NERIS

Third NERIS Workshop

"State of the art and Needs for further research for emergency and recovery preparedness and response"

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PROCEEDINGS

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Edito

On 17-19 May 2017 in Lisbon, NERIS organised its third workshop in cooperation with the Institut Superior Tecnico and the Agência Portuguesa do Ambiente. The Workshop gathered 75 participants and 40 papers dedicated to the 3 challenges of the updated NERIS Strategic Research Agenda: i.e. i) radiological impact assessments during all phases of nuclear and radiological events; ii) countermeasure and countermeasure strategies in emergency and recovery, Decision support and Disaster informatics; iii) setting-up a multi-faceted framework for preparedness for emergency response and recovery.

At the beginning of this workshop, the main challenges for NERIS research activities have been emphasized. To be successful in promoting useful and efficient researches in the following years, NERIS aims to reinforce joint research at European Union level in interaction with the other research platforms in radiation protection (i.e. MELODI for low-doses, ALLIANCE for radioecology, EURADOS for dosimetry, EURAMED for medical exposure). In the same dynamics, it is important to consolidate the connection with organisations involved in the management of Chernobyl and Fukushima accidents, notably with ICRP and Japanese organisations. NERIS will pursue the dialogue and consultation with organisations in charge and/or concerned with the preparedness for emergency response and recovery management in the perspective of improving harmonisation of emergency and recovery approaches in Europe.

Among the large number of topics addressed during the workshop, it is worth to notice the series of papers analysing the effectiveness of the countermeasures and countermeasure strategies on the light of the lessons learned from Fukushima. Further analyses on evacuation, sheltering and agricultural countermeasures have been presented with a focus on the need to integrate the specificity of the affected region as well as the societal and ethical aspects to be considered for the evaluation of effectiveness of countermeasures. Similarly, the recent developments in modelling and decision support systems have been largely dedicated to further refine their ability to cope with regional characteristics. Recent developments and perspective on inverse source term methodologies were presented, pointed out the new capacities provided by mathematical development and big data technologies.

The workshop provided also the opportunity to report about the European research projects developed within the EURATOM framework programme. As mentioned above, the recent developments tend to improve the multi-disciplinary approach for a better integration of European radiation protection research. In this spirit, the recommendations resulted from the SHAMISEN project (funded under the OPERRA research project) were presented, dedicated to the preparedness and implementation for medical and health surveillance of affected populations taking into consideration the objective of improving the living conditions of these populations. The two new research projects CONFINDENCE and TERRITORIES, selected for funding under the first call of the EJP CONCERT, were introduced.

- The CONFIDENCE project (2017-2019) will perform research focussed on uncertainties in the area of emergency management and long-term rehabilitation, with a focus on the early and transition phases of an emergency. The work-programme includes uncertainty of meteorological and radiological data and their further propagation in decision support systems, consideration of social, ethical and communication aspects related to uncertainties, improvements in modelling and combining simulation with monitoring, as well as decision making principles and methods.

- The TERRITORIES project (2017-2019) targets an integrated and graded management of contaminated territories characterised by long-lasting environmental radioactivity for existing exposure situations involving post-accident and natural radionuclides. A graded approach, for assessing doses to humans and wildlife and managing long-lasting situations will be achieved through reducing uncertainties to a level that can be considered fit-for-purpose.

At the end of the workshop, the challenges for developing the NERIS roadmap were discussed. The main issues at stake are:

- Increased capabilities to assess the different radiological situations, including improved modelling, monitoring and data assimilation;
- Further methodological development for the implementation of optimisation, with improved decision-making using analytical platform and knowledge database, and better knowledge on countermeasures and countermeasures strategies;
- Development of guidance framework for establishing successful stakeholder engagement process;
- Further consideration on integration of citizen science in radiological risk governance, and improvement of preparedness and response on health surveillance programme;
- Better addressing ethical, societal and economic aspects in the decision-making processes.

Session 1 – Challenges in countermeasures and countermeasure strategies in emergency & recovery, decision support & disaster informatics

An investigation of the effectiveness of sheltering versus evacuation

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Introduction

In the event of an unplanned release of radioactive material into the atmosphere, there are various actions that can be taken to protect the public. Two such actions are sheltering and evacuation. Both aim to reduce the radiation dose received. Sheltering inside a building, with windows closed, and air conditioning systems off, reduces the amount of radioactive material that can be inhaled, reduces the exposure to the plume as it passes overhead, and reduces the exposure to any radioactive material deposited on the ground and other surfaces. In comparison, evacuation removes people from the area affected by the plume. Ideally, evacuation would be completed before the plume arrives in order to maximise the dose saving; however evacuating whilst the release is ongoing may be appropriate if it can be implemented quickly, and may be especially advantageous if the release is expected to continue for a prolonged period.

When planning both sheltering and evacuation, the main benefit of both actions is the dose saving that can be made. However, decision-makers would need to balance this benefit against other factors, such as disruption, societal impact, economic cost and other hazards. For example: evacuation may increase the chance of road traffic accidents; evacuating residents from nursing homes or patients from hospitals may adversely affect their health; appropriately resourced centres would need to be set-up to receive the evacuated population. On the other hand, the risks of evacuation may be reduced if it is well-planned and there are significant challenges in servicing a sheltered population.

The aim of this study is to investigate whether sheltering or evacuation is consistently better for reducing radiation doses. The two actions are compared over a range of nuclear power plant accident scenarios with variation in source term characteristics, weather conditions, evacuation routes and location types. Non-radiological effects of the two actions are not studied.

There was agreement between PHE and BfS that a collaborative assessment would allow a deeper investigation of the problem and give greater weight to the results. It was decided that the two organisations would proceed with their own models and approaches but that, where possible, key assumptions and input parameters would be shared to ensure results that could be usefully compared.

Common assumptions

In order to test their effectiveness, it was decided that sheltering and evacuation would be considered side-by-side, each implemented in separate model runs which were otherwise identical. Each scenario considered a single point of release with multiple possible evacuation routes.

It was assumed that the evacuated cohorts travel at a constant speed of 5 km/h, which is equivalent to typical walking pace. This speed would be expected to lead to the least protective evacuation actions since under most conditions, reduced travel times would lead to lower levels of exposure. It was also assumed that there is a delay between the start of the release and evacuation beginning.

Common source terms were agreed in advance and were based on realistic estimates of potential reactor releases. For some scenarios, the lengths of the releases were altered, to investigate the effect of release duration on the results.

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

PHE approach

The PACE (Probabilistic Accident Consequence Evaluation) tool (Charnock et al, 2013), which is developed by PHE, brings together a number of models to predict the transfer of radioactivity through the environment, and subsequent health and economic consequences. The spatial domain – a 100 x 100 km square centred on the point of release – was divided into individual grid squares and the UK Met Office's Lagrangian dispersion model NAME III was run over 144 historical meteorological sequences evenly spaced over 1 year to calculate environmental concentrations. PACE dose modules were then used to calculate the dose that would be received in each grid square, for both "indoor" (sheltering) and "outdoor" (evacuating) cohorts.

For sheltering, a simple approach was used. It was assumed that the population remain indoors for the duration of the accident or until the end of the modelled time (48 hours). Dose reduction factors of 0.5 for inhalation, 0.2 for external gamma exposure due to material in the plume and 0.1 for external gamma exposure due to deposited material were applied. It is recognised that in reality the protection offered by sheltering would vary with building type and countermeasure duration, among other factors.

To model evacuation, network analysis was performed using real road networks to identify the likely evacuation routes that individual cohorts would take. Each cohort shelters in their grid square of origin for one hour, and then travels to their closest reception centre (in terms of travel time), following the road through intervening grid squares along the way (Figure 1). These routes were then combined with the calculated outdoor doses in each grid square to estimate total transit doses for the evacuated cohorts. It was assumed that once they reach the reception centre, the evacuated cohort continues to accrue dose, but with indoor location factors applied. A "cost barrier" was introduced in the network analysis to discourage cohorts from travelling along routes that took them past the release location.

For each scenario, reception centres were placed at fixed locations on the arc of a circle around the release location. Separate scenarios were devised to look at the effect of varying the diameter of this circle, looking at diameters of 10, 20, 30 and 40 km (Figure 2). Reception centre locations were chosen to coincide with real conurbations to remain consistent with features of the road network.

Two hypothetical release locations were chosen to scope the difference between an inland site and a site situated on the coast. The locations were selected for differences in their geographic features, population, and density of the road network.

Just two of the source terms have been considered in the PHE analysis to date: FKA_10th (5 hours), and FKF_mod (40 hours).

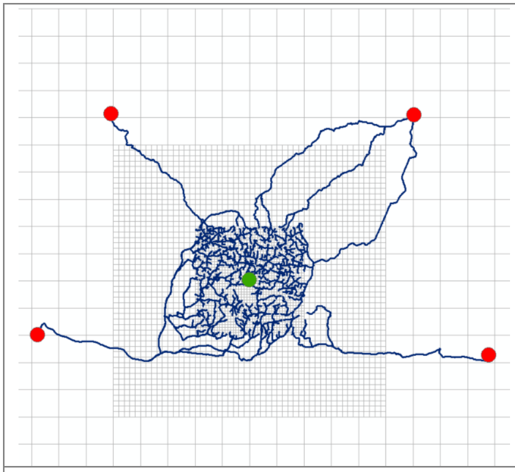

Figure 1: *Example evacuation routes: starting from each grid square within 10 km of release location, and travelling to closest reception centre (each ~40 km from the release location)*

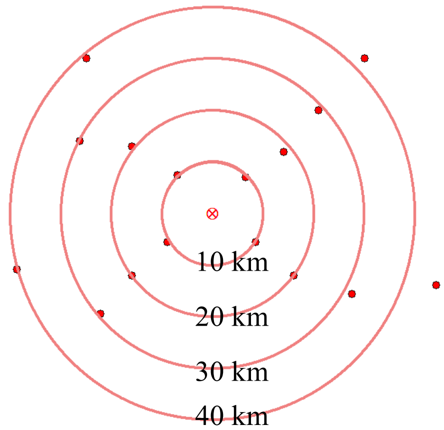

Figure 2: *Locations of receptions centres around the release location*

BfS approach

The RODOS (Real time On-line DecisiOn Support) system (Ehrhardt and Weiss, 2000) was used to calculate the effective dose in the first days after an accident in a nuclear power plant based on real numerical weather data and the source terms mentioned above. A total of 365 model runs were performed per release scenario to cover most possible meteorological conditions and transport patterns throughout one year. The model runs cover the period from 01 November 2011 until 31 October 2012 with one release per day. The time of day of each release was determined on a random basis. The atmospheric transport model RIMPUFF was used to calculate the atmospheric dispersion. It was driven by meteorological fields from the

German weather service DWD. The simulation time for each run was set to 48 hours using a 1 hour calculation time step. The output grid covers an area with a radius of 100 km around the release point.

Four locations with a distance of 2 km from the release site were set North, East, South and West of the release site serving as start points for the evacuation. Eight linear evacuation paths into the directions 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315° (clockwise starting from north) were set up for each location (Figure 3). Typically, evacuation plans will avoid evacuation in the direction of the emitted plume. Therefore, all evacuation directions leading towards the release site were excluded in the default setting of the analysis and only five evacuation directions (out of the eight simulated directions) per location were used. The total effective dose for the emergency measures of sheltering and evacuation were assessed for the four locations and the five evacuation directions. Hence, a maximum of 43800 data sets were available for the present analysis (365 days × 6 source terms × 4 locations × 5 evacuation directions).

The evacuation zone was set to a radius of 20 km around the release site. The evacuation speed was 5 km/h and the evacuation integration time step 2 min. The total effective dose was calculated for a 48 hour simulation period. Simulations included an additional delay of 120 minutes from the start of the release before evacuation was initiated, i.e. the evacuation started 120 minutes after the first release. A shielding reduction factor (RF) of 0.33 was applied for every time step during sheltering. For evacuation, people were considered to stay indoors during the 120 minute delay before evacuation and the time the people spent outside the evacuation zone following evacuation.

The analysis was limited to evacuation scenarios where the estimated effective dose for 7 days for children exceeded 100 mSv in at least one location (“ge 100 mSv”).

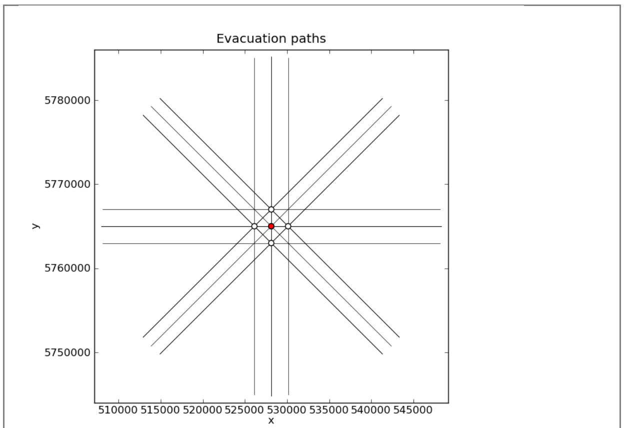

Figure 3: *Starting points for evacuation (white circles) and release site (red circle). The black lines show the available evacuation paths.*

PHE approach

For each scenario (source term, reception centre distance) a probabilistic analysis was performed across all 144 met sequences. The results over all weather conditions are presented in the form of histograms with the cumulative collective dose for both sheltering and evacuation. It is noteworthy that large numbers of population are not included on the graph since they experience a dose below the minimum axis value.

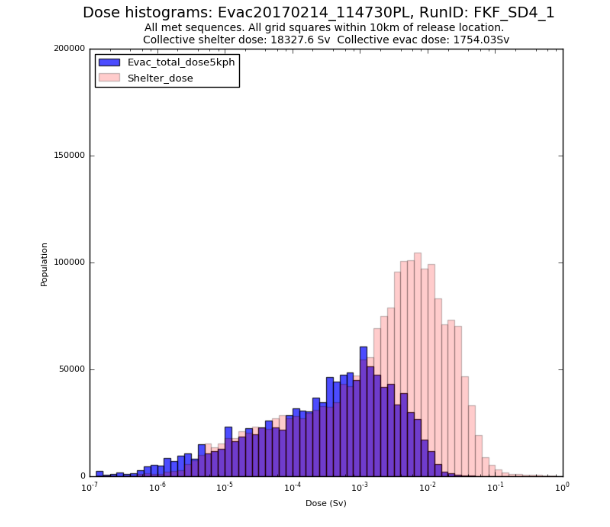

Figure 4: *Population-dose distributions for evacuation (blue) and sheltering (pink) within 10 km of an inland site (41 hour FKF release)*

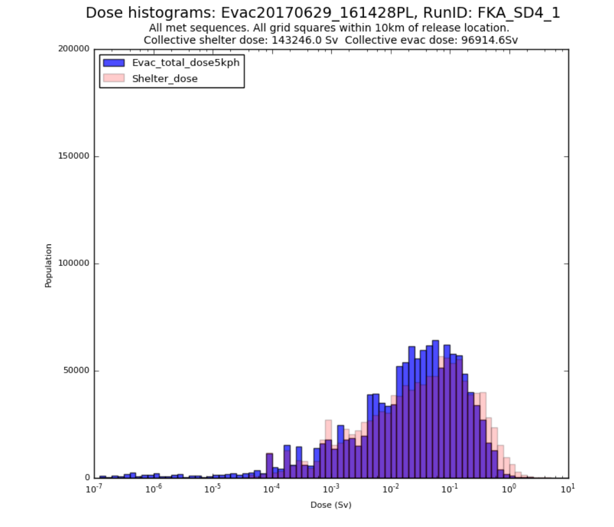

Figure 5: *Population-dose distributions for evacuation (blue) and sheltering (pink) within 10 km of an inland site (5 hour FKA release)*

Comparison of the distributions for the long duration release (FKF) as in Figure 4 shows a clear shift left under the evacuation regime, with fewer high doses and a far smaller collective dose. However, in the case of the shorter release (FKA) as in Figure 5, the difference between the two countermeasure regimes is less marked and the collective doses are of the same order of magnitude.

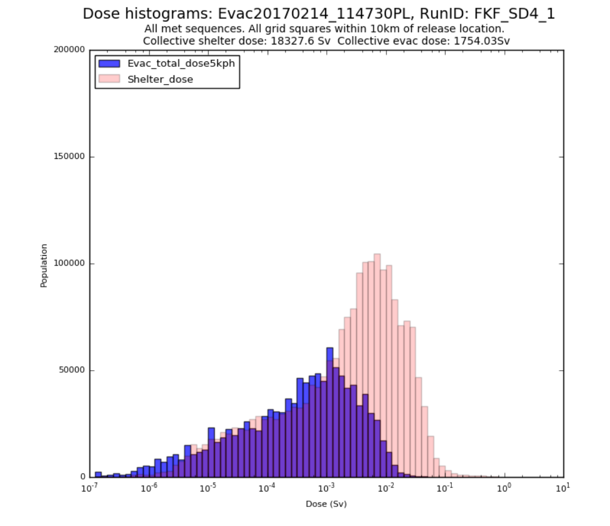

Figure 6: *Population-dose distributions for evacuation (blue) and sheltering (pink) within 10 km of an inland site (41 hour FKF release)*

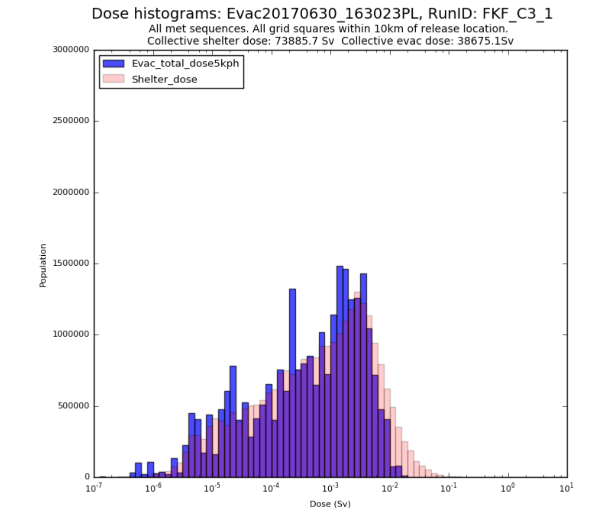

Figure 7: *Population-dose distributions for evacuation (blue) and sheltering (pink) within 10 km of a coastal site (41 hour FKF release)*

A direct comparison of results for inland (Figure 6) and coastal (Figure 7) release locations reveals far less difference in dose reduction at the coastal site.

BFS approach

Sheltering and evacuation were compared on a case to case basis by subtracting the effective dose for evacuation from the effective dose for sheltering for every single case, i.e. location and event day. The total number of cases where evacuation or sheltering is preferable was normalized and displayed in Figure 8. Grey areas depict cases where evacuation and sheltering lead to an equal effective dose. Except for the very short release scenarios, evacuation is preferable in more than 60% of the cases.

However, Figure 9 shows that the net-benefit of evacuation does not exceed 10mSv in the majority of the cases. The grey areas in Figure 9 show the fraction of cases where the difference between evacuation and sheltering is less than 10mSv. The maximum fraction of cases when the net-benefit of evacuation exceeds 10mSv and where evacuation is preferable appear for the long release scenarios with 40% (FKA) and 25% (FKF).

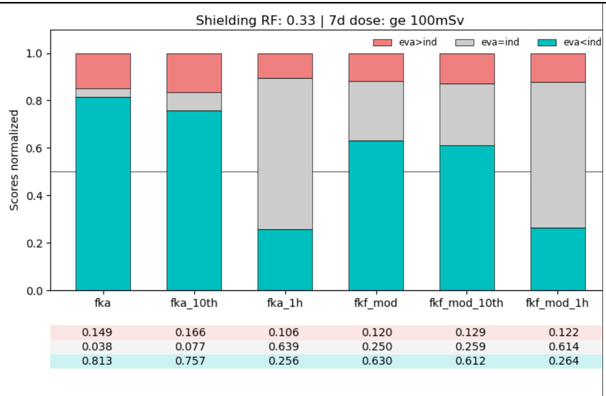

Figure 8: *Normalized scores (0-1) for all six scenarios for cases where the difference of eff. dose for sheltering minus eff. dose for evacuation is: <0mSv (red), =0mSv (grey), >0mSv (blue).*

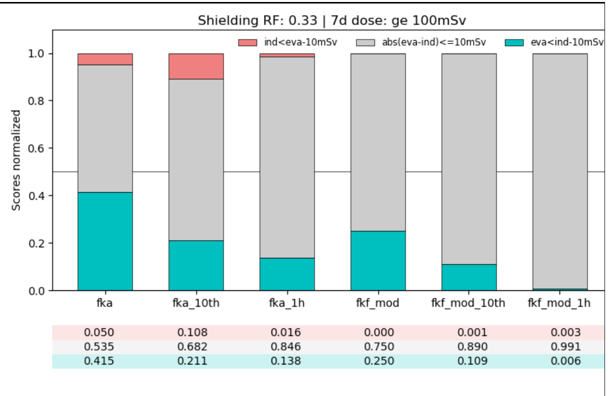

Figure 9*: Normalized scores (0-1) for all six scenarios for cases where the difference of eff. dose for sheltering minus eff. dose for evacuation is: <-10mSv (red), <=abs(10)mSv (grey), >10mSv (blue).*

The probabilistic analyses from both approaches (PHE and BfS) suggest that, for the scenarios studied, evacuation is more protective than sheltering for the majority of cohorts. Comparison of the collective dose in equivalent populations supports this. However, the results are clearly dependent on a number of factors, not least the release duration. It has been shown that for long duration releases (tens of hours) there is the potential for evacuation to greatly reduce exposure over sheltering, but for shorter releases (of a few hours) this pattern is far less apparent.

Moreover, where it has been shown that evacuation may reduce exposure for the majority of cohorts for long duration releases, it does not follow that it does so under all meteorological sequences, or for all individuals in a given meteorological sequence. Within a given scenario, it is often possible to identify individual meteorological sequences under which one or other of the countermeasures is preferred. Although not shown here it is possible to subdivide the area of interest by bearing or distance from the release and identify subsets within which the protectiveness of each countermeasure are differently balanced.

Results for the two sites with network analysis, one inland and one coastal, suggest that evacuation is more favourable at the inland site. This may be because there are a greater variety of evacuation routes available for the inland site. For a coastal site, where for the meteorological sequences of interest the contamination is dispersed over land, there are fewer possible “good” evacuation routes and destinations.

While the analysis of the benefits of one emergency measure over the other on a case to case basis shows that evacuation is preferable in the majority of cases, the non-radiological disadvantages of evacuation must be considered alongside the radiological advantages. Therefore, the net-benefit of the emergency measures was analysed and this demonstrated that in many cases the net-benefit of evacuation is less than 10 mSv.

Further analysis, for example to investigate the effect of the distance to the source or the influence of different meteorological conditions, is in progress. Extensions to the planned work may explore other conditions and assumptions in more depth. Of particular interest are the effects of variations in release duration, urban density and whether the release occurs at a coastal or inland site. A method to allow more detailed evacuation modelling (e.g. reception centre(s) chosen on the basis of initial wind direction) is in the early stages of development.

Probabilistic analysis of results so far appears to show that even if carried out at walking pace, evacuation is more often the more radiologically protective countermeasure for long duration releases. For short duration releases (of a few hours), the results are more mixed and the conclusion is unclear.

Only the dose-saving consequences of countermeasures have been considered in this study. These results must be considered alongside the disadvantages of evacuation, including the risks and costs of implementation. Where the radiological advantages of evacuation are less clear – as they appear to be in the case of short duration releases – it may be more difficult to balance that benefit against the overall harm.

