ESSEM COST ACTION ES1006. Evaluation, improvement and guidance for the use of local-scale emergency prediction and response tools for airborne hazards in built environments.

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INTRODUCTION

Accidental or deliberate releases of hazardous materials into the atmosphere induce growing concern in the society. Instantaneous releases from industrial sites, energy facilities, transportation of hazardous materials or even a CBRN terrorist attack can lead to catastrophic consequences in terms of population casualties and damage to ecosystems and infrastructures. A major challenge in applied environmental sciences is therefore the development and assessment of local-scale emergency response tools for tracking and predicting airborne hazards from accidental or deliberate releases, in particular in complex topography and geometry. In fact, in case of accidental or deliberate emission episodes, the situation is generally greatly complicated, since the duration of the release is often very short (minutes) and the source and emission characteristics are usually only partially known (e.g. amount and type of material released). Moreover, in a typical local threat scenario the time for reacting to handle a threatening release is short and the local meteorological conditions, determining the dispersion of the airborne hazards, are generally not instantly available at the desired level of accuracy.

A crucial part of the tool is represented by the airborne hazards dispersion model. The models allow emergency first responders and management to plan for, to train for and to respond to accidents adequately, also at the very local scale, where the related risks and threats are extremely high. Different types of numerical models have been developed, improved and partially validated and progress was achieved in the quality and quantity of model results dealing with air quality control and environmental health risks at local scale. Different approaches for modelling the dispersion of airborne hazards are applied, ranging from simple parametric models and Gaussian methods to Lagrangian dispersion models and advanced pre-accidental CFD-based modelling with subsequent fast data access. The various methodologies have specific advantages and disadvantages regarding efficiency, quality and reliability of the results generated for a given release scenario. In this context, it is fundamental to assess the limitations of an individual modelling approach, the applicability of different models to different scenarios and conditions, the degree of confidence in their performance and the reliability of their predictions. Because of the variety of methodologies developed in different countries by various legal bodies involved in emergency response management, even for a well-defined 'hazardous incident' a variety of answers is expected to be given to the emergency response personnel depending on what simulation tools are used. The new COST Action ES1006 involves and supports the existing capacity-building activities but explicitly extends the focus towards the short-term and small-scale threats; the emergency services are facing most often. The activity builds on the results of previous COST Actions, such as 710, 715, 728 and 732, with the aim to develop and implement up-to-date methodologies in local-scale emergency response systems. Based on the joint expertise and contacts with international programs, the Action is expected to harmonize with the most recent developments in the US and Japan.

RESEARCH BACKGROUND AND THE ACTION GENERAL PLAN

The European Security Research Advisory Board ESRAB formed in 2005 signalized Europe's intent to significantly contribute to homeland security research. Member States are encouraged to develop national security research programs and a significant amount of EU research funding is attributed to security-related research whereas emphasis is put on increasing the security of citizens. Contributions were made, for example, within FP6 by the EURANOS project, focusing on nuclear and radiological emergency management and rehabilitation. Larger-scale emergency response and decision support systems such as RODOS were established and improved, providing real-time on-line decision support for off-site nuclear emergency management in Europe. The ARGOS consortium formed by several European countries as well as Australia, Brazil and Canada, developed an information system for enhancing Crisis Management for incidents with CBRN releases. The EU/ESA GMES initiative (Global Monitoring for Environment and Security) has been successfully established, implementing an Earth observation service system based on satellites as well as ground based and flying sensors to monitor the planet's environment and to support the security of citizens. Within FP7, the GMES Emergency Project SAFER has been initiated. SAFER develops rapid mapping services for actors involved in crisis and emergency management and is intended to potentially address all types of disasters, including technological accidents and civilian-military crises. Substantial efforts are undertaken in order to improve sensor techniques and data collection using advanced technologies such as UAV's (e.g. COST Action ES0802) in order characterize local airborne hazards.

