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Summary and recommendations from the workshop 'Integrating measurements and atmospheric-dispersion modelling to enhance the UK response to radiological atmospheric releases'

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Abstract

Effective preparedness and response to an atmospheric release following a radiological incident relies on information concerning the source, transport and eventual removal of the contaminant. A notable improvement to emergency preparedness and response in the UK to airborne releases of radiological contaminants can be achieved through the integration of information sources, in particular environmental radiological measurements and atmospheric-dispersion modelling. A one-day workshop was organised by the UK Met Office and the University of Bristol, comprising private nuclear facility operators, public bodies, academia and others, on 6th February 2020 in Bristol, UK. The workshop reviewed the current capabilities and challenges of measurements and modelling of airborne radiological contaminants and their integration, and identified improvement pathways. This memorandum provides a summary of recommendations from the workshop.

Keywords: radiological incidents, environmental measurements, atmospheric-dispersion modelling, emergency preparedness, emergency response, inverse modelling, data integration

1. Introduction

The workshop took place at the South West Nuclear Hub at the University of Bristol in the UK on 6th February 2020. It was attended by representatives from 13 organisations from private nuclear facility operators, public bodies, academia and others. The workshop was organised by the UK Met Office, who hold the official responsibility for UK Government for forecasting airborne transport and deposition of contaminants following radiological accidents, and the Atmospheric Chemistry Research Group at the University Bristol, who have worked with the UK Met Office on implementing an inverse modelling framework for evaluating a release. The motivation for the workshop was a perceived disconnect between communities involved in modelling and measuring radioactivity in the environment following a radiological incident, and the need to unite these communities in the quest to improve adoption of products developed, and working practices employed, by such communities.

The workshop was supported by the South West Nuclear Hub and the natural hazards and disaster risk theme of the Cabot Institute at the University of Bristol.

2. Workshop background and objectives

Workshop objective: *[initiate discussion on how the community can] make better use of measurements and modelling data by combining the strengths of both data types to improve advice and decision making in an emergency response to an atmospheric release of radioactive material.*

The effectiveness of emergency preparedness and response for an atmospheric release following a radiological incident depends on the quality of information received by authorities on the transport, dispersion and deposition of the contaminant. The primary sources of this information are measurements of in situ air and deposition concentrations and dose rates determined by monitoring systems, and atmospheric-dispersion modelling. Integration of these data sources for UK (civil) incident response has no formal framework, yet integration of modelling and measurements has resulted in marked improvements in, for example, the response to and forecasting of volcanic ash clouds [1] and forecasting radionuclide plumes by organisations outside the UK [2,3]. The benefits this brings are readily apparent.

The integration of radiological modelling and measurements will provide significant benefits to the emergency response community. Inverse modelling would aid enhancement and verification of source-term information (radionuclides, release rates) determined by stack and site monitors and/or behaviour analysis of the reactor or other components, or be the primary source of such information if measurements and/or analysis are limited (as was the case during the accident at Fukushima-Daiichi in 2011). For atmospheric-dispersion modelling at the Met Office, the improvement in the estimation of a source term would improve the air concentration and deposition quantities forecasted and use of measurements either through inverse modelling or validation assessments would provide quantification of the confidence in the forecast. For Public Health England, the food standards agencies and environment agencies, it would result in significant improvements in the provision of public health, food and environmental protection advice during an emergency response, respectively. For local authorities, the revision of temporal and spatial variations in plume propagation will inform the effectiveness of protective action advice.

The workshop aimed to answer the overarching question, "How can the community get the best information from the combined use of measurements and modelling to inform emergency response?". To address this question, the workshop reviewed the strengths and challenges to current UK measurement capabilities, UK atmospheric-dispersion modelling capabilities and integrated measurement and modelling capabilities in the UK and abroad, informed by a series of presentations and discussions. Following this, attendees discussed the challenges posed by the integration of measurements and modelling by answering the question, "What are the strengths and weaknesses of current radiological measurements and atmospheric-dispersion modelling used in emergency response?". A further discussion aimed at addressing the questions, "How can the community work together to better use measurement and atmospheric-dispersion modelling data currently available to address questions arising during a radiological emergency response? What should the community aim for in the future?".

This memorandum provides an overview of the workshop.