There are many complicating factors in modelling evacuation. Further investigation of the sensitivity of the results to these factors will be valuable and allow the methods to be refined.

Reference

1. Charnock, T.W., Bexon, A., Sherwood, J., Higgins, N. and Field, S. J. (2013). PACE: A geographic information system based level 3 probabilistic accident consequence evaluation program. ANS PSA 2013 International Topic Meeting on Probabilisitic Safety Assessment and Analysis. Columbia, SC, American Nuclear Society.
2. Ehrhardt, J., Weiss, W., (eds) (2000). RODOS: Decision Support System for Off-site Nuclear Emergency Management in Europe. European Commission, Brussels, Report EUR 19144.

A Case study of the use of ERMIN in Portugal after a radiological emergency scenario

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The European Model for Inhabited Areas, ERMIN, included in the RODOS Decision Support System, was used as a tool to assist in the development of the appropriate response strategy for an inhabited area, following a radiological emergency event. The current work is focused in the Belém area of Lisbon, where several monuments and recreation and cultural facilities attract numerous people on a daily basis, thus becoming a sensitive spot if an emergency situation should occur. The impact of a malicious act, such as the use of a radiological dispersal device (RDD) in an inhabited area in different weather conditions was the chosen scenario in this study. These results are presented and discussed and include the contamination dispersion maps, the radiation doses estimated for the population as well as some recovery countermeasures strategies to be considered.

Introduction

In Portugal, like in many other countries, the widespread use of ionizing radiation, with applications in medicine, industry and research, generates several scenarios that could result in radiological emergencies. Incidents and accidents may occur during the use, transport or disposal of radioactive materials and the consequences could have a significant social and economic impact, both locally and nationally.

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

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

The European Model for Inhabited Areas – ERMIN, included in the RODOS Decision Support System – dynamically calculates the deposition on surfaces and the behavior of the radionuclides in the environment. The ERMIN may be used as a tool to assist in the development of the appropriate response strategy for an inhabited area. Following an emergency event, ERMIN may be specifically applied to select the counter-measures that reduce future radiation doses, so that normal life can resume as soon as possible within the affected area. It may also assist in the interpretation of limited data as on-site measurements start to become available and assist in the development of a measurement strategy in inhabited areas and identifying where further measurements would be most useful, Charnock (2010), Ievdin et al. (2010).

The current work is focused in the Belém area of Lisbon, where several monuments, recreational and cultural facilities attract numerous people on a daily basis, thus becoming a sensitive spot if an emergency situation should occur. The impact of a malicious act, such as the use of a radiological dispersal device (RDD) in an inhabited area was the chosen scenario in this study and its results will be presented and discussed. Different weather conditions and different source activities were tested and their respective impact was simulated.

Methodology

The methodology for this work is illustrated in Scheme1.

In short, the place and dates of the events were selected and the weather conditions were chosen accordingly. Normal climatology was used as a base to choose values for wind speed and rain intensity, Alcoforado (2006) and IPMA (2017). The technical details of the RDD were also chosen. All of these data was inputted to JRODOS and the dispersion maps were obtained. Based on these results, the ERMIN, Charnock (2012), was run to obtain the impact of several response strategies.

The detonation point was set to Jardim Afonso de Albuquerque, Belém, Lisbon - in front of the official residence of the President of the Portuguese Republic. The time of the strike was chosen to be during the Changing of the Guard in front of this palace.

Two dates of detonation were chosen: a summer date June, 18th, 2017, 10:00 UTC (scenario 1+2) and a winter date February, 18th, 2018, 11:00 UTC (scenario 3).

For the summer date, corresponding to a dry deposition scenario, two different source activities were tested:

I. The high activity source (Cs-137; 37 TBq) was dispersed using two different weather conditions:
    1. Wind velocity of 8 m/s (90% higher than the average recorded value) and a wind direction from SW (10% frequency of occurrence);
    2. Wind velocity of 3 m/s (70 % lower than the average recorded value) and a wind direction also from SW.

II. Low activity source (Cs-137; 0.185 TBq) was dispersed using a wind velocity of 8 m/s (90% higher than the average recorded value) and a wind direction from SW (10% frequency of occurrence);

In the winter date, wet and dry deposition conditions were used to disperse a high activity source (Cs-137; 37 TBq):

I. Dry deposition (rain fall: 0 mm/h):
    1. Wind velocity of 5 m/s (40% higher than the average recorded value) and wind direction from SW;
    2. Wind velocity: 3 m/s (80% lower than the average recorded value) and wind direction from SW;

II. Wet deposition :
    1. Low Wind velocity 2 m/s (56% lower than the average recorded value)
        i. Rain fall: 2 mm/h

2. Very Low Wind velocity 0.1 m/s
    i. Rain fall: 6 mm/h
    ii. Rain fall: 15 mm/h

The technical characteristics of RDD were chosen to be the following:

I. Radioactive Source:
    a. Radionuclide: Cs-137
    b. Activity:
        i. Low activity 185 GBq
        ii. High activity 37 TBq
II. Explosive mass TNT equivalent: 1 MJ
III. Height of RDD above ground: 1.6 m (considering the device was carried by a person on a backpack).

The dispersion results were calculated by running JRODOS-2014 update. The chosen Model Chain was LSMC+EMERSIM+DEPOM+FDMT. The RDD module using the ATSTEP Atmospheric Dispersion Model was run with weather data by user input, Päsler-Sauer (2007).

The ERMIN model included in JRODOS-2014 update was used. The typical environmental breakdown used for the area affected by the dispersion of radioactive material is shown in Figure 1.

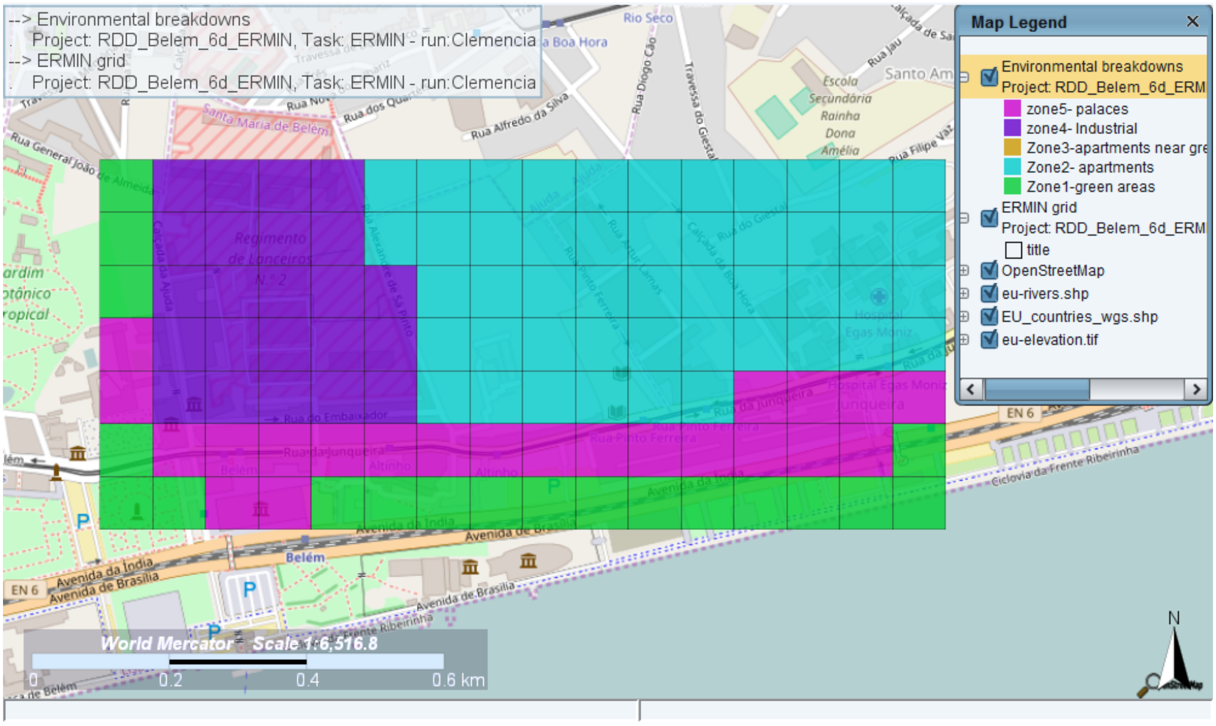
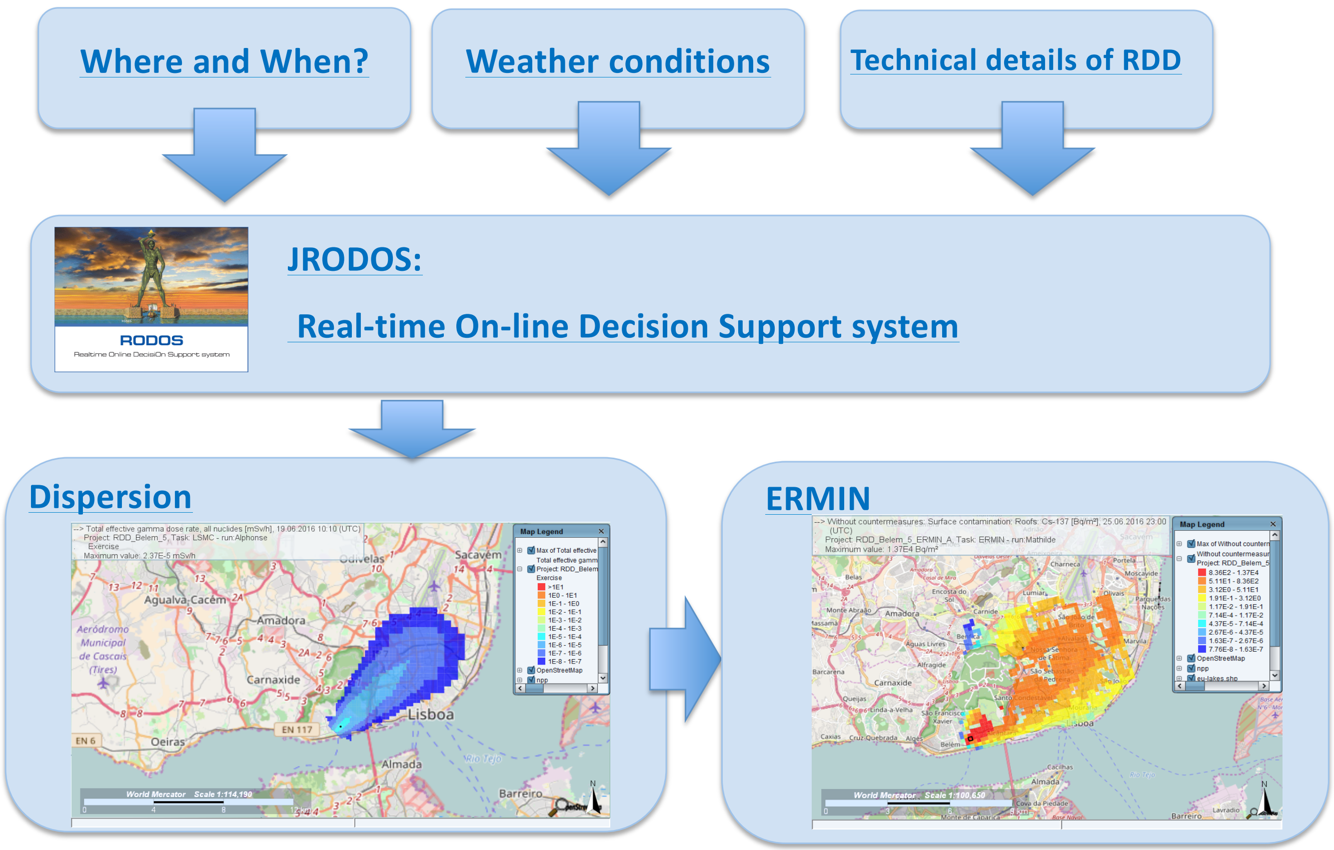


Figure 1: The environmental breakdown used for the area affected by the dispersion of radioactive material



Scheme 1. Principal methodology adopted for this study

Results:

In order to select two different scenarios to feed the depositions to ERMIN, the values for total dose from all exposure except ingestion, effective dose, adults 1year, normal living were used.

I. Low impact scenario: low activity source (Cs-137; 0.185 TBq) + wind velocity 8 m/s and wind direction from SW.
   1. ERMIN run applying no counter-measures. (See output summary in Table 1)

Table1: Output summary of ERMIN run for the low impact scenario.

Summary:: RDD_Belem_5_ERMIN::ERMIN - run: Mathilde Position: No countermeasures (365.0 days)	
The **maximum public individual normal living effective dose in the area** of interest over a defined integration period = = dose from exposure to external irradiation over the period + effective dose from inhalation of radioactivity over the same period	16 μSv
The maximum public individual normal living skin dose from exposure to external beta radiation in the area of interest over a defined integration period	158 μSv

II. High impact scenario: high activity source (Cs-137; 37 TBq) + very low wind velocity 0.1 m/s + rain fall: 6 mm/h

In this scenario, based in the dispersion results, immediate counter-measures like evacuation and food restrictions would be recommended.

The ERMIN was run with several strategies for applying late counter-measures (from day 3 to day 7):

A. No CM;
B. CM1: Roof decontamination (Firehosing roofs);
C. CM2: Wall decontamination (Firehosing walls);
D. CM3: Pavement decontamination (Turning paving slabs);
E. CM4: Soil decontamination (Turf harvesting);
F. CM5: Combined (all of the above).

Some of the results of these runs are presented in Figure 2 to Figure 4. These were selected in order to illustrate the effectiveness of the applied late counter-measures.

The values in Figure 2 correspond to the effectiveness (E_{CM},%) of a given counter-measure. They were calculated based on the projected values of the maximum public individual normal living effective dose in the area of interest over a defined integration period of that counter-measure when compared to the value obtained if no counter-measures where to be applied. (See Equation 1)

$$E_{CM}\,(\%) = \frac{D(no\,CM) - D(CM)}{D(no\,CM)} \times 100 \qquad \text{(Eq.1)}$$

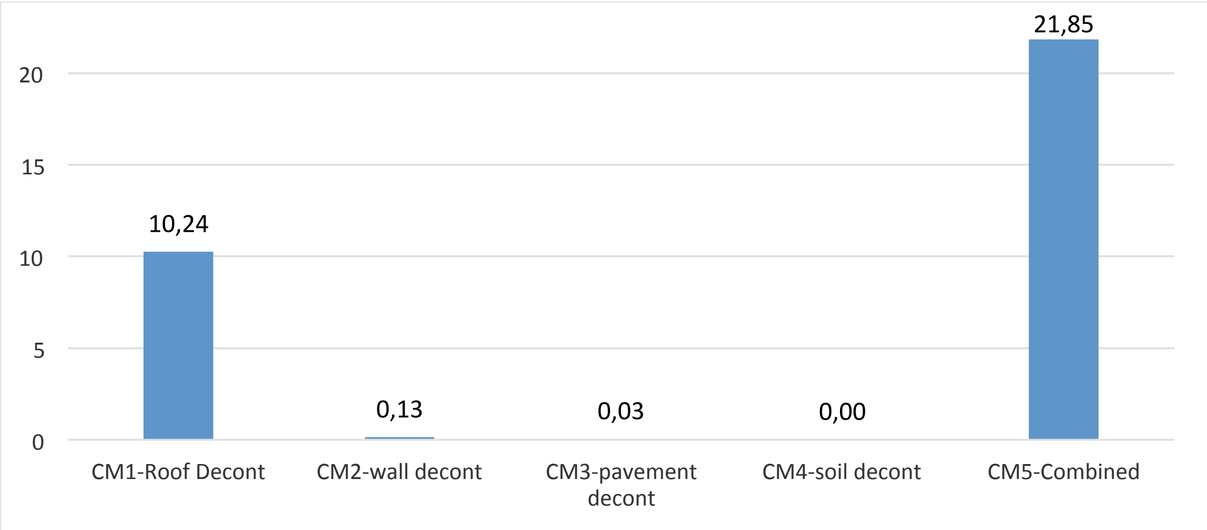


Figure 2: The effectiveness (E_{CM},%) of the counter-measures calculated from the projected values of the maximum public individual normal living effective dose in the area of interest over a defined integration period of that counter-measure

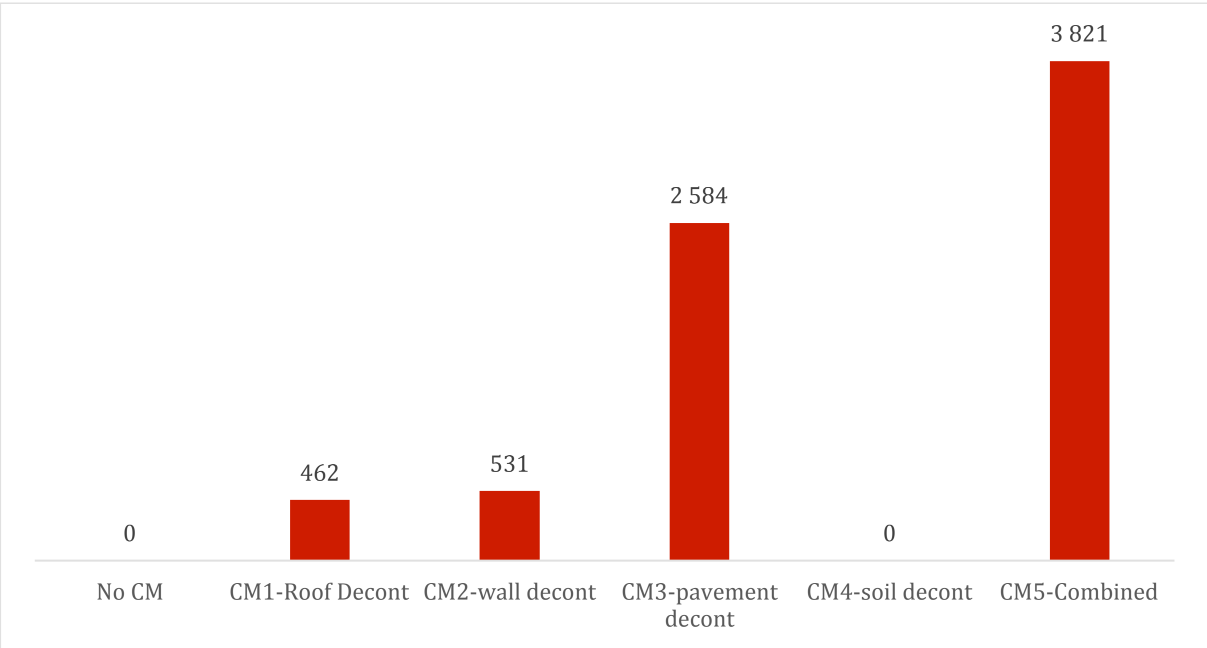


Figure 3: Total amount of work required for implementing the CM (man days)

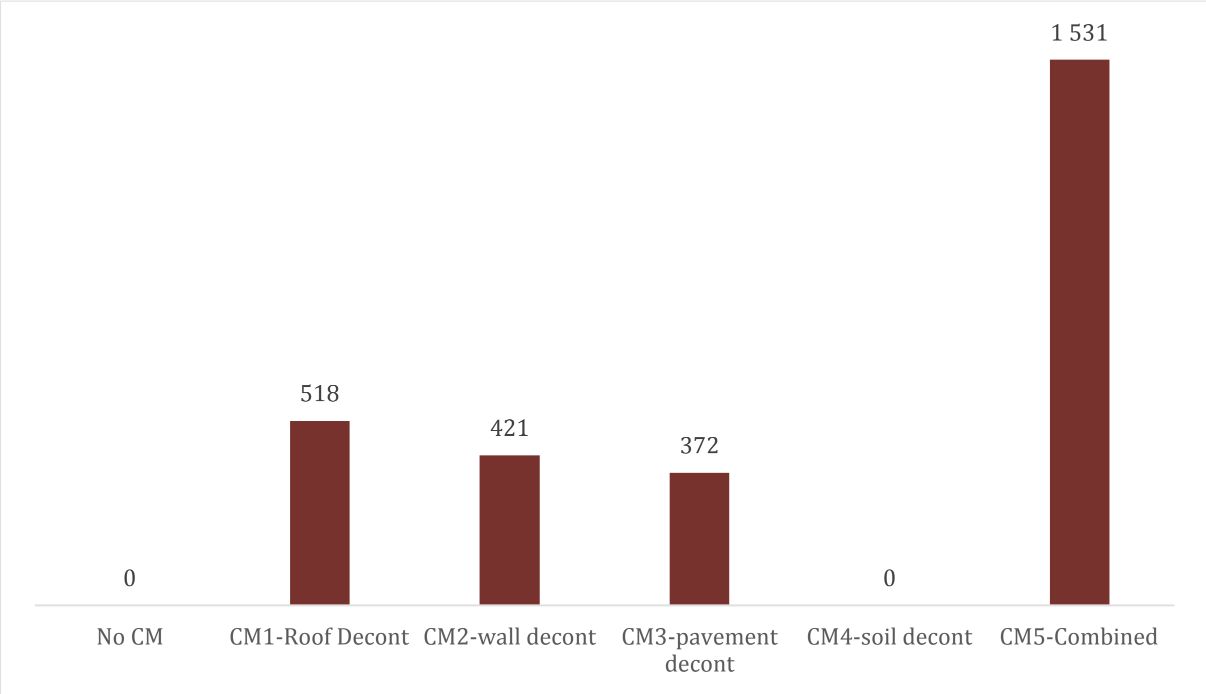


Figure 4: Total cost of the strategy (kEUR)

Conclusions

For the low impact scenario:

I. Prognostic doses do not imply application of immediate counter-measures;
II. Population not affected by the explosion will receive very low doses with a maximum dose of 8.4×10^{-4} mSv well below the 1 mSv/year dose limit for public;
III. Dose rates will be very low compared to Natural Background radiation;
IV. People living in affected areas, subject to ground contamination for a year would receive an effective dose of 7 μSv.

For the high impact scenario:

I. Prognostic doses recommend the application of immediate counter-measures:
    a. Evacuation of the area;
    b. Food restrictions.
II. As to the impact of the late counter-measures:
    a. A combined strategy revealed to be more effective in reducing the doses to the public that result from the sum of the dose from exposure to external irradiation over the period and committed effective dose from inhalation of radioactivity over the same period;
    b. Roof decontamination was the second most effective counter-measure;
    c. As expected, the combined strategy is the most effective and also the most costly;
    d. Some strategies revealed to be very little effective, probably due to the environmental breakdown used for the area of interest;
    e. Roof decontamination might be the most cost effective strategy.

From these results, we may conclude that the impact of a RDD attack is very sensitive to the weather conditions and to the activity of the source dispersed by the device. The effects may range from a very low impact leading to a residual contamination of the area, to a severe emergency conditions requiring immediate counter-measures (like evacuation) and late counter-measures.

For this zone, considering the environmental breakdown that was inputted to ERMIN, and in the case of a high impact scenario, the most cost effective counter-measure is roof decontamination. In the case of the low impact scenario, ERMIN model confirms a very low impact in recovery phase. Nonetheless, fear and panic created in the public might play a major role in this case and cause a higher impact in the social and economical aspects.

As with any case of an emergency situation, regardless of the impact of the scenarios, informing and communicating to the public by transmitting reliable and accurate information is a key factor in preventing undesirable and unnecessary social impacts.