However, it must be stated very clearly that all local-scale monitoring activities generally lack predictive capabilities as they are strongly needed for training for and respond to local scale airborne hazards. Current transnational research activities are not sufficiently addressing the specific conditions and problems related to local-scale emergency response and hazard predictions in built environments. The major problem clearly is one of the most crucial and scientifically most challenging parts of emergency response systems, which is the reliable modelling of airborne hazards dispersion at short and intermediate distances (from meters to few kilometres) and for the shortest release and response times (less than a few hours). Considering that typical industrial incidents or deliberate releases last less than an hour, the development of application-oriented modelling tools and strategies substantially extending existing methodologies is likewise important and challenging. The contribution of the ES1006 Action to this challenge is not an overall widening of modelling capabilities, but to specify and possibly quantify the strengths and weaknesses of available modelling concepts first. This will support focussed and efficient advances in neighbourhood-scale accidental release modelling. Within the COST Action the focus is on conceptual and application-oriented scientific improvements rather than on model diversification.

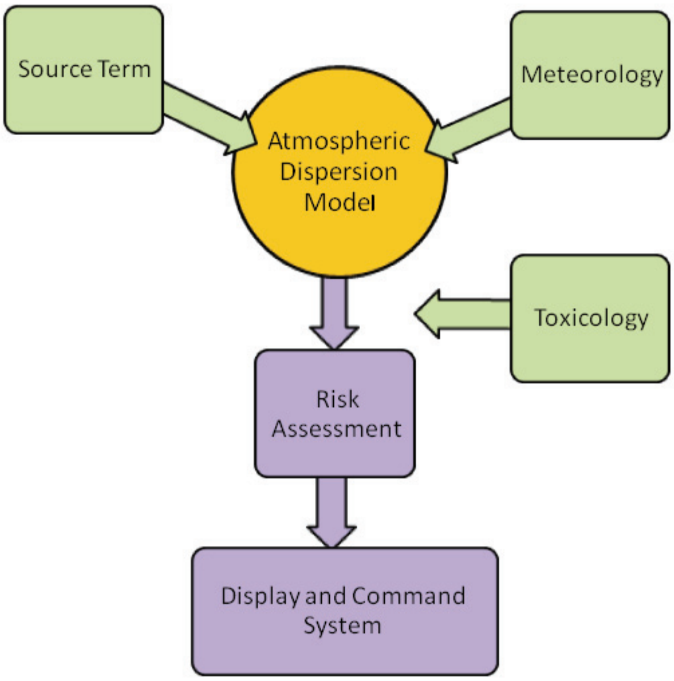
It was timely to introduce the joint activity since related research at national level is well under way. For example, the Austrian ZAMG reviewed the capabilities of existing modelling tools based on a limited set of test scenarios. In a comprehensive study, Baumann-Stanzer and Stenzel (2011) revealed clearly, that the selection of proper model input data, the choice of the model, as well as the model performance are crucial in reacting to local-scale, short-term threats. In France, the Ministry for Environment has established a working group dedicated to 3D modelling of local-scale accidental releases. This activity was initiated after discovering significant discrepancies between model results from established emergency response tools and results from more sophisticated tools applied to similar problems. In Germany, the Federal Office of Civil Protection and Disaster Assistance initiated a pilot study which intends to scientifically and practically evaluate a new approach to reliable local-scale airborne hazards modelling (Harms et al., 2011; Schatzmann et. al., 2011). Combining results from high-resolution pre-accidental modelling with an application-oriented data post-processing enables the results from complex, scientifically justified models to be used even for the purpose of local-scale disaster management and emergency response.

Harmonization is therefore needed so that ongoing research will benefit immediately in the context of the conceptual and application-oriented improvements achieved. The dissemination of the scientific results and the best practice recommendations produced by the COST Action group, through publications and special sessions at conferences and workshops, can have an immediate impact on applied local-scale emergency response modelling and model development. On an intermediate-term perspective, the research work carried out by the Action can reveal the weak points and limitations of currently applied local-scale emergency response models and approaches and can outline the most preferable direction for future developments. Recommendations are based on a much broader scientific base than national efforts can provide. In addition to the best practice recommendations given by the Action, a major outcome will be a comprehensive database, scientifically and practically verified and qualified for benchmarking local-scale emergency response models. Although a few data sets do already exist from previous field and laboratory campaigns, most of them have not been fully summarized, quality-assured and prepared for model evaluation thus far. In this regard, the Action is preparing the basis for a dedicated application-oriented test data base for local-scale airborne hazard models, similar to those available for example for local-scale air quality modelling. Together with a complete inventory of available models and modelling systems, a scientific and methodical reference for local-scale airborne hazards modelling in built environments is established.

