EUR. Decontamination costs per 1 m^2 of the meadow were equal to roughly 109 CZK m^{-2}, or 4.4 EUR m^{-2}. The model considered soil stripping provided by two operators and two excavators. Thereafter, the length of the soil stripping scenario was 33 days. The expected effective dose for the most irradiated person was estimated 3 mSv per year. Then, the annual dose reduction was 17 mSv. Calculated benefits were equal to 27 million CZK, or 1.1 million EUR.

3.6 Scenario comparison

Arising from the results of simulations, benefits of both designed decontamination scenarios (turf and soil stripping) are substantially higher than its decontamination costs. Estimated decontamination costs lie within the same order of magnitude (roughly 240-280 thousand EUR). Concerning lengths of decontamination works, the soil stripping scenario is roughly twice as long as the turf stripping scenario. Contrary to the soil stripping scenario, the annual effective dose in the case of the turf stripping is approximately three times higher (3 mSv per year versus 10 mSv per year). Therefore, the soil stripping scenario is expected to be longer and more expensive (by roughly 16 %), but more efficient in comparison with the turf stripping scenario.

4. Conclusion

The mathematical model of proposed decontamination scenarios was created using the system dynamics approach. The model passed both the units consistency check and the dose calculation test. Two decontamination scenarios were designed and compared with the reference scenario without decontamination. Benefits arisen from selected decontamination methods were several times as high as relevant costs. Results obtained from simulations were related to the selected recreation meadow. However, the model could be modified, extended and applied to other objects. The model could be possibly used for the decision-making in the case of large-scale nuclear or radiation accidents.

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Sources of uncertainty in the ERMIN urban dose model

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Introduction

An important input into decision making during the transition phase of a radiological accident that impacts on inhabited areas, is the prediction of residual doses that the population will receive in medium and long term. The prediction is used in conjunction with a reference level dose to begin to plan and optimise protective actions and according to the International Committee on Radiological Protection (ICRP), "the reference level is set at the end of the emergency exposure situation phase" and "represents a level of dose which is intended not to be exceeded, and to strive to move all individual exposures below this level as low as reasonably achievable, with social and economic factors being taken into account" (ICRP, 2009). Therefore, the prediction of the future residual doses is not only used with a reference level for developing a preliminary recovery strategy, but is also a necessary input to the process of setting a reference level, since without one it is not possible to assess the extent and the duration of the disruption and its associated social and economic costs, that any proposed reference level implies. Furthermore, this is done during transition when many uncertainties about the current situation and future development are high.

The ERMIN model (Charnock, 2010) was developed to predict residual doses with and without clean-up options being applied in an inhabited area. However, like all models it is subject to sources of uncertainty and this paper summarises work undertaken to explore the consequences of this uncertainty on its predictions, with emphasis on the residual normal living dose endpoint (Charnock, 2018)

ERMIN

The main input into ERMIN is deposition (Bq m-2) of a mix of radionuclides in various forms on to a reference surface, which is short grass away from trees, buildings and paved surfaces. The user must also provide a description of the built environment, and this is done by selecting fractions of different idealised environments from the ERMIN database. Finally, the user must specify any clean-up options that are applied.

ERMIN model uses a database of empirical particle and deposition condition dependent ratios to estimate the deposition onto other urban surfaces; paved, roofs, walls, interiors, trees. It then applies empirical functions to calculate the long-term retention on these surfaces and the downward soil migration. Next, it applies environment and radionuclide specific factors to calculate the dose-rates from those surfaces to various locations indoors and outdoors within the environment. Finally, clean-up options are represented by removing or moving activity in the environment, by modifying retention or by modifying the shielding.

The outputs include dose-rates and doses indoors and outdoors in various environments, and, by using assumptions about where people spend time, estimates of 'normal-living doses' with and without recovery options. ERMIN has a database of many clean-up options, including parameters that describe the work rates and costs, and with these ERMIN can estimate how much man-power will be required and what the exposure of the workers is likely to be. Similarly, it can estimate quantity of waste generated (kg), the radioactive concentration of that waste (Bq kg-1), and the cost of implementation.

Sources of uncertainty

As a preliminary step, sources of uncertainty were systematically identified and categorise and their relative importance for the prediction of normal living residual doses was qualitatively assessed. An example of the categories and some of the sources identified are given in Table 1.

Table 1. Example of the categorisation of some of the source of uncertainty identified during the project.

Category	Source
Stochastic (related to physical randomness)	Relative deposition onto urban surfaces
	Urban surface weathering rates
	Soil migration rates
	Occupancy
Judgemental (choice of parameters)	Choice of appropriate 'representative' values for relative deposition, weathering rates, occupancy etc.
Epistemological (lack of knowledge)	Reference surface deposition (including radionuclide amount, mix, physical and chemical form)
	Built environment configuration, e.g. degree of paving
	Protective action timing
Computational (coding on specific hardware)	Grid resolution, temporal step
	Numerical integration
Model uncertainty (simplification from the real world)	Choice and inclusion of urban surfaces
	Continuous empirical functions to represent weathering driven by periodic rain events
	Grid size, time step
Ambiguity (lack of clarity and endpoint uncertainty)	Occupancy weighting scheme
	Meaning of 'other' paved and 'interior' surfaces

Whilst the impact of many of the categorises of uncertainty in Table 1 are hard or impossible to assess quantitatively, it is possible to quantitatively analyse the stochastic and judgemental categories, and the remainder of the project concentrated on these sources.

Parameter uncertainty

The second step of the investigation was to quantitatively assess the impact of parameter uncertainty; a combination of stochastic (uncertainty because of real natural variation) and judgemental uncertainty (decisions on the appropriate 'average' parameters used to represent that stochastic uncertainty).

The investigation focussed on the impact of these uncertainties on the prediction of normal living residual dose as a function of time. Because of the practical constraints of the project, the investigation focussed on caesium in a soluble aerosol form, i.e. a form likely in a typical ‘reactor accident and the form dominant in the Fukushima Daiichi accident and in many areas contaminated after the Chernobyl accident.

For this work the parameter distributions proposed by Andersson (2019) supplemented with distributions compiled under the original development of ERMIN were used (Jones et al, 2007).

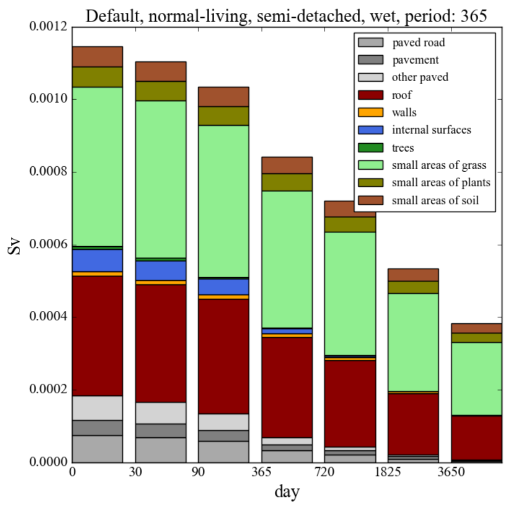
A combination of sensitivity and uncertainty analyses were used to examine the impact of:

- the ratios that distributed the deposited activity onto different urban surfaces, including ingress into buildings,
- the parameters for the empirical weathering/retention functions,
- the parameters for soil migration, and
- and the occupancy parameter that describes how much time people spend indoors.

Whilst the parameter uncertainties on the reference surface deposition, environmental configurations and associated surface dose-rate factors were not directly analysed, the sensitivity and uncertainty analyses performed for other parameters were repeated for both wet and dry deposition scenarios and for several different environments from the ERMIN database. The full results of the investigation are described in Charnock (2018) and just three examples are given here.

Example 1 Initial deposition onto roofs

The current version of ERMIN has a single roof type and a single set of ratios describing the relative deposition onto roofs, for different deposition conditions and different particle groups. In contrast Andersson (2019) proposed parameter distributions for six roof materials; clay tiles, concrete tiles, fibre cement, silicon coated fibre cement, glass, and metal.



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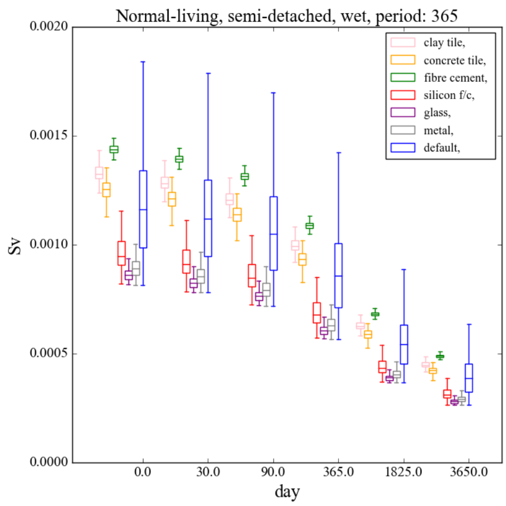

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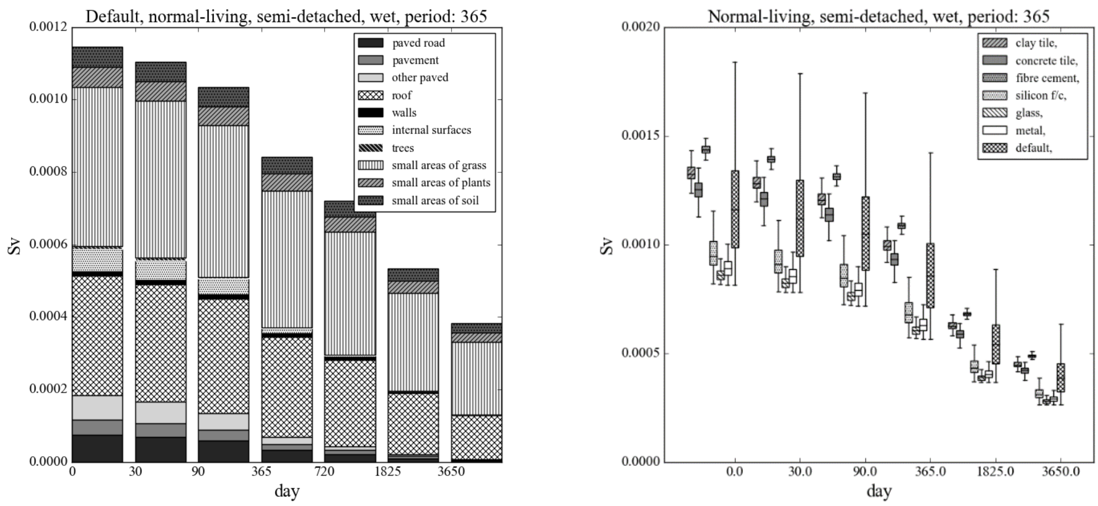

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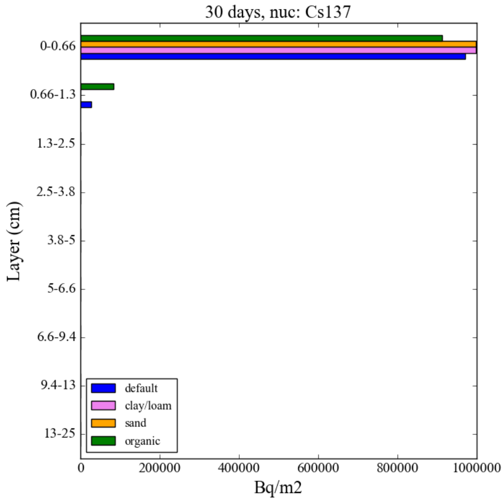
Figure 1. ERMIN predictions of residual normal living dose over a year in a semi-detached brick environment following wet deposition. a) The results using the current default parameters, each column is the dose integrated from the time shown over the subsequent year. b) Spread of dose predictions after a Monte Carlo sensitivity analysis, sampling from the proposed distribution for deposition onto different roof materials. The boxes indicate the inter quartile range (IQR) and the ‘whiskers’ extend to 1.5 × IQR or most extreme result whichever is less.

In the example ERMIN results of Figure 1a, the dose from deposition onto roofs is predicted to be a significant component of the total residual dose, and it would be reasonable to conclude that under these conditions roof cleaning might be a suitable clean-up option.

To examine the sensitivity of ERMIN to the initial deposition on roof it was run repeatedly in a Monte Carlo analysis. In each run the proposed distribution for initial deposition on to a given roof material was sampled to generate a large set of possible dose results. A set was generated for each roof material and for the ERMIN default roof and presented as a box plot in Figure 1b. The figure shows there are significant differences between the materials, maybe as much as 50% more dose between the highest and the lowest doses predicted. The plots fall into two groups that barely overlap; those rougher more pitted materials including clay, concrete and cement having the higher initial deposition and subsequent doses and those smoother more sealed materials including glass, metal and silicon covered fibre cement having a lower initial deposition and subsequent doses.

Example 2, soil migration

As with initial deposition onto roofs, currently ERMIN has a single set of parameters to describe migration down the soil column. Andersson (2019) proposed distributions of these parameters for three different soil types and furthermore proposed radionuclide specific parameters.



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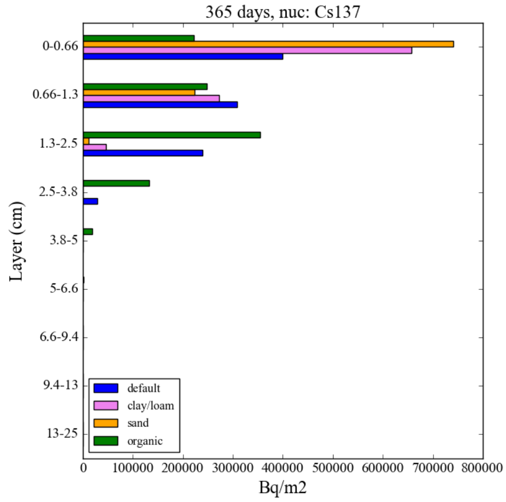

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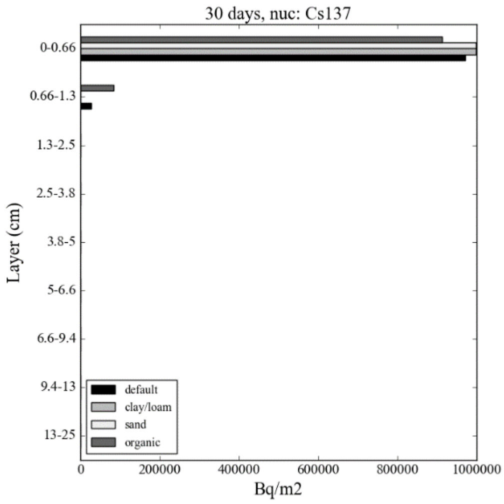

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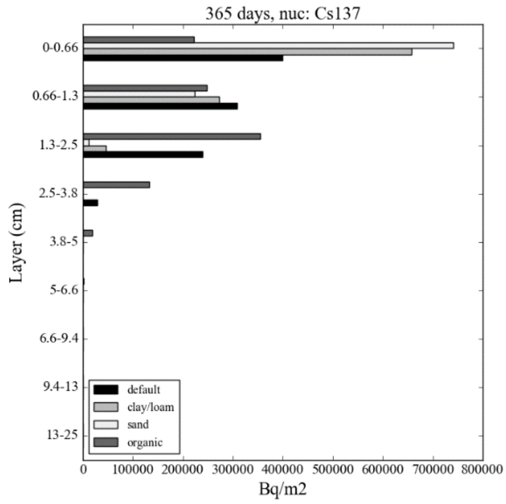

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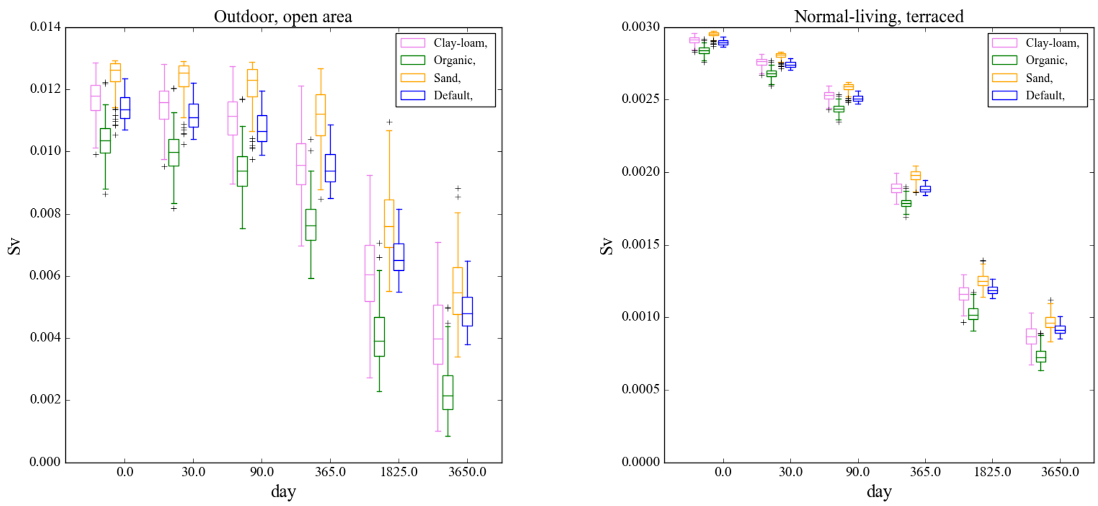
Figure 2. ERMIN prediction of the profile of 137Cs in the soil column at a) 30 and b) 365 days following deposition, using the current ERMIN default values and mean values proposed by Andersson (2018) for three broad soil types.

Figure 2a and b shows the expected soil concentration profile at about 30 and 365 days following deposition of 137Cs to the grass surface using the mean migration parameters proposed for three different soil types, a clay-loam soil, sandy soil and an organic soil, as well as the current ERMIN default soil. At 30 days, the differences are small but by 365 days it is clear that the organic soil is predicted to allow the caesium to migrate much more quickly than the other soils and that sandy soil is the slowest.

The speed of migration matters because of the additional shielding provide by the soil above as the radionuclides migrate downwards. The speed, and the diffusion, also impacts on the effectiveness of clean-up options such as soil removal, because if the radioactivity is confined to a small layer near the top of the soil, then only a small depth of the soil needs to be removed to be very effective.



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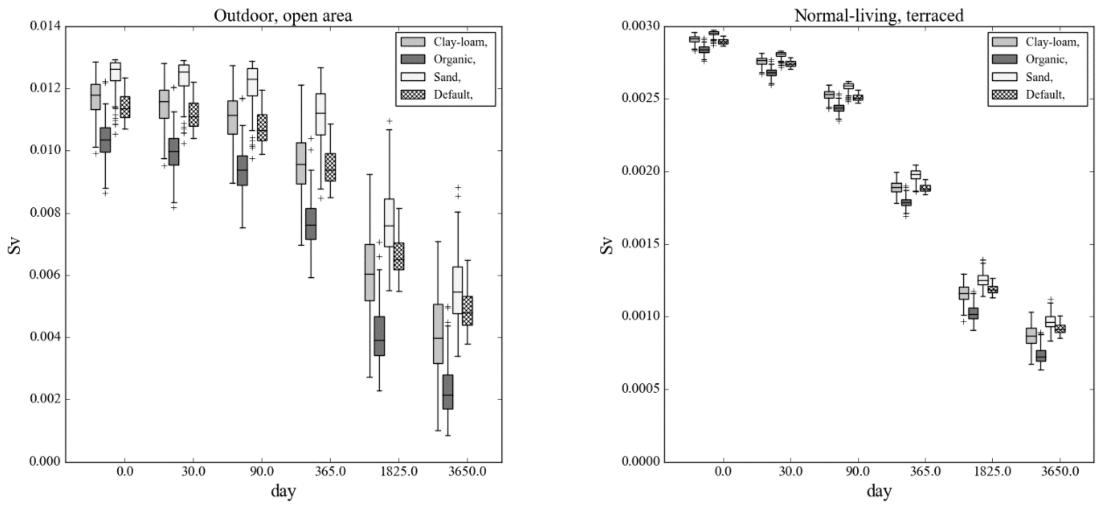

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Figure 3. The spread of ERMIN predictions of residual annual dose after Monte Carlo sensitivity analyses sampling from the proposed distribution for migration in different soil types as well as the current default ERMIN soil. The dose is integrated from the time shown over the subsequent year. a) Outdoor dose in an open field environment. b) normal-living dose in a brick terraced house environment.

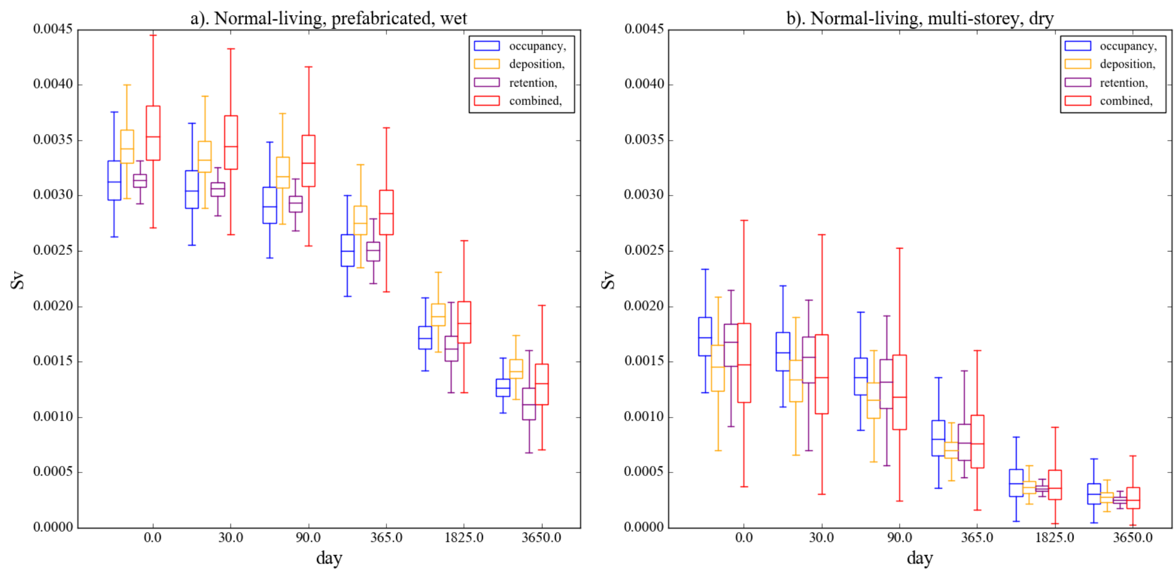
Figure 3 shows the results of two Monte Carlo sensitivity analyses in which all ERMIN parameters were kept at the defaults except for the soil migration parameters which were sampled in each run from the proposed distributions. Figure 3a is an unrealistic situation as it represents someone permanently outside in an open area, in this situation the predicted differences between the soil types are large and grow with time to around a maximum factor of about 5, as the radioactivity migrates deeper into the soil.

Figure 3b shows a more realistic normal living dose prediction for an individual who is assumed to spend 90% of their time indoors in a brick terrace house environment. The differences in predicted residual dose for soil types, do still grow with time but are much smaller at around a maximum factor of 2. Despite this, the inclusion of different mean soil parameter values parameter values instead of a single default soil is a development that would be sensible for future versions of ERMIN because:

- there are clear differences between soil types particularly at long times,
- normal-living residual dose is not the only ERMIN endpoint and user may have direct need of soil profile information, for example,
- groups in the general population may spend a disproportionately large amount of time outdoors (or in lightly shielded buildings such as prefabricated buildings), for example outdoor workers who do not live in the area,
- the difference between soil types are likely to impact on the dose reduction effectiveness of soil removal option (an important option that was used extensively in the response to the Fukushima accident), and also associated endpoints such as the amount of radioactivity in waste,
- it is not an onerous input for the ERMIN user to provide (particularly if defaults are available), and
- preliminary investigation show that differences in migration rates between radionuclides are significant and are also soil type dependant.