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Countermeasures on agricultural areas after the Chernobyl and Fukushima accidents

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1. Context

Extensive countermeasure actions were conducted on contaminated landscapes after the Chernobyl accident in 1986 and the Fukushima Daiichi accident in 2011. Effectively, for both accidents, ^{131}I, ^{134}Cs and ^{137}Cs were the most important dose-forming radionuclides. Following the accident at the Chernobyl nuclear power plant on 26 April 1986, a vast amount of radioactive materials was released into the atmosphere, contaminating the food and livestock feed of several European countries at significant levels from a health point of view. As a result, this accident significantly impacted the agricultural sector. For instance, about 23 % of Belarus territory (46 thousand km²), populated by 2.2 million people and 1.8 million ha agricultural land were contaminated with ^{137}Cs (37 kBq.m^{-2} was a definition of contaminated land) of which 265 000 ha were totally excluded from the agricultural system [2, 3].

In contrast with Chernobyl, the land around the Fukushima Daiichi power plant is ~70% forest on mountainous catchments with agricultural land confined to the lower slopes and valley floors where there are many paddy fields. And the most contaminated area (29 million Bq/m² to $^{134+137}$Cs) is immediately west of the Fukushima Daiichi nuclear power plant. As a result, 600 km² are exceeding 600 kBq.m^{-2} against 13 000 km² around Chernobyl.

2. Countermeasures in agriculture areas in Belarus after the Chernobyl accident

In this context, a large program of countermeasures was conducted to protect the human health from radioactive contamination of great magnitude. Environmental countermeasures have been applied since 1986 to urban, forest, aquatic and agricultural ecosystems [1]. These measures have been taken to ensure that agricultural products were only introduced into the European Union market according to common arrangements which safeguard the health of the population while maintaining the market unity. The implementation of agricultural countermeasures after Chernobyl accident has been extensive, both in the most severely affected countries of the former USSR and in Western Europe. In the first weeks after the accident, the main aim of countermeasures application in the USSR was to lower ^{131}I activity concentrations in milk or to prevent contaminated milk from entering the food chain. The measures concerned for example the exclusion of contaminated pastures from the animals diet (changing from pasture to indoor feeding of uncontaminated feed) and the processing of rejected milk (mainly converting milk to storage products such as condensed or dried milk, cheese or butter) [1]. From June 1986, other countermeasures aimed at reducing ^{137}Cs uptake into farm products were implemented. Particularly in the field of agricultural production for the contaminated territories, the radionuclides concentration in the main food products significantly decreased compared to the first years after the Chernobyl disaster.

Impressive results were achieved between 1987 and 1990 through the implementation, for farms, of complex agro-technical and agrochemicals measures, zootechnical and veterinary measures designed to reduce the transfer of radionuclides (^{137}Cs and ^{90}Sr) in the chain "soil - plants - animals - agricultural production ".

Application of countermeasures aimed at lowering ^{137}Cs activity concentrations in milk and meat was the key focus of the remediation strategy for intensive agriculture. In 1986-1987, in the public sector the production of milk with a higher than the permissible content of caesium-137 amounted to 524.6 thousand tons. In 2008, in the most severely contaminated Gomel region, only about 90 tons of milk with the content of caesium-137 from 100 to 370 Bq/l was produced and supplied for further processing. The levels of caesium-137 in the milk produced by the farms of the Mogilev region and in the Brest region did not exceed 37 Bq/l and 65 Bq/l respectively (with a permissible level of 100 Bq/l). The main aim of agricultural countermeasures was to achieve a production of food products with radionuclide activity concentrations below action levels and to minimize the total quantity of radionuclide activity in agricultural production for consumption and/or distribution. From 1992 to present days (thirty years after the accident), the use of agrochemicals and agro-technical measures continued despite of financial constraints. For instance, in the Republic of Belarus, recommendations were developed with regard to the agricultural production management for the situation of radioactive contamination of lands, as well as the Republican Permitted Levels for caesium and strontium in food products and drinking water [4], [5]. The system of protective measures applied in the agrarian production is shown in the diagram thereafter and some will be detailed during the presentation (soil treatment, caesium binders, etc.) (cf. Fig. 1).

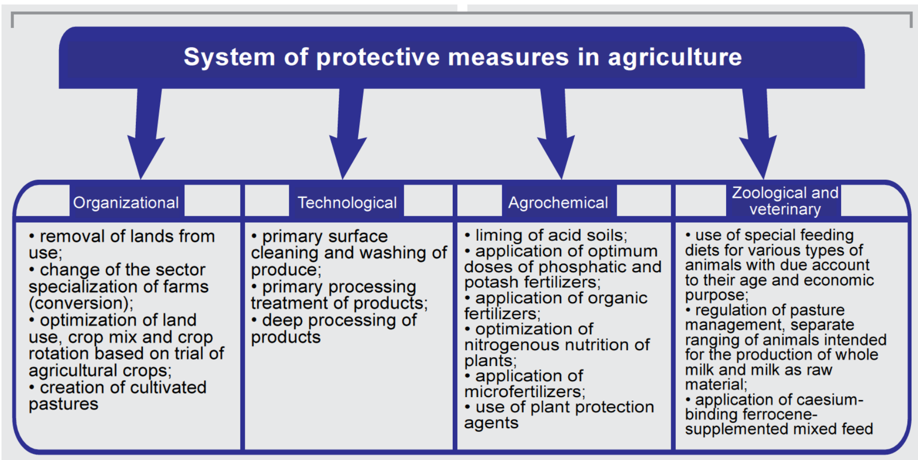

Fig.1: Protective measures System in agriculture in the Republic of Belarus [4]

One of the crucial problems related to agricultural production in the contaminated districts is to limit the entry of radionuclides in food products, to reduce the level of exposure as much as reasonably achievable. Both external and internal exposure pathways were important after Chernobyl accident. The importance of internal exposure pathways, for both agricultural and wild food from forests was highly dependent on the soil type and was often relatively high [7]. This issue can be solved by a set of actions to attenuate the migration of radionuclides in the links of the biological chain "soil to plant" and "plant (forage) to agricultural animals." For example, in Belarus, practice showed that the introduction of protective measures with proven effectiveness and specific processes in the cultivation of plants used to reduce the concentration of radionuclides in production (cereals, potatoes, vegetables) by a factor between 1.5 and 4.0. The introduction of protection measures in livestock (Prussian blue for example) decreases the radionuclides concentration in milk, meat and eggs by a factor of 3 to 7. Moreover, the re-specialization of farms in Belarus towards products minimizing radionuclide concentration is another route to reduce the input of radionuclides in the pathway to human body. These include revenues from the meat and dairy farming, breeding pigs, or the creation of poultry farms. Calculations show that a change in direction of current production (potatoes production, cereals production , dairy) to, preferably, beef, pork and bacon, chicken, fatty dairy products (cream , butter, ghee) would reduce the entry of radionuclides in food products by a factor of 1.5 to 2.0, and proportionally reduce the dose of internal radiation exposure. Currently in all three countries of the former USSR clean feeding remains an important countermeasure to ensure that meat from intensive farms can be marketed. For instance, in the Russian Federation, fertilizers are supplied to intensive farms. For private farms, Prussian blue is provided for privately produced milk and, on request, for privately produced meat intended for market [1]. The effectiveness of the different agricultural countermeasures in use on farms in Belarus is summarized in Table 1. The reduction factors (ratio of radiocaesium activity concentration in the product before and after countermeasure application) achieved by each measure are given.

Table 1: Efficiency of some protective measures in Republic of Belarus [4]

Working method	Efficiency
Combination of the primary and additional cultivation jobs, subsoil tillage (chisel, disk) and minimum cultivation, taking account of the soil type, moistening pattern, application of high-capacity equipment	Reduction of radionuclide accumulation in crops up to 1.3 times
Soil liming	Reduction of radionuclide accumulation in crops by 1.5-3 times
Application of organic fertilizers	Reduction of radionuclide accumulation in crops up to 1.3 times
Application of new forms of slow-acting nitrogen fertilizers	Reduction of radionuclide accumulation up to 1.4 times, nitrates in potatoes, vegetables and feed crops
Application of phosphorus fertilizers	Reduction of Cs-137 accumulation in crops up to 1.5 times, Sr-90 – by 1.2-3.5 times
Application of potash fertilizers	Reduction of Cs-137 accumulation in crops up to 2 times, Sr-90 – up to 1.5 times
Selection of species and varieties of crops with minimum accumulation	Reduction of radionuclide accumulation in crops depending on the plant species up to 30 times, depending on the variety – up to 7 times
Radical improvement of hayfields and pastures	Reduction of radionuclide accumulation in grass stand by 2.5–6 times
Surface improvement of hayfields and pastures	Reduction of radionuclide accumulation in grass stand by 1.5 – 2.9 times
Application of caesium-binding ferrocene-supplemented mixed feed for cattle	Reduction of Cs-137 accumulation in milk and meat by 2-3 times
Special feeding diets for various types of animals with due account to their age and other factors	Reduction of Cs-137 accumulation in milk and meat by 1.5 – 2.5 times

3. Countermeasures in agriculture areas in Japan after the Fukushima accident

After the Fukushima Daiichi accident, Japan faced a large caesium contamination of its land and countermeasures were also taken on agricultural productions. First, the experience gained during the response to the Chernobyl contamination was used as a start, and then specificity of Japanese crops (e.g. rice and soja) and soil was taken into account to adapt the countermeasures. The objectives were the same: to reduce radiation doses from the environment that have resulted from the accident. Food with radiocaesium activity concentration that exceeds the action level is not allowed to enter the food distribution system. Compliance with the action levels for food is demonstrated by an extensive and comprehensive food monitoring program for foods produced in contaminated areas. The low action levels applied in Japan led to extensive restrictions on the use of agricultural land, especially in 2012. To produce food below the action levels, it has necessary to remediate some agricultural land [6], [7]. After the Fukushima Daiichi accident, contaminated land was divided into the Special Decontamination Area (SDA), which was evacuated and divided into three subareas and the Intensive Contamination Survey Area (ICSA) where the additional annual effective dose is projected to be higher than 1 mSv. Also, the main types of remediation applied to farmland, applicable to both SDA and ICSA, depend on the radiocaesium activity concentration (Table 2). Remediation measures for each area of farmland are selected on a case by case basis, taking into account the farmer's opinion. For example, some fruit trees were decontaminated by high pressure washing and whittling (paring shavings from wood) of tree surfaces to remove a major part of radiocaesium. For other cases as the persimmon trees in Date, the choice was not to decontaminate the trees but to remove the upper layer of the land and to support financially the loss of one production year.

In the ICSA, the first decontamination action consisted in removing the topsoil by stripping, which conducted to reduce the dose rate, but has generated a large amount of waste and impoverished the soil. Alternative measures have been then applied to benefit natural caesium sorption in clay and its low transfer to crops (improved by addition of fertilizer and potassium in the soil). To ensure that ^{134}Cs and ^{137}Cs in soil used for agricultural production are not artificially enhanced by the addition of fertilizers, an action level of 400 Bq/kg has been applied for fertilizers, soil conditioners and compost used to grow seedlings. Sewage sludge from water treatment facility in the Fukushima prefecture is now radiologically controlled and contamination thresholds for using them as fertilizer, lower than 400 Bq/kg, are discussion topics between agricultural producers, municipality and population. Moreover, ploughing the soil proved to be as efficient to reduce the dose rate and the volume of waste as removal. This approach has allowed conserving the nutrients in the soil and reducing the amount of contaminated soil that should have been treated as radioactive waste [6]. Soil removal was yet considered when caesium activity concentration was high (cf. Table 2).

The ploughing of many kitchen gardens and orchards soon after the accident contributed to a reduction in the levels of radiocaesium in soils (through the dilution of the upper contaminated layers with deeper uncontaminated soil layers) [6]. Residents of contaminated areas can bring locally produced food from their kitchen gardens, freshwater systems or forests to local measuring facilities.

Table 2: Applicability of remediation measures to reduce both internal and external dose from utilization of farmland in Japan [6]

Applicable techniques	**Radiocaesium activity concentration in soil (Bq/kg dry weight)**			
	<5 000	**5 000-10 000**	**10 000-25 000**	**>25 000**
Cultivation with reduced transfer of ^{134}Cs and ^{137}Cs using potassium, fertilizer	X			
Reversal tillage (fields, rice paddies, grassland)	X	X		
Soil suspension in waste and/removal with extracted water (rice paddies)		X		
Topsoil removal (fields, rice paddies, grassland)		X	X	
Soil removal using a solidification agent		X	X	X
Weed/grass/pasture removal		X	X	X

After the Fukushima accident, the restrictions on food production and food monitoring, combined with generally lower soil to plant uptake, meant that external exposure pathways were more important. Moreover, overall, the comprehensive implementation of food restrictions and monitoring has protected people and improved confidence in farm produce, as reflected to varying extents by the improving market price of some crops. For instance, numerical criteria are used for the management of agricultural sectors (use of criteria lower than the permissible levels because taking into account all the upstream of the agricultural sector including waste used as fertilizer).

4. Conclusions

Finally, the remedial measures used after each accident for agricultural areas are compared below in Table 3. After the Chernobyl accident, the countermeasures essentially concerned measures for animal products. Radical improvement of agricultural land by combining ploughing, reseeding and additional fertilization was extensively used in the first 5 y and was very effective in improving the fertility of the land and reducing radiocaesium uptake onto fodder and other crops [7]. The countermeasures applied in the agriculture of Belarus proved to be highly efficient. The ^{137}Cs activity into food chain has decreased by factor of 20-22, ^{90}Sr – by a factor of 4. The contamination of all foodstuff and raw materials produced in state and cooperative farms are with radionuclide content below permissible level established in 1999 [5]. After the Fukushima accident, the development of countermeasures was focused on crops and particularly paddy fields where additional exchangeable potassium has often been widely applied.

Furthermore, rehabilitation programs need to consider not only radiological protection but also social and economic dimensions. The involvement of rural inhabitants in processes of self-rehabilitation and self-development could be a way to improve the people quality of life on radioactive contaminated territory as a common heritage. It is important that the objective of involving the stakeholders is not to promote the acceptability of the accident but to build trust and understanding between them. All those who were involved expressed that preparedness for managing contaminated goods is crucial to be ready, in order to react promptly if an accident would occur. Especially, long-term perspectives have to be considered while implementing the countermeasure actions (including restrictions over consumption and production, food quality control and redeployment of agricultural activities). Feedback provided by Japanese experts and stakeholders engaged in the follow-up of the Fukushima accident is of upmost importance and these lessons must provide us with reflection to improve our national emergency and post-accidental response.

Table 3: Comparison of agricultural countermeasures [1], [5], [6], [7]

Applicable techniques	Chernobyl	Fukushima
Countermeasures for animal products		
Clean feeding	X	X
AFCF to animals	X	
Live monitoring of domestic animals	X	
Countermeasures in agricultural land		
Radical improvement – ploughing, reseeding, additional fertilization	X	
Soil removal		X
Tillage reversal		X
Soil treatment with additional K and P	X	X
Soil amendement with liming	X	
Application of sorbents and organic fertilisers	X	
Drainage of wet peats	X	
Paddy fields puddling and removal of suspended sediment		X
Removal of plants		X
Soil hardening and removal		X

The presentation focuses both on Chernobyl and Fukushima response to the food and agricultural products contamination.

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Countermeasures in agriculture in emergency and long-term phases of the accident at the Chernobyl nuclear power plant. Experience of Belarus.

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Protective measures that provide effective reduction of internal exposures should be selected based on either of the following categories of people:

1) those who live in contaminated areas,
2) those who live in "clean" areas, but consume food produced in contaminated areas.

Review of acceptable exposure levels in Belarus took place more than once during the post-Chernobyl period. In 1986, a dose limit of 250 mSv/year was established to exclude any deterministic effects of exposure. Later, a life-time dose limit of 350 mSv was set.

The main objective during the early phase after an accident (in case of the Chernobyl accident it lasted 10 days) should be to prevent acute somatic injury and to reduce public exposure to as low as possible by implementing such measures as sheltering, protection of respiratory organs, Iodine prophylaxis and, if necessary, evacuation.

During the intermediate phase after the Chernobyl accident the goal was to minimize potential long-term stochastic effects. This problem was solved by means of scientific justification of the temporary levels of annual doses. Initially, it was assumed that this phase would last 1 year, but in fact it took at least 2 years before transition to the next phase. The second phase, from radiation safety perspective, was focused on minimization of potential somatic-stochastic (cancer) effects and adverse hereditary consequences. Thus, the following dose limits were set for population in the accident-affected area: 100 mSv for the first year after the accident; 30 mSv for 1987; and 25 mSv in 1988 and 1989 each. Moreover, to keep exposures within the set limits, permissible levels of radionuclides in food and feed were set in the country. It should be emphasized, that the risk of long-term effects is determined mainly by an accumulated dose and almost does not depend on variances of dose rates in the range of 5-20 mSv/year. In case protective measures (countermeasures) fail to insure the dose limits set per year in a particular residence area, people living in that area must be relocated.

Implementation of complex countermeasures at different technological stages of agricultural production makes it possible to manage the processes of production and utilization of agricultural produce, which in its turn insures reduction of radiation doses received by population. Because of this fact, the standards for radionuclide concentration levels in foodstuffs should be subject to regular revision. For instance, the national permissible levels in Belarus have been revised six times since the Chernobyl accident. Even so, they always remained much stricter compared with the standards set in other affected countries.
In some other affected countries, radiobiological approaches played much lesser role and countermeasures, national reference levels and standards for foodstuffs were based on social, economic, political and psychological factors.

It should be noted, however, that countermeasures in agricultural sector of the affected areas are well-received by local population; countermeasures lead to reduction of collective and individual doses, and they also result in economic advantages (increase in yields and animal productivity), social and psychological benefits.

Reduction of ^{137}Cs concentrations in agricultural produce occurs exponentially and is influenced by three groups of factors:

1) natural biochemical processes which determine reduction of biological availability of radionuclides in the soil-to-plant chain,
2) protective measures (countermeasures),
3) radioactive decay.

Thus, in the first years after the Chernobyl accident, the major contribution to reduction of ^{137}Cs accumulation by plants on agricultural lands of Belarus where countermeasures were not implemented was governed by natural biochemical processes (95%), whereas contribution of radioactive decay on the same lands with no countermeasures was not higher than 5%. This is due to active fixation of radionuclides in soil and their low biologically availability to be included in agricultural chains of migration. Such processes may still remain dominant factors in reduction of radionuclide uptake by plants even 5-10 years after the accident. After 20 years, however, the most important factor which determines reduction of ^{137}Cs uptake by plants is radioactive decay of this radionuclide. At present, for example, contribution of radioactive decay in reduced ^{137}Cs transfer into farm products makes up 90% and more.

Agricultural practice has shown that implementation of complex agricultural countermeasures provides for production of crop and animal products corresponding to permissible levels of ^{137}Cs and ^{90}Sr concentrations in these products. Countermeasures can vary significantly depending on stages of production and a particular product produced. Agricultural countermeasures are implemented in the key chains of radionuclide transfer into products: soil-to-plant, forage-to-animal, or raw material-to-end product chain.

Implementation of countermeasures, depending on their intensity, may result in 18-36% reduction of ^{137}Cs accumulation by plants in the first period after the accident, 10-23% in the second period, and 5-13% reduction in the long-term.

The most available and feasible protective measures are those aimed at reduction of radionuclide transfer into plants and crops grown on arable lands. Mineral and organic fertilization does not require additional equipment, or modification of cultivation technique, but improves physical and agro-chemical properties of soils and also raises crop yields.

To prevent or reduce internal exposures, it is necessary to implement countermeasures that would lower transfer of radionuclides in forages. Implementation of countermeasures (i.e. root improvement of natural grasslands, re-grassing of cultivated lands) on grasslands and pastures used for milk and meat animal production largely contributes to reduction of internal radiation doses of population in the affected areas.

Disk plowing and tilling with application of potassium and mineral fertilizers reduce ^{137}Cs and ^{90}Sr uptake by meadow grasses on mineral soils 3-5 times. Radical improvement of grasslands is also an effective countermeasure to reduce ^{137}Cs transfer to cultivated grass stands. With respect to ^{90}Sr, however, such methods are not that effective. With time, as cultivated grasses become degraded, increase of radionuclide concentrations in hay and fodders can be observed. Therefore, re-grassing of forage lands should be implemented every 3-6 years, depending on the type of meadows and soil properties.

During 1986-1990, half-life periods of ^{137}Cs transfer to crops was from several months to 1.5 years (grain crops $T_{1/2}$ 1.0-1.8 years; potato $T_{1/2}$ 0.8–1.2 years). In 1991-1998, $T_{1/2}$ was from 5.0 to 13 years. Implementation of countermeasures in agricultural sector during the first years after the Chernobyl disaster provided for 3–8-times reduction of ^{137}Cs transfer to agricultural crops. In the subsequent period, contribution of natural processes (cesium fixation by clay minerals, radioactive decay) prevails over that achieved due to countermeasures. Effectiveness of protective measures during 1992–2010 declined on average by 50–80%. Nowadays, the major contributor to reduction of ^{137}Cs concentrations in agricultural produce is radioactive decay. Vegetable crops have different abilities in relation to ^{137}Cs uptake. Rational selection of crop types is the most available technique insuring lower ^{137}Cs transfers into crop yields.

Primary and technological processing of agricultural products as well as cooking techniques are effective protective measures to reduce ^{137}Cs and ^{90}Sr contamination levels in ready-to-eat food. Thus, for instance, rape and sunflower seed processing leads to 250-times reduction of cesium and 600-times of strontium concentrations in oil end product. After grinding wheat, rye, or barley grains radionuclide contents lower by 2-times when grind for white flour, and by 1.5 times when grind for cereal. Potato and grain processing for alcohol almost excludes any radionuclide concentration in the end product.

Pilled potatoes become 20% less contaminated by ^{137}Cs and ^{90}Sr; potato processing into starch leads to 2% reduction of radionuclide concentrations in the end product.

Processing of milk into butter and rennet cheese makes the end products from 8 to 10 times cleaner from ^{137}Cs and ^{90}Sr contamination: from 4 to 6 times when processed for cream, sour cream or cottage cheese.

If it is impossible to produce clean crop production on the affected lands, or in case consumption of contaminated products contributes to high internal doses, the effective protective measure would be re-specialization of your farm production. Thus, for example, contaminated forage can be fed to animals with a focus on milk production, rather than meat production, and that would give 28-times reduction of collective radiation doses from cesium and strontium ingestion.

The national-local communication in the post-accident period in Belarus associated with continuous and direct interaction between the national level and the residents of the affected areas after the Chernobyl disaster was a challenging process.

Successful communication policy that promotes people's awareness and trust is not as simple in actual practice as it may look in developed action plans. This process requires regular sustainable efforts and never-fading government's attention and support. Approaches for communication and interaction should be developed or modified depending on the progress of the state of things in this particular area.

Communication with population should be continuous and transparent and should be carried out by different establishments at all levels. Not only the local authorities should be involved, but also the top-level bodies (Ministries, National Government), scientific institutions, NGOs, radiation control organizations, community initiatives. The basic interaction activities include social and psychological support of the affected population, training courses, production of educational and methodological materials, field trips of experts, etc. Special training courses for health-care and education professionals in the affected areas can be held in order to teach the medical staff and teachers of how to organize awareness-raising activities for different groups of population and what information should be given.

Radioecological skills of the residents of the affected areas can be improved by different means, including public lectures held by experts, dissemination of radiation-related printed materials, meetings and professional consultations, and so on.
Belarus experience has shown that among all the ways of improving the residents' knowledge of radiation safety in the affected areas, the best effective one is to do it through children and youth.