OBJECTIVES AND METHODOLOGY

The main objective of the Action is therefore to evaluate and improve the reliability of neighbourhood-scale emergency response tools based on a comprehensive and concerted cross-national approach. The core focus is the evaluation of the air dispersion models and their integration in the emergency response systems, as sketched in Fig. 1.

Figure 1: sketch of the atmospheric dispersion model as integrated into the emergency response system



Identifying gaps in knowledge related to local-scale emergency response modelling is one of the main aims, supported by the development of an evaluation strategy specifically designed to consider requirements of airborne hazard modelling. In this context, not only the validity and accuracy of dispersion models is of concern but also their demands regarding input data, their operational performance as well as their robustness considering the uncertainty of model input data. In the process of model evaluation it must be considered that in many situations the first answers of a local-scale emergency response model are not expected to be very precise. Sufficiently safe estimates of the transport path and danger zones might be more important than actual pollutant concentrations, whereas the term 'sufficient' needs to be defined considering different threat scenarios. As an emergency situation develops, the actual concentrations of toxics, their temporal and spatial variability as well as the quantitative evaluation of local hazards becomes increasingly important. There is neither a standard in how the results of a certain dispersion model have to be interpreted with respect to short-term exposure and health risk assessment at very short time scales, nor a sufficient discussion on how to compare with the corresponding threshold values such as the Acute Exposure Guideline Levels (AEGL) if the model output is for example a quasi-stationary mean concentration. With simulations sufficiently resolved in space and time becoming readily available, the limitations of using mean dosage or mean concentration levels as reference can be overcome but consistently defined short-term threshold values are vital. Although time-resolved hazard modelling is expected to increase the reliability of danger zone predictions in complex geometries, it also leads to new difficulties regarding the proper interpretation of model results. The large and more or less stochastic variability of toxic pollutant levels at certain locations requires a probabilistic approach to the analysis of model results as well. For example, not the mean travel time of a cloud of toxics but maybe the faster or slower travel speeds and the likelihood of their occurrence can be of much more value for emergency management. Again, there is not yet a commonly accepted standard in how to use the new quality and quantity of dispersion information efficiently and safely and it is one of the tasks to develop a harmonized approach in this regard.

The main tasks of the action can be summarized as follows.

- To establish a complete inventory of available modelling systems and a scientific and methodical reference for local-scale airborne hazards modelling. Assessing the fitness for purpose of different modelling approaches requires a structured set of local threat scenarios to be established. Possible sources and release situations have to be characterized and categorized considering specific model requirements.
- To setup a dedicated comprehensive inventory of models applicable to local-scale accidental releases. A complete and consistent European catalogue of tools and models is not yet available. A flexible structured, relational model data-base will be developed. This enables efficient access to the desired information such as physical background, computational demands and information on model verification or related performance measures.
- To identify the main gaps, deficiencies and limitations in presently available knowledge and models and to determine the directions for the development of the next generation of models. Future models will have the potential to include substantially more detailed treatment of the source term and intricate processes characterizing the very early stages of an event at distances very close to the release location.
- To address the integration of airborne hazards modelling tools in existing and/or evolving information systems for urban/industrial emergency management. It is fundamental to consider not only the output results of local-scale airborne hazards modelling but also the possibility of information input, to improve the quality of model results, such as meteorological input data.
- To test and evaluate available models by model inter-comparison and by comparison against test data from qualified field and laboratory experiments. To extend the existing model evaluation and validation strategies towards task- and application-specific measures for accidental release scenarios (extreme value prediction, backtracking verification, source reconstruction or exposure assessment).
- To classify existing test data with respect to completeness and usefulness for the present purpose is required. The uncertainty in the test data has to be assessed and possibly quantified. It is planned to define desirable test scenarios for which data may be collected during field and/or laboratory experiments in the future.