3. Review of current capabilities

3.1 Review of current UK environmental measurements

Measurements of radiation in the environment from both facility operators and public bodies, most applicable to integration with atmospheric-dispersion modelling, consist of gamma dose rates from airborne and/or deposition contamination, air concentrations of particulate and elemental material, and surface ground deposition concentrations. Monitoring systems consist of both fixed, in situ and mobile instruments. Fixed measurement devices situated at nuclear facilities are generally a combination of fixed and moving-filter air samplers, which provide continuous measurements of particulate alpha and beta in air (gross counts) and gamma dose rates. Mobile monitoring uses ground vehicles which are equipped with instrumentation to perform similar measurements to fixed air samplers when deployed, along with volatile alpha and beta in air, ground deposition, and gamma spectroscopy. In addition, hand-held monitoring devices are available. Laboratory facilities at nuclear sites are in place to provide more detailed measurements from the samples collected in the field (e.g. radionuclide identification through alpha, beta and gamma spectroscopy). Facility operators also perform routine measurements to develop a "background" understanding of the radiological picture on and around a site; this helps to determine if a reading is within or above "normal" conditions and is key information for a local authority assisting the local community to return to a new normal as soon as possible after an accident.

Co-ordination of radiation monitoring, sampling and analysis during radiation emergencies is the responsibility of Public Health England's (PHE) Centre for Radiation, Chemical and Environmental Hazards (CRCE). In this role, PHE CRCE lead on the overall UK coordination of the activities of organisations undertaking radiation monitoring. Monitoring responsibilities during emergencies lie with several organisations which may, for example, derive from: legislative requirements, an extension of responsibilities under non-emergency conditions, or the recommendations of national reviews of emergency arrangements. The UK Government maintains the Radioactive Incident Monitoring NETwork (RIMNET) gamma dose rate monitors spread across the UK and with a higher density of monitors sited around civil nuclear sites. In addition, PHE operate multiple medium- and high-volume air samplers across Scotland and England, in some cases on behalf of the Scottish Environment Protection Agency (SEPA) and the Environment Agency (EA), respectively. This is supplemented by the business-as-usual monitoring and sampling programmes conducted by contractors on behalf of Government agencies to ensure domestic legislation and international treaty obligations are met (such as the annual Radioactivity in Food and the Environment monitoring programme). Data sharing between organisations undertaking monitoring is facilitated through the RIMNET application. RIMNET will be replaced by a new system called

RREMS (Radiological Response Emergency Management System) which will support both civil and defence nuclear emergency response. RREMS is due to be operational in late 2020.

3.2 Review of current UK atmospheric-dispersion modelling

Atmospheric-dispersion modelling is a simulation, based on physical principles, of the transport of the radiological contaminant in the atmosphere [4, 5]. This may be used in various capacities for emergency assessments: to forecast or nowcast contamination during an incident, for future scenario planning or to reconstruct past scenarios. Atmospheric-dispersion modelling for emergency preparedness and response in the UK generally relies on two approaches to simulate the dynamics of a radioactive plume:

- Gaussian plume modelling which advects and disperses the pollutant based on uniform meteorological conditions, often provided by on-site meteorological stations; and
- Lagrangian particle dispersion modelling which uses a more complex parameterisation of the processes involved (such as turbulence) and is able to use spatiotemporal-varying meteorological conditions.

Gaussian plume models tend to be a preferred approach by organisations seeking a simple-to-apply approach and quick availability of fit-for-purpose results over relatively short temporal and spatial scales. A commonly used model is the straight-line 'R91' model. Lagrangian particle dispersion models are more commonly used by organisations with direct access to the models and associated input data, with the technical expertise to run such models and interpret the model output. Lagrangian particle dispersion models are generally performed over significantly more extensive temporal and spatial scales, preferentially for emergency planning rather than response, and for research purposes. The dominant Lagrangian particle dispersion model in the UK for radiological incident response is the Numerical Atmospheric-dispersion Modelling Environment (NAME) developed by the UK Met Office [6]. This model generates time average and time integrated air concentration and deposition values for a wide range of radionuclides. During a nuclear emergency response, NAME would form part of a range of modelling support including the Joint Agency Modelling (JAM) process [7], which estimates impacts on public health, foodstuffs and surface water from the dispersal and deposition of radiological material.

3.3 Review of the integration of modelling and measurements

The current UK capability of integrating models and measurements is limited. Individual measurements (rather than a collective dataset) are generally used to qualitatively validate model output and to estimate atmospheric-dispersion model source parameters (resulting in the modelled output converging towards monitoring data values). Inverse modelling methods have proved to be an efficient approach to assess the source term of radiological releases, which is informed using a combination of measurements and an atmospheric transport model. The inverse modelling system framework developed by L'Institut de Radioprotection et de Sûreté Nucléaire (IRSN) has the capability to characterise the source term of a radiological release using measurements of air concentration, deposition concentration and dose rate [2,3]. As source-term information such as the release rate of the contaminant is often poorly constrained, inverse modelling frameworks improve source term characterisation, which in turn can improve forecasts. A similar inverse modelling framework has been developed for use at the UK Met Office, in particular for characterisation of an unknown release source [8]. This approach has been developed in response to a number of notable incidents involving releases from unknown sources. In such cases information describing the location and magnitude of the release was not made publicly available. Inverse methods aim to use measurements of the contaminant in the environment alongside an atmospheric-dispersion model to 'work backwards' to characterise the source location and its release magnitude.