This is how the concept of the Centers for Practical Radiological Culture appeared. Created in rural schools in the affected districts, they now represent an essential element of Communication and Radiation Control systems.

Unlike radiation control centers, these new Centers, equipped with the basic measuring instrumentation, not only perform measurements of radionuclide concentrations in food, but also carry out educational work with children and assure dissemination of knowledge by involving in this process their families and friends.

Awareness-raising work of the Centers includes also individual consultations provided to the residents based on the food measurement and whole-body measurement results. This work implies informing critical citizens on the potential reasons for excess levels and the possible ways of their reduction. Whole-body measurements should be performed on a regular basis in order to determine the most critical groups of population and solve the problem of high doses.

Effective operation of Radiological Centers is achieved due to close interaction with all relevant stakeholders, including schools, medical institutions, scientific organizations, mass media and local governmental bodies. Performed in the form of educational lectures or in a more creative way, they can be special video films, lectures, stage plays, workshops, sports events, and many other events in which local population are involved.

Due to active informative and practical roles of the Centers, significant results have been achieved in Belarus. The most important one is, of course, reduction of doses among the residents in the affected areas due to continuous information work and effective cooperation of the Centers with other stakeholders. Another positive effect of this work is the improved credibility of the whole population of the country to the fact that living in the affected territories is not only possible but, what is more important, safe.

Involvement of stakeholders in the processes of post-accident management is an absolutely essential element of recovery and rehabilitation. The better effectiveness can be reached through multi-level complex meetings that combine stakeholders from all levels and areas of activity, from common residents to governmental officials. Such meetings should be focused on raising people's credibility to the affected areas, but may as well have different objectives depending on the target groups of the meetings. In Belarus, for instance, they can be meetings with participation of all groups of local population arranged in schools and so-called houses of culture in the affected areas, with the participation of researchers, forestry and agriculture specialists, local officials, doctors and sanitary services. Apart from discussions and medical consultations, participants can measure the food they bring with them, and be measured on whole body counters, as well as get some free handouts. As a rule, such meetings end up with sports events, where children are involved together with adults, to promote healthy life style. Other meetings can be organized for specialists, including medical professionals, farmers, school teachers and representatives of rural councils, district and regional authorities. However, unlike area-specific seminars, multi-level meetings can be considered most effective as they create a positive environment for discussion and generate the spirit of unity and integrity facilitating better understanding of the importance of public involvement in the post-accident management processes, and return of informed confidence in safety of living and working conditions in the areas regarded as contaminated.

Region-specific parameterisation of spanish mediterranean areas to reduce the uncertainties in the management of the long-term rehabilitation

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1. Introduction

The prediction of food contamination and doses to humans in existing exposure situations, after a nuclear accident, is a key element in the implementation and management of the long-term rehabilitation process. The assessment relies on the ability of the modelling to predict the time dependence of the transfer processes, namely food chain pathway, but also on the availability of reliable parameters. This issue has a significant influence on reducing the uncertainties of the estimated doses and the response of the potential recovery strategies to be applied, as the use of region-specific parameters implies a more realistic assessment of the radiological impact.

The European Decision Support System JRODOS, integrates for this assessment, the Terrestrial Food Chain and Dose Module (FDMT), where the region-specific parameters are covered by Central European values, as default values, being not sufficiently representative of other European regions. Such may be the case of the Mediterranean area, were the parameterisation of the information needed to represent its agricultural and grazing practises is restricted to the constraints imposed by default.

In the European R&D framework some initiatives have been undertaken to improve the food chain modelling and the parameterisation of region-specific values. Within the COMET project (Coordination and Implementation of a pan-Europe Instrument for Radioecology), in particular under the task: Initial Research Activity on Human Food Chain Modelling, an exercise to study the effect of regional parameters (Mediterranean and Nordic regions) on the food chain modelling has been developed.

For this purpose, it has been necessary to derive updated food chain parameter values appropriate for Mediterranean and Nordic terrestrial ecosystems, and apply them in a defined scenario, allowing the comparison of the results obtained in terms of activity concentrations in selected foodstuffs and intake doses for different age groups, to the results obtained from the default parameters.

This paper summarizes the case study for the Spanish Mediterranean region using FDMT-JRODOS.

2. Mediterranean Parameterisation

The selected region-specific parameterisation has been focussed in the following: foodstuff consumption rates, sowing and harvesting periods, leaf area indices, crop yields, feedstuffs and the animal feeding regimes. Where possible, all the information needed has been collected from National statistics, however, assumptions have been necessary in order to adapt the information to the parameters considered and to meet the requirements of the database structure of JRODOS.

2.1 Food Consumption rates

The Spanish parameter values on food consumption rates have been obtained from the National Food Survey ENALIA [1], in an individual basis, carried out by the Spanish Food Safety and Nutrition Agency (AECOSAN). It has been conducted according to a harmonized and agreed approach in Europe, provided by the European Food Safety Agency (EFSA) [2]. The parameter values and databases have therefore a common structure along the European countries, facilitating comparison purposes.

Five age groups are included in ENALIA: 3-11 months, 1-3 years, 4-9 years, 10-18 years and adults. These, are very similar to the age groups considered in JRODOS, and in spite of the slight differences in the age range of children, they have been assumed as representative of them. Regarding the foodstuffs, the selection considered for JRODOS has been kept, although some of the products are not so important in the whole of the Mediterranean diet, while others which are basic components of it, are missing. In order to match both, several assumptions have been necessary, including different grouping and equivalences [3].

2.2 Parameters related to the sowing, harvest, growing periods and crop yields

The National crop calendar [4] has been the source for the sowing, harvesting and mean growing period dates of crops, as indicated in the JRODOS database. The data are given at province and National levels, being these used to obtain the most representative values, for each crop, with the following assumptions:

- The sowing date (D_S), in Julian days, is set the first day of the month with the maximum percentage of seeded surface.
- The date of harvest (D_H) in Julian days is set the last day of the month with the maximum harvested production.
- The mean growing period (MPG), comprises, in days, the D_S and the D_H.

The leaf area development, described as the Leaf Area Index (LAI), is a function of the plant´s growing period. The reference used to estimate the data for the Spanish crops is the plant growth database of the SWAT model [5]. It has been assumed that the growing period is divided into four growing stages, as seen in Figure 1, where:

1. Initial stage (L_{ini}): covers from D_S until the crop covers about 10% of the ground.
2. Crop development stage (L_{dev}): covers from the end of L_{ini} until the crop covers 70-80% of the ground; (not necessarily is the crop at its maximum height).
3. The mid-season stage (L_{mid}): covers from the end of L_{dev} until maturity; it includes flowering and grain-setting.
4. The late season stage (L_{lat}): from the end of L_{mid} until D_H, it includes ripening.

The duration (as fraction of the total growing season) of the various growing stages for the Mediterranean crops of concern, have been extracted from values compiled in the report FAO 56 [6]. Applying these to the values of MPG of the Spanish crops and beginning from the D_S, the dates D_{dev}, D_{mid}, D_{lat} are established. The respective LAI values are calculated for these dates, intermediate point of the sigmoid part of the curve (crop development stage) and intermediate point of the descending straight line (last season stage).

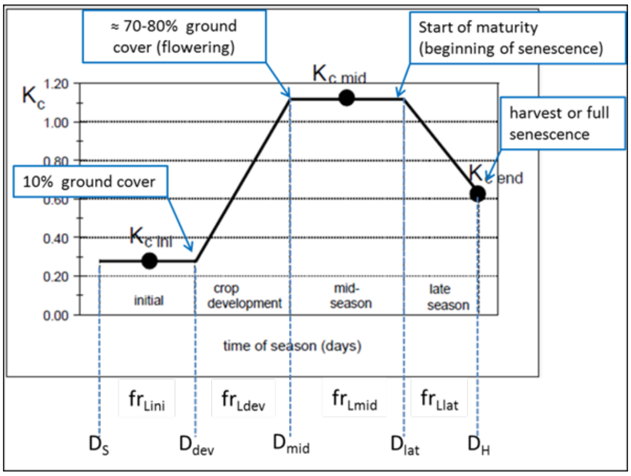

Figure 1. Typical curve of the temporal evolution of crop growing (in this case, represented by the Crop coefficient Kc).

The Spanish crop yield values have been taken from the National agricultural statistics [7], in terms of mean values (kg m^{-2}) per crop type, on dry and irrigated surfaces, at province and National levels. Several assumptions have been made to adapt this information to the JRODOS database, among them the grouping of some crops and in other cases the crop taken as reference [3].

2.3 Feedstuffs and animal feeding regime

Feed resources for animals are set out in the National agricultural statistics under the headings of forage crops, grassland and grazed forest and shrub land [7]. Two feeding regimes are distinguished, extensive, outdoor, with a diet based on natural pastures and intensive, indoor with a diet based on fodder and forage crops. For the Mediterranean parameterisation, it has been assumed that extensive systems are the feeding basis of the livestock for meat, including beef cattle, pork, lamb and goat while the intensive ones are mainly to production of cow's milk. The feeding diets, as daily intake rate throughout the year, have been estimated taking into account the nutritional needs of an animal-type, under each specific feeding regime, the distribution of the forage and grass production along the year and the stocking capacity of the grazing areas [8, 9, 10]

3. JRODOS Results

To study the effect of the region-specific parameters, two scenarios were specified within the COMET project: a dry and a wet deposition scenario, the latter with a specified amount of rainfall. For both, the deposition date was set to 1st of August. Four radionuclides were selected: ^{134}Cs, ^{137}Cs, ^{90}Sr and ^{131}I with a deposit value of, 1000 Bq m^{-2} each. The model used in the Spanish case study is the FDMT included in JRODOS. The calculations have been performed with the JRODOS July 2014 Update 3 version.

The results obtained in terms of activity concentrations in selected foodstuffs and feedstuffs (cow milk, beef cow, leafy vegetables, winter wheat, flour wheat, pork, grass intensive, hay intensive and grass extensive), as well as intake doses for different age groups, have been compared to the results obtained from the default parameters.

The results obtained show clearly that the highest values occur in dry scenarios, both Default and Mediterranean, rather than in wet scenarios. The magnitude and temporal development of the activity concentrations in these foodstuffs, are clearly season dependant. During the selected deposition date, the winter cereals in the Mediterranean areas are already harvested, so the activity concentrations of winter wheat and flour wheat, in the following years, come from the root absorption of the radionuclides deposited on the bare soil and are several orders of magnitude lower. Figure 2 shows the winter wheat as example.

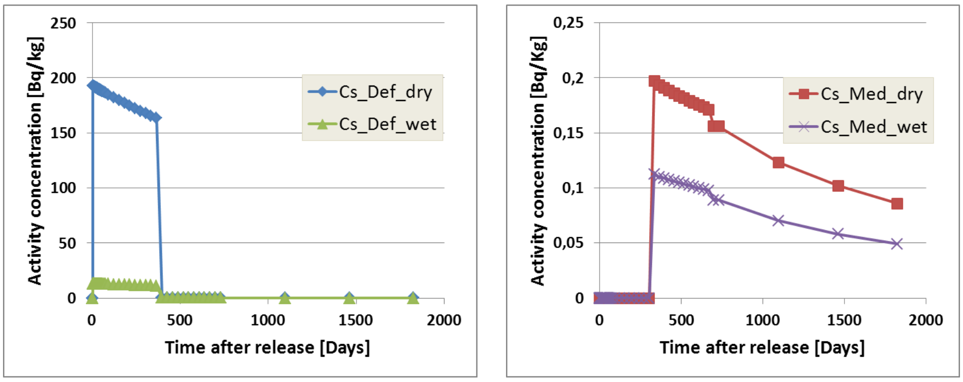

Figure 2. Activity concentration over time of cesium isotopes in Winter Wheat for the scenarios “Default” (left) and “Mediterranean” (right).

This seasonality will also affect the activity concentrations of the animal products due to the time schedule of the animal diet (grazing periods and feedstuffs ingestion). Figure 3, compares the evolution of the activity concentrations of cesium isotopes in Cow milk and Beef cow.

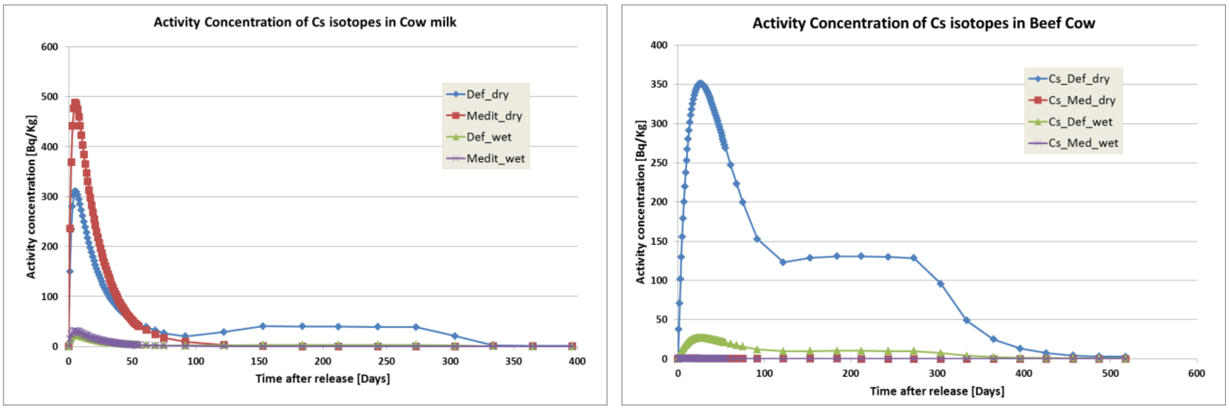

Figure 3. Activity concentration over time of cesium isotopes in Cow milk and Beef cow for the scenarios “Default” and “Mediterranean”.

The ranking of activity concentrations from the highest to the lowest values, among the different scenarios show the following trend:

- **Dry default > Dry Mediterranean >Wet default > Wet Mediterranean**, for the Leafy vegetables and Hay intensive products.
- **Dry Mediterranean > Dry default > Wet Mediterranean >Wet default**, for the intensive and extensive Grass, as well as Pork and Cow milk.
- **Dry default > Wet default > Dry Mediterranean > Wet Mediterranean**, for the Beef cow and Winter wheat products.

The values of the intake doses from Mediterranean scenarios are lower than the respective values from Default scenarios, for the three groups of isotopes studied (cesium, iodine and strontium isotopes). Only the values for cow milk are in the same range of magnitude; in the case of leafy vegetables, pork and winter wheat the doses are between one and two orders of magnitude lower (except for the iodine isotopes, than result irrelevant in the Mediterranean scenarios); in the case of beef cow and wheat flour the values are reduced in 3-4 orders of magnitude.

Regarding the contribution of the different foodstuffs to the intake dose, in each age group, the Default scenario shows, for the age group of 1 year, that the Cow milk is the product that contributes most to the doses, for the three radionuclides considered. For the age group above 10 years the doses come mostly from the ingestion of leafy vegetables, followed by the cow milk and the wheat flour. In the Mediterranean scenarios, the cow milk ingestion, in every age group, is the product that contributes most to the doses, followed by the leafy vegetables. In this scenario, there is a small contribution of Cs and I, due to pork and beef ingestion. Figure 4 shows the contribution of the most relevant products to the effective dose, five years after the accidental release.

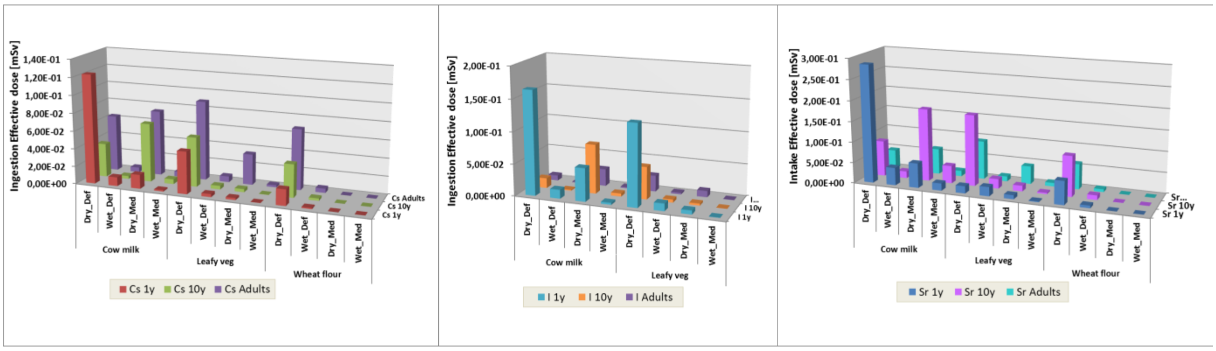

Figure 4. Contribution to the effective dose by ingestion, five years after of the accidental release, of the most relevant foodstuffs according to the isotopes group and age group. From left to right, the graphs show cesium, iodine and strontium isotopes, respectively.

4. Conclusions

In relation to the parameterisation, some difficulties have been encountered, related to both the structure and the parameters considered in the JRODOS databases. The structure, as it is right now, is not flexible enough preventing the incorporation of new foodstuffs and hindering the modification of some of the parameters considered. These have been solved in the best possible way, through various assumptions and guesses. However a more accurate parameterisation would need a new and more flexible structure of the database.

Regarding the execution of the case-study, several problems associated to the JRODOS system have been encountered. Among them, the module DEPOMPP (which should facilitate the input of the deposition values directly to the system) failed. For this reason, in order to fix the deposition values of the radionuclides selected an interpolation from a release scenario was needed. The availability of this module is foreseen as very useful in the long term management of contaminated areas, where the starting point of the assessment are the ground deposition values.

The results in terms of activity concentrations in the selected foodstuffs and feedstuffs show higher values in dry scenarios for both set of parameters, Mediterranean and default. In general, the results show important differences between the Mediterranean and the Central European (default) regions. The seasonality, in terms of deposition date versus growing period of the crops, is a key factor to determine the intake doses over time and consequently remediation strategies to be applied.

The values of the intake doses from Mediterranean scenarios are lower, for the three groups of radionuclides considered, than from the default scenarios; only the intake of cow milk give the same range of doses. These results are directly affected by the food consumption rates, therefore influencing the radiological impact on the population.

This case study has shown that if a realistic assessment of the radiological impact and an effective and optimum recovery strategy are pursued, it is necessary to use region-specific parameters.

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Towards inverse source term estimation using Big Data Technologies

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Introduction

In the field of atmospheric dispersion modelling and its application for supporting decision making during events of atmospheric releases of hazardous substances (including radioactive), "inverse source term estimation (STE)" and "source inversion" refer to computational methods aiming at estimating the location and / or the emitted quantities of the hazardous material using both observations (measurements) and results of dispersion models. Such methods are typically used when the presence of a hazardous substance above the background levels in the air is detected by an existing monitoring network, while its origin is unknown. The most characteristic example of a real case involving radioactive substances that have been detected before the release was officially announced is the Chernobyl Nuclear Power Plant accident. The Algeciras incident is another example of an unknown radioactive release that was traced back after radioactivity levels higher than the background have been observed at very long distances from the release location.

Most commonly, inverse STE methods employ a (potentially large) number of forward or backward, in time, runs of dispersion models for the specific meteorological conditions that prevail at the times when the observations were made. Forward in time dispersion calculations can be made using as sources the potential (suspected) release locations, if these are fewer than the monitoring points where measurements exist. Backward in time dispersion calculations can be made by using the monitoring locations as sources and inversing the meteorological fields of wind velocity, if the monitoring locations are fewer than the potential release locations. The results of forward or backward dispersion calculations are then compared with the existing measurements through objective cost functions (that also include uncertainties of computations and measurements) to identify the most probable release location.

If the meteorological conditions are highly variable in time and space, the terrain is complex and the geographical area of interest is large, the use of advanced dispersion models with high spatial and temporal resolution is necessary. Under these conditions, inverse STE can be very time-consuming, which is a drawback in the frame of emergency response when timing is critical. In this paper we present and evaluate a data-scientific approach for inverse STE in which the bulk of computations by advanced meteorological and dispersion models is made before an actual emergency. The modelling results are stored and, in cases of emergency due to detection of hazardous substances in the atmosphere, they are retrieved and, combined with current measurements, they provide a rapid estimation of the potential source location. In this respect, the aid of Big Data software technologies is necessary.

Methodology Outline

The implementation of the algorithm and the experimental analyses are performed using the Big Data Europe[1] (BDE) platform and application architecture. Part of the BDE project's goal is to create a big-data application aggregator which is versatile and easy-enough to encourage data-related progress in a diverse set of areas of societal impact. The BDE platform provides an aggregation of widely-used and specialised tools employed for big-data storage, processing and analysis. Its architecture is based on containerisation (the current implementation makes use of Docker[2] containers), which is a form of lightweight virtualisation and ensures deployability over a host of different platforms.

The design and implementation of our use-case involves two parallel pipelines of data transformation and control. The first is a batch processing dataflow which processes and analyses weather data to drive plume dispersions based on previously learnt weather patterns. As part of this use-case, we make use of a dockerised version of the WRF modelling system[3]. The raw data are pre-processed to obtain coarse (in spatial and temporal resolution) representations of atmospheric circulations over the European domain in the NetCDF format[4]. In a machine-learning (ML) container the coarse data are being analysed and clustered using several statistics-based approaches to deduce weather patterns. The clustered data are then downscaled through WRF to achieve higher resolution versions of the weather patterns previously learnt. Using an advanced dispersion model, such as HYSPLIT[5] or DIPCOT[6] (the latter also available in JRODOS[7]), we pre-compute plume dispersions originating from specific locations (potential sources of hazardous pollutants) for each of the resulting weather patterns, before we store and index the dispersion-related results in a geospatially-aware database. Once these dispersion data have been indexed, we can match newly observed weather patterns and retrieve potential plume dispersions efficiently.

The second pipeline is interactive and can be used once the analysis described above has been completed. We use a web-based platform for visualising linked geospatial data. The user selects one of a set of weathers previously unseen by the system (in an operational setting this would be the actual currently observed weather) and a few coordinates simulating locations where radioactivity has hypothetically been detected (or real detection locations, in an operational setting). Given this information the system estimates the potential release origin(s) by making use of the use-case's ML component, interrogating the pattern dispersions database as needed. The result is routed back to the user via the graphical user interface.

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[1] https://www.big-data-europe.eu
[2] https://www.docker.com
[3] http://www.wrf-model.org
[4] http://www.unidata.ucar.edu/software/netcdf/
[5] http://ready.arl.noaa.gov/HYSPLIT.php
[6] http://pandora.meng.auth.gr/mds/showlong.php?id=35
[7] https://resy5.iket.kit.edu/JRODOS/

Application and evaluation

The particular use case presented here concerns release and dispersion of radioactive substances due to a hypothetical accident in a Nuclear Power Plant (NPP) located in Europe. The restriction of potential sources to NPPs is only made here to reduce the computational times in order to evaluate the method. The method can be directly extended to take into account any location of potential sources within the considered computational domain, in this case Europe.

Re-analysis global weather data (which represent the best available description of the atmosphere's state) covering a period of 11 years with a time resolution of 6 hours and spatial resolution of 0.7 degrees have been downloaded. We made use of NCAR services[8]—due to better compatibility with the WRF modelling system—to download data originating from ECMWF[9]. The downloaded global data were in GRIB2 format and included a large number of meteorological variables at multiple geopotential heights. From the global weather data, a geographical area covering Europe has been extracted and the corresponding data were processed and converted to NetCDF format through WPS (WRF pre-processor).