Example 3, combined uncertainty

The final example uses uncertainty analysis to bring many different sources of parameter uncertainty together to examine the combined impact on the residual dose prediction.



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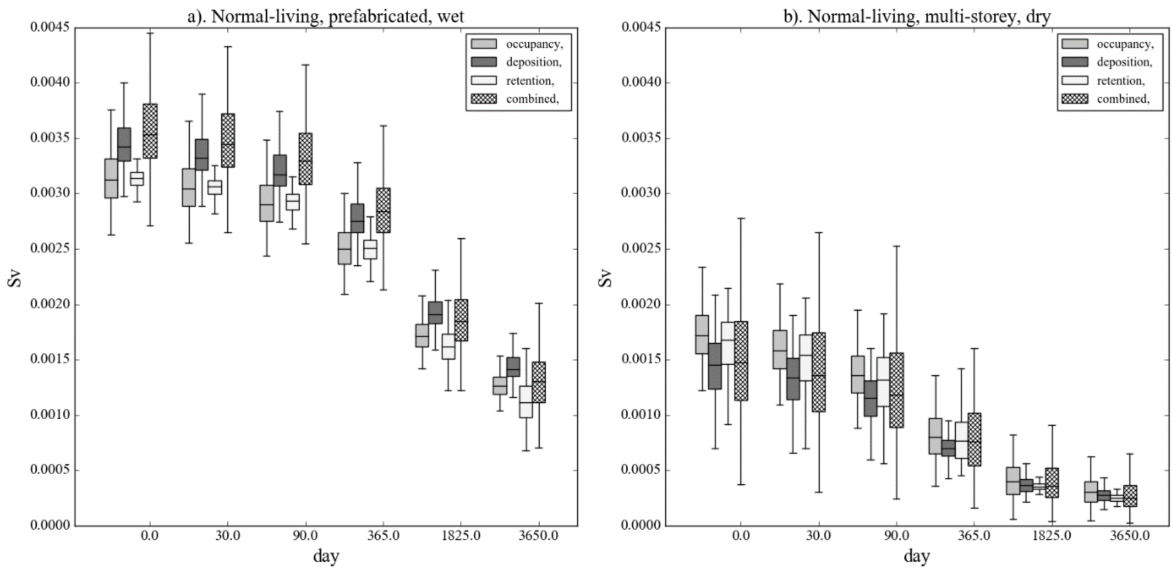

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Figure 4. The spread of ERMIN predictions of residual annual Normal-living dose after Monte Carlo uncertainty analyses sampling from the proposed distribution for subsets of parameters (occupancy, initial relative surface deposition, surface retention including soil migration), and all subsets combined. The doses are integrated from the time shown over the subsequent year. a) a prefabricated (low shielding) building environment following wet deposition and b) a large multi-storey (high shielding) environment following dry deposition.

Figure 4 shows the results of an uncertainty analysis in which distributions for different groups of parameters; occupancy, deposition ratios and surface retention (including soil migration) were sampled in a Monte Carlo fashion independently. Finally, a combined analysis was performed in which all the distributions were sampled independently. Figure 4 gives just two examples of the many analyses performed, Figure 4a shows a lightweight prefabricated house environment with wet deposition and Figure 4b shows a large multi-storey building environment with dry deposition.

The effect of these parameter uncertainties can be large; in the multi-storey environment, there are factors greater than an order of magnitude between the highest and lowest doses predicted.

An interesting feature is the impact of the uncertainty of the retention parameters. In the prefabricated building environment, the impact of these increases with time. This is expected as, following deposition, different rates of weathering on different surfaces will mean dose-rates take time to diverge and so retention only becomes the most significant uncertainty at later times beyond a year.

However, in the multi-storey environment this is not the case. Retention uncertainty apparently decreases with time. This is counter-intuitive, but it is due to the dominance of retention on interior surfaces which, whilst very uncertain, is a relatively short process because of indoor cleaning regimes. Dose-rates from indoor surfaces matter much more in the multi-storey environment because indoor locations are well shielded and remote from radioactivity on exterior surfaces, whereas in the prefabricate environments indoor locations are less shielded and closer to outdoor surfaces. Furthermore, under wet conditions the deposition indoors (driven by dry deposition processes only) is relatively much less than under dry conditions. This means the uncertainty on the indoor retention has a significant impact on total dose in the multi-storey environment which is not apparent in the prefabricated environment. It is also because of this high shielding that in the multi-storey environment dose-rates are very different indoors and outdoors and so the impact of the uncertainty on the occupancy always remains high.

Conclusions

This paper gives a few examples from an extensive project to identify and assess, qualitatively and quantitively, the impact of sources of uncertainty. The full report of the project can be found in (Charnock, 2018). The project identified several specific enhancements for improving ERMIN by reducing sources of uncertainty, including:

- incorporation of soil/nuclide/particle specific soil migration parameters,
- incorporation of different roof materials,
- increased range of environment types in database (especially more built-up environments), and
- augmenting the ERMIN indoor deposition model and parameters.

An interesting discussion is whether to introduce uncertainty analysis as a feature in a new operational version of ERMIN. This project demonstrates that the methodological and data components of such a development are feasible. However, that development is still a long way off because it is unclear if users want this facility, how they would use it, and how best to communicate the uncertainty in a way that is useful. Furthermore, such a development would need to be consistent across all the tools in the decision support systems and allow for uncertainty propagation between tools. Operational requirements mean that run times must be kept reasonably short and that the interface does not place too many demands on the user both in providing input and interpreting and using output.

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Agent-based Negotiation Simulation

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Abstract. Nuclear emergencies are characterized by severe disruptions in society's functionality and adverse impacts on human, environment and economy. How to find out suitable countermeasures and countermeasure strategies is always important for the nuclear emergency management. In the past decades, many works focused on the definitions, simulations and evaluation of countermeasures and countermeasure strategies. However, a key problem remaining open is how to mimic the negotiation process for the stakeholders of different backgrounds when given existing strategies. Our work aims at solving this problem by constructing agent-based negotiation models with the corresponding computational implementations. By using this computer program, various phenomena of negotiation process can be realized numerically and further uncertainty studies, for example, the influence of choices of stakeholders on the final result of negotiations, can be carried out on the basis of statistical analysis of hundreds of numerical simulations.

Keywords: Agent-Based Modeling and Simulation, Automated Negotiation.

1 Introduction

Agent-based modelling is a species of computation, growing up alongside the maturation of computer technology. Since powerful computation increases, the collection and analysis of very large data sets is enabled. These data sets often include data at micro-scale levels, enabling us to extract more insight as to how individuals in society behave. The combination of large data, cheap commutation and high connectivity allows agent-based models to be constructed with millions for individual agents whose properties and behaviors have been validated. Moreover, computational representations are dynamic and executable, allowing for greater interactivity between the user and representation. Perhaps, even more important agent-based representations have particular advantages in that they are easy for people to understand. Agent-Based Model (ABM) consists of a collection of autonomous and heterogeneous agents interacting with other agents and the environment by exchanging their attributes/preferences or states, and the agents have access to past and current values of their own state variables. Agents make decisions using both prescribed rules and analytical functions [1] and [2]. An ABM also includes rules that define the relationship between agents and their environment, and rules that determine scheduling of actions in the model [3].

Negotiation has been an important field of study within organizational behavior and management science. It can be defined as a discussion between two or more parties with conflicting interests aiming to reach an agreement [4]. In recent decade, automated negotiation has stimulated growing interests of researchers and many works have been done, for example, [5] and [6] as two famous publications. The question concerned with in our paper is how to simulate a large-scale negotiation process in a society. The negotiation issues can be about the protection strategies in risk management, the planning in supply chain, the distribution of energies in cities and so on. In our work, the agent-based modeling and simulation is introduced to reproduce the multilateral negotiation process that the stakeholders evaluate prepared strategies individually and held with each other comprehensive and in-depth consultation in order to select together the best solution from these strategies.

Nuclear emergencies are characterized by severe disruptions in society's functionality and adverse impacts on human, environment and economy. Highly efficient decision support can systematically help to identify response and recovery measures, especially when time for decision-making is sparse, when numerous options exist, or when events are not completely anticipated. In the past decades, the works in nuclear emergency focused on recovery strategies to generate by modeling the substances (that is, e.g. physical process, biological process) or the evaluation of strategies by Multiple-Criteria Decision Analysis (MCDA) ([7], [8]). Our work is the first one to model the multilateral automated negotiation of stakeholders dynamically in nuclear emergency and more importantly, to implement the software to simulate negotiations and visualize them. Users can input values in the panel of the software and run it. The system can pre-select suitable strategies from the database, generate the agents by inputs of preference values and simulate the negotiation process among the agents automatically. After running for several seconds, the software gives the results including the ranking of strategies in xml data files, the scores of strategies for each agent by the time series chart and the 2D animation.

2 Agent-baed negotiation simulation

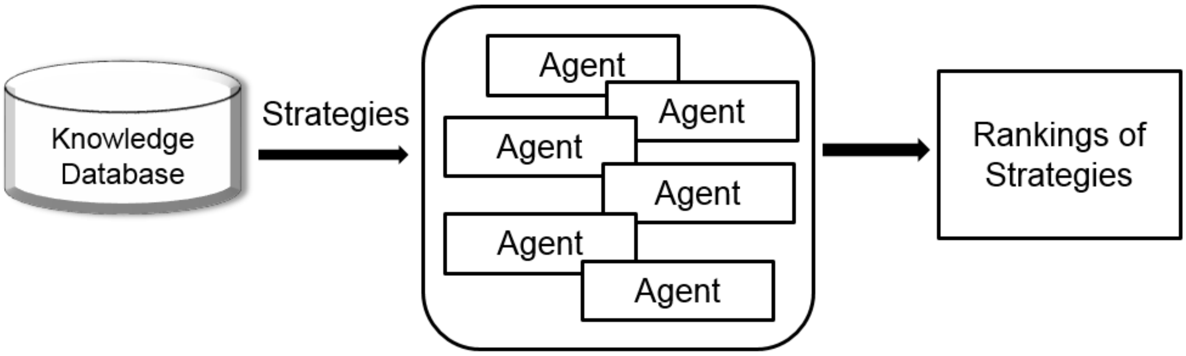

Figure 1. Process of Agent-based Negotiaton Simulation

In this section, the automated negotiation model is presented including the components of the model such as agents, negotiation objects, and negotiation issues and how they interrelate. The following formalized negotiation model is generic and can be used to describe various negotiation scenarios.

2.1 Preliminary

In this section, the whole process of the agent-based negotiation simulation is illustrated as follows. Firstly, we store all the possible strategies in a knowledge database. Then we have a specified scenario and select the suitable cases from the database by some algorithm, for example, cased-based reasoning. The pre-selected strategies are offered to the agents, who will attend the negotiation. The agents will evaluate the strategies individually and then discuss about their evaluations with each other, exchanging the information about the strategies. Finally after enough turns of negotiation, the users get a ranking of the strategies. The top strategy will be recommended to be implemented.
In the following subsections, we will introduce the knowledge database, the mathematical expression of strategies stored in the knowledge databases, the agent-based models, the evaluation and the negotiation process in turn.

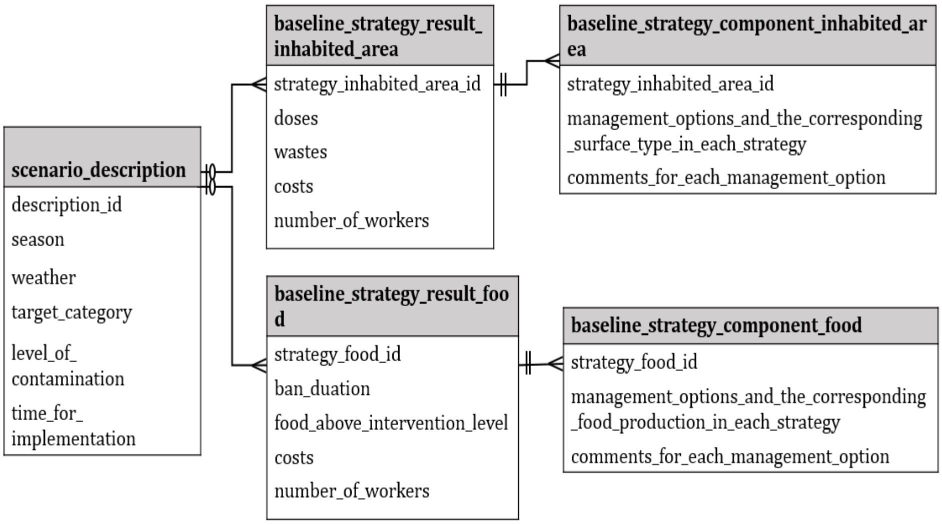

Figure 2. Database Schema of the Knowledge Database

2.1 Knowledge database

The knowledge database has been implemented as a relational database using the open source PostgreSQL database management system. In order to deal with different research projects, the database contains many schemas that are indeed collections of tables. The current database was developed for the OPERRA-HARMONE project shown in Figure 2. It has two parts: the description of scenarios and the strategies. Furthermore, the strategies can also be divided into two parts: the illustrations of countermeasures and the results from the simulations on RODOS about the effects when these chosen countermeasures are taken on the protection targets. Given a scenario, for example, a textual series {summer, dry weather, surface type or food production, lower waste contamination, long-term phase}, the information of suitable strategies can be offered from the knowledge database, e.g. the management options and the corresponding targets, doses assessments, economic expenses, human resources and costs.

2.2 The mathematical expression fo multi-attribute strategies in knowledge database.

The prepared strategies given by $S = \{S^1, S^2, \dots S^l\}$ are presented to agents before negotiation. Each strategy is defined by a vector of attributes X with the length m and the corresponding matrix of attributes of strategies X = (X_j^a) $(j \in \{1, 2, \dots, m\}, a \in \{1, 2, \dots, l\})$, which can be considered as candidates for the alternatives in MCDA. It is not necessary that each attribute of strategy is taken always as one alternative. Sometimes several attributes of one strategy can be used as a combination to define one alternative.

2.3 Agent-based models

Agent-based modeling is a computational methodology that enables one to model complex systems. Agents can been used to represent human beings in intelligent systems as they have the ability of self-learning and self-deducing.

2.3.1 Inputs – Preferences values of agents

Each agent has its own preference values with respect to each criterion. For each agent group, we can construct special distributions for this agent group. The preference values of agents are obeyed to this distribution w.r.t. its agent group. This probability distribution can describe the uncertainty of preferences. In detail, for each agent group, we can give one suggested interval to a specified criterion and assume the agents from this group can take any number in this given interval by obeying a certain distribution, e.g. normal distribution $N(\mu, \sigma^2)$. By mapping the variables and function values of this distribution into proper ranges and adjudging the parameters respectively, we can realize different phenomena of agents' preferences. For example, N(8, 0.5) can be used to describe that the agents select randomly the preference values close to the mean 8, while in the distribution N(5, 10), agents select values more uniformly and they can be approximately any value in the premitable range [0,10]. The different settings of the variances of normal distributions may reflect whether the agents keep an open mind to listen to the opponents or not. From the previous analysis, we can see the setting of suitable parameters of normal distributions is very important to describe the agent group correctly. The qualities of agent-based models on the aspect of individual part are largely depending on the settings of parameters.We suggest that such settings would better base on first-hand reports and also questionares from the stakeholders.

2.3.2 Individual dynamics – Evaluation of strategies for each agent

The model aims to realize the process that one agent evaluates a single prepared strategy by MCDA. Let $A = \{A_1, A_2, \dots, A_n\}$, be the set of agents, S be the strategy, $C = \{C_1, C_2, \dots, C_r\}$ be a set of criteria, $\mathrm{P} = (P_{ik})$ $(i \in \{1, 2, \dots, n\}, k \in \{1, 2, \dots, r\})$ be the corresponding preference values of agents. Remember that $X = (X_j^a)$ $(j \in \{1, 2, \dots, m\}, a \in \{1, 2, \dots, l\})$ be a set of alternatives of S^a. Therefore the utility of the agent in the situation, which is the score of the strategy for the agent $A_b, \forall\, b \in \{1, 2, \dots, n\}$, can be defined as a kind of weighted sums of evaluations of alternatives,

$$U_i^a = \sum_{j=1}^{m} w'^a_j \cdot \sum_{k=1}^{r} w_k \cdot E(P_{ik}, X_j^a) \tag{1}$$

where the weights of criteria are $w_k > 0$ and satisfy $\sum_{k=1}^{r} w_k = 1$. The weights of attributes are $w'^a_j > 0$ and satisfy $\sum_{j=1}^{m} w'^a_j = 1$. Due to several objective factors, agents may not always contribute equally to the assessment of the strategies. Therefore, the weights of the agents $w"_i > 0$ are assigned to the description of various shares of agents and satisfy $\sum_{i=1}^{n} w"_i = 1$. Thus the utility function of agent which is score of the strategy can be defined as,

$$U^a = \sum_{\mathrm{i}=1}^{\mathrm{n}} w"_i \cdot U_i^a \tag{2}$$

The definition of the functional E, which acts on the preference values and the attributes of strategies, depends on the requirements from the problem to be solved in details.

2.3.3 Interaction of agents – Negotiation process

Agents in negotiation are suggested to be rational and obey the following instructions [9]: Agents agree to act as professionals, and making rational arguments is a good way to succeed in a negotiation. Thus, agents should stick to the facts, and use rational arguments to explain their positions. It is very important that agents make rational arguments convincingly by referencing to the facts at hand and do not try to manipulate the others. Agents work for their goals in order to come to a better agreement. They can do this by working together with those who have similar positions. In general, the goal of each agent in negotiation is to reach an agreement with the others that is "good" for all of them.

There can be always more than one strategy to be negotiated. As a working assumption, the strategies are not interdependent and reviewed by agents one after another. An extreme situation should be avoided where agents depress the scores of several strategies deliberately so that the total score of the strategy, which they prefer, will rise dramatically and as a result selected as the best solution after negotiations. However, from the other perspective, the information about ranking specified attributes may be necessary and helpful for scores. For example, two agents consider the size of an evacuation area but according to their preferences, the numbers given from all the strategies are unexpectedly big and close to each other. As a result, the direct distance function between the suggested areas from strategies and the area expected by agents fails to distinguish these strategies very well. In this situation, the utility function of agent can be expanded to reflect the rank of an evacuation area.

2.3.3.1 Protocol

A negotiation protocol is a set of rules that specify how the agents can interact during the process of a negotiation, while a negotiation strategy determines, according to the negotiation history, which offers should be made or whether or not they accept their opponents' offers at a certain time of the negotiation process [6]. There are mainly two parts of protocols, the permissible content of interactions, which agents exchange with one another and the permissible process of intereactions, when and how agents exchange contents. In the current work, we assume that for all the agents several strategies are available before negotiation. They review the strategies independently and give scores to these strategies one by one. Then they sit together (e.g. in a meeting room) and negotiate the acceptances of these strategies on the basis of their scores. During the course of negotiation, they exchange their views on one after one attribute of these strategies and consider carefully the reasons from those who have different opinions. They may see if some leeway is left from the opponents. They may see if they can give special offers to solve the opponents' problems. They may also compromise in some way to try to be unanimous for a certain attribute in negotiation with the majority.

2.3.3.2 Negotiation strategy

Negotiation strategies are often conceptualized as either integrative or distributive, such that they seek to maximize either joint or individual benefits, respectively [10]. A negotiation attribute–based tactic in particular refers to a certain way of handling one or more negotiation attributes in pursuit of a joint or individual goal. The libraries of negotiation strategies have been studied in past decades and many effective tactics have been determined in various negotiation situations. In general, the negotiation strategies can be broadly split into two types, cooperative and non-cooperative types. In the following, we list the simplest mathematical realizations of these two types:

Assume that n agents negotiate for one score of one strategy in the management of risk or bid for the production at an auction. The scores/bids given from the agents are denoted to be $\{s_i\}$,i=1,…,n.
After negotiation, we obtain the final results:

Cooperative type (e.g. trade-off): $final\ score = \frac{\mathrm{Max}\{s_i\}+\mathrm{Min}\{s_i\}}{2}$

Non-cooperative type (e.g. auction): $final\ bid = \mathrm{Max}\{s_i\}\ or\ \mathrm{Min}\{s_i\}$

It will be very interesting yet challenging to find out suitable negotiation strategies with respect to the specified negotiation topics.

2.3.3.3 Cut-down mechanism

In the optimal situation, the agents stop the negotiation when they arrive at an agreement. But sometimes the preferences of agents differ very much from each other. They cannot convince the others of their opinion and therefore the negotiation fails. In this situation, the negotiation process should be cut down. In this subsection, we introduce three indices and their corresponding thresholds to monitor the negotiation process.

The first index is the ranking of strategies for each agent. Usually before negotiation, many agents have different rankings of the strategies; while after negotiation most agents get the same ranking after enough negotiation turns, which means that the negotiation is successful. This is a tip about how to define “most”. It is more than a percentage which can be 60%, 80%, or even 99.999%. The higher percentage means that more agents hold the same ranking of strategies. Naturedly the higher, the better. But sometime, the higher needs more running time and therefore we need to get a balance between them. The second index is the rate of the convergence of the score of strategy for agents. If all the scores of agents are convergent, the negotiation should be stopped regardless of whether the agreement is achieved for most agents or not. The third one is the number of the time steps of the simulation. There are two uses. The first use is to start the check of convergence. The second use is to judge if the process of negotiation should be stopped in order to save the computational resource.

The control flow statements for the cut-down mechanism are described as follows. Check if “most” agents get agreements on the ranking of strategies. If yes, then stop the program; if no, then check if the program runs more than a certain steps, for example, 15. If yes, then check if the scores are convergent; if no, go to the next check; Check if the program runs too many time steps, for example, 40. If yes, then stop the program; if no, then go to the next time step and do negotiation one time. Repeat the checks.

3 Numerical tests:

In this section, we will show numerical results from the simulation experiments. The scenario describes the negotiation process of two agents negotiating on three strategies and successfully agree on the rank of one preferred strategy. The agents are of equal weight they can exchange information with each other in the social network without any restriction. In one iteration of negotiation, one agent talks with the others one time and adjusts its own opinion afterwards according to the aggregation of the opinions from the others. During negotiation, agents may have conflicts because of their individual interests. Different agents may adopt opposite intentions and they want the others to switch to a particular attitude. The negotiation strategy "random Tit-for-Tat" [11] to be chosen in the process can help agents find a reasonable solution to come to an agreement and make a decision to maximize profits as a whole instead for individuals.

Before negotiation, it is obvious in the left subfigure of Figure 3 that for Agent 1, the ranking of strategies is, Strategy 3 > Strategy 2 > Strategy 1, while for Agent 2, Strategy 2 > Strategy 3 > Strategy 1. Agent 1 considers Strategy 3 to be the best one and Strategy 1 to be the worst one. Agent 2 opts for Strategy 2 as the best strategy. The ranking of scores for strategies after negotiation are visualized in the right subfigure of Figure 3. It is obvious that for both agents, the final ranking of strategies is, Strategy 2 > Strategy 3 >Strategy 1. Both agents agree that Strategy 2 is the best one and Strategy 1 is the worst one.

