QUALIFIED DATASETS FOR BENCHMARKING LOCAL-SCALE EMERGENCY RESPONSE MODELS FOR THE PURPOSE OF DISASTER MANAGEMENT

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Abstract: This paper presents a review of the available data-sets for the quality assurance of dispersion models together with a preliminary classification of the datasets, focusing on the characteristics that make them more suitable for emergency-response applications. As part of the Action COST ES1006 (Evaluation, improvement and guidance for the use of local-scale emergency prediction and response tools for airborne hazards in built environments) information on available datasets based on previous and ongoing research work on applied local-scale accidental release modelling has been collected. During this research the main groups of the sources of data and the basic dataset characteristics needed for the validation in this specific COST Action were identified. A parent classification has been 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. The parent classification is outlined and is used in grouping the experiments and datasets described in the current data inventory for benchmarking local scale emergency response models. The dispersion models implemented in emergency response systems are a key element for the prediction of danger zones and health effects. Therefore quality assurance of the dispersion models' predictive capabilities is absolutely necessary, therefore high quality experiment dataset for emergency-response applications should be promoted with high priority.

Keywords: *emergency response, classification of qualified datasets, atmospheric dispersion models, build up and urban areas.*

INTRODUCTION

The development of local-scale emergency response tools for tracking and predicting the dispersion of airborne hazards is one of the greatest challenges in applied environmental sciences. To maintain quality assurance and justify extensive emergency response management systems based on sufficiently reliable dispersion information qualified data are needed. In this respect as part of the Action COST ES1006 (Evaluation, improvement and guidance for the use of local-scale emergency prediction and response tools for airborne hazards in built environments) information on available datasets based on previous and ongoing research work on applied local-scale accidental release modelling has been collected. It is known that specific datasets suited for emergency response models are rare. In order to handle this problem in this work datasets originally gathered in atmospheric dispersion experiments were mainly considered and for each dataset the possible limitations, related to their use when validating models in the frame of emergency response assessment, were discussed and defined. Special attention has been given to data relevant to the dispersion of a pollutant in built up areas and near/within/above the urban environment. The three main questions that have been driven this research are:

- 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?

General requirements for data sets to be used for validation were formulated for instance by Schatzmann and Leitl (2011). These data should have a high representativeness in space and time and detailed information on the external conditions used to be as boundary and, if necessary, initial conditions in the simulations. Furthermore the experimental data should be repeatable with known uncertainty, expressed as a confidence interval. As Schatzmann and Leitl (2011) demonstrate, these requirements are very hard to be fulfilled by field measurements and can be easier guaranteed in well conducted wind tunnel experiments. Wind tunnel experiments can also help to assess the uncertainty in field data (Schatzmann et al., 2010). Hunt et al. (2004) present an extensive list of data-sets available for model evaluations with a focus on instantaneous releases in urban environments. Field experiments have been conducted in real cities and with artificial structures (in most experiments arrays of cubes). Also wind tunnel experiments provide a number of data-sets for modelled realistic cities or artificial structures. The recalculation of real accidents with hazardous releases also gives valuable indication of model performance and short comings as demonstrated by Hanna et al. (2008), who compared the results of six widely used models that include dense gas algorithms (TRACE, PHAST, CAMEO/ALOHA, HGSYSTEM, SLAB, and SCIPUFF) for three 'typical' chlorine railcar release scenarios based on data from real accidents.

SOURCES OF DATASETS FOR EVALUATION OF MODELS USED IN EMERGENCY RESPONSE MANAGEMENT SYSTEMS - CLASIFICATION

As a general approach, the three main groups of sources that can be identified are Field experiments, Laboratory experiments (Wind tunnel / rotating tanks experiments) and Real accidents, where data could be collected, even if sparsely. In the present paper, a parent classification is going to be considered, drawn on the basis both of COST Action ES 1006 main goals and of the specific needs for model evaluation and validation. In fact, as the title of the Action explicitly indicates, the guiding lines to select datasets are (1) Accidental (even when intentional) releases and (2) Built-up environments.