To derive weather patterns, *k*-means clustering has been selected as the most appropriate method based on relevant studies. Two approaches have been tested. In the first approach, *k*-means clustering has been applied on the raw weather data. But clustering may be more effective when operated upon more robust learnt features. In the latter tested approach, dimensionality reduction was performed on the raw data by employing stacked autoencoders. Then, *k*-means clustering was applied on the encoded weather circulation snapshots produced by the autoencoders. The variable considered for the clustering procedure was the geopotential height (GHT) of the 700 hPa pressure iso-surface based on earlier published works. Other variables, such as wind velocity, may also be used. Both procedures produced fifteen clusters (i.e., k=15) of typical atmospheric circulation patterns aiming to represent predominant weather conditions observed over Europe. For each of these typical weather patterns, dynamical downscaling to a finer resolution was carried out using the WRF modelling system. During the first-stage evaluation in the framework of this study, only temporal downscaling was carried out by WRF (i.e., from 6-hours to 1-hour time step). Spatial resolution may also be refined and this will be experimented with during the next stages of evaluating the method.

Using the WRF-calculated meteorological data, dispersion calculations were performed with the HYSPLIT model taking as source locations a limited number (i.e., 20) of European NPPs. These were randomly selected for this evaluation study as potential release locations. As noted, the application can be extended to include all European NPPs and furthermore any potential fixed source location. The dispersion results (concentrations and time-integrated concentrations) were obtained on a 15 × 15 km^2 grid covering the European continent at one-hour time steps and have been indexed and stored in a database.

In a real case of detected radiation levels above background due to an unknown source the actual weather is matched against the typical weather patterns. In this evaluation a past (real) weather is selected, which is not among those considered by the system in the clustering and learning steps. This weather is matched to a stored weather pattern and the

[8] http://rda.ucar.edu/datasets/ds627.0/
[9] http://www.ecmwf.int/en/research/climate-reanalysis/era-interim

corresponding pre-calculated dispersion results of the matched weather pattern are retrieved. The user specifies a number of geographical locations where supposedly radiation readings would have been detected. Ten and thirty locations have been tried to test the accuracy of the method depending on the amount of available information. The model-predicted dispersion patterns are compared to the “measurements” in order to identify the most probable source location. The tests were repeated to derive statistics of the method performance.

In Figure 1 the accuracy of the method in identifying the true release location (top-1) and in including the true release location among the three most probable release locations (top-3) is shown for the different parameters that have been tested (number of detection points and clustering method). It can be seen that for thirty detection points the probability that the true release location is among the three most probable locations suggested by the system is between 60% and 70%.

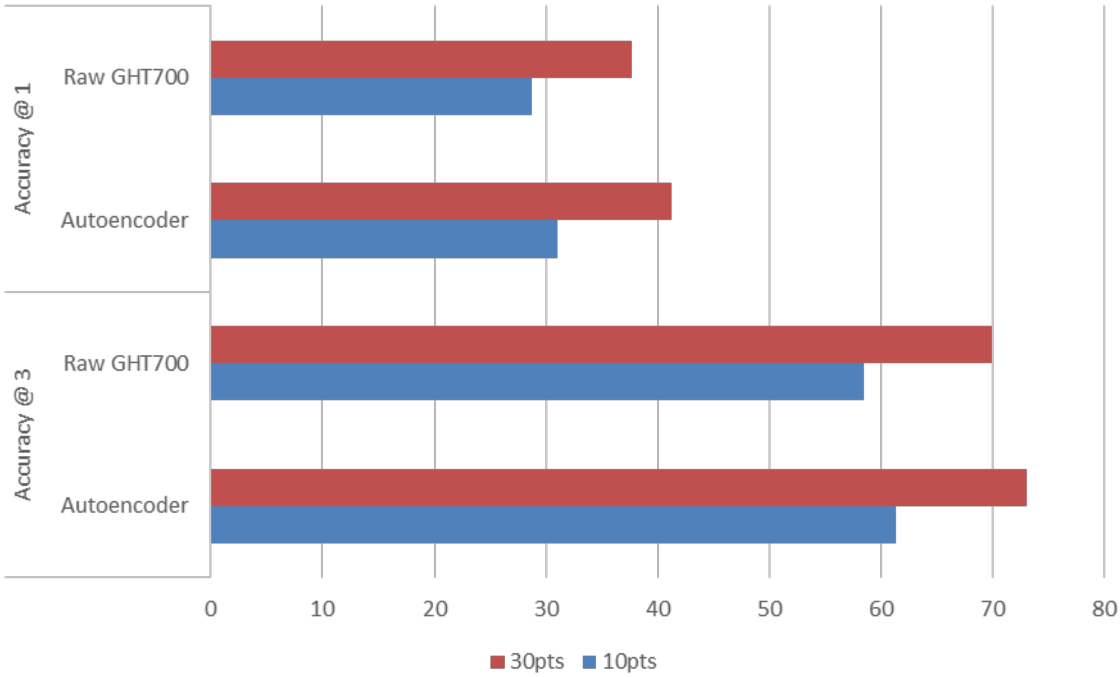

Figure 1: Accuracy of the method (%) in identifying the release location at top-1 and top-3

In Figure 2 a screenshot of the prototype is shown where a NPP is identified as the release location on the basis of the detection positions and the actual weather.

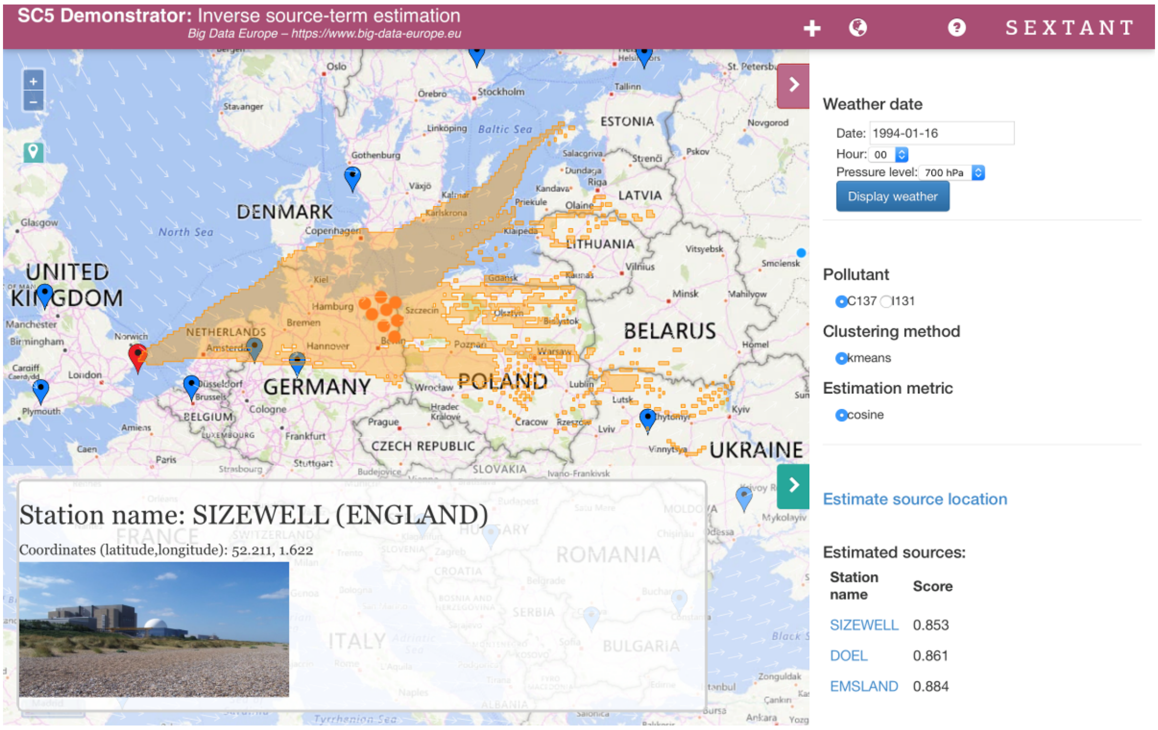

Figure 2: A screenshot of the system prototype

Conclusions

If a radioactive substance of unknown origin is detected in the atmosphere, the release location is estimated via inverse modelling. Depending on various factors such as the spatial scales, the complexity of terrain or of meteorological conditions, traditional inverse modelling can be computationally time-consuming and therefore its application can be problematic when timing is critical. In this paper we presented a data-scientific approach to inverse source term estimation, which allows us to perform the bulk of the processing prior to such an event taking place, therefore allowing for rapid estimation during an emergency. The algorithm has been implemented using the resources of the Big Data Europe platform and application architecture and has been built on two parallel workflows of data trans-formation and control. The first is a batch processing dataflow which processes and analyses weather data to extract and learn characteristic weather circulation patterns and finally create plume dispersions based on them. The latter are stored and indexed in a geospatially-aware database. The second workflow is used once the previous computations have been completed. Through a web-based platform that visualizes the geo-spatial data, the user can select the “current” weather and the locations on the map where radioactivity has been detected. The system matches the weather to the learnt weather patterns, extracts the corresponding plume dispersions and is able to identify the most probable release locations considering the positions where radioactivity has been detected.

The algorithm was evaluated by analysing weather data above Europe for a period of eleven years, extracting a number of weather circulation patterns (testing two different clustering approaches) and calculating corresponding plume dispersions from a number of European

NPPs. Weather data from a period not included in the above eleven years has been used as "current" weather. The accuracy of the method has been tested for different numbers of detectors and can reach 70% probability of including the correct release location among the top-3 most probable locations.

Future work is currently directed towards improving the algorithm by evaluating deeper models for feature extraction and selection and by evaluating different matching metrics and algorithms.

Acknowledgement

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Wind field characterization to improve evaluation criteria for radiological monitoring networks

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Abstract

As a consequence of the Fukushima accident, countries have reviewed and improved their Emergency Preparedness and Response (EP&R) arrangements and capabilities to manage a future nuclear accident with release to the atmosphere. In this context two important issues to be considered are the estimation of the areas likely to be affected by the nuclear release and the capability of the monitoring network in order to spot, delineate and track the potential radioactive cloud. One of the key factors to address is the analysis of the wind field characteristics at the Nuclear Power Plant (NPP), as it provides useful information about the potential displacement of the radioactive plume released. The purpose of the present work is to develop a possible methodology to estimate the areas which are more likely to be affected; being only based on the analysis of the wind field, this method could be used for any kind of industrial risk. Although far from being full-comprehensive as only meteorological data are used, the outcome may provide additional guidance when evaluating the monitoring networks' capabilities in the future. In this paper we explain the methodology proposed, which is based on calculating density maps from the set of air mass trajectories for a 10 years period for each NPP.

Introduction

Nuclear accidents with trans-boundary implications continuously trigger national and international efforts to reduce the impact of the consequences, e.g. by improving the Emergency Preparedness and Response (EP&R) arrangements and capabilities and by testing nuclear emergency procedures. One example is the annual ECUREX emergency preparedness exercise, organized by the European Commission, Directorate General for Energy. The purpose of this exercise is to test and to evaluate the emergency response under the relevant EU EPR arrangements (Council Decision 87/600) based on a simulated accident at one EU NPP. In this way the European Commission is able to test the ECURIE (European Community Urgent Radiological Information Exchange) and EURDEP (EUropean Radiological Data Exchange Platform) systems and carries out a comprehensive analysis on the performance of these emergency support systems.

In general, and at the early phase of an accident, the rapid measurement and assessment of dose rates and air concentration are the main requirements to be accomplished by a network. The spatial distribution of the monitoring stations of the national networks reveals important differences. Efforts to optimize national monitoring networks have been carried out. As an example, within the EU DETECT project, a methodology for optimizing the design of monitoring systems for timely and effective decision making in an emergency was developed (http://cordis.europa.eu/project/rcn/91297_en.html).

To evaluate, optimize or plan new monitoring networks, the factors controlling the scatter of particles in the atmosphere should also be taken into account. The aim of this paper is to describe the development of a method to evaluate monitoring networks' capabilities in order to detect and track nuclear radioactivity transport in the atmosphere based on the wind field characterization.

To achieve this goal, we have characterized the wind patterns at each European NPP by calculating the corresponding density maps from the set of air mass trajectories for a period of 10 years. These maps allow identifying the areas with more possibility of being affected following a hypothetical release from a NPP. In the present paper, we focus on explaining the methodology to obtain the density maps. In the future, this outcome, based on the influence of the wind component (wind direction and speed) on the transport and dispersion of the radionuclides in the atmosphere, combined with the location of the monitoring sites would allow the calculation of measuring parameters (Time of first alarm, waiting time,…) to characterize the network's capability to spot, delineate and track a radioactive cloud.

Methodology: Steps and tools towards density maps

Based on the trajectory points, a density map allows identifying the areas which are most frequently covered by the pass of air masses as well as the areas in which the air masses stay longer. The steps carried out and tools used to produce the density maps are the following (Figure 1):

<u>1) Calculation of trajectories (Figure 1a)</u>

A forward trajectory is defined as the path followed by the air parcel with time from a certain location. The basic methodological approach in this kind of analysis is to generate trajectories for a large number of possible meteorological conditions, so that statistical evaluations of the trajectories can reflect the climatological dispersion patterns of the atmosphere in the respective regions (e.g. Adame et al., 2015). The 10-year period (2007-2016) used in this study is sufficiently long for providing a good profile of the wind conditions. Four daily kinematic three dimensional trajectories (starting time at: 00, 06, 12, 18h) with duration of 96 hours, and at initial height of 100 m were calculated at each EU NPP by using the HYSPLIT model (Stein et al., 2015). A total of 14600 trajectories were calculated and stored for each NPP.

<u>2) Trajectory line into trajectory point (Figure 1b)</u>

A trajectory is no more than a succession of segments connecting consecutive points. So, a trajectory can be easily split into geographical points (latitude-longitude). Once the whole set of 96h forward trajectories for each NPP were calculated, each trajectory was split into its corresponding points. The total number of trajectory points was 1.401.600 for each NPP.

<u>3) Calculate Density map at each NPP applying kernel technique (Figure 1c-d)</u>

In order to obtain the set of density maps, we have applied the following methodology in each NPP: 1) the investigated region is covered by a regular grid, 2) for each cell, a circumference from the center is defined with a unique user-desired radius, 3) only the points within each circumference are considered, 4) the value of each considered point is weighted (obtaining smoothed values) by applying the selected kernel function (Wand and Jones, 1995) according to its distance from the center of each circumference and 5) the density value of each cell is the sum of the above smoothed values.

In the kernel-smoothing techniques the contribution of each value depends on the radius and the kernel-smoothing function applied, i.e. how the contribution of a single point value varies with the radius. The number of grid cells and their dimensions can also alter the final result. In the present study, we have used a grid cell size of 3 x 3 km and a radius of 6.4 km. The selection of this radius is based on the spatial trajectory error calculated for each set of trajectories (e.g. Stohl et al., 2001). Using this radius and this cell size, small differences are obtained in the shape and size of density maps obtained applying different kernel-smoothing techniques. In the present study, we have applied the kernel-smoothing modules implemented in the free and open source QGIS geographic information system (http://www.qgis.org). Considering these similarities, the quartic-weight kernel shape is used (Figure 1c). The label of the density map shown as an example in Figure 1d refers to high or low density of points.

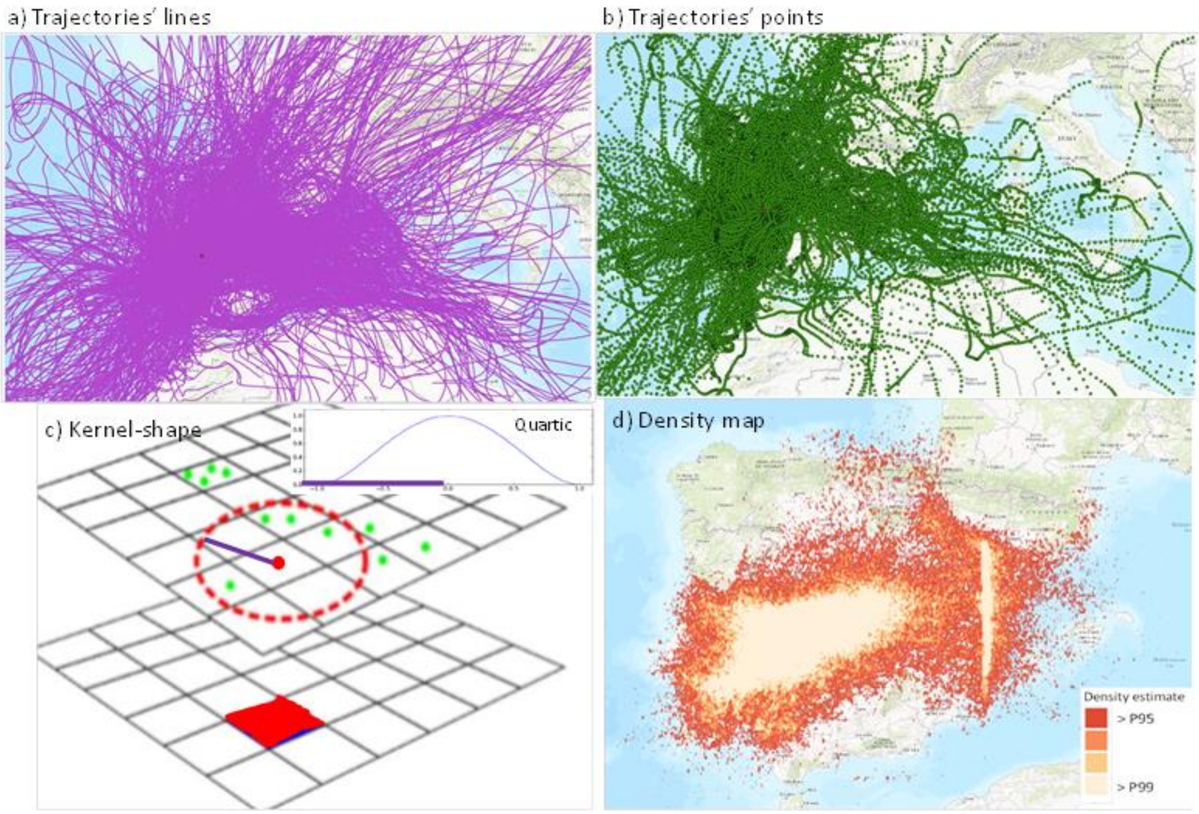

Figure 1. Steps and information used to produce the density maps: a) Set of trajectories from one NPP, b) convert trajectories' lines into trajectories' points, c) the kernel-shape method applied, and d) density map obtained. The density map expresses the probability estimate above 95 %; quartic kernel function bandwidth 6.4km.

Results

The application of the suggested methodology to all of the NPPs in Europe has revealed that the shape and size of the density maps depend on the place where the NPP is placed. As expected, the maps have pointed out the influence of the orographic European features in the wind fields, and therefore, in the dispersion of a hypothetical radioactive cloud. The final results are still under evaluation.

Conclusions

This paper addresses the methodology developed to estimate the dispersion patterns at the NPP and the areas that could be more affected under a potential radioactivity release from each one. The characterization of the wind field by the calculation of air mass trajectories for a long period is the key information to produce the corresponding density maps. The set of density maps are based on the air mass trajectories during the 2007-2016 period. The shape and size of each density map change from one site to another one according with the orographic features surrounding the release point.

In the future, overlapping these maps and the location of EURDEP monitoring stations would be possible to calculate several performance parameters, so providing information about the capability of the monitoring networks to adequately represent the spatial and temporal movement of a radioactive cloud. This outcome is of importance to answer questions such as whether there is an adequate number of sampling stations, whether there is a need of more sampling stations and where, or whether the use of mobile sampling stations or the seasonal change of sampling locations could be considered a solution to enhance the capability of a monitoring network.

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Radioactivity environmental monitoring measurements evaluation and dose assessment for radiation protection purpose in routine and emergency situations

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Introduction

Regulating radiological safety is a national duty. However, radiation emergency may cross borders of individual countries, and it is necessary a close cooperation between all the Member States to promote and increase the radiation protection for the public and the information available to the public by exchanging data and knowledge and by improving competences to prevent accidents and control hazards, to respond to emergencies and to manage any contamination risk.

Under the terms of Article 36 of the Euratom Treaty, Member States shall periodically communicate to the Commission information on environmental radioactivity levels which could affect population in routine and emergency situations. Additionally, the Italian Legislative Decree 230/1995 (transposition of Council Directive 96/29/EURATOM) requires measurement of radioactivity in the environment surrounding a nuclear installation (in accordance with Article 54 of the Euratom Treaty). The environmental radioactivity monitoring data from EU countries must be communicated to the European Commission so that it can carry out evaluations and compare radiation exposure of the population in different countries.

On 03 March 2016, it was signed the ***Collaboration Agreement*** between the ***Radioactivity Environmental Monitoring Group*** of the ***Joint Research Centre (JRC) of the European Commission*** and the ***Radiation Protection Institute (IRP)*** of the ***Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)*** aiming at performing joint research activity on the project "**REMME & DARP-Radioactivity Environmental Monitoring Measurements Evaluation and Dose Assessment for Radiation Protection purposes**". The aim of *REMME & DARP* is to summarize the available information about dose assessment for the public on the basis of the environmental radioactivity data in the European Union.

International overview

The European Union includes 28 countries in the European continent, in 14 Member States there are 128 operating nuclear power plants (Figure 1) and almost 30% of them are distributed in only two nations Britain and France (respectively 22.7% and 5.9%).

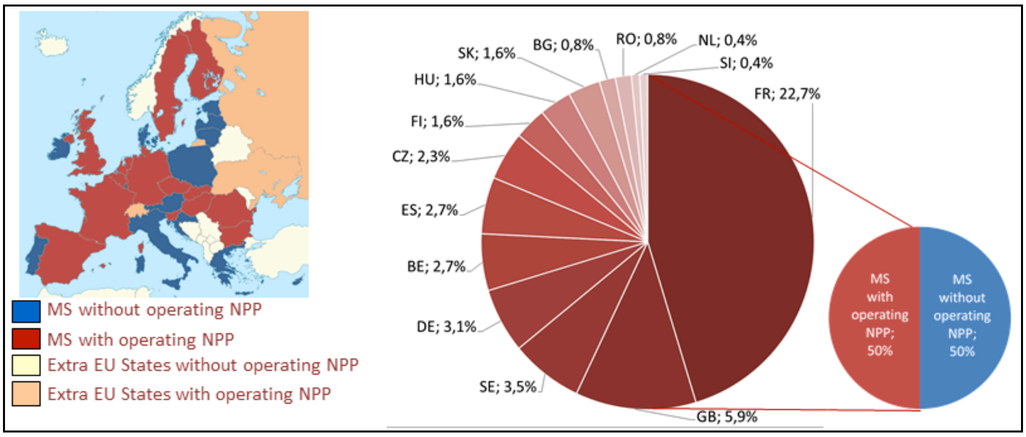

Figure 1 In 14 of the 28 Member States there are 128 Nuclear Power Plants (NPP). The states with the largest number of plants are France and Britain respectively with 58 and 15 nuclear installations.

One lesson learned from the experience during past incidents at nuclear plants is to assess globally the risk to the population in the European and extra European territory; it is obviously not possible to manage a nuclear or radiological emergency only in a national context.

The need for sharing information relating to the safety of the population has risen; the ***European Community Urgent Radiological Information Exchange (ECURIE)*** and the ***Radioactivity Environmental Monitoring (REM)*** database were instituted in the specific field of nuclear safety, managed by the European Commission as part of the Euratom Treaty applications. In addition, the ***European Radioactivity Data Exchange Platform (EURDEP)*** was established on the basis of bilateral agreements between individual member states and the European Commission.