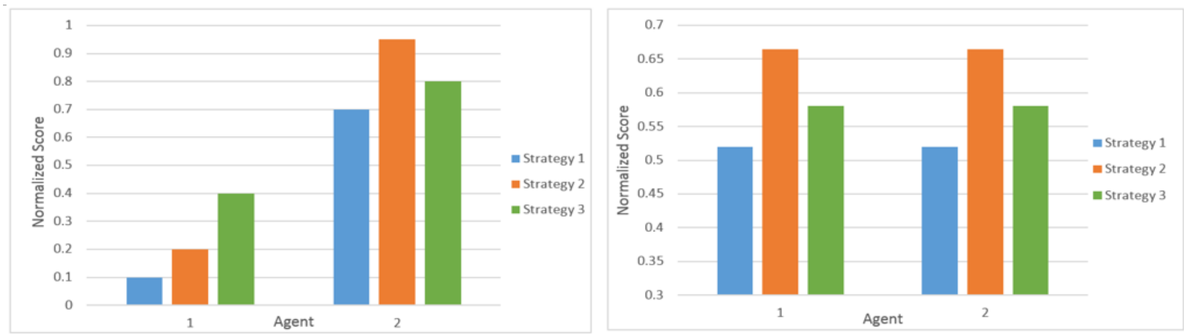

Figure 3. Scores of Strategies for Agents. The scores before negotiation is shown in the left figure and the scores after negotiation is shown in the right figure.

Next, we consider the question that given two agent groups, how two agents randomly selected from these two agent groups negotiate with each other. We collect the results from 50 numerical experiments. In each experiment, two agents are selected randomly from these two agent groups and the scores of strategies for these two agents are inputs for the simulation. For each run, the negotiation simulation stop around 20-40 time steps where the exact number is up to the exact settings of these thresholds for the cut-down mechanism. In Figure 4, the 50 negotiations for two agent groups are shown. We can see that the results can be different in runs but the trend is pronounced. Strategy 3 is the best solution in 45 runs. Strategy 1 is ranked

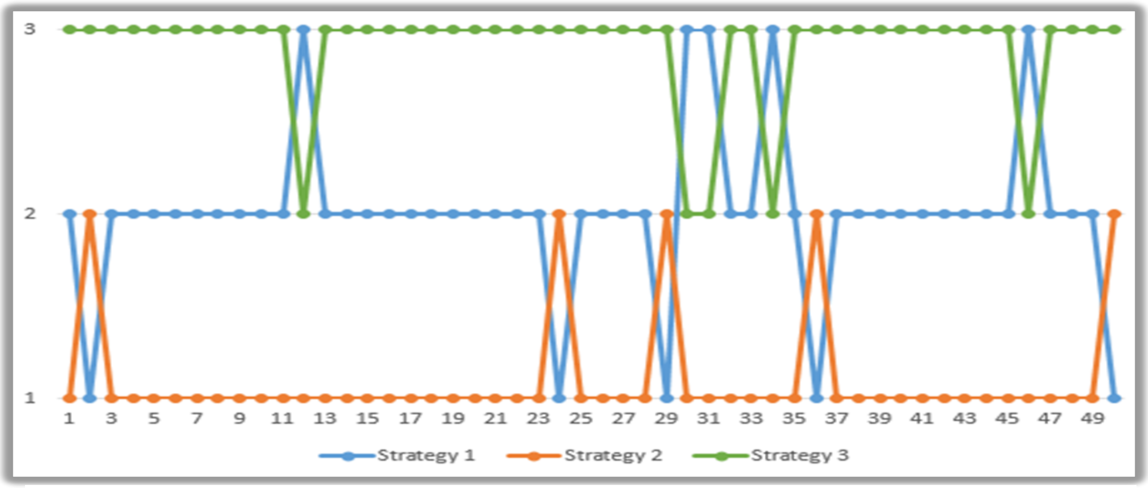

Figure 4. 50 negotiations for two agent groups. Y-axis represents the ranking of the three strategies and X-axis shows the time step.

as the second good solution in 41 runs. Strategy 2 is the worst solution in 45 runs. Therefore, we have the conclusion that Strategy 3 is the best solution statistically.

4 Current work

In our current work [12], an intelligent strategy evaluation system based on the agent-based negotiation simulation has been introduced in order to simulate the decision making process of stakeholders on computationally tractable assumptions. In the framework of the system, agents can score the recommended strategies before negotiation and negotiate them by using different negotiation skills. The intelligent strategy evaluation system has been applied to nuclear and radiological emergency management and preparedness. Five special agent groups were defined, which are expert, politician, lawyer, NGO and industry/consumer, and 25 agents were created for these agent groups. The four criteria were defined as effectiveness, cost, acceptance and resources needed. Each criterion has a particular preference for each agent and is of equal weight. In our software, users can enter the required values in the panel and start the negotiation respectively simulation process by simply clicking the run button. The simulation will take several seconds. The users can obtain the results of the negotiation

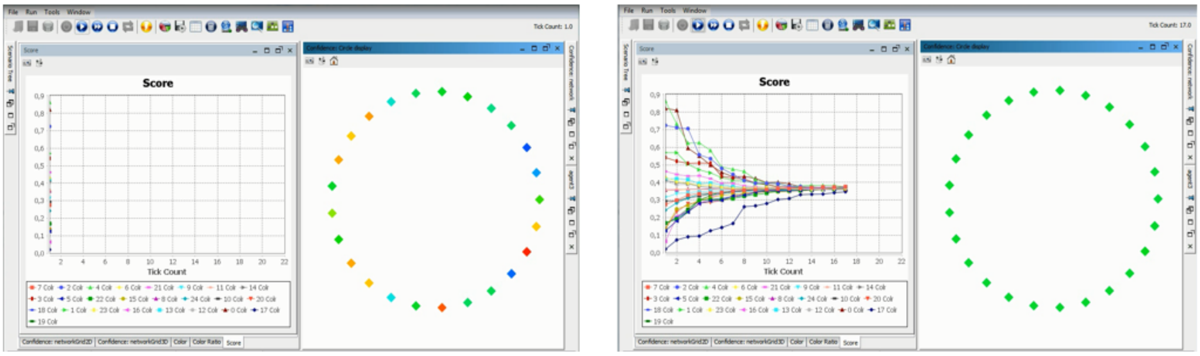

Figure 5. Two screenshots of the video from results of the intelligent strategy evaluation system.

including the ranking of strategies in xml data files, the scores of strategies for each agent by the real-time time series chart and a 2D animation.

The negotiation process for one strategy for the 25 agents is shown in Figure 5, where each screenshot has two displays. The left one shows 25 time-series of the scores of one strategy related to 25 agents. The x-axis is the time step of the negotiation. The y-axis is the “relative” score which is calculated as follows: Take the maximum and minimum of all the possible scores and calculate the relative score by (true value – min)/(max-min). The right one shows the negotiation process. Agents are represented by the diamonds and their relative scores to the given strategy are represented by the colors. Different color indicates different score. At the initial tick count, the agents had different opinions and gave different scores to the strategy in negotiation. The colors of diamonds are correspondingly various, e.g. light red, dark blue. After several negotiation times, the agents got to agreement. Accordingly the color of diamonds turn to be the same, green. The negotiation process can also be observed from the left display of time-series, where all curves go closer and tend to a limit.

5 Conclustion

The agent-based modeling and simulation of the multilateral negotiation process have been introduced in the paper. General topics related to negotiation skills, for instance, the design of strategy, agent, protocol, negotiation strategy etc. have been considered in the ABM system. Moreover, the ABM system for negotiation has been implemented as a Java application. By running the program, the agents are created from existed agent groups by using stochastic processes and negotiation with each other by agent-based negotiation simulation. The numerical results have been analyzed in the paper. An intelligent strategy evaluation system was developed for the nuclear and radiological emergency management and can be further applied to support the decision making of many different stakeholders of various types of risk management. The application of this system demonstrates the advantage of ABM system in risk management and strategies evaluation.

In our future work, we will keep updating on the modelling of the ABM for negotiation and the data acquisition for simulations. Possible extensions are for example nonlinear negotiation models (trade-off, multi-issue, etc.). A survey study to consider internal and external social relations of agents in groups during negotiation may be carried out for better modelling. Another possible way is to generalize our data types and expand the data structure in the knowledge database to adapt many types of risk managements. Furthermore, the Java application can be added new properties and additional visualizations.

AKNOWLEDGEMENTS

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Application of the RODOS system to determine the restricted use area for the planned nuclear power plant in Poland

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Abstract

According to the Polish Programme of Nuclear Energy, the first nuclear power plant should be constructed approximately in the next fifteen years. Two possible localizations are considered in the Pomerania region, and five technologies are taken into account in the process of the selection of the vendor. Following national regulations, one of the elements that should be verified before the final decision concerning the choice of technology will be undertaken is the estimation of the possible area of the restricted use and emergency planning zones. In accordance with national atomic law, some criteria concerning the estimation of various doses have to be checked assuming both different types of the scenarios of nuclear accidents and releases during the normal operation period. For this purpose, the RODOS decision support system has been applied as a main tool for the calculations of possible doses to the public taking into account a variety of meteorological conditions. The results of the performed simulations will be presented with the emphasis on the general applicability of the RODOS system and, in particular problems and difficulties encountered in such application. Possible solutions to these problems and alternative approaches will be discussed. Some general comments concerning the needs of further research in the field will be also given.

Introduction

The goal of our work was to perform simulations of the dispersal of radioactive contamination in atmosphere, terrain contamination and dose calculations from ionizing radiation in the neighborhood of NPP, making use of the RODOS models in order to compare potential size of the restricted use areas and emergency planning zones for five technologies of nuclear reactors considered in the Polish Nuclear Energy Programme. There were considered two potential localizations in the Pomerania region, i.e. Lubiatowo-Kopalino and Żarnowiec.

Several criteria were applied following binding national rules and IAEA guidelines or EUR requirements – they concern emission during normal operation and various types of accidental situations: without and with core melt, design basis accident and with design extension conditions, as well as accidents representative for emergency planning. In each category of accidental conditions, limiting accidents concerning the consequences of radiation impact on the population was applied. This is the first such vast technical analysis made in Poland and the results can be applied in the discussion concerning the introduction of possible changes in the Polish Atomic Law and regulations related to the design, construction, and operation of NPP.

In this paper we focus solely on the methodology of establishing the restricted use area, bound by the following criteria [1]:

- **OOU1**: Annual effective dose received from all exposure pathways in normal operation period – zone limiting value: 0.3 mSv/year

- **OOU2**: Annual effective dose received from all exposure pathways in case of an accident without core melt - zone limiting value: 10 mSv/year.
- **OOU3**: In case of design basis accident: 2-days effective dose received due to external and internal exposure except for ingestion - zone limiting value: 10 mSv. Criterion relates to sheltering.
- **OOU4**: In case of design basis accident with extended conditions: 7-days effective dose received due to external and internal exposure, except ingestion – zone limiting value: 100 mSv. Criterion relates to evacuation.
- **OOU5**: In case of design basis accident with extended conditions. Criterion relates to permanent relocation:
  - OOU5a: lifetime dose (50 years for adults, 70 years for children) effective dose received due to external and internal exposure except for ingestion – zone limiting value: 1 Sv, or
  - OOU5b: if 30-days effective dose received due to external and internal exposure except ingestion does not decrease below 10 mSv during the first 2 years from the occurrence of a radiation accident.

Assumptions

The underlying assumption was to use exclusively only data delivered by the potential technology vendors. In case of the releases during normal operation, there were quantities given for one of the following periods: whole year, quarter or month. Taking into account, the basin of Żarnowiecki lake different release heights were assumed for both locations: in case of Lubiatowo-Kopalino location 100 m, while for Żarnowiec 150 m.

A significant factor for simulation was the choice of meteorological conditions. The main problem was, that Polish Atomic Law [1] does not define precisely the way of their selection – it contains the following general formulation: „While estimating effective dose, [...] data and information are taken into account related to [...] location of nuclear object, including natural environment in the neighborhood, in particular: lay of the land, geological structure, climate conditions, taking into account the most adverse meteorological conditions [...]".

To determine meteorological sequences, the data from the closest synoptic station in Łeba in the period of 1973-2016 were applied. According to general climate consideration, this station is representative for the considered region. Taking into account that the way of the choice of the most adverse meteorological conditions can be interpreted in different ways, i.e., basing on:

a) the length of the occurrence of atmospheric inversion,
b) the conditions favorable for long transport of particles, or,
c) the conditions favorable for high exposures (i.e., concentrations or activities of radionuclides) or depositions,

three different methods were developed for the selection of meteorological data related accordingly to points a)-c) mentioned above.

In any case, the implementation method consisted of two stages. In the first one referential year was defined for these three variants in the following way:

a) Sequences with following stable atmospheric conditions were analysed. A year with the highest sum of such stable periods was chosen as a referential year – it was 2005.
b) The frequency of the wind occurrence higher than 10m/s in the direction towards Trójmiasto was analysed (taking into account that this is the most significant population

area close to the potential location of NPP). The year with the highest frequency was chosen: it was 2012.

c) The frequency of simultaneous occurrence of stable atmosphere and precipitation was analyzed – in this case, 2010 became a referential year.

Applying this approach in the second stage we have selected the meteorological sequences basing on three criteria mentioned above, to be used in simulations for determination of the restricted use area.

Table 1. Meteorological datasets used in different criteria for determination of the restricted use area

Dose criterion	Meteorological data
OOU1	The most adverse referential year for exposures and deposition (i.e., 2010): simulations performed for each month separately (12 simulations)
OOU2-OOU5a,b	115 selected sequences according to three methods developed for consideration the most adverse meteorological conditions

Models applied for dose calculations

In the computations, RODOS [2,3,4] was the primary system to determine doses from ionizing radiation as a consequence of the dispersal of radioactive material in the atmosphere. RODOS ensures comprehensive and continuously analyzing assessment of population exposure to ionizing radiation in case of accidental release of radioactive material (or risk of such release) to the atmosphere and/or water bodies. A nested chain of models predicts the dispersion and deposition of the released material. These models simulate dispersion and deposition processes, in principle, in two ranges: local scale on the area of 160 km x 160 km and long distances even up to a few thousands of kilometers. The RODOS models have been chosen among many available models – the ones satisfying the best system requirements were selected. The model chain contains RODOS Meteorological Pre-Processor RMPP [5], atmospheric dispersion cloud model RIMPUFF (Risø Mesoscale PUFF model [5,6], early countermeasure model EMERSIM (Emergency Simulation) [2,3,4] and terrestrial food chain and dose model FDMT (Food Dose Model Terrestial) [2,3,4]. To simulate atmospheric dispersion we have applied RIMPUFF model [5] designated to estimate concentration and doses resulting from the dispersal of the material in the air. The model well copes with nonstationary and non-uniform meteorological conditions, which are often subjects of interest concerning computations applied to the estimation of short term (accidental) releases of volatile material to the atmosphere. The model consults both uniform and non-uniform terrain of moderate topography in the scale up to 50 km and deals with variable meteorological conditions. It can simulate temporal changes during the emission of volatile material by subsequent releases of Gaussian puffs with constant speed on a defined grid.

However, not always RODOS could provide proper simulations: Specifically, there is a lack of some models:

- doses for the fetus - they were determined according to British document [7] ;
- doses from C-14, H-3 – thus PC-CREAM [8,9] was applied to calculate doses from tritium and carbon C-14 for normal operation period; UFOTRI [10] model applied for tritium release in an accidental situation;

- doses for eye lens - they were calculated by combining tables from ICRP-116 related to the relation between absorbed dose and fluence for various energies.

Additionally, the RODOS system has not been designed for dose estimations in normal period operation (for example due to limited simulation time) although it contains some statistical tool, which unfortunately in our case were not used because of their limitations (problems with statistical management of various accidental situations). Therefore some results of the simulations had to be combined out of the RODOS system.

Results

To estimate the restricted use we have determined the restricted areas corresponding to each of the criteria OOU1-OOU5a,b. We have observed that in case of the restricted use area decisive criterion is OOU2, where in fact, it is assumed that during the whole year after the end of the release contaminated food products from agrarian areas around NPP will be consumed.

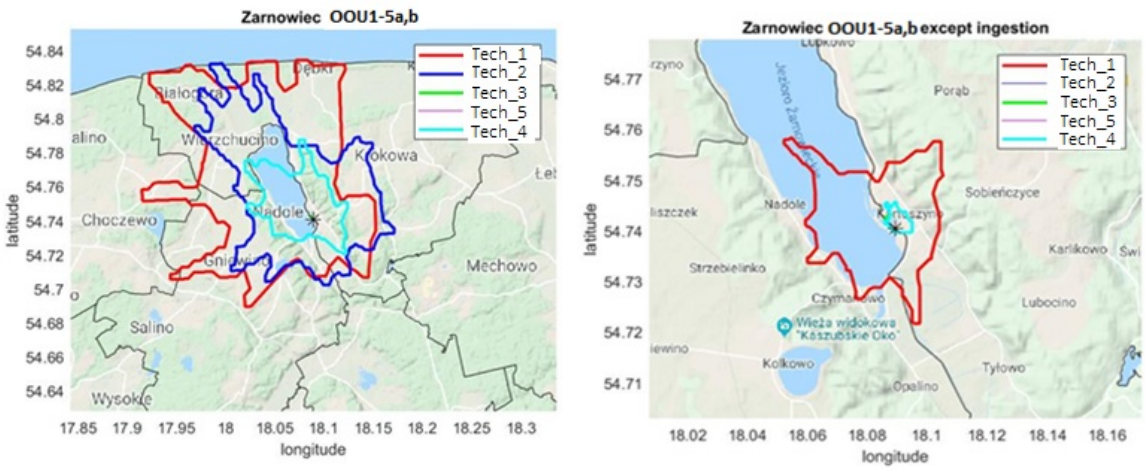

Figure 1. Fig. Borders of the restricted use area obtained taking into account all the criteria OOU1- OOU5a, b (right panel - in the case when the food dose was omitted in the OOU2 criterion) for all considered technologies in the Żarnowiec location

To have comparison, we have estimated the restricted area excluding from the OOU2 criterion the ingestion dose. This change drastically reduced the restricted use area in the case of all considered NPP technologies and locations. The difference can be seen by comparing the areas obtained for Żarnowiec location presented in Figures 1.

Performed calculations have led to the conclusion that in case of the restricted use area decisive criterion is OOU2 based on the mentioned above assumption of one-year consumption of the food from the contaminated area. This assumption is doubtful – hence it seems that this rule of the Atomic Law concerning the criterion for the accident without core melt (1-year limiting effective dose from all exposure pathways is 10 mSv) should be annulled or:

- ingestion dose in the limiting dose should be excluded (as it is in other criteria related to intervention levels), and

- an interpretation of the formulation „taking into account the most adverse meteorological conditions" should be based on applying 95% (or even 90%) quantile to the results of the calculation for the meteorological dataset.

Conclusions

The RODOS decision support system has been applied for the preliminary estimation of the restricted use area and emergency planning zones for five possible technologies of the nuclear reactor and two possible localizations. Although the system was originally designed for the management of crisis situation caused by the accidental release of radioactive material, it can be also used in other applications, because as an integrated system it enables to perform comprehensive simulations of the development of radiological situation after such various releases. Some problems have been however identified, related to the lack of the possibility in the determination of doses for some organs and radioisotopes. Similarly, application of the RODOS system for normal operation period is straitened due to the limitations of the simulation time. Although the system provides several tools for post-processing in our case most of the results had to be processed using in-house software. All these areas mentioned above can be considered as an indication for further improvement of the system. It should be stressed, however, that the RODOS system enables to perform simulations in which a chain of the selected models can apply to cope with several various problems and therefore it can be considered as a useful tool in different applications.

Acknowledgments

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Seasonality influence in the elaboration of risk maps associated with the transfer of radioactivity through the food chain.

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Introduction

In a nuclear post-emergency situation, large areas of agricultural land may be affected by the accumulation of radionuclides in soils. Their transfer through the food chain can have public health and socioeconomic consequences and therefore, have a clear impact on the way of life of the affected population.

The risk posed by radioactive releases, at any specific place, is a function of factors such as the amount and composition of the radionuclides released, their atmospheric dispersion and deposition patterns, the radiological vulnerability of the affected area (in terms of its potentiality to transfer the contamination to the population), but also of the socioeconomic structures affected such as the land use, the agricultural and husbandry production and the number of persons potentially exposed.

The elaboration of nuclear risk maps is one of the actions that facilitate the assessment of the consequences derived from radioactive releases, once the initial emergency phase has passed [1]. They show the geographical distribution of the contaminated areas, allowing their categorization, considering, both the deposition received and their radiological vulnerability. The identification of the most affected areas, defined as those which show the highest levels of soil-to-crop transfer values, will allow the prioritization of where to act on, helping in the design of the most appropriate recovery strategy.

Under the framework of the ANURE Project (Assessment of the NUclear Risk in Europe-A case Study in the Almaraz Nuclear Power Plant, Spain), a Specific Agreement signed between the JRC and the CIEMAT, a methodology has been designed to establish the geographical distribution of the risk caused by severe accidents in European NPPs, taking into account all the factors considered before, to elaborate risk maps associated to the transfer through the food chain pathway.

Undoubtedly, the exposure of the population through this pathway will vary in the following years after the release. It depends not only on the radioactive decay of the radionuclides present and the processes that affect their leaching and fixing in the soil. It also depends, on the time of the year in which the release and deposit takes place, which in turn will determine, according to the agricultural land use at that moment, the growth stage of the crop. The existence of a more or less developed biomass, at the time of the deposit, influences the amount of contamination received by the soil and therefore the subsequent soil to crop transfer process.

The influence of the “seasonality”, understood as the season of the year in which an accidental release would pose a greater risk due to the food chain exposure pathway has been accomplished in the ANURE methodology. For this purpose, a statistical analysis of the seasonal variations of the activity concentrations in different relevant food stuffs, prepared for consumption, has been carried out. The values have been estimated with JRODOS from a set of daily simulations, over a period of five consecutive years, of a severe accident with off-site consequences, taken place in the Spanish site of Almaraz Nuclear Power Plant. This paper shows the methodology developed and results obtained.

Methodology

The methodology follows two developments. The first one aims to estimate the ground deposition probabilistic pattern as a consequence of an accidental release occurred at the Almaraz NP and the second, its degree of severity to radiation exposure, in different food stuffs, regarding the month of deposition and the temporal evolution.

The Statistical Tool included [2] in JRODOS Decision Support System (DSS) [3] was used to undertake a probabilistic study of deposition of radionuclides and their transfer to food chain, covering a large range of possible release events on each day along five consecutive years (2012-2016). The modules RIMPUFF (Atmospheric Dispersion Model) and FDMT (Terrestrial Food Chain and Dose Module) were used in the modelling of the ground deposition and the subsequent activity concentration in feedstuffs and foodstuffs.

The module RIMPUFF, is a Lagrangian mesoscale atmospheric dispersion puff model [4], that estimates the ground deposition pattern following a hypothetical release event. Two main inputs are needed for the calculations, as shown in Figure 1: the meteorological conditions at the time of the release, which determine the temporal and spatial distribution of the plume and the source term characteristics, which determine the timing and magnitude of the radioactive release to the environment from a specific source.