The UK already has a wealth of expertise in using atmospheric measurements and inverse modelling frameworks to estimate source properties, for example in emergency response for volcanic ash forecasting [1,9,10], and routine estimates of pollutant releases for greenhouse gases and ozone depleting substances [11].

4. Strengths and challenges of current capabilities

The first discussion set out to identify the strengths and challenges of current measurement and atmospheric-dispersion modelling capabilities as sole sources of information in the UK. The key strengths and common challenges identified are summarised in Table 1. In addition to the aspects highlighted in Table 1, another relevant modelling strength identified, most notably in terms of improving communication and knowledge exchange, was Joint Agency Modelling (JAM), which is a national capability for UK emergency response to radiological incidents.

5. Steps towards better integration

The second discussion aimed to identify steps towards better integration of measurements and atmospheric-dispersion modelling for emergency preparedness and response. We have separated the identified steps and highlighted issues into three loose themes concerning strategic decision making, information exchange and emergency preparedness and response procedures. The remainder of this section summarises the outcome of the discussion under these themes.

5.1 Improving advice primarily based on an improvement in measurement capability

- More comprehensive data on background levels, realised through increased monitoring of background levels.
- Unmanned aerial vehicles (UAVs) and manned aerial vehicles could significantly increase spatial measurement coverage. UAVs have the added benefits of not exposing human operators to radiation risks and providing repeatable results at high resolutions. However, given the experimental nature of current operations, a greater understanding of the characteristics of the data collected by these platforms (and how it is processed) is needed by the emergency response community to ensure ease of integration with model output.

5.2 Using measurements to improve modelling and vice versa

- The source term, which drives atmospheric-dispersion models, is often poorly constrained. The uncertainty in the source term translates into an uncertain forecast, which can be constrained using additional information (see Figure 1 for a schematic representation).
- A common source of information describing monitoring data, listing common formats, limits and uncertainties of the instruments, enabling a more streamlined feed into model forecasts and inverse modelling frameworks.
- To broaden the scope of measurement data considerations from the primary aspects, i.e. gamma dose rates, air concentration and deposition concentration measurements; to secondary aspects, e.g. the physical and chemical form of the release. These data may already be collated but there is a need for a formal process to ensure that they are made available as quickly as possible.
- Modelling, including Joint Agency Modelling, could evolve to make use of measurement data to improve the evaluation of current model endpoints and to estimate uncertainties in the dispersion and deposition patterns.
- The planning of co-ordinated monitoring strategies could utilise output from Lagrangian particle dispersion models, such as NAME.

5.3 Community engagement and information exchange

- Decision makers often encounter difficulty in reconciling information shared by the scientific community, which spans multiple data types, including methods of presentation.
- A common data-sharing platform containing measurement data (from all possible operational sources), source term estimates (including first guess source-term estimates informed by reactor experts and/or site consequenc assessments), atmospheric-dispersion model output (both for viewing and data download) and communication exchanges.
- The workshop was seen as a major step towards better integration of modelling and measurements. Future cross-disciplinary meetings focusing on measurements, atmospheric-dispersion modelling and their integration would benefit the emergency response community.
- There could be more exercises of a different nature to the existing regulatory exercises. One particular example of this is to conduct exercises further down the response timeline in order to fully test the response of all impacted organisations (including the data flow of modelling and measurements), especially focusing on the move from the emergency to recovery phase. A further example is to perform exercises using historic incidents to train experts and to improve modelling and knowledge exchange both nationally and internationally.

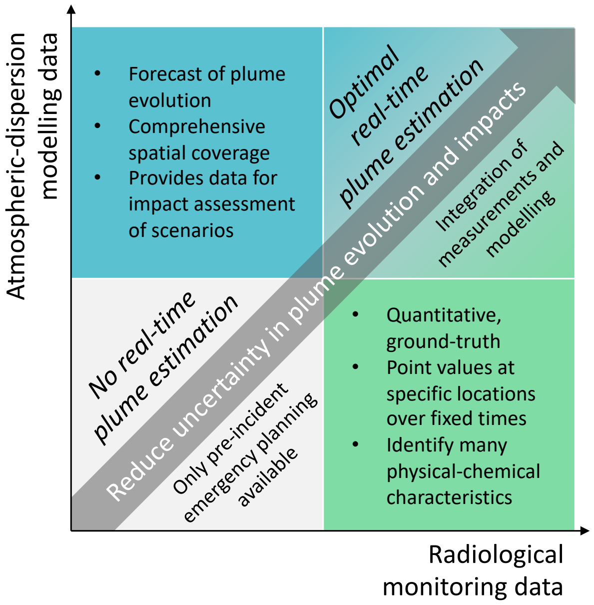

Figure 1. A schematic to show some of the benefits of atmospheric-dispersion modelling and radiological measurement data, and how integrating these data can lead to a reduction in the uncertainty in the description of the plume evolution, and therefore its impacts.