Member States shall ensure that the dose limits for public exposure shall apply to the sum of annual exposures of a member of the public resulting from all authorized practices and the limit on the effective dose for public exposure is fixed at 1 mSv in a year (Art. 12 Directive 2013/59/Euratom [1]).

In order to ensure the control of population exposure to ionizing radiation across the whole of Europe, it is important that the Commission will be informed in a timely and consistent data on levels of environmental radioactivity measured in each Member State; therefore in the Recommendation 2000/473/Euratom the types of samples and the reference environmental measurements for monitoring in dense and sparse networks were tabulated, and the reportable levels for different environmental samples and various radionuclides were also defined. It is useful the review of existing operational procedures for dealing with long lasting releases, cross border problems in monitoring and food safety, as already has been studied in the NERIS PREPARE project.

All Member States shall take into account the maximum permitted levels of radioactive contamination in foodstuffs and animal feed following a nuclear accident or any other case of radiological emergency as defined in Euratom Regulation 2016/52 and CE Regulation 733/2008. In addition in the Directive 2013/51/Euratom, starting from the assumption that the water is an important pathway of incorporation of radionuclides, it is necessary the control of radioactive concentrations in water for human consumption: e.g. the concentration of radon, tritium and artificial radionuclides. Furthermore in compliance with the COUNCIL DIRECTIVE 2013/59/EURATOM a new concept of exposure situation was introduced on the basis of epidemiological studies on prolonged exposure to indoor radon, and National action plans are considered necessary for addressing long term risk.

Consideration for Dose Assessments

The dose evaluation is an important part of the radiation protection system to verify and ensure the health of the population. The term *dose* used in this work refers to the *effective dose, E,* reported in millisievert (mSv) which is usually used for *a priori* estimation and dose assessment. The *Effective Dose, E,* represents the sum of the annual dose from external irradiation (E_{ext})and the committed effective dose following the intake of radioactivity (E_{int})in a solar year. The intake of radionuclides includes inhalation and ingestion of radionuclides respectively present in the atmosphere and incorporated into foods [1].

In order to assume the ingestion rates of various foods in the calculation of individual dose, it is possible to refer to different data set publications such as EC or National Statistical publications; reports of the *Food and Agriculture Organization of the United Nations (FAO)*. Habit data, like inhalation rates, consumption of water and occupancy fraction, were reviewed in line with the main recommendations from international bodies concerning realistic dose assessment [4, 5] or conservative generic values [6].

The realistic estimation of doses should consider different groups of individuals which are representative of the different subset of the population (e.g. infant, child, adult).

The annual committed effective dose could be computed by using the formula:

$$E \quad E_{ext} \mid E_{int}$$

Relevant aspects to be considered can be the following:

- In the dose assessment on the basis of environmental monitoring data, the E_{ext} depends on the used measurement quantity; generally the absorbed dose in air (reported in Gy) is converted in external effective dose to adults using the factor 0.7 Sv/Gy [1]. The occupancy fraction is related to the time spent indoor and the shielding factors of buildings [1].

- The contribution from deposited radionuclides should be computed considering the effective dose equivalent factors for external irradiation outdoors. The contribution to the dose of the public from the nuclear reactors release could be calculated applying the collective dose per unit release [1].

- Internal doses should be calculated using data concentrations of radionuclides in the environment and the different intake pathway (concentration in water and food expressed in Bq/l and Bq/kg; concentration in air expressed in Bq/m^3).

- Dose coefficients are given for members of the public for intakes by inhalation and ingestion for a large number of radionuclides, relating the intake of a specific radionuclide to the corresponding organ and effective dose committed within 50 years for adults and 70 years for children [2, 3].

Furthermore the dose assessment should be divided in two different categories:

a. The specific dose assessment for the reference group of the public: which is the critical group representative of those receiving the highest doses (e.g. citizens of villages near NPP)
b. The generic dose assessment for the public of a regional group of a specific MS not necessary located near a nuclear facility.

In the first case (a), it is possible to analyse the collective effective dose (S) reported in man-sieverts (man Sv), which is defined as the sum of all the individual effective doses received in the reference group and is accompanied by the total number of individuals.

Preliminary analysis of National reports

The preliminary study of the National reports has shown the inhomogeneity in the results of dose assessment for the public resumed in figure 2 [7]. The ***United Nations Scientific Committee on the Effects of Atomic Radiation*** (***UNSCEAR)*** methodologies is the most commonly cited to calculate the dose for the public because this Committee has historically described the exposure of members of the general public to several different natural and man-made sources of radiation [8]: cosmic radiation, terrestrial radiation, natural sources (e.g. radon gas), sources of naturally occurring radioactive material (NORM), man-made sources for peaceful and military purposes, radionuclide from accident.

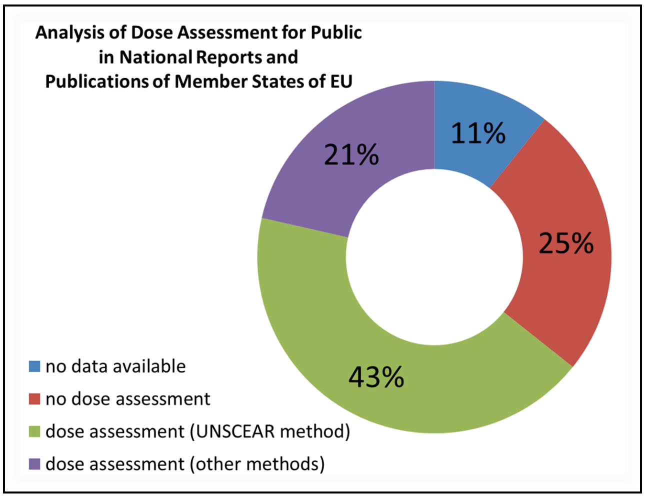

Figure 2 Preliminary results of the study on dose assessments to the population of the European Union [7] show that no data was found for 3 countries, in 7 national reports there were not dose evaluations and for 18 Member States there are dose assessments for public in available publications (in 12 cases the dose calculations refer to UNSCEAR methodologies)

In the publications analysed there are rarely diversification in dose assessments for different population groups (adults, children, and infants), while in some specific site monitoring reports, the effective collective dose is estimated within 30 km from the site.

In some cases the dose data are also integrated with specific values of nuclear site monitoring, with reference to atmospheric releases and artificial radionuclides present in the various matrices, and sometimes are analysed the dietary habits of the reference group.

In dose assessment due to the intake of artificial radionuclides by foods, Cs-137 is the reference radionuclide and in many cases Sr-90 and C-14 are also considered. Data are presented in a very heterogeneous way but can identify three different data classes:

- Concentrations of radionuclides expressed (Bq/liter, Bq/kg) evaluated for water and reference foods (e.g. milk, cereals, vegetables, fruit, fish, meat), comparable to the notifiable levels or international reference values [9], without any reference to food consumption.
- Daily intake values per person (Bq /day), calculated from the activity concentrations measured in fresh and raw food samples and statistical indications of average food consumption.
- Average concentrations of artificial radionuclides evaluated on average meals consumed in representative places (e.g. hospitals, universities, restaurants).

In all documents it is concluded that the analysed data reveal a good radiological state for foods consumed in all Member States and most of the time the results of measurements are less than or equal to the detection limits of the equipment used. Rarely the theoretical dose values due to the introduction of artificial radionuclides (from food, drink and inhalation) are supported by in vivo measurements on population target groups.

Conclusions

In the first phase of the ***REMME & DARP project*** of the ***Collaboration Agreement between Radiation Protection Institute (IRP)*** of the ***Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) and*** *the* ***Radioactivity Environmental Monitoring Group*** of the ***Joint Research Centre (JRC) of the European Commission*** the procedures for public dose assessment were analysed starting from the available data of different reports of the Member States.

Globally the information presented by each Member State could be considered of good quality. However, the provided information highlighted inhomogeneity in data themselves and in the assessment methods (e.g. the periodicity of the data publication from monthly to every two years, the structure and the presentation of the results). Moreover, the use of the own language in almost all the national reports requested specific efforts to allow the overall analysis.

Eventually, the variability of dose assessment methods reflects the different amount of knowledge within the overall data system and the inconsistency of the results is generally strictly related to each assumed hypothesis for each method. Therefore, for a way to evaluate the “quality of dose estimation” could be obtained developing a sensitivity analysis of the input parameters which have the greatest influence on the doses.

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Session 3 – Uncertainty handling issues for emergency and recovery

Handling uncertainty in the threat and early phases

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Introduction

In the event of a likely or actual unplanned release of radioactivity to atmosphere, decisions must be made rapidly on the necessity for actions to avoid or reduce serious health effects. Possible early actions include evacuation, advice to shelter, the administration of stable iodine, and restrictions relating to foodstuffs. While protective actions within a few kilometres of a nuclear site will usually be triggered on the basis of a pre-existing emergency plan, large releases of radioactivity require decisions on the possible need for actions over greater areas.

The understanding of the situation and estimates of both short term and projected doses are likely to be very uncertain in the first few hours. The emphasis will be on major health protection decisions rather than on detailed and comprehensive coverage. Measurement information may initially be limited and contradictory. Modelling has a role in developing an improved comprehension, but will also contribute substantial uncertainties. Aspects that might not be known, or, at best, poorly understood include what has been released (amounts and radionuclides), the time profile, what influence the weather has had in the affected area (for example, in conjunction with particle size and release energy), and various alternative weather forecasts and their effect on the dispersion and deposition of continuing releases.

Decisions require estimates of projected dose across the affected area, and these in turn require estimates of activity concentrations in air and deposited activity on the ground. Rapid and comprehensive data for all significant radionuclides cannot be achieved by measurements alone; modelling, even with its uncertainties, can fill gaps in measurement data and can also extrapolate to predict future impact. Assessments should consider not only available data, but also what significant information is not yet known. Decisions on protective actions must be taken in spite of a lack of knowledge. However, in decision-making the large uncertainty that is likely to be associated with early estimates of dose needs to be counterbalanced by the known health risks associated with early emergency countermeasures, and in particular the risk associated with evacuation. For example, the rapid evacuation of large numbers of people has the potential to cause more health injuries than exposure to radiation from remaining in sheltering, and needs to be justified by the severity of the situation.

Combining the individual uncertainties in these factors leads to a range of different predictions of dose. Presentation of these alternatives, with the confidence associated with the different outcomes, can form the basis for improved decisions. In the UK, work has been undertaken to explore with decision makers the best way of presenting this information.

The ADMLC project

The work described here was part of a project funded by the UK Atmospheric Dispersion Modelling Liaison Committee (ADMLC)[1]. The project's focus was on how information could be presented to the scientific advisors to the UK's national crisis response group in the event of an unplanned radiological release. The project involved a range of activities, including a substantial literature review; however, its key elements related to workshops which used hypothetical scenarios to focus their discussions and illustrate the many uncertainties that arise in responding to a release of radiation.

During each workshop an accident scenario was presented, stepping through the first few hours and explaining what would be known at each time, what would not be known, what seemed most likely to happen, and what the radiological and health impacts might be. In our scenarios the key uncertainties related to the source term (including release duration, composition and height) and weather (including windfield, precipitation, and the timing of any sudden changes such as that caused by a frontal passage).

The first UK workshop sought to understand the current processes of information presentation and discussion. It involved members of government departments and agencies, who might well be involved in advising on the handling of an actual radiological emergency. Discussion focused on how to advise senior ministers and officials on the significance of the uncertainties involved in predicting the course of the plume, the impact of this on health and the likely need to prepare resources to support recovery.

At present, no or very few uncertainties are quantified in the information that UK agencies, responders and plant operators provide to the advisors or emergency managers. In the discussion at the first workshop, the group tended to focus on the 'reasonable worst case' (RWC) – 'how bad might the situation get?' The reasoning was that this was necessary to enable appropriate resources to be put in place. While it sounds sensible to prepare for the reasonable worst, it is important to realise that an actual event may not evolve into such a negative extreme and placing undue emphasis on a RWC is known to have disadvantages. Further, no single RWC case illustrates all potential negative impacts (for example, one RWC may be the worst for local doses, another for wide-spread land contamination, yet another for economic consequences).

After the workshop consideration was therefore given to ways of avoiding focus on a single reasonable worst case, by developing alternative scenario analyses, to offer crisis managers and decision-makers several potential scenarios to consider. Scenario analysis is used throughout business and government to develop strategic thinking and there is a growing interest in using scenarios to tackle problems with deep uncertainty (deep uncertainty occurs when there is insufficient data or time to produce agreement on probabilities). The most basic forms of scenario analysis develop a series of maybe 4 or 5 scenarios that are of interest.

These may be:

- reasonable best and worst cases of some form – useful for bounding possibilities, and could be extended to cover two or three reasonable worst cases to illustrate alternative negative impacts;

- a likely case – useful for maintaining a balanced perspective;

- an assumption that a particular event does or does not happen e.g. a significant event such as further structural damage to a containment building.

New visual information was therefore developed on the potential geographical spread and impact of a radiation plume and this was used in the second UK workshop. This had similar attendance to the first, but this time focused on the presentation of information using display techniques to convey the uncertainty in alternative scenarios, and then reflected on how useful these approaches were. A hypothetical accident was created in which there was a possibility that a small early release might be halted, but if not it could develop into a second very significant release. The meteorology included a frontal passage with an associated change of wind direction, which could take the plume out to sea, so the timing of any second release was important, but very uncertain. If it went over land, the plume could reach a sizeable town and also would have considerable agricultural impact with extensive food restrictions. Several scenarios with different combinations of source terms, release times and meteorology were developed. Figure 1 shows a selection of these presented at the workshop, in this case dose bands integrated over 2 days.

Presentation of these alternative scenarios led to considerable discussion in the subsequent workshop. It was noticeable that the group still displayed a desire to select the 'worst' as a RWC and concentrated on that in their decision-making, despite the presentation of alternative (and potentially more likely) scenarios. Some members of the group also wished to focus on health concerns rather than, for example, potential agricultural issues. Despite this, there was general agreement that the presentation of a few alternative outcomes was helpful to the decision-making, although the number presented should not be large, perhaps 3-5 being the most that could be absorbed in a short timescale.

The more explicit introduction of probabilities into such a forum would be challenging, partly due to the deep uncertainties involved, and insufficient data and/or computational time to undertake a probabilistic analysis. Even if this is not possible in a real accident at present, exploring such ideas in training exercises may help emergency managers develop an awareness of the value in deliberating on the uncertainties and the full implications of *not* considering these.

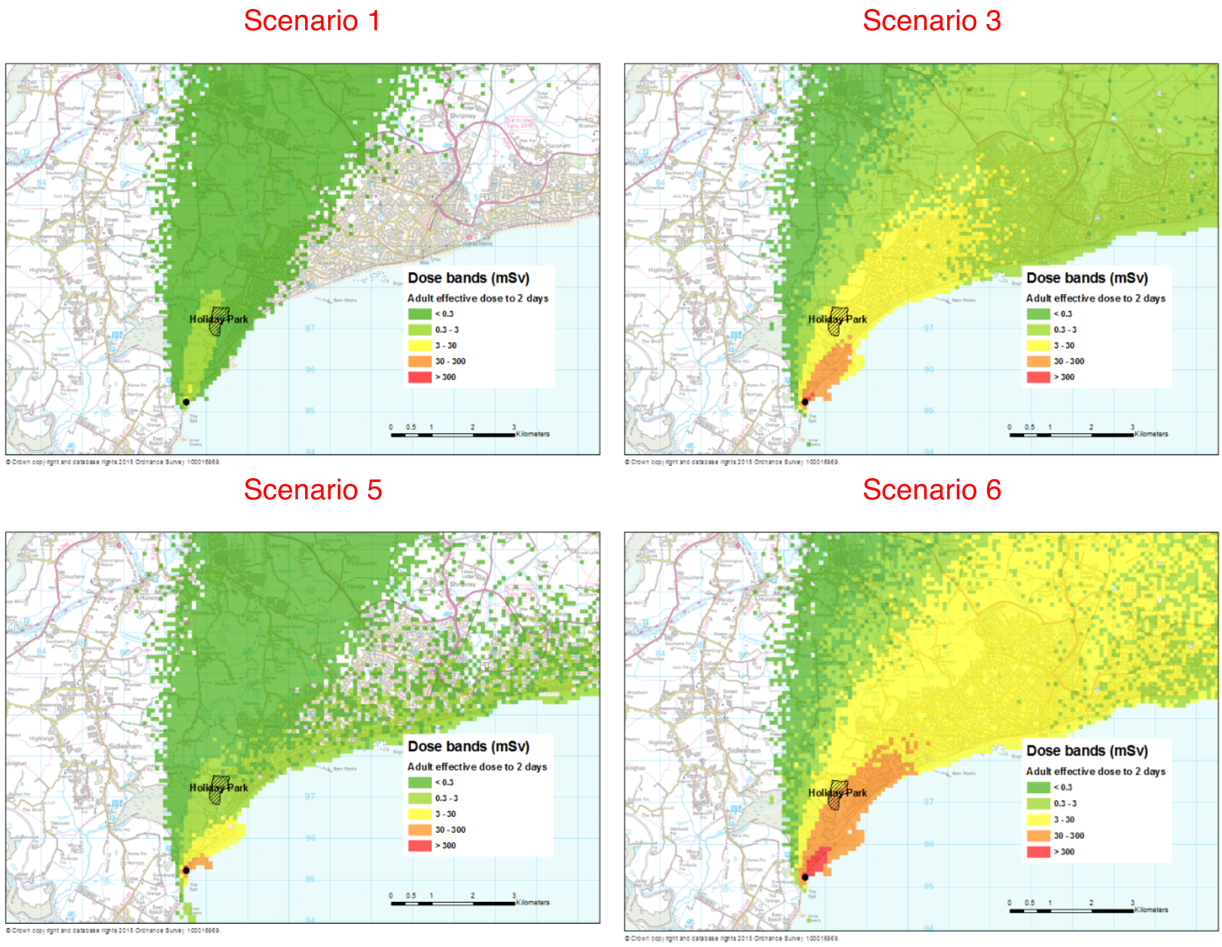

Figure 1: Plots of dose bands from four scenarios used in the second workshop

Note: These are entirely hypothetical scenarios based on a hypothetical site.

The plots are not probability distributions, but rather are predicted dose given the different scenarios' assumptions on source term and meteorology. These four scenarios presented to the workshop are the ones selected to span the range of outcomes, taken from a larger number that were developed and investigated by the analysis team.

How to improve

Due to the inevitable gaps in data and associated uncertainties the best approach is to base the dose assessment on a combination of calculations and measurements. In all aspects there will be uncertainties and other limitations, which need to be recognised and efforts made to assess their extent. It is unlikely that there will be the information available to carry out a full quantitative uncertainty analysis. Improved source term estimates based on plant knowledge in combination with early measurements is vital in reducing early uncertainties in dose estimates. The development of tools which rapidly integrate monitoring and modelling results, with the use of real-time modelling of dispersion and deposition processes based on fine resolution meteorological information is also important for improved decision-making, as is the development of systems which can reflect and visualise uncertainty in key areas (for example, alternative release durations and alternative weather developments).

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Uncertainty quantification of atmospheric transport modeling of radionuclides

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1. Introduction

Atmospheric transport and dispersion modelling is indispensable for emergency response and recovery preparedness in case of airborne radioactive releases, as they allow to predict the movement of airborne radionuclides (the "forward" problem), and they allow to estimate the release parameters of radionuclides when radionuclide measurements are available (the "inverse" problem). For example, the Realtime Online Decision Support System for nuclear emergency management (RODOS) uses atmospheric transport and dispersion modelling to provide information on the future radiological situation.

Since models are projections of the reality rather than reality itself, an uncertainty quantification on the model output is important and of great value for decision makers. However, outcomes from atmospheric transport and dispersion models contain uncertainties that are difficult to quantify. Three types of uncertainty can be defined (e.g., Rao, 2005): (i) data uncertainty, arising from uncertainty in input parameters and meteorological data, (ii) model uncertainty, arising from inaccurate parameterisations of physical processes and (iii) stochastic uncertainty, resulting from the turbulent nature of the atmosphere.

Harris et al. (2005) assessed the sensitivity of trajectories and found that trajectories were most sensitive to the meteorological input data. Similarly, Hegarty et al. (2013), who evaluated Lagrangian particle models with measurements from a controlled tracer release experiment, found that outcomes from ATM differ more when using different meteorological input data than when using different ATM models with identical meteorological input.

In this paper, we discuss a method to quantify uncertainty of atmospheric transport and dispersion modelling by using the ensemble technique. We focus on the uncertainty arising from meteorological data since it is the largest contributor to the total uncertainty. However, the ensemble method can readily be used to include other types of uncertainty, although at an increased computational cost. We illustrate the atmospheric transport modelling and the uncertainty quantification by simulating radionuclide activity concentration observations from the International Monitoring System that verifies compliance with the Comprehensive Nuclear Test-Ban-Treaty.

2. The ensemble method allows to quantify uncertainty

Errors in individual meteorological fields are correlated in time and space and are furthermore connected with other meteorological fields via the governing equations of motion, energy conservation and mass conservation. As such, adding some random perturbation to meteorological fields does not allow to quantify uncertainty in a scientifically sound way. Instead, a widely used method to quantify uncertainty in meteorology (and recently, also in climate science) is the use of ensembles, where different scenarios are calculated with either perturbed initial conditions, perturbed model physics, or a blend of both. A point to consider is the significant increase in computational cost associated with ensembles compared to deterministic simulations. However, compared to the cost of computing numerical weather prediction ensembles, an atmospheric transport and dispersion modelling ensemble is computationally feasible if a meteorological ensemble is already available.

One of the key challenges of a good ensemble is to construct perturbations that fully sample the uncertainty in the most efficient way. For instance, if all the ensemble members suffer from the same errors, the uncertainty from these errors will not be quantified. Furthermore, if some of the ensemble members are hardly distinguishable in a systematic way (thus by construction, not because of the state of the atmosphere), they do not provide extra information and resources are not well spent. Multimodel ensembles typically risk to suffer from such features (see for instance Potempski et al., 2008; Stein et al., 2015).

The uncertainty quantification can be assessed by plotting the spread-skill relationship, or by constructing a rank histogram (also called a Talagrand diagram). A description of how to interpret such rank histograms and associated pitfalls are described in Hamill (2001).

Besides providing an uncertainty quantification, another feature of the ensemble is that it can outperform a deterministic simulation. A pseudo-model can be constructed from the ensemble, for instance by taking the ensemble mean or ensemble median (in case not all members are equally skilful, different weights can be given to each member). The Brier score is a common score for probabilistic forecasting of binary events. Simulated and observed activity concentrations can be transformed into a binary event by defining a certain activity concentration threshold, which turns every data point into 0 or 1, depending whether the threshold has been exceeded. The Brier score is defined as:

$$B = \frac{1}{N}\sum_{i=1}^{N}(p_i - o_i)^2$$

and can be interpreted as a root mean square error in probability space. The continuous ranked probability score integrates the Brier score over different thresholds and is therefore also a useful metric to evaluate probabilistic forecasting:

$$CRPS = \frac{1}{N}\sum_{i=1}^{N}\int (p_i(x) - o_i(x))^2\, dx$$

3. Application: the forward modelling problem

3.1: Data and methods

The Comprehensive Nuclear Test-Ban-Treaty bans underground, underwater and atmospheric nuclear tests. An International Monitoring System is being setup that will use seismic, hydroacoustic and infrasound technology to verify compliance with the treaty. Furthermore, radionuclides will be monitored at eighty stations worldwide, of which forty stations will also be able to detect noble gases (specifically certain radioactive xenon isotopes). To date, 84% of the system has been installed.