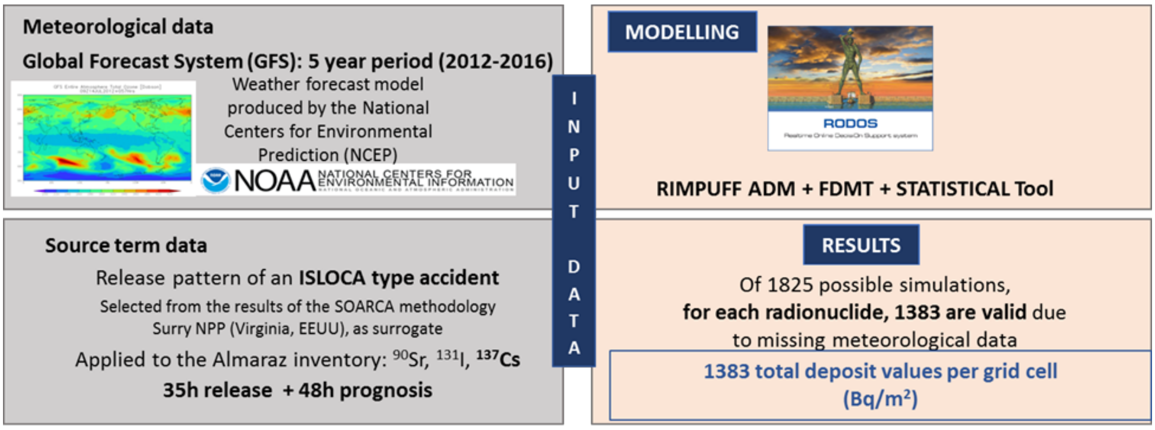

Figure 1. JRODOS input data and outcomes.

The meteorological data used in this study, for a 5 year period 2012-2016, were taken from the Global Forecast System (GFS) which is a global numerical weather prediction model (NWP) run by NOAA (National Oceanic and Atmospheric Administration of Unites States of America). The NWP files format used is the GRIB2.

Regarding the source term, the data selected correspond to an ISLOCA type of accident with 35 hours of release. The information has been gathered from previous studies made in the Surry NPP [5], chosen as surrogate of the Spanish Almaraz NNP. The data were conveniently applied to the Spanish NPP inventory for ^{137}Cs, ^{90}Sr and ^{131}I.

From the statistical tool 1825 release events were generated for the ISLOCA accident scenario, although due to gaps in the meteorological files and/or missing files, finally, 1383 were valid. Each simulation was performed for 83 hours (35 hours of release and 48 hours of prognosis period).

The module for simulating the transfer of radioactive material in food chains, and for the assessment of doses via all relevant pathways (internal exposure via inhalation and ingestion, external exposure from the plume and from deposited radioactive material) to the population, is the FDMT [6]. The input data needed comes from the output of the atmospheric dispersion modules, in particular the activity deposited on soils. Although JRODOS can estimate the activity concentration for a large number of food stuffs, a selection of them has been made in this seasonality exercise: leafy vegetables, cow milk and beef meat. The regional data used has been the default data, for Central Europe, because they are the only ones implemented actually in the system.

The criteria chosen for this selection is based, mainly, in the importance of the food stuff both in terms of its agricultural production and in the diet. However, the food products chosen are also useful to represent exposure scenarios with operational purposes, such as scenarios for Food pre-analysis or Food post-analysis of IAEA Operational Intervention Limits (OILs) [7].

Once the food stuffs are chosen, the severity to radiation exposure as a function of the activity concentration of the deposited radionuclides regarding the seasonality is undertaken. For this purpose, only one grid cell was selected; the first studies have been made in the first cell of the calculation grid, but the considerations made for the chosen cell would be valid for all the others. Several steps had to be followed to obtain the results:

- Grouping the activity concentration (Bq kg^{-1}) of each radionuclide, in each food stuff, according to the month in which the release occurred.
- Normalising (dividing the activity by the corresponding total deposition in the cell by each run) [Bq kg^{-1}/Bq m^{-2}] and the time after deposition [days or years].
- Estimating the mean, standard deviation and other statistics.
- Obtaining a ranking of severity of contamination in each foodstuff according to the month of the deposition to map the risk.

Figure 2 shows for the cow milk, respectively, the grouping of the activity concentration of ^{137}Cs, in relation to the month in which the release took place, its normalisation, regarding the total deposition in the cell and the estimation of the mean and standard deviation of the normalised activity concentration.

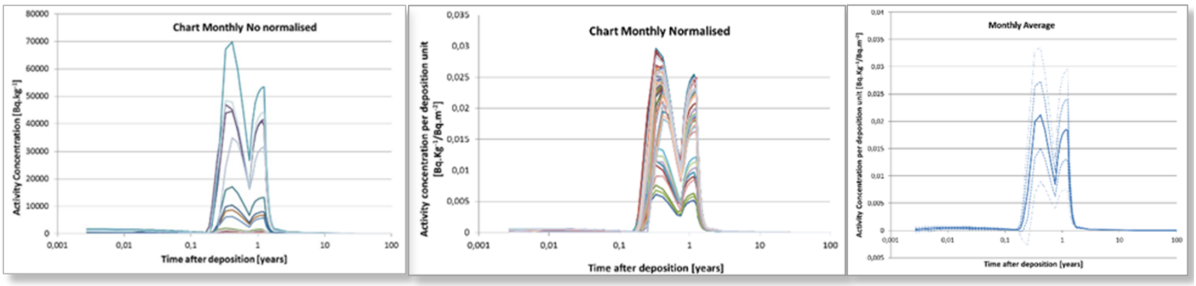

Figure 2. Example showing the steps to group, normalise and estimate statistics used in the study from the curves obtained for the temporal evolution of the activity concentration of radionuclides in products (in this case ^{137}Cs in cow milk) resulting from possible accidental release during a specific month in the year .

Results

Following this procedure, differences are seen in the magnitude and shape of the curves representing the mean activity concentration values, for each food stuff and radionuclide, regarding the month of release. Figure 3 shows the differences obtained among the average and standard deviation activity concentration values for beef meat, between January and May, for ^{131}I, ^{137}Cs and ^{90}Sr. As seen, the peak of activity differs from nuclide to nuclide, and month to month, influenced, in this case, by the feeding regime of the cow.

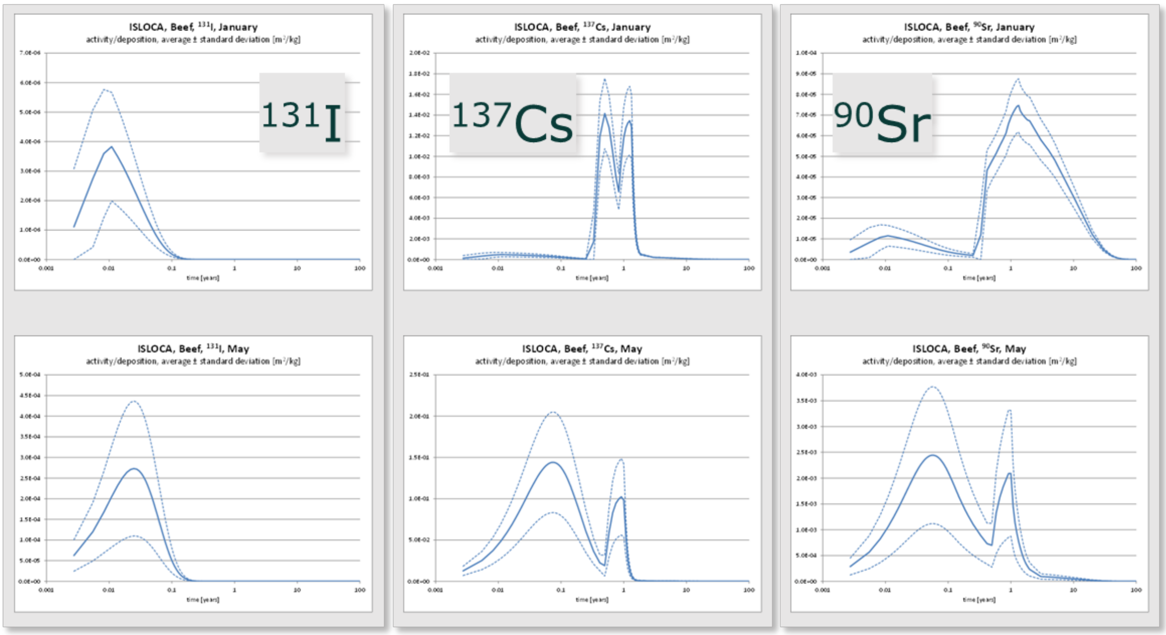

Figure 3. Average activity concentration curves for beef meat, for each radionuclide considered.

For comparison purposes of the seasonal behaviour and obtainment of relevant conclusions, ^{137}Cs was selected. This radionuclide has more relevance for long term exposure and a higher magnitude than ^{90}Sr.

A first comparison was made for the seasonal variability of the ^{137}Cs activity concentration in food stuffs per deposition unit (Bq kg^{-1} per Bq m^{-2}), regarding the month of deposition. The Figure 4 shows this variability for vegetables, cow milk and cow beef. The magnitude of the activity concentration changes in each food stuff, depending on the month when the deposition takes place.

As seen, the contamination magnitude and temporal evolution for leafy vegetables seems to show less fluctuation regarding the month of deposition than the animal products, surely, because the production of vegetables is more homogeneous along the year that the animal products. However, it will be necessary to take into account the range of variation of the data to obtain conclusions. In the case of the animal products, it is possible to identify the worst situation that for beef and milk, occurs when the releases take place between June and October.

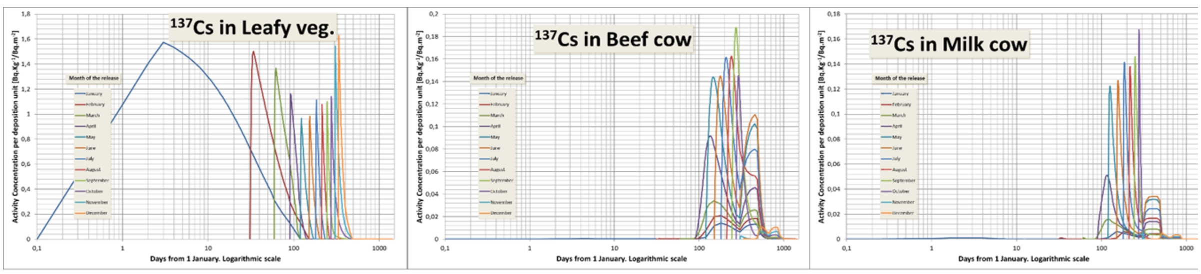

Figure 4. Seasonal variability of the ^{137}Cs activity concentration in different food stuffs regarding the month of deposition.

This variability is mainly due to regional farming practices, as cow feeding regime and the sowing and harvesting dates and growth cycle of grasses and other forages. Figure 5 shows the correlation for the cow milk, between its maximum activity concentration and the grass yield peaks, which matches also with the grazing period. It also explains the appearance of a second smaller peak in the temporal evolution curve. When the feeding regime changes to hay, there is an increase in the activity concentration of the product due to the concentration of the contamination in the forage, obtained by cutting the previously contaminated grass.

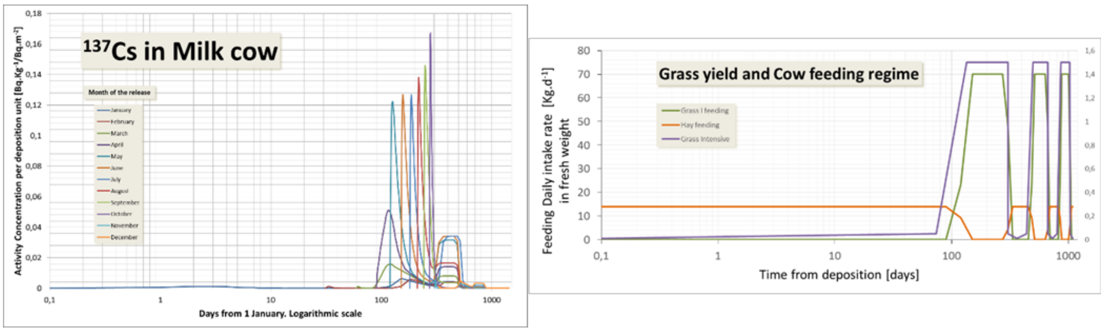

Figure 5. Regional factors affecting the seasonal variability.

A second comparison was made for the temporal evolution of the ^{137}Cs activity concentration in food stuffs, per deposition unit (Bq kg^{-1} per Bq m^{-2}), regarding the elapsed time after deposition, as shown in Figure 6. The maximum peaks occur during the first days, due to the direct deposit on crops and grasses. The difference in the magnitude of such peaks reflects mainly the dependence on the growth stage of the crop when the release occurred. After one year and beyond, the contamination of the food stuffs will depend on the soil-to-crop transfer, which produces smaller peaks.

Finally, using the magnitude of the peaks of the curves, a relative ranking of severity can be proposed allowing the quantification of the importance of the seasonal variability.

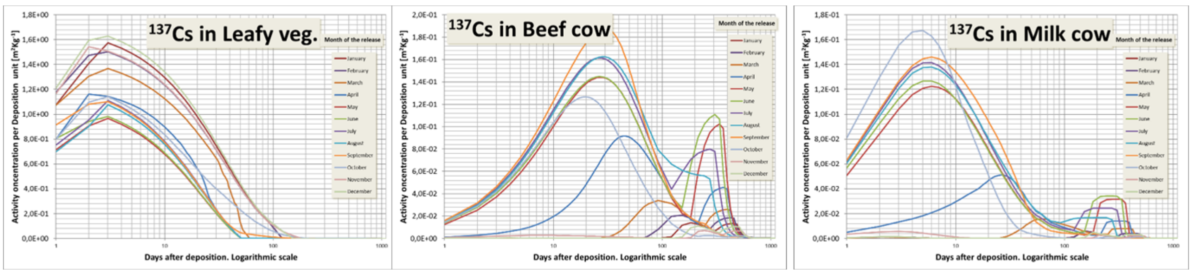

Figure 6. Temporal evolution of the activity concentration in food stuffs per deposition unit (Bq kg^{-1}/Bq m^{-2}) according time after deposition.

The peaks obtained in the first days can give an idea of the severity of the direct deposition and the ones obtained around a year after, can be indicators of the risk contamination through the food chain. Table 1 shows the ranking of the severity of contamination in cow milk, as a function of the month of deposition. The time after the deposition when the peak appears and its activity concentration, relative to the lowest peak, are indicated for the short term scenario and the long term food chain scenario.

Table 1. The dark shading cell shows the relative activity regarding the lowest peak for the worst release event and in the light shading cell that for the best situation

	First Peak (Short term scenario)		Second Peak (Long term Foodchain scenario)	
Month of deposition	**Time after deposition [days]**	**Activity ratio to lowest peak in the year**	**Time after deposition [days]**	**Activity ratio to lowest peak in the year**
April	26	44	334	9
May	6	106	304	20
June	6	109	273	22
July	6	122	273	**22**
August	6	119	243	2
September	6	126	243	**1**
October	5	**144**	212	2
November	3	5	181	3
December	3	1	151	11
January	3	**1**	151	4
February	3	1	151	4
March	2	1	59	10

These outcomes can be applied to operational purposes estimating levels useful in the preparedness for recovery plans. For instance, knowing that the Maximum Permitted Levels (MPL) for ^{137}Cs in milk are 1000 Bq kg^{-1}, will allow to make the reverse calculation, that is estimate the activity concentration deposit on soils that would lead to an activity concentration in food at the MPL. Depending on the deposition time the values will change, as shown in table 2. The lower the deposit needed to reach the MPL, the worse the scenario. In this case, the worst deposition scenario in the short term will be October and in the long term, July.

From these results, applying to the deposition pattern obtained in the study, the risk maps related to the transfer of radioactive contamination to the food chain can be obtained. In Figure 7, the probability of exceeding the threshold corresponding to the deposition value for the MPL of the ^{137}Cs in the cow milk, in both worst-case scenarios, for the short term (in October) and for the long term (in July) are shown.

Table 2. The dark shading cell shows the activity concentration deposited in the soil for the worst release event and in the light shading cell that for the best situation

Month of deposition	Deposition [Bq.m^{-2}] for MPL	
	Short term (10 d)	**Long term (1 y)**
April	9,47E+00	4,97E+01
May	9,14E+00	4,60E+01
June	8,19E+00	4,60E+01
July	8,40E+00	**4,42E+02**
August	7,94E+00	1,00E+03
September	6,92E+00	4,83E+02
October	**2,00E+02**	3,13E+02
November	8,22E+02	9,40E+01
December	1,00E+03	2,50E+02
January	9,74E+02	2,52E+02
February	9,63E+02	9,91E+01
March	1,00E+03	7,38E+02

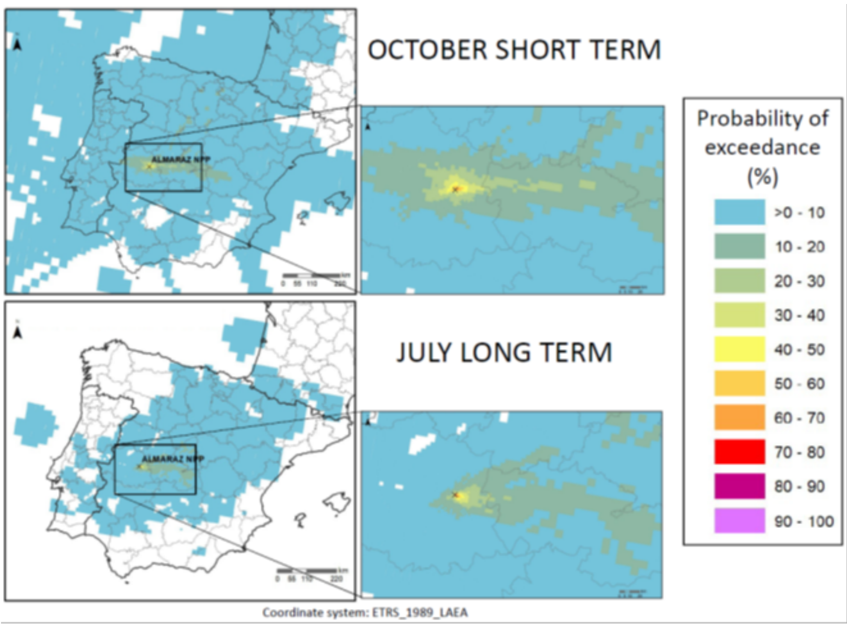

Figure 7. Probability of exceedance the threshold corresponding to the deposition value for the MPL in July (short term) and in October (long term).

Conclusions

The main conclusions reached in this seasonality exercise are summarised as follows:

- A methodology to assess the influence of seasonality in the severity of the radioactive contamination in foodstuffs from an accidental deposition has been studied.
- The ranking of the seasonal scenarios of contamination can be combined with other indexes of severity, as the strength and probability of deposition and the soil-plant transfer capacity, to map the nuclear risk for preparedness and response in an emergency and post-accidental recovery purposes.

Work to be done in future:

- Studies in representative cells with have a significant number of valid values (> 50%).
- Study the influence of factors such as the type of soil in the root-transfer pathway.
- Analyse the most sensible crop to seasonality or that of greater economic impact.
- Study the influence of regional factors (other climatic environments) on the magnitude and temporal behaviour of the activity.
- Determine the influence on the determination of other intervention operational levels, such as those proposed by the IAEA.

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The Regional Radiological Emergency Programs in Spain

The Valencian Community case

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1 History of the Nuclear Energy in Spain

Nuclear energy started in Spain in 1948, when a group of military and scientists created an organization to study and extract uranium mineral. In 1951, the Nuclear Energy Board (Junta de Energia Nuclear) was created. This new organization was well established and launched the first generation of spanish nuclear power plants (NPP): The José Cabrera (1968 - 2006), the Santa Maria de Garona (1971-2012) and the Vandellos I (1972-1998) NPPs. In 1980, after the advent of democracy in Spain, the Nuclear Energy Board was dissolved and replaced by two new organizations: the Nuclear Safety Council (CSN) [1] was in charge of the regulatory functions in nuclear and radiological safety matters and the Center for Energy, Environmental and Technological Research (CIEMAT) [2] took the research duties in four different domains: fundamental research (fission and high energy physics), nuclear technologies, radiological protection and environmental protection. Additionally, in 1984 the National Company of Radioactive Waste (ENRESA) was created to take the management of radioactive waste in Spain.

Figure 1: Map of the nuclear power plants in Spain. In red the active reactors and in grey the dismantled ones [3].

In Spain, 10 nuclear reactors in 7 di_erent facilities have been commissioned, shown in Fig. 1, but at present there are only 5 NPP with 7 active reactors in operation [4]. In total, 3 different generations of NPP were built, but all the plants of the first generation are presently stopped and dismantled, or in process of decommissioning. All our active reactors are pressurized water reactors (PWR) except that of the Cofrentes NPP (Valencia region) which is a boiling water reactor (BWR) [5]. Recently, it was announced the intention closing the entire nuclear park between 2027 and 2035 [6].

2 Authorities in nuclear and radiological matters in Spain

2.1 Political structure of the territory

Spain is divided into 19 different regions, 17 autonomous communities and 2 autonomous cities, as displayed in Fig. 2. Each of this regions has a similar parliamentary structure and its own local government with a well defined set of powers and responsibilities, although their scope of vary for the different communities. The national authority for nuclear and radiological matters is the Nuclear Safety Council (CSN) but the regions may ask for the transfer of the authority in nuclear and radiological matters not related to the working of the nuclear power plants, which authority is always hold by the CSN.

Figure 2: Map of the Spanish autonomies [7].

2.2 The authorities in radiological matters

In Spain, as in the rest of the developed world, in the las two decades an increase of the use of radioactive materials in radiopharmacy, research and industry has taken place. In addition, in the last years new risks have emerged around the world related to the possible use of radioactive materials in malevolent actions, the smuggling of radioactive sources, the accidental reprocessing of radioactive sources in steel foundries and the accidental fall of an artificial satellite. These new risks have to be faced with appropriate regulations and emergency plans. Moreover, there are the risks associated to the transport of dangerous goods, which has since 1996 its own emergency plan including the transport of radioactive goods; the authority belongs to the local government of the concerned region [8]. In the case of accidents related to a NPP, there exist a Basic Nuclear Emergency Plan intended for serious risk situations. This plan is divided into two different plans, the Internal Emergency Plan, which responsibility fall entirely to the NPP owner, and the External Emergency Plans, whose responsibility is hold by the state, which delegates on the Nuclear Safety Council [9].

Besides the two aforementioned plans, there are also environmental monitoring plans for the NPPs surrounding areas. Furthermore, in the case of a radiological accident in a nuclear or radiological facility not related to the NPP, the government established in 2010 some guidelines for planning the corresponding actions [10].

3 The Environmental Radiological Monitoring Plan

This plan has the purpose of controlling the surrounding area of the active NPP in Spain. As a part of this plan, the owner of the NPP must carry out periodical measurements of environmental matrices to verify that the activity levels are under the allowed limits. In order to guarantee the quality of the monitoring measurements, the CSN has the duty of checking between the 5 and the 15% of the monitoring measurements through independent and qualified laboratories. This duty can be tranferred to the local governments to their requirement.

The Valencia Community has requested and obtained the responsability of the environmental measurements of the surroundings of the Cofrentes NPP since the beggining of its operation. The corresponding measurements are delegated to the laboratories of the University of Valencia and the Politechnical University of Valencia, which share the monitoring of lands and waters near the Cofrentes NPP. Simultaneously with the NPP owner, a number of periodical measurements of water, soil, vegetables, food and air filters, displayed in Table 1 are carried out by the university laboratories for being compared to the results delivered by the NPP owner.