The work in the Action is carried out in three dedicated Working Groups. **Working Group 1 - Threats, Models and Data Requirements** - is characterizing and categorizing existing models as well as typical release scenarios. Since the availability of reference data qualified for model testing and evaluation is crucial for testing airborne hazard models, a major task is to evaluate, complete and uniformly document existing test data. One goal is to define and strictly follow application-oriented test data requirements which are mandatory in order to allow for further improvement of neighbourhood-scale airborne hazard modelling. In this regards, specific research questions asked and tasks to be performed are for example:

- What are the currently applied models and methodologies and what is the current state-of-the-art in operational neighbourhood-scale emergency response modelling?
- Which model types and model systems are currently under development and favoured for future application?
- How are the emergency response models usually operated (pre-/post-accidental, on-site/off-site, operational/ event driven, manual/automated input, etc.)?
- How can models be efficiently classified regarding physical background, computational demands and application requirements?
- What information is available from past events of short-term releases of hazardous agents in urban and industrial environments?
- Which models are available, how have they been applied during actual accidents or training scenarios and how did they perform?
- What are the critical and challenging situations identified during a post-accidental analysis of real events?
- What are the threat scenarios and source terms specified by the different communities involved in local-scale emergency response such as civil protection, homeland security and industrial safety?
- What data is already available for testing emergency response models? Is existing data of sufficient quality?

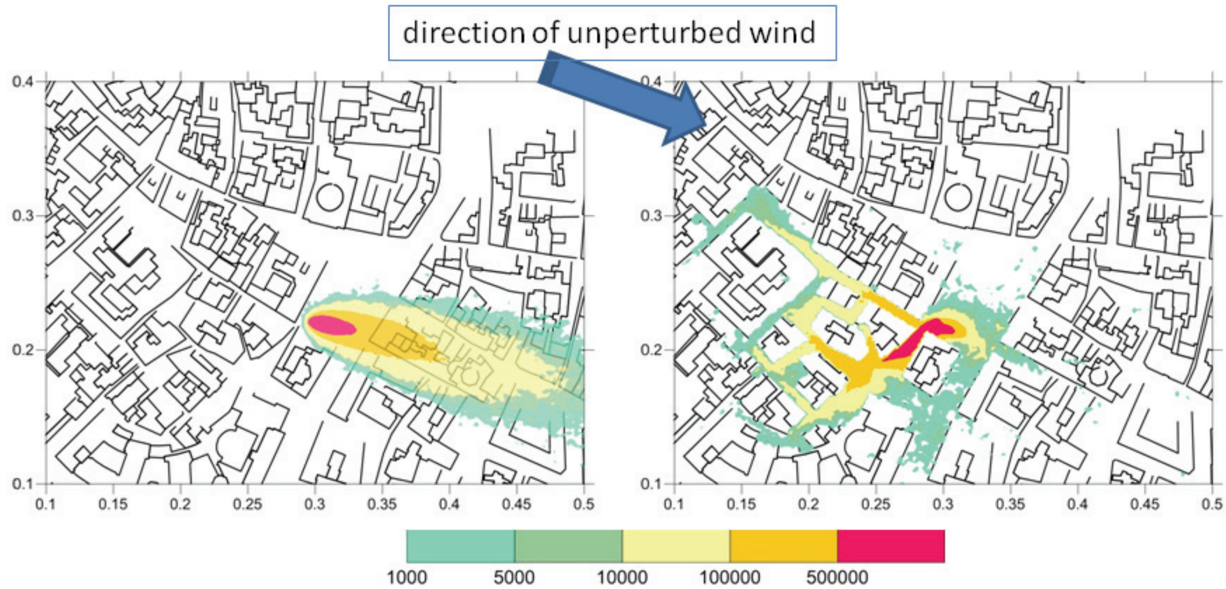
A summary of the state-of-the-art of emergency response tools for airborne hazards from accidental/deliberate releases in complex urban and industrial areas is compiled and a dedicated model inventory will be established. This inventory will also allow for model-specific guidance regarding an efficient and reliable use of different model tools. As a second task, Working Group 1 is collecting, characterizing and documenting typical and relevant local-scale threats from releases of toxics in populated areas, guiding model development towards the present and future needs of emergency response management. A third important task to be performed by WG1 is an application-oriented identification of critical model input requirements as well as the development of strategies for efficient provision of required data.