One of the noble gases that will be monitored is 133Xe, which is created during a nuclear explosion. Since xenon is a noble gas, it is chemically inactive. Furthermore, it is not subject to dry or wet deposition, which facilitates its observation and modelling. However, 133Xe is also released by civil sources, mainly by a few medical isotope production facilities, but also by nuclear power plants. Although this background of ^{133}Xe is detrimental for the network performance, it has on the other hand the advantage that it can be used to test the atmospheric transport and dispersion models when ^{133}Xe emissions are known. We have used emission data from the Institute for RadioElements (IRE) in Fleurus, Belgium and observations from the International Monitoring System noble gas station RN33 in Schauinsland (near Freiburg) in Germany. Although the Institute for RadioElements is the main regional emitter of ^{133}Xe, other sources such as nuclear power plants also contribute to the measured activity concentration at RN33. Since no detailed emission data was available for the nuclear power plants, annual estimates of the releases from nuclear power plants (Kalinowski and Tuma, 2009) have been used.

We have used the Lagrangian particle model Flexpart (Stohl et al., 1998, Stohl and Thomson, 1999, Stohl et al., 2005), which has been validated with data from the ETEX controlled tracer experiment and is widely used by the scientific community. The meteorological input data was generated by rerunning an 11-member subset (10 perturbed and 1 control member) of the Ensemble Prediction System (Leutbecher and Palmer, 2008; Buizza et al., 2008) of the European Centre for Medium-Range Weather Forecasts. We run our atmospheric transport and dispersion model repeatedly for each ensemble member, thus obtaining 11 atmospheric transport and dispersion scenarios. The spread between these scenarios represents the uncertainty originating from the meteorological data.

3.2: Results

Fig 1 shows the observed and simulated ^{133}Xe activity concentrations at station RN33 for February 2014. The Minimum Detectable Concentration or MDC is the concentration that can be measured by the system with a likelihood of 95%. It can be seen that the general trend is well captured by the simulation, although the day-to-day values can differ from the observations. The uncertainty on the atmospheric transport and dispersion simulations, represented by the blue vertical bars, has been obtained by taking twice the standard deviation of the activity concentration at RN33 as obtained from the ensemble members. The uncertainty changes from day to day, a desired feature since the meteorological uncertainty depends on the atmospheric state (that is, certain cases are more predictable than other cases). Additional results and validation can be found in De Meutter et al. (2016).

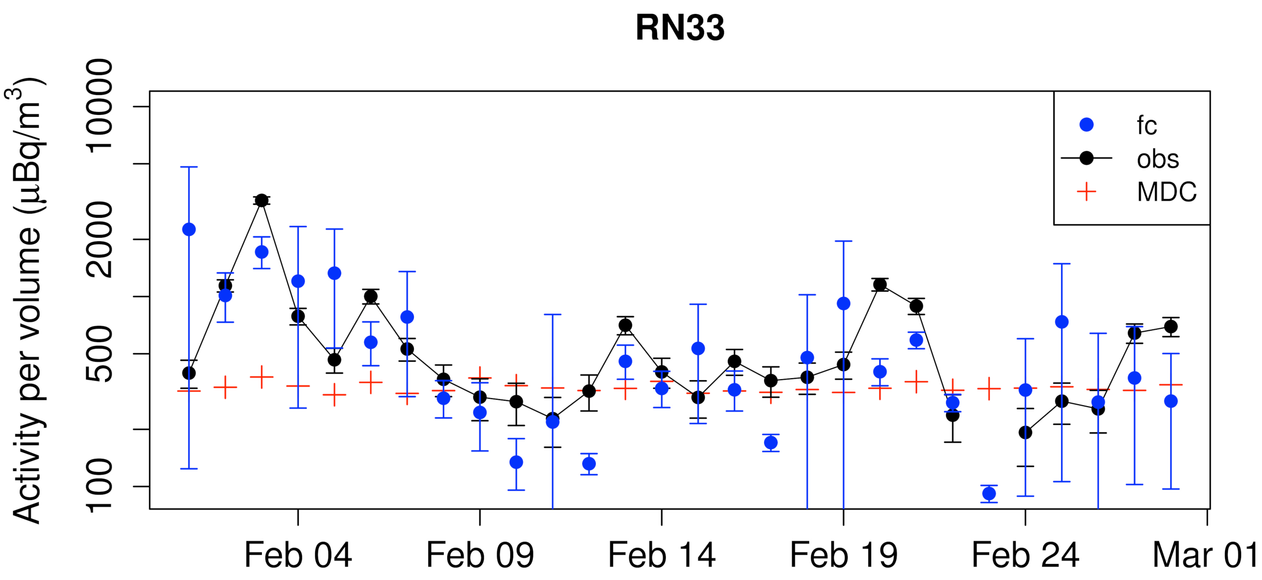

***Fig. 1**: Simulated (fc) and observed (obs) ^{133}Xe activity concentration for the station RN33 for February 2014. The minimum detectable concentration or MDC is also shown, representing the activity concentration that can be measured with a likelihood of 95%. The black error bars represent observation uncertainty, while the blue error bars represent the simulation uncertainty.*

4. Application: the inverse modelling problem

The inverse modelling problem in atmospheric transport and dispersion modelling deals with finding the source term characteristics by using observations, typically concentration observations, but also other types of information can be used, such as gamma dose rate observations (Saunier et al., 2013), or deposition observations (Winiarek et al., 2014). A source-receptor-sensitivity matrix **M** (Seibert and Frank, 2004) is obtained from the atmospheric transport and dispersion model (note that **M** is also known as the transfer coefficient matrix, see for instance Chai et al., 2015). The task now consists of finding a source term **x** that best explains the observations **y**. A cost function can be defined in order to solve the optimisation problem.

$$\mathbf{y} = \mathbf{M}\ \mathbf{x}$$

Ensembles can also be used to provide an uncertainty quantification for the inverse modelling problem (De Meutter et al., 2017). Each ensemble member results in a different **M** matrix. The optimisation problem can be done for each **M**, so that a set of **x** is obtained. Similarly to the forward problem, pseudo-models can be constructed from that data, such as the average or median solution (Potempski et al., 2008). Furthermore, quantile maps can be easily constructed for chosen thresholds. Probability maps can be easily generated from the ensemble. In the case that not all members are equally likely to occur, however, it should be first investigated which weighting should be given to each member.

5. Conclusions

Atmospheric transport and dispersion modelling involves many uncertainties, of which the meteorological data used by the transport and dispersion model are the main contributor. In meteorology, a widely used technique to quantify uncertainty is the use of an ensemble. Such an ensemble consists of different scenarios that are perturbed in a cleaver way. The spread between the individual scenarios contain information on the uncertainty.

In this paper, we have discussed the use of a meteorological ensemble as input for the atmospheric transport and dispersion modelling, to quantify the largest part of atmospheric transport and dispersion modelling uncertainty, both for forward and inverse modelling problems. The ensemble can readily be extended to include other sources of uncertainty, although an increase in ensemble size comes with an increase in computation time.

Several tools exist to evaluate the performance of an ensemble, such as the rank histogram to evaluate how well the ensemble is able to represent the uncertainty. Besides providing an uncertainty quantification, ensembles also generally outperform deterministic simulations. This is typically evaluated by calculating the “Brier score” or the “continuous ranked probability score (CRPS)”.

Finally, the ensemble method is technically feasible when an numerical weather prediction model ensemble is available, since computational resources for dispersion calculations are much lower than those for numerical weather prediction models. A good selection of ensemble members is crucial for constructing a good ensemble, and therefore, one should be careful when using a multimodel ensemble.

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A semantic information service to support resilience after a nuclear accident

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Introduction

During a post-nuclear-accident situation, people living in contaminated areas need information to protect and rebuild their lives. They need to know what to do and how to perform some practical activities required to assess and reduce their exposure to ionizing radiations. Generally, radiation safety experts and emergency authorities deliver highly technical information, that may not fit the needs and expectations of the population. Moreover, top-down communication policies tend to hinder the commitment and the motivation of citizens. To deal with this serious issues, we have design and developed a mobile web application, Ginkgo, aimed to support knowledge access and sharing among the people affected by such a disaster. This application relies on Semantic Web technologies. In this paper, we present the context of use of this application, we give some details about semantic technologies and we describe some main functionalities of Ginkgo.

Background

Crisis generates uncertainty and knowledge gaps. After a nuclear disaster, communication process refers to the information collection, processing and sharing activities that are required by the management of a specific crisis (Coombs, 2010).

Crisis Communication in a Post-Nuclear-Accident Situation

Major nuclear accidents are large scale disasters, contaminating wide areas with radionuclides for decades. Nuclear disasters are usually divided into two main temporal phases. The first phase, emergency, refers to the accident per itself: a malfunction or a human mistake causing the leakage of radioactive substances into the environment, and the effort undertaken to stop that leak. After a few weeks or months begins the post-accidental phase, when the consequences of the accident need to be dealt with (CODIRPA, 2012). During the post-accidental phase, people living in contaminated areas may be chronically exposed to low doses of ionizing radiations, threatening their health (Bandazhevskaya et al., 2004; ICRP, 2007).

To limit these adverse effects, citizens need to reduce their exposure and rebuild their life, either by leaving the area or taking protective actions. The choice and the implementation of these countermeasures requires a large corpus of highly technical guaranteed knowledge and verified information (SAGE Project, 2005).

On the contrary, during any past nuclear accident (e.g. TMI, Chernobyl, Fukushima Daichi), residents have received a series of contradictory news from media and government officials. These inconsistencies make trust weak and trust shapes a community's ability to react to a catastrophe (Ozawa, 2012). But when civic engagement and respect for truth is violated, then trust can quickly disappear.

Semantic Web and Crisis Communication

The Semantic Web can be considered as an extension of the original Web, interlinking formally expressed knowledge, readable by both humans and machines (Berners-Lee, Hendler, & Lassila, 2001). The Resource Description Framework (RDF) defines basic units of knowledge in the form of {subject, predicate, object} triples. More complex data structures can be represented through thesauruses and ontologies. Thesauruses are controlled vocabularies whose concepts can be linked by hierarchical and associative relations (Pidcock, 2003). Ontologies allows the definition of richer relations and datatypes, through formal logic principles. Moreover, ontologies offer unified representations of a specific domain knowledge and contribute to the semantic interoperability between different actors and different systems (Sheth, 1999). Interoperability is a key component of crisis communication, as crisis management often requires the collaboration of numerous organizations.

To this end, several ontologies have already been developed to model the concepts related to danger, crisis response, resources, damages (Liu, Shaw, & Brewster, 2013). Nuclear disasters management requires a particularly high level of interoperability, due to their scale and duration that increase the number of actors involved. The International Atomic Energy Agency has undertaken efforts to use semantic web technologies to create vocabularies and models that could be shared by the different actors of the domain (IAEA, n.d.). A thesaurus and an ontology of radiation safety concepts have also been proposed to ease knowledge access by citizens (Furuta, Ogure, & Ujita, 2005; Konstantopoulos & Ikonomopoulos, 2015). Nevertheless, these semantic resources have been built on documents written by experts and for experts, but citizens and experts have different skills to understand a crisis and thus different information needs (Heath, Palenchar, & O'Hair, 2009). Moreover, experts' terminologies often hinder the communication between emergency authorities and citizens (Reuter, Pipek, Wiedenhoefer, & Ley, 2012).

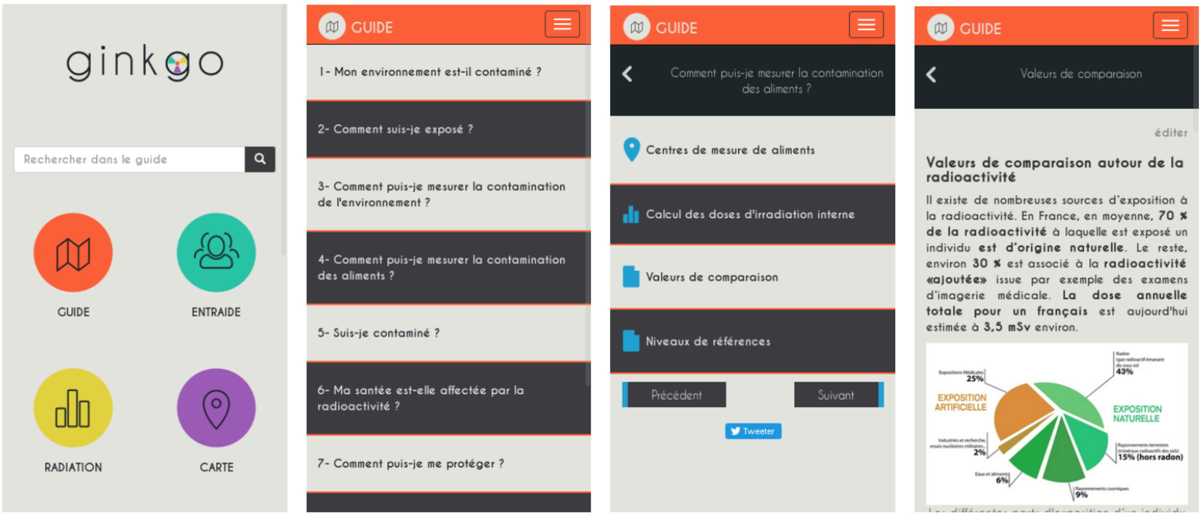
To overcome these difficulties, we advocate the use of user-centered methods for the development of such semantic models.

Ginkgo Web Application

We have developed Ginkgo to support knowledge access and sharing among people living in contaminated territories. The interface gets its contents and functionalities using AJAX queries over a set of Web APIs. It relies on the Bootstrap Responsive Web Design framework to support the use of a large range of devices, from smartphones to desktop computers.

Ginkgo's main functionality is a semantic guide presenting users a large range of practical information. To build this guide, in cooperation with CEPN we have firstly selected a set of nine practical issues from the post-nuclear-accident management literature (CODIRPA, 2011). For each of these issues, we have identified a few information resources from a handbook written for citizens and local decision makers in contaminated areas (SAGE Project, 2005). The guide contains three different types of resources (Figure 1):

- guide pages: HTML pages containing some texts, pictures and diagrams to explain theoretical concepts (e.g. health effects, counter-measures)
- maps: interactive infographics displaying geographical data (e.g. radiation levels, measurement facilities, the location of some medical centers)
- tools: small web application providing support for precise tasks (i.e. calculating radiation doses, communicating with people located nearby)



(a) Ginkgo homepage (b) Metascenario's menu (c) "Food contamination" scenario (d) "Comparison value" guide page

Figure 1. Resources available in Ginkgo

A fourth resource is used to represent web links, accessible through the semantic search engine that we describe in the next section.

Semantic Search and Related Readings

Ginkgo provides a search engine to help people looking for specific resources when the proposed scenarios doesn't fit their needs. While traditional keyword-based search engines rely on the similarities between the text of the user's query and the textual content of the documents, semantic search engines process the concepts that are expressed in both the query and the documents (Lei, Uren, & Motta, 2006).

Thus, semantic search engines also match the documents that do not contain the exact terms of the query, but still refer to the same concepts, because they might be synonyms, come from another language, or simply contain spelling mistakes (Ruotsalo, 2012). In Ginkgo application, documents and queries are annotated using concepts extracted from a thesaurus of radiation safety concepts.

To create this thesaurus, we have analyzed a set of documents written for non-expert readers, to include the non-expert terminology of the domain (Segault, Tajariol, & Roxin, 2015). For each document, the Ginko semantic search engine can also suggest some “related reading”, by selecting the resources linked to similar concepts.

Social Media Connections

We connected Ginkgo to Twitter to benefit from the existing knowledge sharing activities that are carried out on social media platforms during crisis (Palen, Vieweg, Liu, & Hughes, 2009; Vieweg, Hughes, Starbird, & Palen, 2010). Each resource thus includes a button for easily sharing it on Twitter, and support for other social media websites may be easily added. Ginkgo also includes a social media monitoring system that collects in real time all relevant tweets through the Twitter Streaming API. The collection is currently based on a set of predefined keywords, but we still evaluate a more complex solution to provide a better coverage of emerging topics, using a focus crawler whose keywords change over time (Zielinski, Middleton, Tokarchuk, & Wang, 2013). The collected tweets are annotated by the same module which annotates queries in the semantic search engine, and the resulting annotated tweets are stored in the Ginko platform to be available through the search engine.

Conclusions and Future Works

In this paper, we presented Ginkgo, a mobile web application designed to support knowledge access and sharing amongst people facing a post-nuclear-accident situation. It includes several information resources, a semantic search engine and is interlinked with Twitter's microblogging service. Social media functionalities stress the importance of the conversational aspects of knowledge seeking and the common elaboration of knowledge resources in the aftermath of a nuclear disaster.

Acknowledgments

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Citizens measurements: their role in radiation protection and emergency preparedness and response - the pros and the cons

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Introduction

An important issue of the emergency preparedness, response and remediation of the affected territories is the stakeholders and general public involvement into the process of effective decision-making problems in order to gain their confidence in the Information on radiation situation provided by the authorities.

The experiences gained from the Fukushima Dai-ichi NPP accident in Japan in 2011 have shown, that lack of public confidence to officials especially in case of severe accident with significant consequences in large inhabited areas was caused mostly rather due to lack of proper communication between the official authorities, the public and the stakeholders, as well as by their restricted access to the information. This may have extremely negative impacts on the public and stakeholders' proper understanding of actual situation, its possible risks, on their acceptance of necessary protective measures and their participation in remediation of the affected areas.

A rather effective way to improve the situation can be implementation of citizen radiation monitoring on voluntary basis in this field. Making sure, the official results are compatible with public self-measured ones, we can expect that the public gains more confidence in them.

Approach in the Czech Republic

In the Czech Republic implementation of such an approach is tested in the framework of the security research founded by the Czech Ministry of the Interior - RAMESIS research project solved by SURO in collaboration with UTEF (Institute of Experimental and Applied Physics of the Czech Technical University in Prague) and NUVIA (Engineering and supply company providing comprehensive solutions and services). The RAMESIS project is aimed at a support of establishment of citizen monitoring network based on a net of fixed monitoring points equipped with newly developed, simple, cheap, fixed monitoring stations, on mobile monitoring performed using the Safecast bGeigie nano portable devices and preparation of methods and tools for incorporation of these citizen networks into the national radiation monitoring network operated by the state in order to improve the efficiency of obtaining necessary information for fast and effective evaluation of the radiation situation in case of accident.

RAMESIS research project activities description

Analysis of available equipment for citizen measurements and networks has been performed both for fix-stations and mobile monitoring, considering technical parameters, price, easy to use for public, etc. The suitable systems for this analysis have been chosen for the development of demonstration of the citizen monitoring network – see Fig.1.

Fig. 1a Detectors and systems public available chosen for analysis – single units

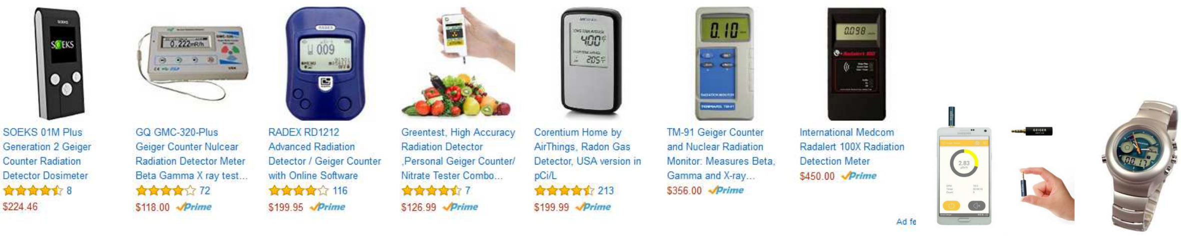
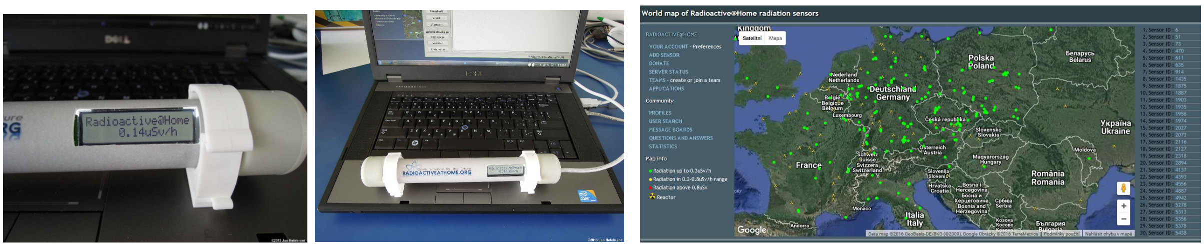


Fig. 1b Detectors and systems public available chosen for analysis – networks

a) system radio@home (Poland)



b) system MOSTAR (Czech Republic)

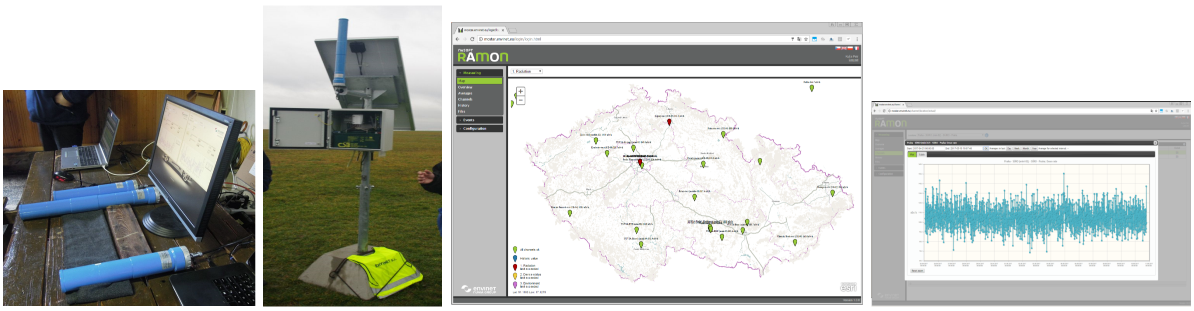
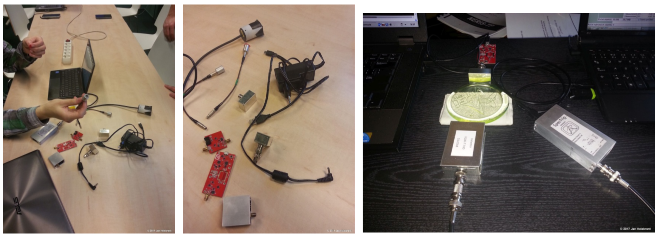
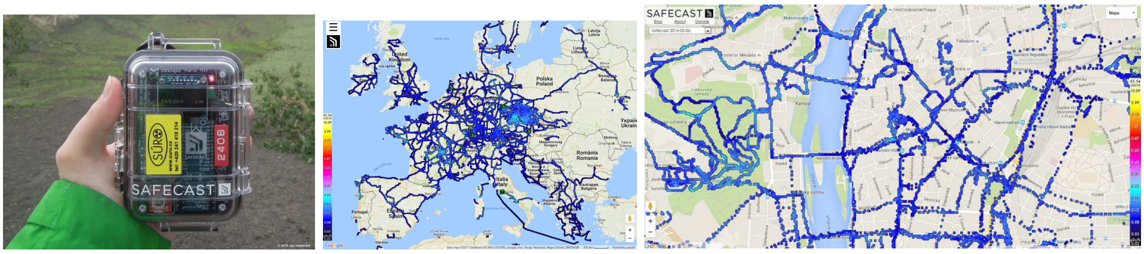


Fig. 2 Detectors used in RAMESIS project

a) fix-stations detectors - based on Si-diode with remote-control and data transfer via internet, newly developed by UTEF have been chosen.