Table 1: Monitoring measurements

Sample	Collection	Analysis
Raining water	continuous	gamma spectrometry and $^{89}Sr/^{90}Sr$
Drinking water	punctual	gamma spectrometry, beta total & beta rest, $^{89}Sr/^{90}Sr$ and ^{3}H
Superficial water	punctual	gamma spectrometry, beta total & beta rest, $^{89}Sr/^{90}Sr$ and ^{3}H
Underground water	punctual	gamma spectrometry, beta total & beta rest and ^{3}H
Crops	punctual	gamma spectrometry and $^{89}Sr/^{90}Sr$
Dust filters	continuous	gamma spectrometry, beta total and $^{89}Sr/^{90}Sr$
Goat's milk	punctual	gamma spectrometry, $^{89}Sr/^{90}Sr$ and ^{131}I
Cow milk	punctual	gamma spectrometry, $^{89}Sr/^{90}Sr$ and ^{131}I
Foods	punctual	gamma spectrometry
Indicator organisms	punctual	gamma spectrometry and $^{89}Sr/^{90}Sr$
Sediments	punctual	gamma spectrometry and $^{89}Sr/^{90}Sr$
Floors	punctual	gamma spectrometry and $^{89}Sr/^{90}Sr$

4 The Radiological Emergency Program

As it was aforementioned, in 2010 the Spanish government established a number of guidelines to elaborate different radiological emergency programs in the regions asking for the transfer of this power. At present, Aragon, Castilla la Mancha, Canarias, Cataluna, Comunidad Valenciana, Extremadura, La Rioja, Madrid, Navarra and Pais Vasco have developed their own local emergency plans for radiological and radioactive emergencies [11].

These programs are specific for each autonomous region and have the purpose of planning actions to be taken by the local authority in case of a radiological or radioactive accident not included neither in the emergency plan for NPP nor in the emergency plan for accidents of transport of radioactive items. These plans include situations such as: the fires and other kinds of accidents in radiopharmaceutical industries, research centers and other sites holding radioactive sources, the falling of an artificial satellite, malevolent actions as a dirty bomb, and orphan sources abandoned during the course of illicit traffic of radioactive material.

Therefore, these plans are very general and have to prove their effectiveness in a very wide range of emergency situations.

In the Valencia Community, the radiological emergency plan has been elaborated taking advantage of the knowledge obtained from the Environmental Radiological Monitoring

Program of the Cofrentes NPP. The laboratories of the universities are part of the local Radiological Emergency Program and are in charge of analysing the contaminated samples from the accident site, providing the isotopic composition and activity of the contamination, and moreover to bring forth scientific advice in order to help the authorities in the choice of the corresponding actions.

It is important to realise that the measurements to be taken in an emergency situation have different characteristics from those of the Environmental Radiological Monitoring Program.

In the first place, the monitoring program sampling is carried out periodically in well defined and accessible sites and there is a long experience of how normal results should look like while in the emergency case, contaminated lands are with a high probability in zones of difficult access and, consequently, samples should be taken by trained personnel, such as firefighters, following the indications of scientist in order to avoid self-exposure and to collect the necessary amount of samples. In the second place, samples for environmental monitoring are transported directly to the environmental measurement laboratory while in an emergency case precautions have to be taken to avoid accidental contamination of this laboratory. Preliminary evaluation of the activities should be carried out in a hot laboratory where subsamples of sufficiently low activity to avoid unnecessary dead time in germanium detectors have to be prepared. This is a crucial point because, in the case of an accident, a large number of samples may have to be measured in very short times.

Other characteristic of emergency situations is the need of drills for testing if the various personnel involved is able to coordinate efficiently and to avoid mistakes in the execution of the plan. In our case, the local authorities have carried out up to now two different drills:

- The case of an industrial radioactive source of high activity that failed to close with an injured worker without mobility remaining in the neighbourhood of the source. During

the drill, the fire fighters approached the source and remained near it in a way that, in a real situation, would have produced high exposure to them, in spite of the correct marking of the source position with barriers and danger signs.
- The case of a high activity source found in a container in Valencia harbour. In this case, high communication difficulties emerged, as incorrect radio tuning and different language employed by the different bodies intervening in the drill, in a degree that prevented mutual understanding and slowed the actions.

A first conclusion drawn is that a lack of understanding of the peculiarities of a radiological accident and of the importance of radiological dose by may appear in people used to work in other more frequent catastrophic events as fires and floodings. Training is necessary to check that all the involved people employ the same language and that the main concept and units are understood and also to check that all the people involved are able to coordinate among themselves.

More realistic drills as the making of a dirty bomb in order to measure the distribution and range of radioactive material and the efficiency of the cleaning procedures in a real situation, in a safe place, would be conceivable. It was suggested the performance of a drill consisting in a dirty bomb explosion made with a short life time isotope such as 99mTc, which is widely available in hospitals. But the Spanish authority, the Nuclear Safety Council, would not allow such a test.

The laboratories of the universities need to develop some additional skills to be able to proceed in a fast way in sample measurement and to minimise statistical and systematic errors in the case of a radiological emergency. In which concerns soil sampling, large inhomogeneities are expected. The reduction of soil to a liquid sample would reduce greatly the sample inhomogeneity and would facilitate the preparation of a subsample of conveniently low activity to be measured in a environmental radioactivity laboratory. To achieve this goal, studies will be carried out it in the near future in the framework of a project devoted to the study of contaminated lands in Spain. Our two best candidates as procedures for soil homogenization are lixiviation of initial samples by acids and dissolution of samples in hydrofluoric acid.

Although the resulting sample has to be treated carefully from the chemical point of view, it is easy to reduce its activity to the required range for measurement with available detectors.

5 Conclusions

Radiological accidents by their own nature and by lack of experience in tackling with them, involve many unknowns. Although a universal knowledge was gained in large accidents around the world, as Chernobyl and Fukushima, this knowledge is not easily transferred to non-experienced people in radiological accidents, independently of how large their experience is in more frequent accidents of large magnitude as fires and floodings.

In the case of Spain, local governments are publishing regulations to handle the new radiological risks produced by technological advance, international trade and international terrorism but there is a difficulty produced by the lack of a general protocol to stablish procedures to tackle these new risks at the international or the European level. Although there is a number of publications accessible essentially to scientist and with a limited scope, a publication describing the main points to be addressed to tackle radiological emergencies at the local level, the instrumentation that should be ready at any moments and the basic drills to be routinely trained by potentially involved people, is missing. This kind of publication, addressed to concerned organisations, would be highly appreciated.

In the Valencia Community case, we work to adapt the existing protocols of the local environmental radioactivity monitoring program of the Cofrentes NPP to a possible radiological emergency situation, taking into account that for emergency situations, measurements have to be carried out quickly and consequently, samples of high activity have to be reduced to measurable activities in order to avoid sizeable dead-time, in a short time delay, and that measurements procedures should be of the fast type .

In radiological emergency situations, problems of communication between different emergency services involved may appear, due to the new language employed, not used in usual emergency situations, and to the fact that in radiological emergencies more people would participate than in usual emergency situations. Therefore, periodical training of professionals involved and periodical drills to deal with the different aspects and concepts of radiological emergencies are necessary.

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How the EU strengthens CBRN response capacities outside the European Union: 2 examples from the Western Balkans and the Black Sea Region

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Introduction and Objectives

The European Union Chemical Biological Radiological and Nuclear Risk Mitigation Centres of Excellence Initiative (or EU CBRN CoE) was launched in response to the need to strengthen the institutional capacity of countries outside the European Union to mitigate CBRN risks. These risks may have an intentional, accidental or natural origin. The countries that join the initiative, work together in eight regions, headed up by a secretariat at regional level. The two projects that are presented here have been implemented in the SEEE region, consisting of 9 countries in South East and Eastern Europe (Figure 1).
Training of respectively the first responders and the forensic science institutes' staff as well as enhancing networking are the main objectives of two closely related Projects in the SEEE region within the CoE Initiative, *i.e.* Project 44 and Project 57. The Project 44, which ran from 2015 until half 2018, was created with the intention to improve the readiness of the first responders to deal with a CBRN incident, while Project 57, which started in 2017 and is still ongoing, aims to strengthen the forensics expertise for the crime scene investigations in the environment of a CBRN incident.

Figure 1. South East and Eastern Europe countries (SEEE region).

Activities

Both Project 44 and 57 have a number of activities in common. Activities in the two projects can broadly be subdivided in the following categories: (1) Assessment of the current situation, (2) Study visits (3) Development of Standard Operating Procedures (SOPs), (4) Equipment procurement (via parallel project), (5) Train-the-Trainer courses, (6) Table top and field exercises.

Assessment of the current situation includes an assessment of the legal framework and organizational structure, including a gap analysis and recommendations on: CBRN first response action plans, trainings, incidents (Project 44) and the general CBRN and disaster management framework, the existing forensics framework (Project 57).
During both Project 44 and Project 57 a number of study visits to relevant institutions on national and international level were performed to demonstrate systems, organizations, cutting-edge techniques and most recent developments in the field of respectively CBRN first response and CBRN forensics. Visits were e.g. done to firefighting stations and CBRN armed forces in Poland and Slovakia (Project 44), the National Training Centre (NTC) in Vught and the National Institute for Public Health and the Environment (RIVM) in the Netherlands, and the Belgian Nuclear Research Centre (SCK•CEN) (Project 44 and 57) and the Belgian Defense Laboratories (Project 57). For Project 57, the participants also attended the final meeting of the European Commission funded research project GIFT (Generic Integrated Forensic Toolbox) and they visited the Dutch Forensic Institute in The Hague, The Netherlands and the IAEA in Vienna, Austria.

For both projects, the review of existing Standard Operating Procedures (SOPs) showed that SOPs in the beneficiary countries are very limited in number and scope, and that structure, size and organization of existing response teams and forensic structures are different between the countries and often based on a rather ad hoc approach, based on the expertise of the experts. For this reason, it was not possible to offer a standard system that could be implemented in all the countries. Therefore general documents were worked out that could be used as guidelines to prepare a country's own systems and SOPs. The SOPs itself were developed by local experts that were hired for this purpose.

Project 44 and 57 targeted also at the identification of respectively the equipment required for sound CBRN emergency response and forensic equipment needed for CBRN crime scene investigation in participating countries. The aim was to provide a list of the missing basic equipment in this field, mainly personal protection and detection equipment, in each participating country. Technical specifications were developed for the equipment requested by participating countries to allow proceeding with the subsequent procurement via a parallel project.
For Project 44, equipment delivery took a considerable amount of time, which was partly due to administrative problems in the participating countries. Also, basic training on how to use, store and maintain the new equipment was not or not sufficiently provided by the parallel project. For Project 57, we learned from this experience, and urged the implementers of the parallel project to continue with equipment delivery and include training.

In Project 44, the consortium organized four similar train the trainers courses (TTT), of 5 days each. Based on the needs analysis with the beneficiaries, each TTT course had been set-up as one training including all CBRN aspects. Topics that were covered during the course included amongst others theoretical and practical sessions on: teaching skills, CBRN threats, hot zone management, use of PPE, detection and identification of CBRN agents, reconnaissance and victims rescuing, decontamination procedures. In total, 52 participants from the beneficiary countries concluded the courses. In Project 57, the concept of the TTT course was somewhat different: here a 3-weeks TTT was organised in which each week had a different focus. Week 1 was of a more general nature, while week 2 focused on B and C, and week 3 on RN and included as well integrated exercises (CBRN) (Figure 2). Topics that were covered during the course included amongst others: hazmat and crime scene management, incident zoning, reconnaissance, detection and sampling of C, B, RN agents, risk management, preparation of action plan, challenges in chain of custody, use of PPE, teaching skills, decontamination, packaging and transportation. In total 23 participants from the 9 beneficiary countries participated to the full 3-weeks course, while another 13 participants took part in one or 2 weeks of the course.

For Project 44, after the train the trainers' courses, each Black Sea country organized national trainings with support from the Consortium, under responsibility of the trainers who completed the train the trainers course. Over 15 participants from different decision-making levels took part in each national training. For P57, these national trainings are currently being organized in every country (not only the Black Sea countries).

Figure 2. Training of Trainers on respectively handling a C, B and RN crime scene (Project 57).

In Project 44, 2 national exercises (one table top exercise and one field exercise) per country have been organized (18 national exercises in total), whereas 6 sub-regional exercises have been realized, one table top exercise and one field exercise respectively for the Armenia – Georgia sub-region, for the Moldova-Ukraine sub-region and finally for the Balkan sub-region (Figure 3).

Figure 3. Regional field exercises in Armenia, Ukraine and the Balkan (Project 44).

The exercises were very important for the improvement of inter-agency and sub-regional collaboration and countries made a lot of effort in organizing them (e.g. a lot of participating organizations, large deployment of manpower and equipment/material, scenario development by local team, supported by consortium if required). In Project 57, 6 sub-regional exercises on crime scene CBRN forensics (3 field and 3 table top exercises) are planned in the course of 2019, of which one table top exercise already has been completed. This table top exercise was implemented through the internet, meaning that all participants stayed in their own country and communication between the countries involved in the exercise and with the overall exercise leader (the consortium) was done via exchange of emails. The common debriefing after the exercise was done using a video tool.

Enhancing project sustainability

The CoE aims to strengthen regional security by increasing local ownership, involving local expertise, encourage local ownership of CBRN action plans, policies and project proposals.
In Project 44, a number of actions were taken to enhance sustainability of project results. For the accomplishment of the work packages, a substantial amount of local experts were involved for most countries. These local experts also developed the SOPs in the domain of CBRN first response. In the organization of the table top and field exercises, a bottom-up approach, including the main local stakeholders was applied. This approach is indispensable for a sustainable continuation of exercises. Finally, the TTT allows the participating countries to have trained experts that will be able to conduct trainings at their national level and thus transferring the acquired knowledge and expertise.
From the experience we gained in the implementation of Project 44, we even put more effort in enhancing project sustainability in Project 57. In this project, we aim at having the SOPs officially endorsed an adopted by a higher authority and have the TTT integrated in the existing curriculum of the national police.

Conclusions and lessons learnt

One single project cannot resolve all the problems of a country. From the discussions and country presentations that were held at the final meeting of Project 44 (29 – 30 May 2018 in Vienna), it became clear that continuation of actions in the region is required in four domains: (1) Legislation and SOPs, (2) Training, (3) Exercises and (4) Equipment. From the observations we did so far in Project 57, we estimate that future actions in these four domains will be required as well.

Acknowledgements

Project 44 (lead SCK•CEN, partners RIVM (The Netherlands), IPO (Poland), ISEMI (Slovakia and IRE (Belgium), 57 (lead SCK•CEN, partners RIVM, ISEMI, NFI (The Netherlands), NICC (Belgium), FSI IV (Croatia)) are funded by the European Union Chemical Biological Radiological and Nuclear Risk Mitigation Centres of Excellence Initiative, respectively ref. IFS/2014/347634 and IFS/2016/374993.

Modification of the regulatory framework for radiological protection and nuclear safety in Portugal

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Abstract

A recent Portuguese legislation was approved establishing a new legal framework for radiological protection, nuclear safety, safe management of radioactive waste and spent fuel, as well as the competencies of the regulatory authority and of the inspection authority for radiological protection and nuclear safety. This new legislation transposes Directive 2013/59/Euratom of the EU Council, of December 5th, into the national legal framework, laying down the basic safety standards for protection against the dangers arising from exposure to ionizing radiation.

This work elucidates the changes brought by this new diploma and the new paradigm for Portugal on dealing with nuclear and radiological Emergency Preparedness and Response.

Introduction

In Portugal, there are around 10.000 authorized facilities using artificial radiation sources with a wide range of applications. Some of these include:

- 1 Research Reactor (currently in transition to decommissioning);
- Transport of radioactive sources;
- Storage of uranium concentrate;
- Radioactive waste disposal;
- Use of radioactive sources;
- Use of radiation sources.

As a part of the national radiological assessment we should also consider foreign nuclear powered vessels sailing through national waters and visiting national harbours and nuclear power plants in neighboring countries.

Figure 1 shows the geographical distribution of artificial sources of ionizing radiation in the Portuguese continental territory and the nuclear power plant sites in neighboring countries.

The authorized practices involving artificial sources of ionizing radiation in relative numbers are shown in Figure 2.

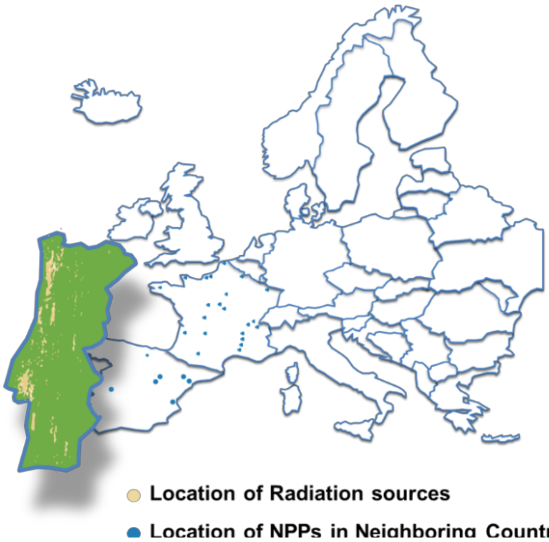

Figure 1. Location of radiation sources in Portuguese continental territory and NPPs in neighboring countries

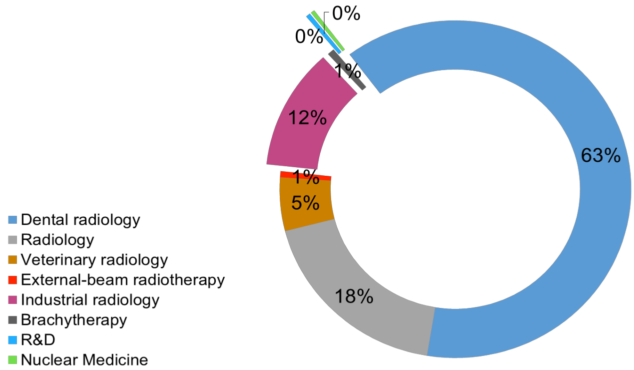

Figure 2. Authorized practices (Source: DGS)

It should be noted that, although there is a large number of radiological facilities and activities for medical, industrial, research and teaching purposes, the only nuclear facility in the Portugal is the Portuguese Research Reactor (RPI), currently in transition to decommissioning.

Goal

The goal of this work is to describe the changes promoted in the Portuguese regulatory framework for radiological protection and nuclear safety by the transposition of the Directive 2013/59/Euratom of the EU Council.

Previous legal framework

In Portugal, up until recently, the competencies of regulatory authority were distributed by several institutions, namely: the Portuguese Environment Agency (APA), the Directorate-

General for Health (DGS), the Instituto Superior Técnico (IST) and the Regulatory Comission for the Safety of Nuclear Installations (COMRSIN). Some of these institutions accumulated both regulatory and operator roles and resources were shared with other tasks.

The inspection duties were performed by Regional Health Administrations (ARS's); Instituto Superior Técnico (IST); Regulatory Commission for the Safety of Nuclear Installations (COMRSIN) and Agency for Competitiveness and Innovation (IAPMEI) that did not have specific departments for carrying out their inspection programmes nor, in most cases, adequate human resources to perform their inspection competencies.

The competencies of institutions involved in preparedness and response to radiological and nuclear emergencies, regulatory tasks and inspection duties can be summarized in Figure 3 and Figure 4.

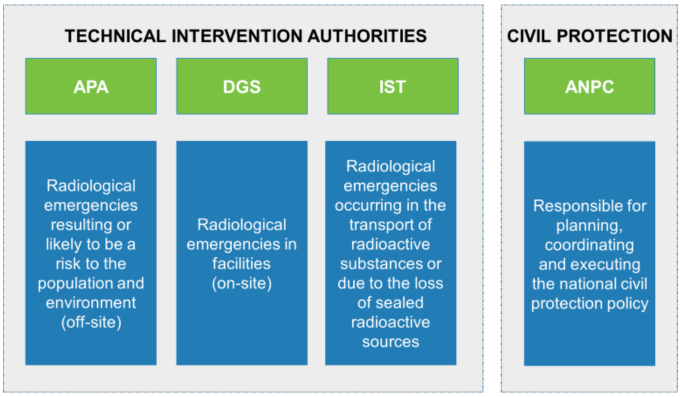

Figure 3. Institutions involved in radiological and nuclear emergencies (see text for acronyms)

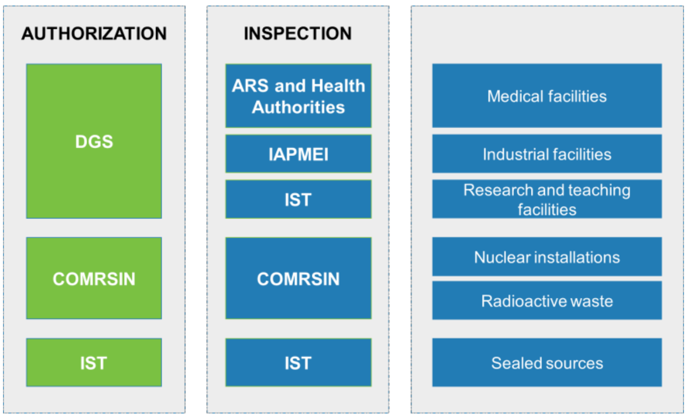

Figure 4. Institutions involved in authorizations and inspections (see text for acronyms)[2]

New legal framework

The Decree-Law no. 108/2018 of December 3rd establishes a new legal framework for radiological protection, nuclear safety and safe management of radioactive waste and spent fuel. It also establishes the competencies of the regulatory authority and for the inspection authority for radiological protection and nuclear safety. This document transposes lays down

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APA - Portuguese Environment Agency; DGS - Directorate-General for Health; IST - Instituto Superior Técnico; ANPC - National Civil Protection Authority; COMRSIN - Regulatory Commission for the Safety of Nuclear Installations; ARS's - Regional Health Authorities (and their Regional Government counterparts); IAPMEI - Agency for Competitiveness and Innovation.

basic safety standards for protection against the dangers arising from exposure to ionizing radiation.

This Decree-Law also transfers the mission and competencies of the Regulatory Commission for the Safety of Nuclear Installations (COMRSIN), attributed by the transposition of the Directive 2009/71/Euratom of 25 June 2009, as amended by Council Directives 2014/87/Euratom of 8 July 2014, and Council Directive 2011/70/Euratom of 19 July, and extinguishes this commission.

The new competent authority also assumes the role and competencies of all the previous entities with regulatory competencies in the field of radiation protection.

For the purposes of the above mentioned Decree-Law, the Portuguese Environmental Agency (APA) is the competent authority while the General Inspection for the Environment (IGAMAOT) will be responsible for the inspections and enforcement.

The specific competencies of the competent authority and the inspection authority are defined in Decree-Law no. 108/2018 of December 3rd, and are summarized in Figure 5 and Figure 6.