6. Conclusions and next steps

The UK can better integrate its use of monitoring and atmospheric-dispersion model data for response to atmospheric releases from radiological incidents. Using inverse modelling to improve the characterisation of a source term was seen as an important step for emergency response systems, as the description of a source term is recognised as the most uncertain input within the atmospheric dispersion modelling process [12] and crucial in the provision of advice and decision making in an emergency response. Inverse modelling for incident response in the UK is mature in other areas (e.g. volcanic ash) and this has helped to establish an initial capability developed in response to the 2017 Ruthenium event [8]. The Met Office should continue to develop its inverse modelling capability for radiological events, ensuring that it can make best use of all necessary readily available data sources, including the UK's gamma dose measurement network. This could be progressed through collaboration with other national bodies, such as IRSN. The ultimate goal would be to integrate such a capability within the operational response framework, which would naturally lead to integration of measurement and atmospheric dispersion modelling data in national exercises. Many of the challenges faced are founded upon improvements in knowledge and data exchange, and the communication of uncertainties for decision making. These challenges are linked, as improved communication of uncertainties often stems from knowledge exchange.

In the short-term it is recommended that the observations and findings of this workshop are promulgated within the attendees' own organisations and like-minded fora. Furthermore, a matrix of value gained as a result of progress within each identified challenge (in Table 1) versus the barriers inhibiting progress (such as the level of effort required) could be developed in an effort to determine the "low-hanging fruit".

Recommendations for long-term progress include the establishment of a working group, or integration into a current working group or organisation, with clear objectives and defined governance to ensure Government are aware of the workings of this group through available reporting routes. Part of this role is to hold future meetings on the integration of measurements and atmospheric-dispersion modelling. Exercise opportunities should be identified to allow the challenges outlined in this paper to be assessed in the context of radiation emergency scenarios. Changes and/or additions to the existing exercise programme should be considered by Lead Government Departments. We recognise the need for the community to continue to strive to identify further mechanisms to better use measurements and modelling in combination, beyond that already identified during the workshop (for example a global measurement strategy).

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Table 1 The strengths and challenges for measurements and atmospheric-dispersion modelling of radiological releases in UK civil emergency preparedness and response

Measurement strengths	Modelling strengths	Common Challenges
• There are numerous measurement systems that allow intercomparison of data and exploration of uncertainties and measurement quantities. • Measurements can be used to ground-truth incidents, giving confidence in the current contamination in an immediate area • Measurements are typically more accurate than modelled forecasts at their measured locations. • There is the potential to identify many characteristics, e.g. radionuclides, quantity, chemical form, particle size, shape, density and solubility. • Deployable measurement instruments can assist with making measurements where they are most needed. • Validation of model forecasts by tactical placement of measurement instruments in key areas forecast, e.g. hot-spots of deposition, edge of plume.	• Models provide the ability to forecast and undertake planning. • Models are well-suited to releases of the full-range of magnitudes. • Dispersion models can be called upon as needed and can be run with ease and relatively cheaply (providing the expertise is available). • The output data are not limited by physical access requirements (e.g. road networks). • The differing complexities of the physics and differing run times of models can be utilised for different applications. • The physics in the models has a well-established improvement pathway, where the model's physics used operationally is generally behind the state-of-the-art (e.g. plume-rise physics). • Models provide complete spatial coverage over an area of interest (although typically dependent on model runtime).	• To harmonise data sets from various sources so they can be easily compared and integrated. This includes access to an improved sharing platform, which is both secure and easy to use, with consistent data formatting and units. • Understanding of model output and measurements by all stakeholders to minimise and preferably avoid confusion, misinterpretation and incorrect application (e.g. multiple sources of potentially "conflicting" information). • To minimise the time lag in making data available. • To utilise expertise available, especially when exploiting models and measurements in unison. This includes being aware of expertise available, provision of suitable training, and ensuring knowledge exchange between communities. • Develop and maintain expertise to exploit the latest techniques in integrating measurements and modelling for operational use in an emergency response. • To better utilise measurements to constrain uncertainties in dispersion modelling, e.g. to use measurements to better approximate the chemical and physical forms of radionuclides. • To better understand and communicate the uncertainties in measurements and model outputs.