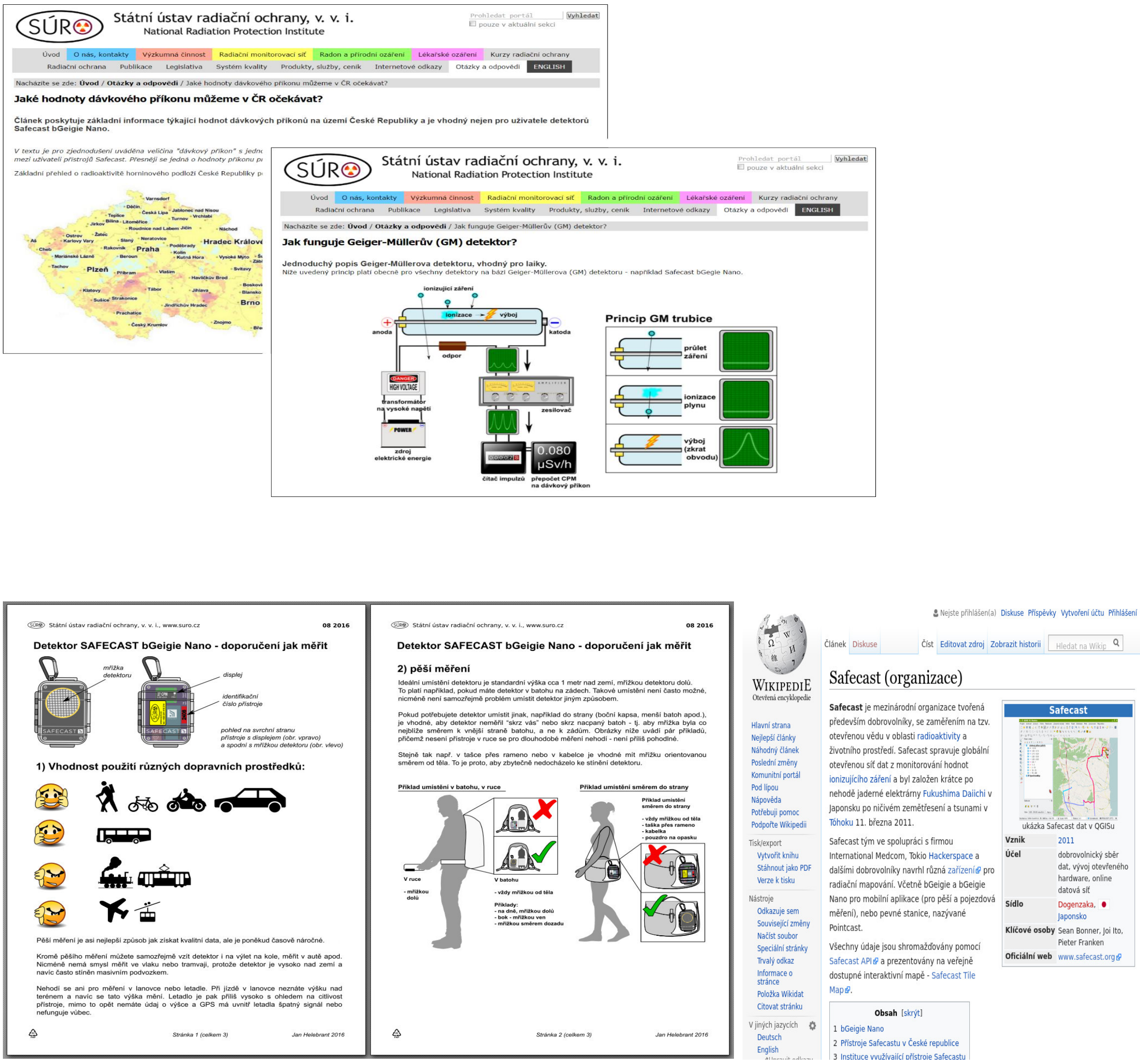
b) mobile monitoring detectors - the Safecast bGeigie Nano (Japan/USA) device, based on GM pancake probe, equipped with GPS sensor, providing continuous data recording capability on removable memory card has been chosen.



The Citizen Monitoring Network based on the above mentioned measuring devices and central application is designed, developed and implemented to enable transfer, storing, processing and presentation of measurement results together with their appropriate evaluation and explanation of their role in emergency preparedness and response.

Another important part of the project is preparation of Information materials, guides, manuals etc. for users and public to improve their understanding of radiation problematics on the nationwide level and to enable active and informed engagement of the public in emergency preparedness and response – see Fig.3.

Fig 3 Examples of information materials prepared for the users and public



Example of capabilities of Citizen monitoring networks

The analyses of possible capabilities of citizen measurements networks and experiences from their worldwide expansion after the Fukushima accidents show, that all roads on the whole territory of the Czech Republic can be monitored for only one day(!) by means of them, using merely 300 devices. Therefore areas with higher levels of contamination which need professional monitoring can be easily identified. Our survey clearly shows that the civil monitoring network can provide useful information not only during the first phase of a radiation accident, but also in the phase of remediation of the territory in detail for the population, as well as for the assessment of development of radiation situation and the effectiveness of remedial measures.

CONs and PROs of engaging citizen monitoring in coping emergency

experience from Chernobyl and Fukushima accidents:

- **public will demand for informatio**n –in case authorities and/or NPP operator fail in providing complex, reliable and in-time information they will **loose credibility** at all…
- **public cannot be stopped or restricted in attempts to obtain information**, including purchasing of detectors and performing measurements
- public will **share results** of monitoring **on social networks**

CONs - questions/risks:

- **will the public be able to properly interpret the results?**
- appropriate evaluation of radiation situation and prognosis of its development mostly cannot be done only by considering the total dose-rates measured by simple detectors usually used by the public !!!
- expert engagement is inevitable, providing evaluation etc. based on as much complex information on the situation as available and of deep knowledge (example – noble gas release from the Fukushima NPP)

- **risk of data misinterpretation and/or hoaxes** - may cause incommensurate reactions of public and even panic behavior…
- **overwhelming of the authorities** by requests for evaluation/explanation etc., often followed by endless discussions of possible (including not reasonable) alternatives
- **demands of public for „alternative opinions" by „independent" experts** - who are they?

PROs – benefits

- in the event of an accident an enormous amount of data could be obtained by citizens (very quick and cheap) at the time when government could have only limited capacity of measurements
- **citizen data can help in more efficient usage of response capabilities**
- **citizens (stakeholders) involvement in measurements in advance** *(under normal circumstances yet)* could help in their **education for better understanding** of radiation risks and **their confidence resulting into engagement in response** to emergency
- even in case of a large/total blackout there will be available at least local data

Conclusions

- **engaging public in monitoring** performed on voluntarily basis can help keeping or even **raising credibility** of public to recommendation for proper coping the emergency
- for proper understanding of the radiation situation, giving chance for wide adopting necessary radiation protection measures by the public,

the public must get appropriate information and education in advance.

The paper shows selected results of selected security research projects aimed this field, supported by the Czech Ministry of Interior (projects “RAMESIS” and “STRATEGIE ŘÍZENÍ NÁPRAVY ÚZEMÍ PO RADIAČNÍ HAVÁRII”).

Politics, populism and radiation risk: learning from Japan's anti-nuclear movement

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I. Introduction

G.K. Chesterton observed that "art, like morality, consists of drawing the line somewhere" (in Clarkson, 2014:1). So too does radiological protection. At every turn, practitioners are asked to ink boundaries: between the habitable and the uninhabitable; the edible and the inedible; those who need additional care (Potassium Iodide pills, for example) and those who can do without. The essential questions of governing radiological risk pertain to how these lines are established. Where are they drawn? On what basis? And by whom?

This paper concerns the attempt to delineate the habitable from the uninhabitable. More specifically, it concerns Japan's contentious decision to raise the threshold for civilian exposure from 1mSv/yr to 20mSv/yr in response to the 2011 Fukushima Daiichi nuclear power plant disaster – a decision that was met with widespread suspicion and resistance. Although this controversy has received a great deal of scholarly attention, many continue to propound what Wynne (1993) famously called the "deficit" model; extolling the need for experts to "correct" public opinion through risk communication initiatives. Offering a concise critique of this strategy, I call for a participatory approach to risk management, in which scientists engage public stakeholders as co-experts.

In so doing, I draw attention to the need for sensitivity to the effects of popular discourse, focusing particularly on how the anti-nuclear movement has narrated against establishment attempts at risk communication. By framing the issue of civilian exposure as part of a wider struggle between "the people" and a pro-nuclear elite, the movement has called the integrity and motivation of the government into question, severely limiting the efficacy of its risk communication initiatives.

II. Methodology

This preliminary paper draws on ongoing PhD research into how expert authority is claimed and contested in conditions of low public trust. Specifically, its analysis of the anti-nuclear movement's narratives draws on:

- observation of public demonstrations;
- textual analysis of a corpus of materials circulated by demonstrators; and
- 15 semi-structured interviews, of one to five hours in length, with prominent members of the anti-nuclear movement.

For the purposes of this study, "prominent members" were defined as those engaged in an organisational capacity, or invited to speak on behalf of anti-nuclear NGOs. To encourage a frank and open exchange, all interviewees were offered anonymity, but many volunteered to waive this right, including: Dr Tetsuji Imanaka, a former Assistant Professor at Kyoto

University and one of the vocally anti-nuclear researchers dubbed the "Kumatori Six"; Dr Hiroaki Koide, another member of the "Kumatori Six", who has been described as the "rockstar" of the nuclear debate; and Dr Hisako Sakiyama of the Takagi School, who was a member of the Diet's Nuclear Accident Independent Investigation Commission and has provided expert testimony on behalf of plaintiffs protesting the 20mSv/yr limit. The interpretation of their comments is mine alone.

III. Context: Fukushima Daiichi and the 20mSv/yr threshold

Damaged by the "3.11" earthquake and tsunami, Units 1 to 3 of the Fukushima Daiichi nuclear power plant began to haemorrhage radiological material in March 2011. Recognised as a level 7 ("major accident") on the IAEA's INES scale, Fukushima is the most serious nuclear disaster the world has faced since Chernobyl: responsible for an estimated ¥22 trillion ($195 billion) in damages (including the cost of decommissioning the reactors and compensation) and the displacement of more than 160,000 people.

The evacuation of the area surrounding the Fukushima Daiichi plant has been iterative. As an emergency response, Japan evacuated citizens on the basis of proximity – successively ordering those within a two, three, 10 and 20km radius of Fukushima Daiichi to evacuate during the first 48 hours of the crisis. One month and seven days later, Japan began its shift to a model of evacuation based on exposure, when those living in areas with an air dose of more than 20mSv/yr were asked to leave within a month.

In justifying the 20mSv/yr limit, government representatives have emphasised that it is consistent with ICRP recommendations, which suggest a threshold effective dose for public exposure of: 1mSv/yr in normal conditions; between 20 and 100mSv/yr in an emergency exposure situation; and between 1 and 20mSv/yr in an existing exposure situation, such as the wake of a significant accident (ICRP, 2007)[10].

The decision to use a 20mSv/yr reference level has nevertheless proven controversial from the outset. On 29 April 2011, Special Advisor to the Cabinet on issues of radiation safety, Professor Toshiso Kosako tearfully resigned in protest of the week-old threshold. Insisting that emergency limits should be applied for "two to three days, or at most, one or two weeks," he called for the use of a reference value between 1mSv/yr and 5mSv/yr; arguing that the principles of "common sense and humanism" dictate that "babies, infants and primary school students" should not be exposed to any greater risk (Kosako, 2011). He was not alone in his objection. At the time of Kosako's resignation, 800 organisations and 34,000 individuals had signed a petition requesting that the limit for civilian exposure be lowered significantly. In the years that have followed, the 20mSv/yr policy has remained a subject of public debate, owing to its influence on compensation and state financial support for evacuees.

IV. Deficit model

In responding to this public controversy, the Japanese government has adopted an attitude to risk communication akin to Wynne's (1993) famous (knowledge) "deficit model", attributing

[10] ICRP Publication 103 defines an emergency exposure situation as "unexpected situations such as those that may occur during the operation of a planned situation, or from a malicious act, requiring urgent attention"; while existing exposure situations are "exposure situations that already exist when a decision on control has to be taken, such as those caused by natural background radiation" (ICRP, 2007:13-14).

public criticism and hostility to a lack of understanding. Confident that the public would support the policy, if only they knew the relevant facts, scientific advisers have emphasised that the critics "are not scientists…doctors …[or] radiation specialists" and "do not know the international standards, which researchers worked on very hard" (Yamashita, 2011a). In the eyes of government advisors, like the Adviser to the Governor of Fukushima Prefecture on Health Risk Management, Professor Shunichi Yamashita, the problem is "that people believe gossip, magazines, even Twitter" (ibid). Consequently, the solution was imagined to be communicating accurate information on radiation risk to the public.

This understanding has motivated a series of top-down risk communication strategies, aimed at "correcting" public opinion by "fixing" the knowledge deficit. Scientists have entered public forums, not to engage in a participatory discussion about what constitutes an "acceptable" level of exposure, but to assuage public fear: emphasising that the object of the discussion is not "safety"[11] but "peace of mind"[12]. Speaking to an audience of concerned citizens, Yamashita stated that he "tr[ies] not to use the word 'safe'" and was "talking to [them] in the hope that [they] will feel safer" (2011b) In so doing, he placed the virtues of the 20mSv/yr threshold outside the remit of the conversation and made the public's understanding of science its sole focus. Safety and peace of mind are "totally different," he went on to insist: positing safety as an objective quality, that "can be recognised by anyone" and "feeling safe" as a subjective experience that "differs from person to person" (ibid). In this view, "the meaning of 'safety' is really narrow, but safe is safe for everyone" (ibid), and the task of experts is to educate the public, teaching them to overcome their subjectivities and accept that the government's policy ensures their safety.

While the deficit model paradigm epitomised by Yamashita remains politically influential, it has long been subject to criticism within the academic community. Indeed, the "deficit model" is not a label claimed by actors or organisations to describe their own framework for action, but a term ascribed to them by critics. The phrase is a *Kampfbegriff* (battle term), coined by Wynne at a workshop held by Lancaster University in May 1988[13] to name and denounce a common set of assumptions (Wynne, 1993:335). Hence, our very recognition of the phrase should be seen as an implicit recognition of the model's shortcomings.

Perhaps the most common criticism of the deficit model is that it serves to marginalise legitimate democratic discussion. As Edward Lazo of the OECD-NEA has emphasised, the choice of a threshold value is a political decision, informed by science but not dictated by it: "1mSv, 10mSv, 20mSv – that is not science, that is a political judgement" (Lazo, 2016). To present questions with contentious technical and ethical aspects (what Latour calls "matters of concern") as purely technical questions (or "matters of fact") is problematic, as it forecloses the possibility of lay stakeholders engaging in the political process (Latour, 2004).

A related objection is that the deficit model promulgates an unsophisticated view of "the public" as a monolithic entity whose attitudes to risk are determined solely by scientific literacy. Dan Kahan and his colleagues at Yale's Cultural Cognition Project are among the

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[11] 安全 - "*anzen*"

[12] 安心 – "*anshin*"

[13] Wynne writes that he first used the term in a draft paper for a workshop held by the Economic and Social Research Council – Science Policy Support Group under the Phase I Public Understanding of Science Research Initiative.

latest to demonstrate that this characterisation is inaccurate; identifying a number of cases in which it is ideology that most strongly determines our perception of risk (Kahan et al, 2012). Indeed, ideological groups can become more polarized as scientific literacy and numeracy rises, they report. These findings invite us to develop a more sophisticated understanding of "the public" and its perceptions.

Such a reading would recognise that "the public" is not homogeneous and people are not "blank slates": they enter political debates with their own interests and ideologies, which shape how they engage with new information. It must also recognise that publics are not just passive "recipients" of information "donated" to them by experts. Publics engage in political controversy actively, bringing their own facts, meanings, and narratives to the table, including reflexive narratives about the nature of the risk communication schemes they are subject to and the interests of the expert organisations engaged in these activities. By way of illustration, let us consider the manner in which Japan's anti-nuclear movement has framed post-2011 attempts at risk communication.

V. Populism and the Anti-nuclear Movement

The anti-nuclear movement has narrated the debates over radiation risk management as a struggle against vested interests. Nuclear policies are "an expression of our beliefs and the way we run our society," one activist explained; adding that the controversy is understood to reflect a "division between the people who get the benefit and the people who get the bad stuff." More specifically, it is narrated as a struggle between "the Japanese people" and "the nuclear village"[14]: a powerful pro-nuclear interest group, that draws its members from the government, civil service, nuclear industry, media and academia.

This notion of a "nuclear village" is best understood as a populist discourse. Populism is not an ideology, the late Belgian scholar, Ernesto Laclau (2005) argued; but a way of articulating politics as a conflict between "the people" and what is variously called "the elite", "the establishment", "the system" or, in this case, "the nuclear village". Compatible with the demands of both the political right (e.g. the UK's Vote Leave campaign, with its rejection of "experts" and "the liberal elite", demanded stricter controls on immigration) and the left (e.g. Occupy Wall Street and its calls for the reallocation of wealth), populism is defined by its form not its content. The shibboleth of a populist movement is not a particular political cause, but the claim to be *vox populi*.

Given their common populist logic, it should be no surprise that the boundaries between Japan's anti-nuclear movements and Occupy Tokyo were so porous. Face-masks inscribed with "99%" were no strange sight at the former, just as placards that collaged the message "no nuclear" with "occupy together" were not unusual at the latter. Nor should we be surprised that in 2016, anti-nuclear demonstrators marched shoulder-to-shoulder with those protesting against exploitative employment practices[15] or reforms to Article 9 of the Japanese Constitution, meandering between the issues in their chants. In each instance, the root of the problem is perceived to be the abuse of power by a parasitic "elite", demanding correction by "the people".

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[14] *原子力村 – "genshiryoku-mura"*

[15] *ブラック企業 – "black-kigyou"*

This populist framework engenders fierce resistance to top-down efforts at risk communication, which are experienced not as an education but as an establishment tool of oppression. In 2012, Founding Director of the NGO Green Action, Aileen Mioko Smith's list of "*The 10 strategies taken by the state, prefectural governments, academic flunkies and companies in the cases of Minamata and Fukushima*" was published in The Mainichi Shimbun, one of Japan's daily newspapers (see: Oguni, 2012). The list accuses the nuclear village of deliberately "conduct[ing] tests or surveys that will produce underestimated results on damage" (strategy no. 6) and "creat[ing] an official certification system that narrows down victim numbers" (no. 8). More to the point, the organisation of international conferences (no. 10) is interpreted not as an attempt to collate and disseminate information, but as part of a broader strategy to "stall for time" (strategy no. 5) and "wear victims down until they give up" (no. 7). Examples like this are not uncommon. Like Smith, many derisively refer to the government's risk communication efforts as a "feel-safe campaign". Others are more blunt, simply using the term "propaganda". And while many translate "*goyo-gakusha*"[16] more charitably (and more literally) as a "government patronised scholar", rather than "academic flunkie" (Smith in Oguni, 2012), the derogatory connotation is the same: suggesting a perceived lack of independence that stems from the scholar's desire to maintain the government's favour, with its attendant financial and reputational benefits.

One could certainly argue that the anti-nuclear movement and its attitudes are not representative of the Japanese population. Japan's civil society is often said to be relatively passive. For many Japanese citizens, "democracy is about going and voting", one NGO director told me. "Anything else is only for special kinds of people - politicians or activists." Although this attitude changed somewhat in 3.11's immediate aftermath – as evidenced by the emergence of the Metropolitan Coalition Against Nukes (MCAN), who staged the largest demonstrations Japan had seen in 50 years[17] - pressure groups have struggled to maintain mass engagement. According to MCAN, the "Friday rallies" held in front of the Prime Minister's Office gathered 200,000 people in March 2012. By February 2016 they gathered less than 1000. Over time, the movement has become an increasingly small sample of "the people" it claims to speak for.

Nevertheless, the antinuclear movement has profoundly shaped Japan's popular discourse. The term "nuclear village" is said to have been in use since the 1970s[18], but in the wake of the Fukushima Daiichi disaster it has become a touchstone of the Japanese political lexicon. Once uttered only by committed anti-nuclear activists, this appellation is now used by the mainstream media, politicians, and bureaucrats (Samuels, 2013). Even Tatsujiro Suzuki, vice-chairman of the Japanese Atomic Energy Commission (JAEC), is reported to have admitted that "Yes, I am living in the village hall" (in ibid:118). The moniker may not always be used explicitly, but the idea of a "tightly knit elite with enormous financial resources", promoting a nuclear program that is "immune to scrutiny by civil society," is now ubiquitous,

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[16] *御用学者 – "goyo-gakusha"*

[17] Although the 2012 demonstrations were still relatively small by European standards, participants described it as "a kind of revolution…in Japanese society…because it involved people who had never been to a demonstration – who had never thought that they would be involved in something like that…there were mums that came in with their baby buggies, or salary men that came before they went out drinking on Friday night."

[18] In contrast to Samuels' claim that "the metaphor [of the nuclear village] originated in a 1997 critique by Iida Tetsunari who, like Professor Koide, became an outspoken insider critic of nuclear power", Koide has suggested that the term dates back to the 1970s.

implying that distrust (perhaps, even active suspicion) of the government and its risk communication initiatives is widespread (Kurokawa et al, 2012:9).

VI. Conclusions and policy suggestions

By narrating radiological policy as a struggle between "the people" and the nuclear village, the anti-nuclear movement has fostered a suspicion of the government's motives. The damage this has caused to the credibility of risk communication schemes highlights a need for a reflexive engagement with popular controversies: one that recognises that publics construct narratives about the identities and motivations of those that attempt to engage them. Shifting from the binary format of the deficit model to a participatory approach, in which experts engage stakeholders as "co-experts", may offer one means of disrupting the populist opposition of "the establishment" and "the people" and the possibility of rebuilding trust.

On the local and international level, efforts to stage participatory forums are already being made. One notable example of "co-expertise" in practice has been the ICRP Dialogue initiative, which has hosted 17 stakeholder meetings to date. Organised with the support of local (e.g. Date City) and international partners (e.g. OECD-NEA's committee on Radiation Protection and Public Health), as well as those from the civil sector (e.g. Nippon Foundation), each meeting brought experts and public stakeholders together for a dialogue held in the spirit of mutual co-operation. To date, however, the national government's engagement in such forums has been more limited.

State involvement in participatory forums would pose both new opportunities and new challenges. The authority of the state promises the possibility of "upstream" stakeholder participation: engaging in the normative debates about the costs and benefits of different radiological protection strategies. However, the same authority could threaten the integrity of participatory forums, creating environments in which prefectural officials and citizens are reticent to speak.

Hence, further research into best practice will be required if state representatives are to engage more fully. As Yamamoto and Yamakawa (2017:177) have argued, "small innovations and 'tricks' matter"; illustrating their point by describing how the moderator who asks a Japanese public forum the question: "does anyone have an opinion?" Is liable to be met with silence. Far more effective is the method of passing a microphone around the room, inviting each and every person to speak. As this vignette illustrates, the process of participation will not only involve learning about how stakeholders understand particular issues, but also how best to engage the stakeholders.

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