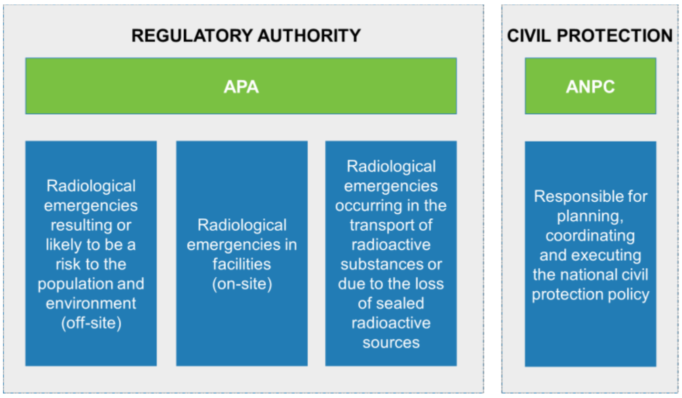

Figure 5. Institutions involved in radiological and nuclear emergencies as defined by the new Portuguese legal framework (see text for acronyms)

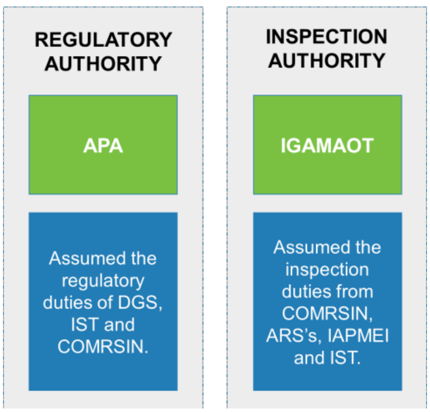

Figure 6. Institutions involved in authorizations and inspections as defined by the new Portuguese legal framework (see text for acronyms)

The competent authority shall ensure a high level of radiation protection and nuclear safety and the safe management of spent fuel and radioactive waste.

The competent authority shall exercise the regulatory attributions defined in this Decree-Law independently and shall be functionally distinct from any other body or organization related to the promotion or use of practices covered by this Decree-Law. It should be endowed with its own human, technical and financial resources necessary for its operation. In order to fulfil these requirements, APA was chosen to aggregate the competencies in this area.

The main competencies that have been assigned to the new competent authority include namely:

- Issue, alter, suspend or revoke licenses or registers for practices or activities covered by this Decree-Law and define the respective conditions for its exercise;
- Authorize the detention, transfer, introduction into the national territory, sale, lease, assignment or any other type of transmission of sealed radioactive sources or sealed radioactive sources of high activity or equipment incorporating them;
- Encourage training and information activities in the area of ionizing radiation protection, with the participation of health authorities and in collaboration with other public or private entities, where appropriate;
- Participate in intervention actions in cases of radiological emergency or prolonged exposure, in accordance with the applicable legislation in force;
- Monitor the nuclear and radiological safety aspects associated with the risk of accidents in installations where fissile or fertile materials are used or produced;
- Maintain a continuous measurement network in order to detect situations of abnormal increase of radioactivity in the environment and to update the recording of measurements carried out by this network;
- Recognize services and specialists, as well as service providers in the area of radiation protection;
- Ensure the monitoring of radioactivity in the environment and manage the corresponding monitoring program.

The General Inspection for the Environment (IGAMAOT), as an inspection authority, shall inspect the compliance with this Decree-law, independently, namely through planning and executing ordinary or extraordinary inspection actions. For this purpose it shall:

- Inspect all practices covered by this Decree-law, the operation of facilities and equipment that continue these practices and activities, as well as the application of regulations and the terms and conditions of issued authorizations, and require the demonstration of compliance;
- Order corrective measures, including any amendment or revocation of licenses or registers issued, operating conditions or operating procedures, or the temporary or

APA - Portuguese Environment Agency; ANPC - National Civil Protection Authority; IGAMAOT - General Inspection for the Environment permanent closure of installations, with the necessary provisions for the protection of workers, the general public and the environment, and the mitigation of radiological risks associated with practices;

- Apply the necessary legal procedures in case of non-compliance with this decree-law, applicable regulations or the terms and conditions of the licenses or registrations issued;
- Verify that corrective actions are taken if unsafe or potentially unsafe conditions are detected in facilities where authorized practices are carried out.

Conclusions

The publication and entry into force of the Decree-Law transposing the Directive 2013/59/Euratom of the EU Council, of December 5th, promoted major changes to the Portuguese regulatory framework for radiation protection and nuclear safety, namely Regulatory and Inspection competencies are consolidated in APA and IGAMAOT respectively.

These institutions carry out their competencies independently and functionally separated from any other organization related to the promotion or use of practices, with human, technical and financial resources needed for its functioning.

These institutions will be provided with the necessary resources allocated to adequately perform their competencies.

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Participation in an IAEA ConvEx-2c Exercise: Preparation, Performance and Outcomes as an 'Accident State'

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Abstract

Each year Ireland participates in Convention Exercises (ConvEx) organised by the International Atomic Energy Agency (IAEA) Incident and Emergency Centre (IEC). In 2018, the IAEA IEC invited Ireland to participate as the 'Accident State' in a ConvEx-2c exercise, the purpose of which was to test the arrangements for a transnational radiological emergency. The exercise scenario was a malign CBRN incident involving the detonation of two radiological dispersal devices in Dublin city centre. This exercise provided a unique opportunity for Ireland to engage, on a practical level, with both national and international counterparts through this simulation.

The practical arrangements undertaken both nationally and internationally in advance of the exercise are outlined. The performance of the exercise is also addressed. The accident scenario was useful in identifying areas that worked well in Ireland's national arrangements for such an incident as well as identifying areas for improvement, that would not have been so evident if Ireland did not participate as the 'Accident State'.

The lessons learned from the exercise are outlined. These outcomes will provide Ireland with the basis for improving practical arrangements for preparing and responding appropriately if such an event were to occur. In addition, the exercise provided an insight into how such an event might evolve in real time and was a valuable learning exercise for all involved at the national level.

Introduction

Ireland routinely participates in international exercises organised by the International Atomic Energy Agency (IAEA), the European Union and the OECD Nuclear Energy Agency (INEX series). These exercises are an important way to test the national response framework for a nuclear accident abroad or a large-scale radiological event in Ireland.

Exercises are organised each year by the IAEA to test the operational arrangements under the Convention on Early Notification of a Nuclear Accident (Notification Convention) and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (Assistance Convention) [1]. The purpose of these exercises is to evaluate and further improve the international framework for emergency preparedness and response. Further information on the different types of Convention Exercise (ConvEx) can be found in the IAEA Emergency Communications Manual [2].

In 2018, Ireland through the Environmental Protection Agency (EPA) agreed to participate as the ‘Accident State’ in a ConvEx-2c exercise, the purpose of which was to test the arrangements for a transnational radiological emergency. Being the ‘Accident State’ meant that the scenario for the exercise would be based in Ireland. The exercise scenario that was agreed between EPA and the IAEA was a malign CBRN incident involving the detonation of two radiological dispersal devices in Dublin city centre. This paper describes the exercise and the lessons learned in Ireland from taking part as the ‘Accident State’.

ConvEx-2c Exercise

ConvEx-2c exercises are held once or twice every four years on a specified announced date. In advance of the exercise, the IAEA Incident and Emergency Centre (IEC) invited all National Competent Authorities under the Notification and Assistance conventions in Member States and relevant International Organisations to participate. In total 65 Member States (including seven Member States with two organisations) and three international organisations registered to participate in the exercise. The IEC defined several objectives for the exercise including the testing of the notification process, the sharing of information between the IEC, Members States and International organisations, processing requests for assistance and the coordination of public information [3]. In Ireland, the objectives included the testing of communications with the IEC and testing of the national protocol for responding to CBRN incidents.

ConvEx-2c exercises start with the ‘Accident State’ communicating messages about a hypothetical radiological emergency in their state. The IEC can provide input messages in advance to support this, if necessary. The IEC then forwards messages from the ‘Accident State’ to participating contact points and publishes the information submitted on the IAEA’s Unified System for Information exchange (USIE) exercise website. Other participating National Competent Authorities access information on the USIE exercise website and confirm that they have read and understood messages and respond appropriately to any requests for advice or information.

Exercise Preparation

The EPA in Ireland accepted an invitation from the IEC to be the 'Accident State' in September 2018. A national exercise was not planned in Ireland when the invitation was received, and it was decided that a full-scale national exercise would not be organised in the available time before the scheduled date of the exercise. Contact points in the IEC and EPA were assigned to work together on arranging the exercise. EPA worked closely with the IEC to develop a scenario which would be of interest to other participating countries. The exercise scenario was then refined to ensure that it was realistic while still ambitious. All preparation was done by email and teleconference and was not resource intensive.

To make the exercise scenario more realistic, the source of the radioactive material which would be used in the radiological dispersal devices needed to be clarified. To do this it was decided that the radioactive material would be iridium-192 sealed sources which were stolen some days earlier in Ireland. Standard Report Forms providing notification of the theft of the sources were submitted by EPA to the IEC the week before the exercise and published for all exercise participants at the start of the exercise.

EPA identified and engaged with key stakeholders with a role in response to CBRN incidents in Ireland. Given the short preparation time, it was not possible to include all Departments and

Agencies who would be involved in responding to a real malign CBRN incident in Ireland in this exercise. In a real event, it is likely that the National Emergency Coordination Group (NECG) would be convened. The NECG is made up of representatives from all Government Departments and many Government Agencies. In Ireland an all-hazards approach to emergency management is used and this same NECG can be convened anytime a national response is required to an emergency regardless of the emergency scenario. For this exercise representatives from the Department of Justice and Equality and the Irish Police Service (An Garda Síochána) who are the lead Government Department and lead Agency, respectively, in responding to a malign CBRN incident, agreed to participate.

Within EPA, coordination took place between teams that have a role in preparedness and response for such an incident. This included staff with a role in technical assessment, communications and the regulation of ionising radiation. Press releases for use in the exercise were prepared in advance.

Conduct of the Exercise

In the exercise scenario the first explosion took place at the Convention Centre in the centre of Dublin city at 07:20 UTC on 27th November 2018. Participants attending a large international conference were arriving just as the explosion happened. A second explosion occurred in Dublin city centre five hours later at Leinster House where the Irish Government sits. Both explosions involved multiple fatalities and casualties with many foreign nationals involved. The exercise scenario also included an inject mid-morning which involved a man presenting himself at a hospital outside Dublin exhibiting signs of radiation sickness. It was suspected that the man had been contact with the stolen sources. The purpose of this inject was to raise the possibility of other individuals being exposed to radiation from the stolen sources prior to their use in the radiological dispersal devices.

The exercise took place between 07:30 and 16:00 UTC on 27th November. The Irish response was based in EPA offices in Dublin with representatives from the Department of Justice and Equality and An Garda Síochána along with staff from EPA in attendance. EPA's communications staff were based in EPA Headquarters in the south-east of the country and regular contact was maintained with them throughout the day. While there were no changes of staff involved in the Irish response, there was a shift handover procedure in the IEC midway during the exercise. This was to allow the IEC to exercise their handover procedures in an emergency.

Over the course of the day, seven USIE Standard Report Forms and a Request for Assistance Form were submitted through the USIE exercise website to the IEC. Three press releases were also finalised and submitted through the USIE exercise website. After each submission on the USIE exercise website, the IEC contacted EPA to acknowledge the submission and verify the details. Two sets of measurement data which were provided in advance by the IEC were submitted to the exercise version of the IAEA's International Radiation Monitoring Information System (IRMIS exercise).

A few issues arose for Ireland over the course of the exercise. Firstly, there were significant time pressures as the exercise took place over a relatively short time frame and it was difficult to keep to the exercise timeline. Those participating in the Irish response were under time pressure to assess the available information while at the same time maintaining communications with the IEC. In a real event, the EPA's emergency response plan for an incident such as this makes provision for at least two staff to be dedicated to international communications. This would allow radiation experts in EPA assess the potential radiological consequences of the incident and to interact with national stakeholders. It was felt that the exercise scenario was perhaps overly ambitious given the time allowed for the exercise. In addition, the volume of emails which were received from USIE during the exercise was very large. Again, in a real event at least one person would be dedicated to reviewing these emails. At one point during the exercise there was a problem accessing the USIE exercise website during to a time-out issue which required a laptop reboot. Another issue was that although press releases were drafted in advance of the exercise, it took some time to reach agreement on them by the exercise participants in Ireland. Finally, decisions on cordon sizes took longer than expected and there were lots of discussions on the disclosure of information regarding the nationality of victims.

Lessons Learned

It is very important to never underestimate the time required for national and international communications in an emergency response situation, including exercises. Dedicated staff should be assigned to reviewing information received from the international notification systems and preparing information for submission. This would allow staff involved in the technical assessment more time to concentrate on this work. It is also important to ensure that enough trained personnel are available to use international notification systems such as USIE. This exercise took place over nine hours and during this time all individuals involved were operating at full capacity. For an exercise carried out over a longer period it would be necessary to have a changeover of staff. A longer exercise would be useful in testing handover procedures.

It is important to allow some flexibility in the exercise timeline. While it is very helpful to have a list in advance of the times at which the exercise injects will occur, it may not always be possible to strictly adhere to them. It may happen that unforeseen issues arise, or more in-depth discussions are required which can lead to the exercise timeline being adjusted accordingly.

There were lessons learned during the exercise that relate to emergency preparedness and response arrangements in Ireland. One of these was the availability of electronic personal dosemeters (EPDs) for first responders (fire service and police) in an emergency involving radiation. There is no national policy on the requirement for fire crews to have EPDs. A decision on this is made at a local level based on a hazard assessment of the licensed radioactive sources in the area serviced by the fire crew. This does not take into account the potential for an incident involving the unlicensed use of a radioactive source.

Queries were also raised during the exercise on when the National Emergency Coordination Group (NECG) would be convened for an incident such as this. Ireland's CBRN protocol envisages a high-level group convened to provide advice to the senior officer in charge of the incident. In this situation it was not clear when, or if, the high-level group would require the NECG to be convened.

During the exercise detailed discussions took place on the choice of distances to be used for setting up cordons. While there are generic initial cordon distances which are used by first responders pending further risk assessment, the city centre location added extra complexity to the situation when deciding on cordon boundaries and when making decisions to reduce and remove the cordons.

During the exercise many requests were received by the IEC from Member States on the nationality and identity of victims. The IEC had provided EPA with a list of countries who had citizens who were victims. However, this information could not be released by EPA during the exercise. In Ireland, this information can only be released by the coroner. There are several reasons why there would be a delay in issuing this information. Firstly, victims' families must be notified before the information becomes publicly available. Family Liaison Officers may need to be appointed by An Garda Síochána to obtain DNA from family members to help identify victims. In addition, incident sites such as these are also crime scenes. This means that the scene may need to be preserved for evidence gathering and this could delay the retrieval of bodies. If this is a terrorist incident there may also be security issues that could delay the release of information.

This exercise was an excellent practical test of the IAEA's USIE exercise website. This was particularly useful for training new staff who had recently joined the emergency preparedness team in EPA.

Conclusion

The scenario used in this exercise was useful in identifying areas that worked well in Ireland's national arrangements for such an incident as well as identifying areas for improvement that would not have been so evident if Ireland did not participate as the 'Accident State'. This also provided a unique opportunity for Ireland to engage, on a practical level, with both national and international counterparts through this simulation.

The lessons learned have provided Ireland with the basis for improving practical arrangements for preparing and responding appropriately in the future if such an event were to occur. In addition, it also provided an insight into how such an event would evolve in real time and engaged the relevant national stakeholders in a manner that would not have been possible otherwise.

To make best use of the experience of being the 'Accident State', enough time should be allowed for national preparations. It would be particularly beneficial if the exercise was scheduled to take place the same time as a national exercise where all relevant stakeholders are involved.

Staff in the IAEA IEC were very helpful and supportive to EPA during preparation and at all stages of this Convex-2c exercise. The EPA is grateful to the IAEA IEC for the opportunity to take part as the 'Accident State' and for all the assistance provided. Based on this experience, the EPA encourages other countries to volunteer to act as the 'Accident State' for future IAEA ConvEx exercises.

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The use of non-radiological resources to support nuclear and radiological emergency response

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1 Environmental Protection Agency (EPA), Ireland

Abstract

In 2014, the Radiological Protection Institute of Ireland (RPII) merged with Ireland's Environmental Protection Agency (EPA). This merger resulted in a much larger organisation with additional human and laboratory resources that had the potential to increase capacity to respond to nuclear or radiological emergencies. Therefore, the Emergency Preparedness (EP) section of the EPA rolled out a training programme across the EPA so other areas of the organisation can assist if such an event were to occur. This work outlines the progress made to date and the work planned in the future to ensure the EPA can make full use resources and skills available in the organisation.

The work carried out to date has primarily focussed on three areas:

- Raising awareness of the EPA's role in nuclear and radiological emergencies and incidents.
- Utilising the regional presence of the organisation to respond to radiological incidents
- Provision of training and equipment to the EPA's chemistry laboratories to expand radiation measurement capabilities within the organisation.

This work has been conducted through general communications to staff and specific training sessions to laboratory staff on the basic concepts of radioactivity and radiation protection in conjunction with practical sessions on radiation detection and measurement. A table-top exercise was also conducted in 2018 involving all radiation and environmental monitoring staff that identified additional resources and skills that can be utilised in emergency preparedness and response.

This work is ongoing but has already resulted in improving internal practical arrangements and has identified additional skill sets within the organisation that can be utilised in response to a nuclear or radiological emergency.

National Emergency Plan for Nuclear Accidents (NEPNA) and the establishment of the RPII

In the aftermath of the 1986 accident at the Chernobyl Nuclear Power Plant, the international community, including Ireland, recognised that it was not sufficiently prepared to respond to a similar event if it were to reoccur. As a result, the Irish Government published a National Emergency Plan for Nuclear Accidents (NEPNA) in 1992 to set out a framework for a coordinated response from stakeholders at a national level to radiation incidents abroad with widespread consequences for Ireland. The NEPNA was enshrined in radiological protection legislation.

That same year, the Radiological Protection Institute of Ireland (RPII) was established (taking over from Ireland's Nuclear Energy Board) with a mission to protect people in Ireland from the harmful effects of ionising radiation. It maintained the only accredited laboratory (per ISO 17025) in the country capable of measuring radioactivity concentrations in food and environmental samples such as water, milk, soil and agricultural products. This laboratory is based in Dublin.

The RPII's role in NEPNA involved developing a network of environmental radiation monitoring stations, emergency notification, undertaking a technical assessment of the potential or actual consequences of a nuclear accident, analysing environmental and food samples, participating in a national/international collective response and providing advice to the Government, the public and field monitoring teams.

All organisations with roles in NEPNA were required to prepare a sub-plan describing their contribution. Accordingly, the RPII's NEPNA sub-plan described its emergency preparedness arrangements, its emergency response structure and the roles of teams/individual staff members in responding to a radiation emergency.

The NEPNA was updated in 2005 [1] and a revised version is due to be published in 2019. This new version reflects European Council Directive 2013/59/EURATOM [2], the International Atomic Energy Agency's General Safety Requirements Part 7 published in 2015 [3], the 2017 Irish National Risk Assessment [4], Stakeholder discussions and the findings from the IAEA's Integrated Regulatory Review Service visit to Ireland in 2015 [5].

The establishment of the EPA

Meanwhile, in 1993, the EPA was established with a mission to protect and improve the environment as an asset for the people of Ireland. The Headquarters of the EPA is based in Wexford on the south-east coast of Ireland with regional inspectorates/offices in seven other locations around the country. As an organisation, the EPA maintains several laboratories to carry out chemical analysis of environmental samples.

Merging of the RPII with the EPA

In 2011, it was decided to merge the RPII and the EPA as part of the Irish Government's Public Sector Reform Plan [6]. By August 2014, when the merger between the two organisations was completed, the 332 employees in the EPA had been augmented by 44 colleagues from the RPII. The organisational structure within the EPA was adjusted to accommodate this merger with the creation of an Office of Radiation Protection and Environmental Monitoring (ORM). The new Office joined the existing Offices of Communications & Corporate Services, Environmental Enforcement, Environmental Sustainability and Evidence & Assessment.

The EPA's new responsibilities encompassed environmental licensing, enforcement of environmental law, environmental planning, education, guidance, monitoring and reporting on the environment, regulating greenhouse gas emissions, environmental research, waste management as well as radiological protection. In effect, the RPII's NEPNA sub-plan became the EPA's NEPNA sub-plan. The EPA also had a role in Emergency Preparedness and Response (EPR) due to its legislative requirements and international conventions.

In effect, the merger resulted in a much larger organisation with additional personnel and laboratory (non-radiological chemistry/water) resources that could be made available to respond to nuclear or radiological emergencies on a national level.

Extending the EPA's capacity to respond to a nuclear/radiological emergency

In 2016, the EPA launched its Strategic Action Plan for the period 2016-2020 [7]. One of the Strategic Actions in the plan was to extend both the EPA's capacity to respond to environmental/radiation emergencies and the EPA's NEPNA sub-plan to include all relevant EPA capabilities. According to Ireland's Strategic Emergency Management National Structures and Framework published in 2017 [8], the EPA had been assigned a principal support role to the Lead Government Department in 12 emergency scenarios (including nuclear accidents abroad, local radioactive contamination and a malign Chemical-Biological-Radiological-Nuclear incident).

Towards the end of 2017, a Strategic Review of Emergency Response/Emergency Arrangements in the EPA was carried out. It was noted that scalable arrangements within the organisation would be required to manage national incidents. In response to a nuclear/radiological emergency, for example, it was important to consider how the EPA could make full use of its non-radiological resources.

Work on extending the EPA's capabilities in response to nuclear/radiological emergencies began with raising awareness of the EPA's role in responding to such emergencies and incidents, utilising the regional presence of the organisation to respond to radiological incidents and providing training and equipment to the EPA's chemistry laboratories to expand radiation screening capabilities within the organisation.

Progress with using non-radiological resources to support nuclear/radiological emergency response

In January 2018, an in-house team involving staff from the ORM's EP section, the radiation monitoring laboratory and the regional chemistry laboratories, was set up to oversee measures to expand EPA's capabilities to respond to nuclear or radiological emergencies.

Figure 1. Processing environmental samples in the EPA's radiation monitoring laboratory.

In February 2018, the EP section purchased radiation survey meters and electronic personal dosemeters for all EPA Regional Offices. The EP Unit also commenced specific training sessions with laboratory staff in the various EPA regional offices. These sessions involved a presentation on the basic concepts of radioactivity and radiation protection together with practical demonstrations on radiation detection and measurement.

Raising awareness of the EPA's role in nuclear/radiological emergencies was conducted by the EP section through general communications such as regular internal meetings and newsletter articles.

In May 2018, members of ORM, who comprised of the EP, Air Quality and Radiation Regulation sections as well as the regional chemistry laboratories, participated in a Table-Top Exercise. The purpose of the exercise was to raise awareness of the role of the EPA in nuclear and environmental emergencies, identify areas of expertise and skills that could be utilised by the EPA in an emergency and identify knowledge gaps and areas for improvement that needed to be addressed so the EPA could prepare and respond effectively in an emergency.

Based on a scenario involving a severe nuclear accident at a nuclear power plant in the UK that impacted on Ireland, the participants were asked what they thought their role would be if this event were to occur. The participants then discussed specific EPR topics such as internal/external communications, the role of the Regions, external and Cross-Office resources and the status of emergency response across the EPA.

The EPA was recognised as having many internal strengths in relation to its emergency preparedness arrangements. It was noted that the EPA's regional presence could be used in an emergency to log samples into the EPA's Laboratory Information Management System, screen samples for radioactivity content and send samples that require a higher accuracy measurement to the radiation monitoring laboratory in Dublin. Further, all ORM staff were willing to help in the event of an emergency, existing EPA contacts with other State/non-governmental bodies (for example, local authorities and third level bodies) could be used to carry out sampling and EPA vehicles could be used to transport samples.