The second **Working Group 2 - Test, Evaluation and Further Development** - is defining (partially blind) test scenarios, will test and assess different modelling approaches and will work on scientific strategies for improving the implementation of corresponding tools. Working Group 2 comprises model developers and model users in order to facilitate a direct information exchange. Specific problems the group is working on are:

- quantifying and documenting the performance of modelling approaches with regard to efficiency (speed and computational demands) and reliability (quality of application-oriented model results) based on qualified test schemes that will be developed,
- quantifying the scatter of results inherent in model results when different models and tools are applied to exactly the same threat scenario,
- quantifying the effect of uncertainties in input data (meteorology, release conditions, source term, etc.) on relevant model results such as cloud travel time and location, displacement of the maximum concentrations, dosage or the persistence of hazardous materials in built environments,
- developing and testing strategies for defining 'worst case' conditions to be applied when models are operated without detailed knowledge about the release and boundary conditions of an accident/release as usual for emergency response planning,
- demonstrating and evaluating the potential of integrated information systems as source of improved input data for simulations,
- developing and testing a structured application scheme for providing instant guidance in the selection of optimum simulation strategies for given threat scenario,
- developing model/tool-specific user training and guidance documents in the form of a dedicated best practice guideline

Working Group 2 is generating the biggest scientific added value of the Action. In this context, the Action’s scientific interest is not to rank or pillory individual modelling concepts but to facilitate open discussions on specific reasons for diverging model results and possible ways for improving modelling quality. In Figure 2 an example is given considering two simulations of a release in the city of Rome, performed with the same Lagrangian model (MicroSPRAY, Tinarelli et al., 2007) when including (right) or not (left) the buildings. The difference is clearly indicating the fundamental importance of correctly describing the complexity of the geometry and its effect both on the flow and dispersion to produce reliable answers from modelling tools.

Figure 2. Example of ground level concentrations obtained by Lagrangian particle dispersion model simulations without (left) and with (right) buildings.



In this frame, Working Group 2 delivers a critical review of the application-oriented model quality assurance procedures applied. The strengths and weaknesses of particular modelling concepts are identified, quantified, and documented in order to stimulate further improvement of model quality. Additionally, a first version of a best practice manual for the application of neighbourhood-scale airborne hazards models will be compiled and released in order to immediately improve the quality of model results.

Working Group 3 - Applicability, Implementation and Practical Guidance – is dealing with the practical constraints in the use of local-scale emergency response models. The specific needs of first responders and authorities in charge of neighbourhood-scale emergency response management have to be taken into account in order to successfully implement scientific improvements. From a clear user's point of view, the work covers tasks such as the collection of requests and demands of the emergency-response experts for improving the practical applicability of the modelling systems, the provision of guidance regarding the suitability of different types of models and methodologies for specific problems at the different stages of an incident or the identification, characterization, visualization and quantification of the uncertainties of emergency response modelling facilitating the proper interpretation by decision makers.

RESULTS ACHIEVED IN THE FIRST YEAR

As described in former sections, the core focus of the Action is the evaluation of the air dispersion models and their integration in the emergency response systems.

During the first year of the Action's activity, the three working groups have been established and their work plans have been drawn. Two main results have been achieved at present and they materialize in the first official publication corresponding to the Background Document and in a working document drafting the inventory of available test databases from qualified field and laboratory experiments and possibly real accidents.

The Background Document

A large effort have been spent by the Action members to address and analyse the important issues related to the applicability and improvement of atmospheric dispersion models into the emergency response tools, with a particular attention to the specific needs raised by the expected timely response and the reliability of the present local scale modelling. The Background Document (Trini Castelli et al., 2012) is a state-of-the-art report on a modelling-oriented characterization of local-scale threat scenarios, as seen by emergency management and first responders.

The document is organized in different chapters and each of them offer a thorough analysis of the topic treated, hereafter briefly summarized in points.