Conversely, there were several challenges associated with educating staff in the basics of radioactivity, improving staff awareness on their role in the EPA's emergency plans, equipping all laboratories appropriately and adequately training staff in the use of monitoring/measurement equipment.

Several recommendations were proposed to continue raising EPR awareness such as conducting regular emergency exercises, informing EPA staff about the Emergency Response Management Information System on the EPA's intranet and identifying a designated contact person for emergencies in each EPA region.

Future work

Significant work in harnessing the use of non-radiological resources in the EPA to support the response to a nuclear/radiological emergency has been achieved to date. Internal practical arrangements have been improved and additional skill sets have been identified. Future work will involve conducting training, information sessions and emergency exercises. The EP section will continue to engage with the EPA's regional laboratories to purchase equipment, train staff and develop their IT systems.

Conclusion

The EPA, as a principal support agency in selected emergency scenarios, has used the expertise gained from the merger with the RPII as a platform for engaging its non-radiological resources across the country to increase its capacity to respond to nuclear or radiological emergencies.

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Challenges in estimating the source term and operational radiological picture (on-site versus off-site)

Identification of atmospheric contamination source in an urban area by Approximate Bayesian Computation methodology

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Abstract

We present the framework for the identification of the parameters of the airborne contaminant source in the urbanized area. The framework is based on the Approximate Bayesian Computations (ABC) working algorithm to the identification of atmospheric contamination source in an urban environment based on the concentrations reported by multiple sensors. We present the dedicated modifications of the sequential version of ABC algorithm that improve the estimation of the posterior probabilistic distributions of source parameters. The proposed algorithm works in real-time. Assessments of source parameters are dynamically updated with the use of online arriving concentrations of released substance registered by sensors network. We validate the proposed methodology on real data coming from a full-scale field experiment DAPPLE conducted in London. We demonstrate the successful estimation of six parameters characterizing the contamination source, i.e., contamination source position (x,y,z) in a city environment, the mass of release (q), the release start time (t) and its duration (l). As the forward model to predict the concentrations at the locations of the sensors, we utilize the advanced Quick Urban & Industrial Complex Dispersion Modeling system (QUIC), developed by Los Alamos National Laboratory. The obtained results prove the utility of the proposed approach for event reconstruction problem in any complex urban environment with the use of any suitable dispersion model.

Introduction

In emergency response management it is important to know the exact area that might become contaminated following a release of dangerous materials. This is especially important when the release takes place in urbanized areas, where the number of potentially exposed people is very high. Although accurate modeling of atmospheric contaminant transportation in a dense urban area is not trivial, in principle, given a gas source and a wind field, with an appropriate atmospheric dispersion model, it is possible to calculate the expected gas concentration for any downwind location. On the other hand, even with good knowledge of concentration measurements, the arrangement of buildings, wind field, and other atmospheric air parameters, identifying the release source is complicated. This task can be understood as presenting the dispersion model reproducing the actual contamination. Such inverse problem has no unique analytical solution, but instead, it might be analyzed with probabilistic frameworks, such as the Bayesian approach, where all quantities are modeled as random variables. This randomness can be interpreted as a lack of complete knowledge of parameter values and is reflected in the uncertainty around true values. Bayesian approach transforms the inverse mentioned above problem into searching for a posterior distribution based on the sampling of an ensemble of simulations using a priori knowledge and observed data.

In this paper, we recommend an efficient model for the atmospheric contamination source reconstruction in an urban area. Inside reconstruction model, we apply the Approximate Bayesian Computation (ABC) algorithm [1] and Quick Urban & Industrial Complex (QUIC) [2] Dispersion Modeling System to compute mean flow fields around buildings and QUIC System as the forward model to predict the concentrations at the sensor locations. A thorough analysis of the reconstruction procedure and the discussion about source term estimation is presented in next section.

Reconstruction model in Source Term Estimation

The goal of source term estimation (STE) [3] is to estimate the parameters that describe the source of a gas release, e.g. location and strength. Thus STE model uses a network of sensors measuring concentration on the ground which are indicated as $d_{obs}^{1:t}$. Measurements of concentration are fused with prior information and background meteorological data I to estimate the unknown source parameters. The estimation has been performed using a probabilistic approach based on Bayesian inference (1). Regardless of the sampling algorithm, source parameters θ are passed to a forward dispersion model to generate predicted concentrations that are compared with the observations. The overall goal of these methods is to find the most likely match between the predicted and observed data using the distance measure, as illustrated in Fig. 1. The ABC approach allows inputs used in the algorithm to be specified via a posterior probability density function. Below is given the description of the individual elements of Fig. 1.

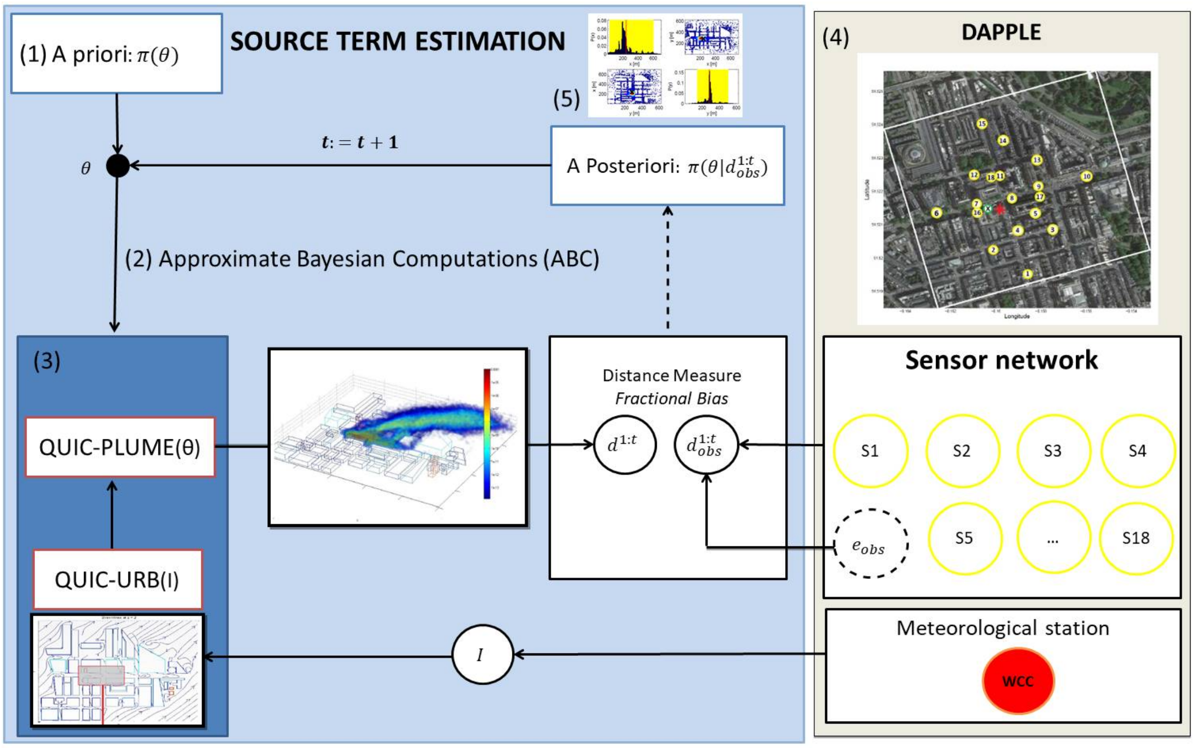

Figure 1. Mutual relations between data and models included in the reconstruction. A sensors network transmits the measured concentrations. Description of individual elements in the content of the publication [4].

Bayesian Model (1)

Let θ be a source term parameter vector, given the prior distribution $\pi(\theta)$. The goal of Bayesian inference is to approximate the posterior distribution:

$$\pi(\theta|d_{obs}^{1:t}) = \pi(d_{obs}^{1:t}|\theta)\pi(\theta),$$

where $\pi\left(d_{obs}^{1:t}\middle|\theta\right)$ is the likelihood of θ given the observed data $d_{obs}^{1:t}$ from sensor network in subsequent time t. The following parameters vector describe the source of the release $\theta \equiv (\mathrm{x}, \mathrm{y}, \mathrm{z}, \mathrm{q}, \mathrm{l}, \mathrm{s})$. The (x, y) is source position within computing domain, (z) is the height of source location above ground level, (q) is a mass of release, (s) is the start time of release and (l) is duration time. To estimate this source characteristic, it is necessary to use the advance sampling algorithm.

Sampling Algorithm - Approximate Bayesian Computation (2)

The main idea of Approximate Bayesian Computation (ABC) methods is to accept θ as an approximate posterior draw if its associate (modeled) data $d^{1:t}$ is close enough to the observed data $d_{obs}^{1:t}$. Accepted parameters are a sample from $\pi\left(\theta\middle|\rho(d_{obs}^{1:t}, d^{1:t}\right) < \varepsilon)$ where the $\rho(d_{obs}^{1:t}, d^{1:t})$ is the chosen measure of a discrepancy, and ε is a threshold defining 'closeness margin'. If ε is sufficiently small then the distribution $\pi\left(\theta\middle|\rho(d_{obs}^{1:t}, d^{1:t}\right) < \varepsilon)$ will be a good approximation for the posterior distribution $\pi(\theta|d_{obs}^{1:t})$. It is often difficult to define an adequate distance function $\rho(d_{obs}^{1:t}, d^{1:t})$ between the simulated and observed data. To calculate data

$d^{1:t}$, which are the productions of concentration in sensors location, it is necessary to apply the appropriate forward dispersion model.

Forward Dispersion Model – QUIC-PLUME (3)

The Quick Urban Industrial Complex (QUIC) [2] Dispersion Modeling System is intended for applications where the dispersion of air pollutants released near buildings must be computed very quickly. The QUIC system comprises of a wind model QUIC-URB, a dispersion model QUIC-PLUME, and a graphical user interface. The modeling strategy adopted in QUIC-URB uses a 3D mass-consistent wind model to combine properly resolved time-averaged wind fields around buildings. The mass-consistent technique is based on a 3D complex terrain diagnostic wind model. The basic methodology involves first generating an initial wind field that includes various empirical parameterizations to account for the physics of flow around buildings.

Next, this velocity field is forced to be divergence free, subject to the weak constraint that the variance of the difference between the initial velocity field and mass consistent final velocity field is minimized. The QUIC-PLUME is a Lagrangian particle model which describes gas dispersion by simulating the release of particles and moving them with an instantaneous wind composed of mean and turbulent components.

Testing data - DAPPLE experiment (4)

The Dispersion of Air Pollution and its Penetration into the Local Environment (DAPPLE) experiment took place in central London, where average building height in the area is 21.6m. The experimental site was chosen to have a diameter of approximately 500m to cover the whole dispersion field. We selected the time-resolved contamination experiment carried on 28 June 2007. The chosen data consist of a sequence of ten samples taken over a 30 minute sampling period at each of 18 receptor positions. The sampling regime comprised the collection of ten samples averaged over 150s interval at each of 18 sites; each sample separated from the next by 30s. Fig. 1 (4) shows the position of source locations (green X point) and monitoring sites (numbered yellow points). The total mass emitted from the point-source release was 323mg of perfluoromethyl-cyclohexane (PMCH, C7F14). Two sets of long-term reference measurements were taken to generate the wind data sets. Data from the rooftop of Westminster City Council (WCC) (18m) has been used by in our calculations as model element I.

Examples of results – A posterior distribution (5)

The summarized results of the reconstruction procedure are presented in Fig. 2 as a trellis plot of evaluated posterior probability distribution. The colored contour lines are enveloping a higher probability of the joint posterior distributions. The diagonal plots are marginal empirical posterior distributions of the parameters (x, y, z, q, l, s). The target parameters values are highlighted with a vertical red line in diagonal subplots and black cross markers on others subplots. The distributions presented in Fig. 2 confirm that the proposed reconstruction model satisfactorily estimated parameters of continuous atmospheric contamination source in the urban area. A detailed description of the results can be found in [4]

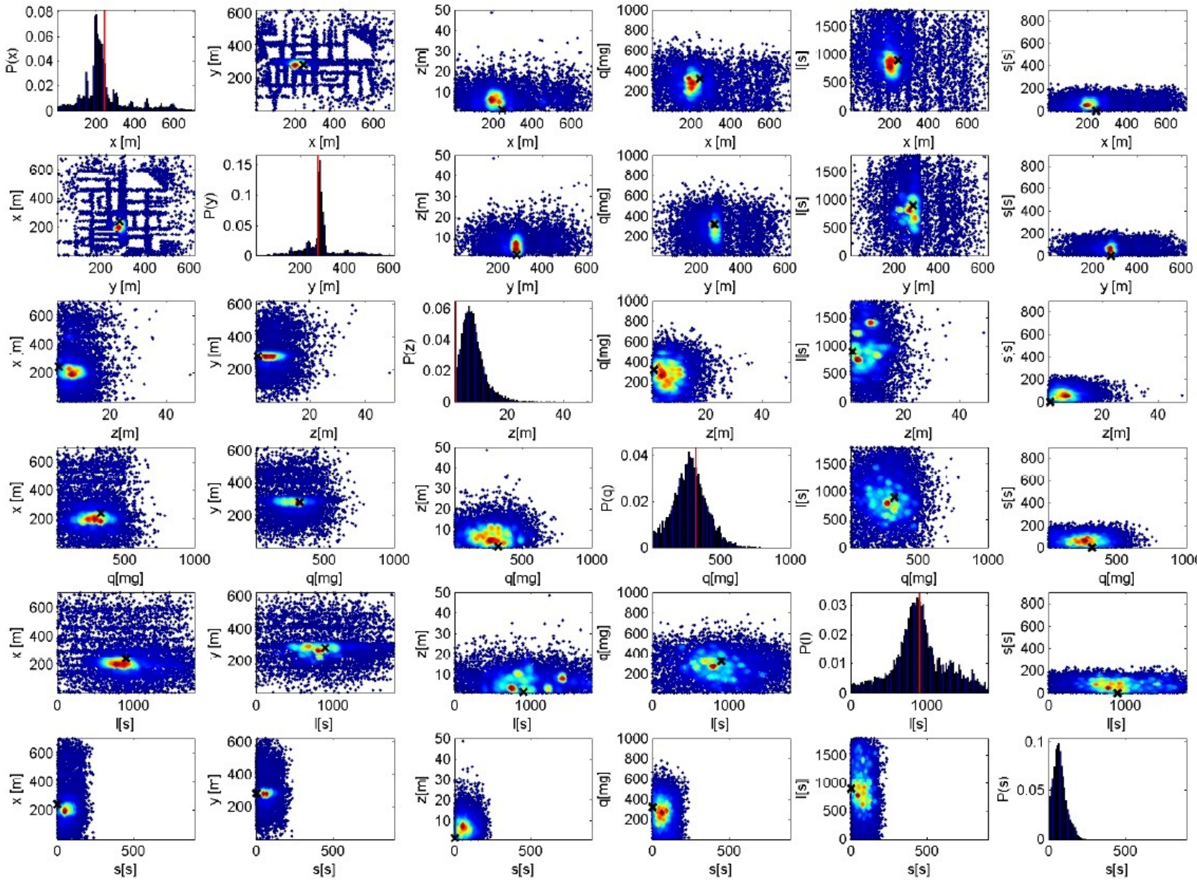

Figure 2. The bivariate and marginal posterior distributions for all searched parameters (x,y,z,q,l,s) [4].

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Source term reconstruction module in JRODOS

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Abstract. In the frame of the European project PREPARE (Innovative integrated tools and platforms for radiological emergency preparedness and post-accident response in Europe), two source term estimation modules were developed. Both are using gamma dose rate monitor information outside the plant boundary and gamma dose rate data calculated by an atmospheric transport and dispersion model. By comparing both, the measured and the calculated value, mathematical methods are used to estimate the unknown source term. The simple source term estimation module, developed by VUJE, Slovak Republic, is implemented in JRODOS. It uses a simple Gaussian type algorithm to estimate the gamma dose rate information. The locations for these estimations have to be close to the site boundary. To estimate the source term, the monitored and estimated gamma dose rate information is compared to pre-calculated gamma dose rate data stored in a database for 10 representative radionuclides. This paper presents the application of this tool for source terms of different complexities as well as for different meteorological conditions. Applicability and constraints of the method for decision making in the early phase of a nuclear accident will be discussed

1 Introduction

The European project PREPARE (Innovative integrated tools and platforms for radiological emergency preparedness and post-accident response in Europe) aimed at closing gaps that have been identified in nuclear and radiological preparedness following the first evaluation of the Fukushima disaster. Among others, improved source term estimation and dispersion modelling was one of the work packages of the project. At the end of the project a simple and a complex method were developed. However, only the simple method was implemented in the JRODOS DSS (Ehrhardt J. and Weis A., 2000, Ievdin et al., 2010, Duran, J., 2016). Implementation was delivered with the version 2018 of JRODOS (update 3) and this paper documents some first tests performed on that version.

2 Methodology of the simple source term approach

The simple source term module compared measured dose rate information with pre-calculated dose rates that were generated using a Gaussian type dispersion model. The pre-calculated data sets comprised normalized dose rate (from cloud and deposit exposure) calculated for the following parameters:

- Release height (10 classes of height – maximal height 200 m)
- Initial width (radius) of cloud (10 classes of width – influence of reactor building cavity)
- Category of stability class (6 classes)
- Wind speed (10 classes)
- Intensity of precipitation (10 classes)

The dose rate is calculated for 10 nuclides representing the following nuclide groups

MELCOR groups	Representative element
Noble Gases	Xe
Alkali Metals	Cs
Alkaline Earths	Ba
Halogens	I
Chalcogens	Te
Platinoids	Ru
Early Transition Elements	Mo
Tetravalents	Ce
Trivalents	La
More Volatile Main Group	Cd

The following information is used as input data:

- current meteorological measurements from the NPP site:
    - wind speed [m/s]
    - wind direction [deg]
    - stability category class [-]
    - precipitation intensity [mm/h]
    - date [dd.mm.yyyy] of measurement
    - time [hh:mm] of measurement
- current gamma dose rate measurements in the near vicinity at the fence:
- values of dose rate [Sv/h] from all detectors (averaged for each 10-minutes)
    - date [dd.mm.yyyy] of measurement
    - time [hh:mm] of measurement

To use the methodology, monitor stations have to be close to the fence and limited to 1km distance as maximum. The estimation of the source term is performed in 10 minutes intervals. A further precondition is that more than one station is affected by the plume. Thus the number of stations around the fence is an important factor. If too small, the method will not be applicable. Therefore, artificial stations were introduced for the tests. To summarise, the module tries to solve N linear algebraic equations for M unknown parameters (N measurements, M nuclide activities). If less than 10 stations are affected, no direct solution of the matrix is possible. This method is named “PREPARE”.

A clear advantage of that simple tool is the fact that no “a priori” information is needed. The only information that is required refers to the nuclide vector. This should discriminate between solely noble gas releases and releases dominated by aerosols. A combined release is at present a limitation factor of the tool.

3 Test set-up

Figure 1 shows the location of the tests that was Borssele as this site was also used for work inside CONFIDENCE.

When performing a test case, several steps have to be performed. First, a “reference scenario” for the gamma dose rate monitors has to be prepared. The setup of the reference scenario is the following

1. Selection source term
2. Time step of prognosis is 10 minutes

3 Weather provider selection without adaptation
4 Emersim (countermeasure simulation) selected, FDMT selected
5 Grid has to be set to Swiss and one ring with smallest resolution of 50m (40000 points in total)
6 Display “total gamma dose rate” and select “interpolate to points”
7 Prepare meteorological data for the tool by using the time function functionality for one location close to the site and store them as EXCEL files
   a. Wind speed (10m)
   b. Wind direction (10m)
   c. Stability
   d. Precipitation

These EXCEL files have to be transferred into RTTF format for each scenario.

In this respect, the reference dose rate measurements and prevailing weather is generated to be used by the source term reconstruction tool.

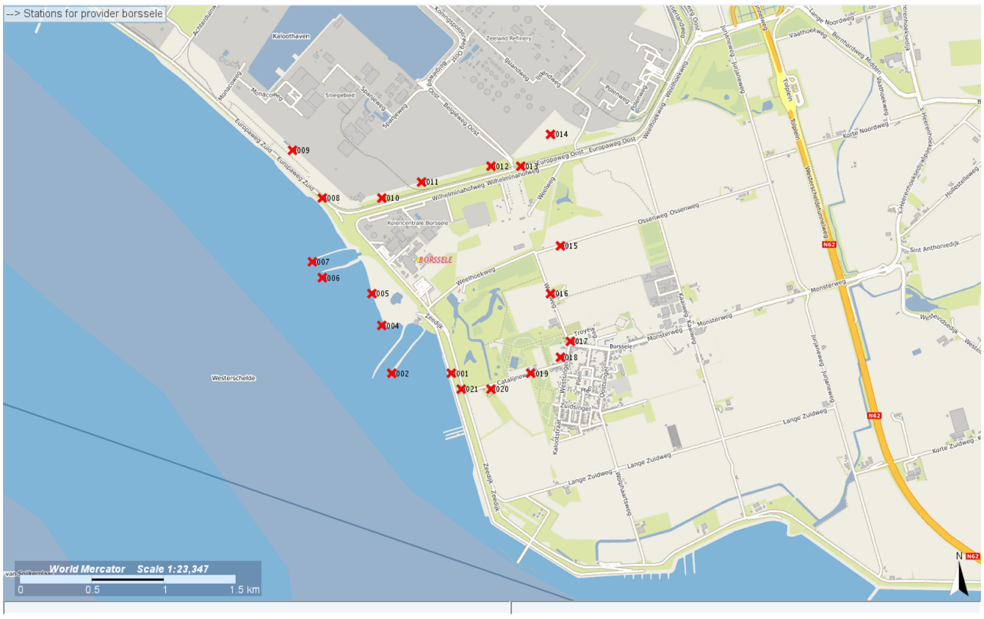

Figure 1. Red crosses indicate the gamma dose rate monitors around Borssele

The next step is the application of the source term reconstruction module with the above generated gamma dose rate measurements and prevailing meteorology at the site – the reconstruction module only digests local weather data and no numerical weather prediction data. As result of that step, a “reconstructed” source term becomes available.