- Identification and illustration of the present and future threats and of the challenges related to their handling. After defining the concept of threats, a detailed description is presented of threat scenarios and source terms which are of concern for the different communities involved in local-scale emergency response, such as civil protection, homeland security and industrial safety. Critical and challenging situations when handling real events are also elaborated and identified.
- Introduction and review of the different modelling approaches and tools currently in use or under development. The limitations of both simple and advanced models, and their consequent applicability to different scenarios, are addressed. A first analysis on the known discrepancies is offered and well-known limitation and deficiencies of emergency response systems are discussed from a current perspective.
- The general analysis presented in previous two points is driven towards the specific problems related to the dispersion modelling for emergency planning and response. The peculiar challenges for contaminant dispersion modelling applied to the local scale are presented and discussed. The needs for future model development are addressed.
- The important issue of dealing with the uncertainties related to the application of modelling systems in emergency response framework and their treatment and interpretation is then addressed. The present status of the evaluation process for the local-scale dispersion models is analyzed. How to pursue the quality assurance of local-scale models, the specific requirements and datasets and related evaluation methodologies are thoroughly discussed and the first guidelines for the evaluation and validation of the models are outlined.
- Practical constraints, regulations and legal issues are then outlined and the framework for their implementation is presented. The importance of the interaction of scientists and model developers with end users and decision makers and the needs for a mutual effort and exchange of expertise are also discussed. First conclusions are finally drawn and guidelines for the working plan of subsequent phases in the Action are presented.

The Database Document

This document represents the first step towards the classification of existing test data with respect to completeness and usefulness for the purpose of validating dispersion models specifically for emergency response systems is required. In the frame of a STSM (short term scientific mobility) programme, a first inventory of the available datasets that could be useful for this purpose was drafted (Tsiouri and Trini Castelli, 2012).

The main questions that have been driving this research were:

- Which are the main sources of data?
- What is needed to test and validate a dispersion model to be integrated into an emergency response tool?
- Which are the peculiar characteristics needed from a dataset for this specific type of validation?

It is already known that specific datasets suited for emergency response models are rare; therefore the datasets originally gathered in atmospheric dispersion models are mainly described in this document. For each dataset the possible limitations, related to their use when validating models in the frame of emergency response assessment, are discussed.

In the present report, a classification of databases has been established on the basis both of the Action's main goals and of the specific needs for model evaluation and validation. The guiding lines to select datasets are mainly to consider (i) accidental (even when intentional) releases; (ii) built-up environments. However, this classification has been further elaborated in order to include all datasets that can bring a contribution to the understanding of important processes and the following improvements of models, going beyond the stringent criterion of considering built environments.

As a consequence, four groups of databases have been identified:

(1) Experiments in built-up areas and urban environments
(2) Experiments from radiological studies for emergency preparedness and response
(3) Experiments concerning dense/light gas releases
(4) Real accidents

As sub-classification in each of first three groups, databases have been divided between field experiments and laboratory experiments. The final selection of datasets to be adopted during the Action will be an outcome of a general consent among MC and WG members.

Starting form the analysis and the application of the selected experiments and databases, it is planned to define desirable test scenarios for which data may be collected during field and/or laboratory experiments in the future.

CONCLUSIONS

The COST Action ES1006, devoted to the evaluation, improvement and guidance for the use of local-scale emergency prediction and response tools for airborne hazards in built environments, is presented and the first results achieved in the research activity are discussed. A major challenge in this field, concerning applied environmental sciences, is the development and assessment of local-scale dispersion models, to be integrated into emergency response tools, when dealing in particular with complex topography and geometry. The Action ES1006 follows a multidisciplinary, transnational approach to document the state-of-the art in applied local-scale airborne hazard modelling, to verbalize and quantify the strength and weaknesses of existing modelling approaches and to improve the reliability of applied emergency response modelling by giving guidance and best practise recommendations for model developers and end users. The very positive impact of previous ‘model quality assurance related’ activities is carried forward to the specific field of local-scale emergency response modelling. Predicting transient dispersion of toxics and dealing with the related model uncertainties is a very challenging research task and involves a wide range of expertise. Likewise, flow and dispersion modelling, source term characterization, hazardous material chemistry as well as emergency response management and policy issues have to be considered when evaluating and improving tools and models currently in use. A special effort is devoted to bring together scientists and experts in emergency response, in order to further develop the state-of-the-art scientific methodologies for local-scale airborne hazard modelling in emergency response systems. The major outcomes expected from the Action are best-practice recommendations, an up-to-date inventory reviewing the current modelling tools employed in emergency preparedness and response, a comprehensive database of experiments, scientifically and practically qualified, for benchmarking local-scale emergency response models. The final goal is to outline the most preferable direction for future developments

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