To compare the original and the reconstructed source terms, the following has to be done

- Perform a prognostic calculation for the cases, using the original source term and the reconstructed source term
- Same resolution as for the “reference scenario”, with 10 minutes time step and 50 m spacing
    - Comparison of gamma dose rate at different points
    - Comparison of nuclide specific source term

- Perform a prognostic calculation for the cases with JRODOS default parametrisation with original and reconstructed source term
  - time step 60 minutes
  - grid, standard 200km resolution (100 km radius)
  - Comparison of areas affected (e.g. evacuation, sheltering)

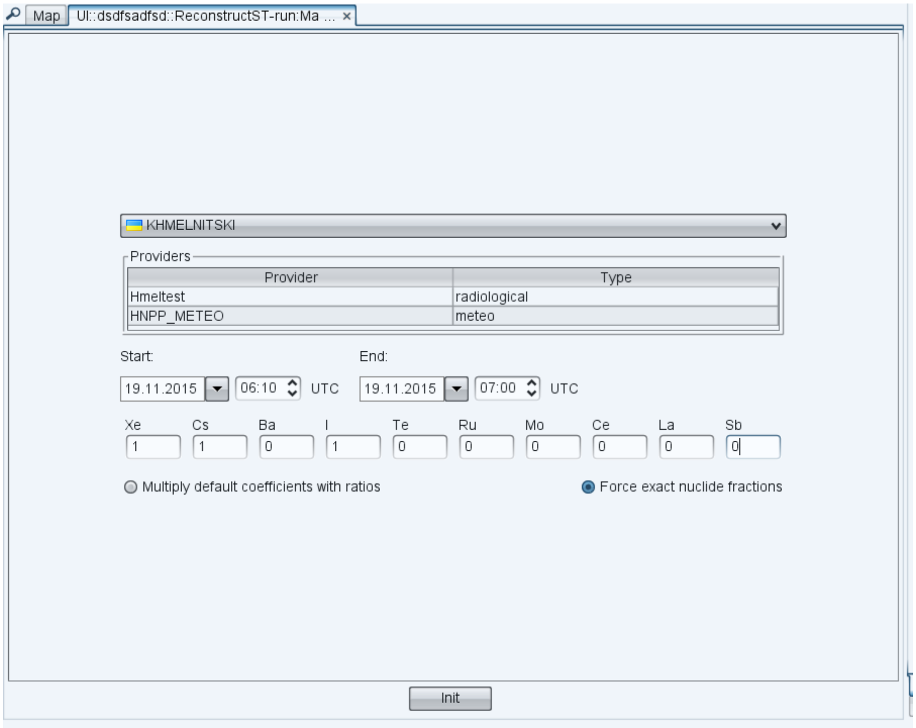

Figure 2. User interface for the Source Term reconstruction module in JRODOS (bottom left is the indicator for the PREPARE method, bottom right the indicator for the SUM approach)

4 Tests performed

4.1 Simple source term and simple weather

This case is a release of Xe-133 only with straight line weather and constant wind speed

0.00 h -	0.17 h	1.00E+15 Bq
0.17 h -	0.34 h	0
0.34 h -	0.50 h	0
0.50 h -	0.67 h	0
0.67 h -	0.84 h	0
0.84 h -	1.00 h	0
1.00 h -	1.17 h	0
1.17 h -	1.35 h	1.00E+18 Bq
1.34 h -	0.50 h	0
1.50 h -	0.67 h	0
1.67 h -	0.84 h	0
1.84 h -	2.00 h	0
2.00 h -	1.17 h	0
2.17 h -	2.34 h	0
2.34 h -	2.50 h	1.00E+16 Bq

Figure 3. Original Xe-133 source term with three peaks

The source term reconstructed is shown in Figure 4. For that simple case, the reconstruction is acceptable with the correct timing and the order of magnitude with a slight overestimation.

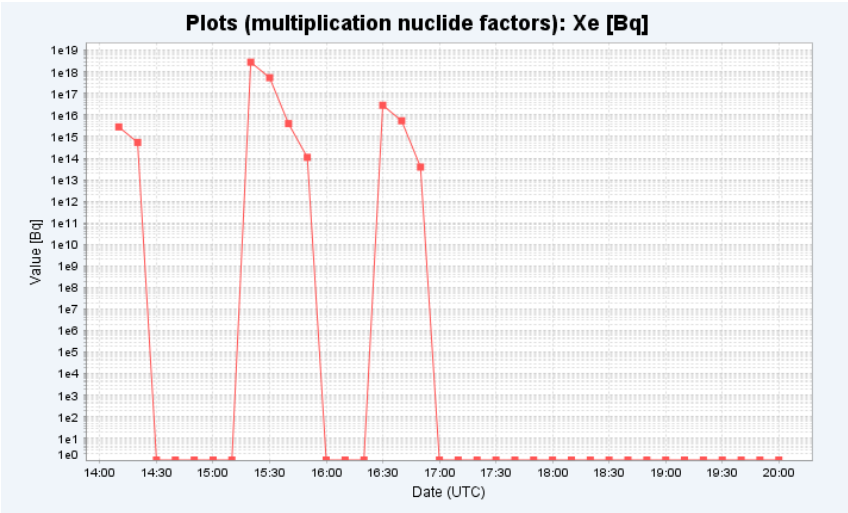

Figure 4. Source term reconstructed with the PREPARE method

4.2 Complex but short source term with simple weather

This example uses a short but high source term from the German risk study phase a named FKA that is part of the database of JRODOS. The duration of the release is three hours and

25 nuclides are used for the original calculation. Figure 5 shows the dose rate at one representative station for two approaches. One with an estimation of the nuclide vector and one without. Both overestimate the dose rate and probably the source term, however still close to the reference value.

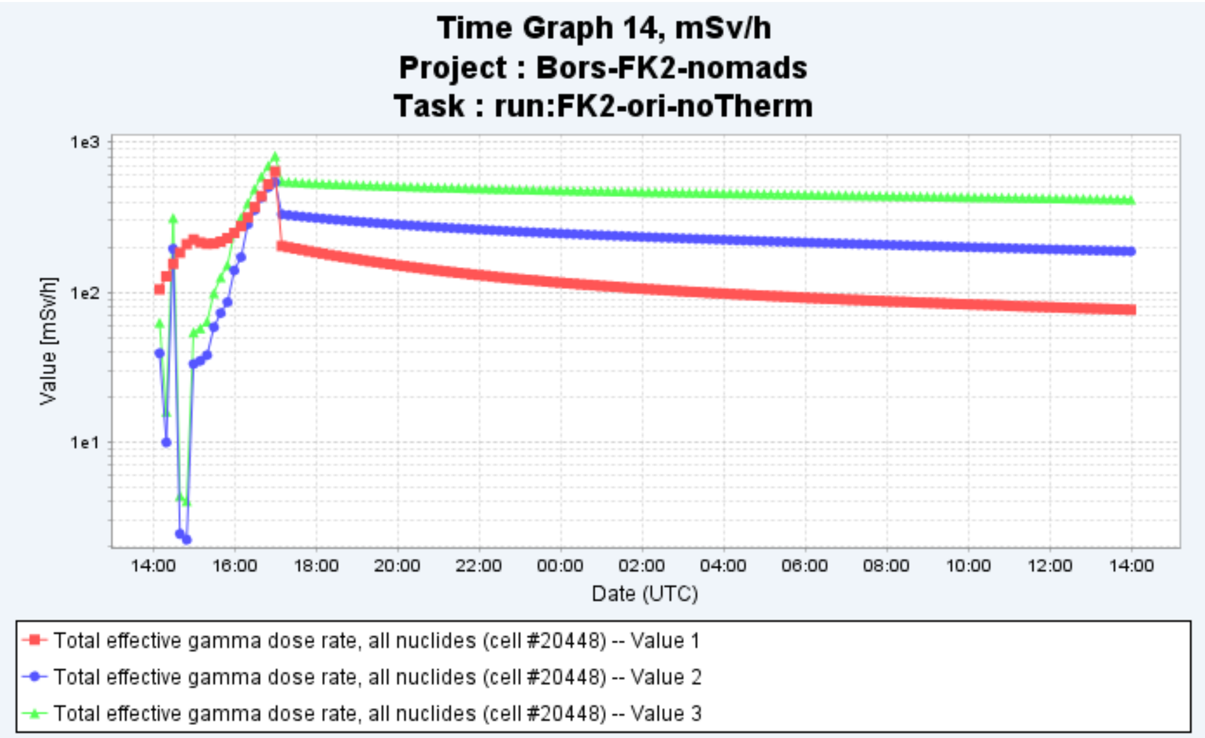

Figure 5. Dose rate at one station with original source term (red), reconstructed with the estimated nuclide vector (blue) and the unified nuclide vector (green)

5 Conclusion

In general one may conclude, that the approach for simple cases and a very limited number of nuclides, reproduces the timing and the amount released in a reasonable manor. When the source term becomes complex in terms of number of nuclides and timing, the performance is not as good as before. The drop in performance is linked to the method that requires a high number of monitoring stations to reconstruct a larger number of radionuclides. Further, the database was constructed with one specific dispersion model that might not reflect the characteristics of the ones used for the reconstructions runs.

Nevertheless, we are confident that there are possibilities to improve the performance as this simple approach has the great advantage that no prior information of the source term is necessary. Further, if a source term reconstruction method can limit the uncertainty of a source term within one order of magnitude, decision making can surely improve. If the error is much larger, such tools might be not applicable.

Acknowledgement

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Analysis of the Fukushima Source Term: Implications for Source Term Estimation from Radiological Observations during Emergencies

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1. Scope and objectives

On behalf of the German Federal Ministry of Economic Affairs and Energy (BMWi), GRS participated in the OECD/NEA project: "Benchmark Study of the Accident at the Fukushima Daiichi Nuclear Power Plant (BSAF)". Within the first phase of this project (2012-2014), deterministic analyses for the severe accident (SA) progression during the first days for the Units 2 and 3 of Fukushima Daiichi nuclear power plant (NPP) have been provided by GRS. The second phase of the project (2015-2018) extended the scope of the SA analyses and added the topic of the comparison of measured local dose rate (LDR) on-site and off-site with calculated releases of radioactive material to the environment, the source term (ST). Forward and backward calculations of radionuclide releases have been performed to assess the appropriateness of the results provided by the SA analyses based on an independent approach. Within this scope, the main objectives of our backward calculations have been to reconstruct radioactive releases from measured LDR on-site Fukushima Daiichi NPP or nearby and to compare our findings with available measured plant parameters as well as with the results of SA analyses performed [1].

2. Methodology and data

Several studies address the reconstruction of radioactive releases from Units 1 to 3 of the Fukushima Daiichi NPP based on environmental data. Among them, a detailed source term estimation published in [2] is based on the coupling of the WSPEEDI-II (Worldwide version of System for Prediction of Environmental Emergency Dose Information) model to an oceanic dispersion and deposition model. For the reconstruction of atmospheric releases monitoring data around the Fukushima site (distance: 4 km to 81 km) and over the ocean are used together with earlier ST estimations and information on specific events during accident progression in the plant. The focus of our study is on the very local scale, i.e. based on radiological observations on-site and in the near vicinity of the plant (distance: 300 m to 19 km). The data have been made available within the OECD/NEA BSAF project to the partners. A deliberately “blind” approach is followed which omits the use of any plant information for identification of release phases or quantification of releases. As no radiological observations over the Pacific Ocean have been available to the OECD/NEA BSAF project partners, our analysis is confined to phases where radioactive releases are dispersed over land. The results published in [2] are used for comparison (referenced as “WSPEEDI”) as explained later.

2.1 Outline of analysis method

Our reconstruction method aims at the optimized use of available radiological measurements at or nearby the Fukushima site. It thus focuses on the evaluation of the numerous local dose rate measurements, while the nuclide composition must be estimated from a limited number of available soil samples. The reconstruction scheme is based on the following steps:

- *Step 1: Calculation of surface contamination from local dose rate and specific soil activity:* For this purpose, the measured LDR record is first subdivided into cloud phases when a radioactive cloud passes by the monitoring point (MP) and ground phases when ground shine dominates observed LDR. Subdivision is based on characteristic differences in the change rate of LDR. Nuclide-specific surface contamination is estimated during ground phases by relating ground shine to the nuclide composition of deposited nuclides. This composition is determined from soil samples.
- *Step 2: Calculation of air activity concentration from surface contamination and information on precipitation:* During cloud phases, the difference between measured LDR and calculated ground shine is assumed as cloud shine. Air activity concentration is calculated from total increase in surface contamination during the respective cloud phase. Deposition rates are assumed proportional to cloud shine magnitude and are varied according to available precipitation information. This method yields estimates for air concentration of aerosols and gaseous iodine. Activity concentration of noble gases is guessed from the residuum between total cloud shine and calculated contributions by aerosols and gaseous iodine.
- *Step 3: Calculation of radioactive releases from LDR, air concentration and modelled dispersion:* For this step, Eq. (2) is solved for each LDR monitoring post included. Gamma submersion factors are obtained from atmospheric dispersion modelling performed with the Lagrangian dispersion model ARTM (Atmospheric Radionuclide Transport Model) which has been developed by GRS [3].

All dates and times indicated in the remainder of this paper refer to Japan Standard Time (JST). Source term reconstruction has been performed for the period of March 12 00:00 to March 26 00:00. Calculations have been processed with a uniform time step of 10 minutes.

2.2 Observational database

Measurements of LDR on-site Fukushima Daiichi NPP and Fukushima Daini NPP have been published by Tokyo Electric Power Company (TEPCO). They are complemented by a set of LDR observations at 26 MP in the surroundings which have been made available to the OECD/NEA BSAF project. Six MP on-site and eight MP off-site have been employed for ST reconstruction. Another subset of eight MP in the surroundings of Fukushima Daiichi NPP with shorter data records has been used for validation of the reconstructed ST.

Samples of specific soil activity for Te-132, I-131, Cs-134, Cs-137, and eight other nuclides are available at eight locations on-site Fukushima Daiichi NPP from March 21, 2011. This data set has been complemented by numerous soil samples of I-131 and Cs-137 in the surroundings of Fukushima Daiichi NPP published by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) in 2011 and digitally archived by GRS at that time.

Measurements of wind direction and velocity as well as precipitation information at Fukushima Daiichi NPP published by TEPCO are used. Until the afternoon of March 16, 2011, additional weather data recorded at Oono MP have been made available to the OECD/NEA BSAF project, which are combined with measurements at Fukushima Daiichi NPP for dispersion calculations.

3. Results

Nuclide composition of radioactive deposits has been determined using the soil samples described above. All samples are decay-corrected to the date of the first sample (March 21 00:00). By this time, possible releases in the first few days of the accident of short-lived nuclides like I-132 would be no longer detectable in the deposits. Comparison of nuclide ratios relative to Cs-137 shows that the nuclide composition is quite homogeneously distributed over all samples for all nuclides except for Iodine. Ratios of I-131 to Cs-137, however show a systematic dependence on dispersion direction. On average, a higher ratio is found where dry deposition dominates compared to the ratio where deposition is influenced by rainfall. These systematic differences are used to discriminate between dry and wet deposition of Iodine. Contributions of short-lived isotopes I-133 and I-135 are then calculated from the respective reactor core inventory ratios to I-131. I-132, which is continuously produced by decay of Te-132 in the reactor cores after shutdown, is tentatively assumed to be in radioactive equilibrium with Te-132. With these additional assumptions for Iodine and the respective ratios for all other nuclides taken from the average over all soil samples at the NPP site, a basic nuclide composition for the radioactive deposits has been derived.

Calculated ground shine from the basic nuclide composition can thus be directly compared to measured LDR during assumed ground phases. For this purpose, the amount of deposited nuclides on the ground is calculated by a least square fit approach which minimizes the difference between the calculated ground shine and measured LDR. Unexpectedly, this comparison reveals large discrepancies between calculated ground shine and measured LDR during the first days of the accident while the agreement improves later. This disagreement is for example, evident in the mismatch between measured LDR (blue squares) compared to calculated ground shine (orange crosses) in Fig. 1 for MP “Main Gate”. Like in this example, especially at MPs at or close to the accident site, observed LDR decreases significantly faster than would be expected from radioactive decay in the basic composition. To explain these discrepancies, several possible alternative causes have been investigated, such as slowly passing radioactive clouds, changes in release intensity or reduction of surface contamination by wind-driven resuspension and/or runoff by rainfall. However, an in-depth analysis of the characteristic timescales of these processes shows that only radioactive decay can explain the LDR behavior during the phases in question [4]. Moreover, the distinction between cloud phases and ground phases seems to be consistent with the observed LDR curves.

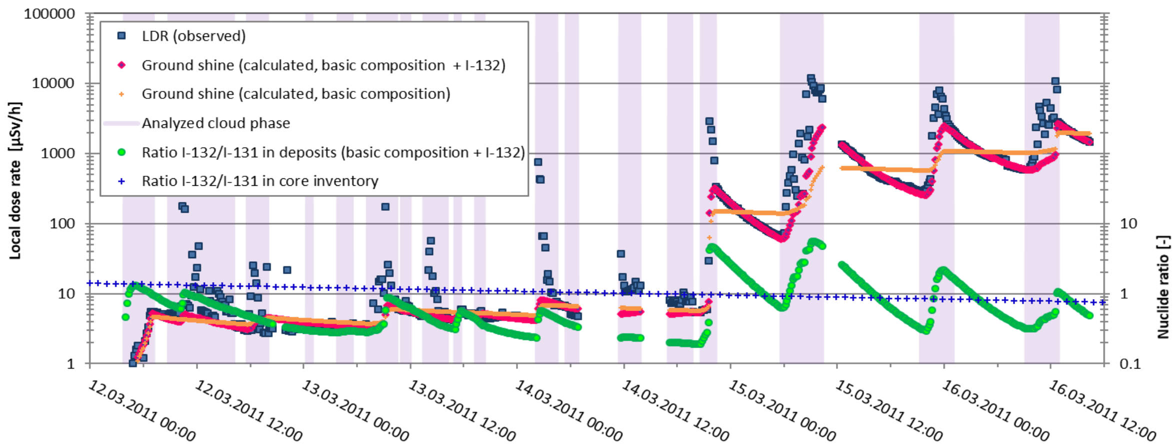

Figure 1. Comparison between observed LDR and calculated ground shine with (purple diamonds) and without (orange crosses) excess release of I-132 for MP "Main Gate". Calculated ratio of I-132 to I-131 in deposits is compared to respective ratio in core.

Hence, it seems reasonable to assume additional contributions by short-lived nuclides to surface contamination. Such nuclides would no longer be detectable in the available soil samples. Faster radioactive decay of these would explain the observed decrease rates in ground shine. Such an effect can be qualitatively attributed to higher release fractions of I-132 (with a half-life of 2.3 hr) compared to those of Te-132. Such excess releases would lead to the deposition of larger amounts of I-132 than of Te-132 and subsequently to a faster decrease in ground shine. I-132 is thus chosen as representative for short-lived nuclides which contribute to surface contamination. Amounts of additional I-132 which are suitable to explain observed LDR are again calculated by a least square fit approach. Results of this calculation for MP "Main Gate" are shown in Fig. 1. Agreement between observations (blue squares) and modelled ground shine (purple diamonds) is remarkably improved in contrast to the use of the basic nuclide composition.

In line with theoretical considerations, calculated peak ratios of I-132 to I-131 (green circles in Fig. 1) agree with the respective core inventory ratio (blue crosses) for nearly all analyzed cloud phases until March 14, 2011 afternoon. These peak rations seem however unrealistically high especially in the night from March 14 to March 15, 2011. It seems likely that additional short-lived fission products contribute to ground shine during those phases. On the other hand, sensitivity tests show that the actual choice of short-lived nuclides does not significantly affect the calculated amounts of longer-lived nuclides. Therefore, I-132 has been chosen as sole representant of short-lived nuclides.

By the inclusion of I-132, surface contamination can be satisfactorily estimated from local dose rate also at the on-site MP whose employment in our ST reconstruction would otherwise bias the results of analysis step 1. Air activity concentration and radioactive releases are then determined for each MP according to steps 2 and 3 described above. The source term is then reconstructed from the results for the 14 MP included by weighted averaging, considering the magnitude of dispersion coefficients to reduce the effect of errors in the dispersion modelling.

Results are shown for Cs-137 and I-131 in Fig. 2. As mentioned above, source term reconstruction is confined to time phases when releases are dispersed over land. An observational coverage of about 50% is obtained for the investigation period. Validation of the ST reconstruction by independent measurements of local dose rate at 8 MP generally shows qualitatively good agreement between calculated and measured local dose rate (not shown). At most of the MP, differences are within a range substantially less than an order of magnitude.

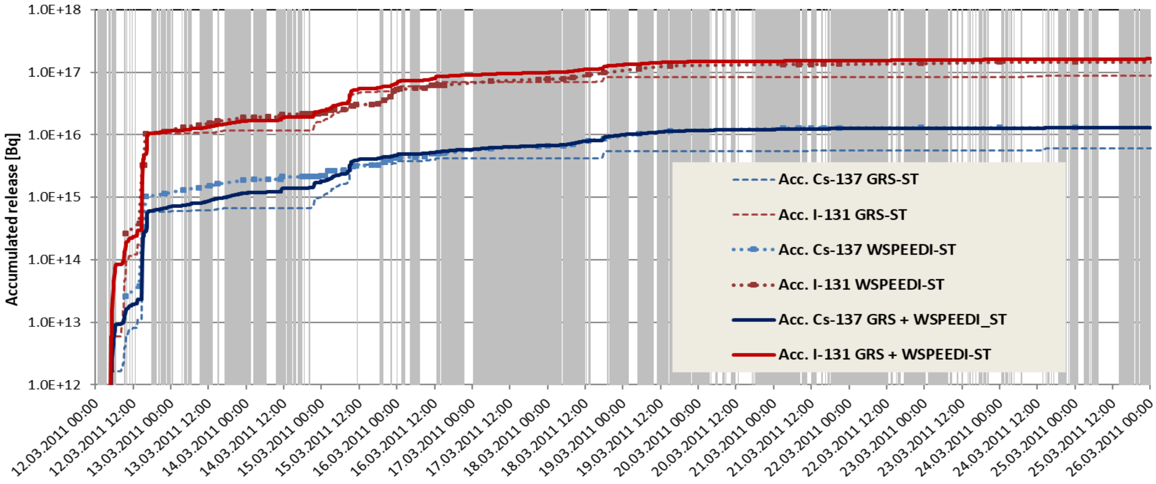

Figure 2. Comparison of accumulated releases of Cs-137 (blue) and I-131 (red) by GRS (dashed) and WSPEEDI (dash-dotted) ST reconstruction methods. Shaded: No observation by MP ensemble used for GRS backwards calculation possible. Solid lines: Accumulated releases for combined GRS + WSPEEDI ST (see text)

The reconstructed source terms obtained from WSPEEDI [2] and GRS backwards calculations are also compared in Fig. 2. A clear advantage of the WSPEEDI method is the coverage of the whole investigation period, including those periods when the radioactive releases are dispersed over the ocean. On the other hand, the GRS method enables the use of LDR measurements on-site very close to the location of release. By this, the temporal resolution of source term reconstruction is enhanced. The agreement between the results of GRS and WSPEEDI calculations is remarkably evident in the accumulated releases. The calculated accumulated releases are nearly identical by the afternoon of March 16, 2011. Thereafter, the GRS ST estimates are lower, due to reduced observational coverage for the GRS calculations.

Because of the striking agreement between GRS and WSPEEDI source term results during periods covered by both methods, it seems reasonable to combine the source term results. For periods covered by both GRS and WSPEEDI results, the GRS results are taken as source term data because of their higher temporal resolution. For periods not covered by GRS data (wind direction towards the Pacific Ocean) GRS results are completed by WSPEEDI results. This procedure combines the advantages of both datasets.

4. Conclusions

The quality of the results obtained by our source term reconstruction approach crucially depends on the careful analysis of measured LDR and specific soil activity. This analysis reveals that only contributions by short-lived nuclides which have already decayed in the soil samples can explain observed LDR. The consideration of such short-lived nuclides turns out to be a prerequisite for inclusion of on-site LDR measurements in our reconstruction approach.

In comparison to results obtained from the Japanese WSPEEDI decision support system, the employment of on-site LDR measurements by GRS enables a higher temporal resolution during phases covered by both methods. On the other hand, the WSPEEDI results also cover situations when radioactive releases are dispersed over the ocean. The agreement between GRS and WSPEEDI results justifies the combination of the ST calculation results provided by both methods. The blended ST data set combines the advantages of each reconstruction method. It allows for an independent validation of the ST predicted by SA analyses as well as for an improved understanding of the accident progression.

The results and methodology of our analysis are currently being incorporated into a source term estimation tool based on radiological data for emergency situations. This tool is especially designed for the use of on-site and nearby radiological measurements.

Acknowledgements

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