In principle, selection of useful datasets should be then pursued on the basis of these two main criteria. However, as already noted in the introduction, specific datasets to be applied for model validation in the frame of emergency response assessment are rare and most of available data come from atmospheric dispersion studies and experiments. Some of them are not carried out in built environments but are devoted to explore specific aspects that may be of interest for investigating the possibility of improving specific modules in the dispersion models. Among these studies and in relation to releases of hazardous substances, negatively or positively buoyant gas emissions play a key role, since they are aimed at improving the description of the source term and the characterization of the emission. It is easily recognized that a correct description of the source is fundamental to obtain a reliable performance of the models, being the source term one of the core aspects from where uncertainties and errors may be generated. The source term estimation (STE) problem for every accident poses some unique challenges that have yet to be fully addressed by the scientific community. In particular, when dealing with nuclear power plant accidents an unknown quantity of radioactive material is released into the air. For instance, accurately characterizing the radiation released from the Fukushima plant is an ongoing process for Japanese researchers and government officials who support decisions impacting the safety of people living and working near Fukushima. Innovative computational methods have been recently developed for estimating the unknown emission rate of radionuclides in the atmosphere. The algorithms based on assimilation of measured data in atmospheric dispersion model are used in the framework of the nuclear emergency response systems. The algorithms can be extended to address the challenging unanswered questions and can be used to provide a better quantification of the amount of airborne radiation released from the power plant accidents. It is therefore important to investigate these aspects even when the related experiments did not take place in complex geometries. As regards real accidents, obviously no concentration data can be easily available at the moment of the release and often not even in the following time periods. However, it is generally possible to retrieve meteorological data, at least at the regional scale, which can be describing the atmospheric conditions in the area where the accident occurred. In these cases numerical modelling experiments and model intercomparisons become the main approach to study the accidents and to infer useful information on the model performance. For the previous reasons the parent classification has been 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. The parent classification is outlined hereafter and is used in grouping the experiments and datasets described in this inventory, as follows:

(I) Experiments in built-up areas and urban environments
(II) Experiments from radiological studies for emergency preparedness and response
(III) Experiments concerning dense/light gas releases
(IV) Real accidents

Basic dataset characteristics for emergency response models validation

The atmospheric dispersion models used in emergency response management systems have some traits that influence the choice of datasets for evaluating this group of models. Our criteria for selecting /rank the selecting datasets include (we followed the criteria used by Hanna et al. (1991) :

- meteorological data should be concurrently available at sensors located close to the release site;
- measurements of concentrations should be available at more than one distance downwind: a sufficient lateral resolution should be also assured in order to document the spatial structure of the plume/cloud;
- the time frequency of the concentration measurements should be high enough to resolve the smallest release duration or travel time from the point of release to nearest sampler.

These three main criteria can be accompanied by more stringent requirements:

- a wide range of meteorological conditions should be documented in the dataset;
- both instantaneous and continuous releases should be described;
- both passive and buoyant (positively or negatively) gas releases should be included.

DISCUSSION ON THE AVAILABLE DATASETS FOR COST ES1006 RESEARCH ACTIVITY

In principle, as discussed in the first COST ES1006 state-of-the-art document, the proper datasets to be used for the validation of hazardous material dispersion models should be specifically prepared for the different phases of emergency response, as well as for pre- and post-accident analysis. The inventory and the classification provided in this paper want to be the first basis on which to build a consensus in COST ES1006 Action on (1) which data are important for the validation of hazardous material dispersion models and (2) in which form they are most

useful. A qualified dataset for model testing and demonstration of model performance in emergency response in built environments should be representative of an accidental release, both if data are a product of a real accident or of an experiment; it should represent a case with presence of obstacles or it should address some important aspect or issue affecting the dispersion modelling reliability; it has to provide concurrent meteorological and concentration measured data; a high-quality experimental data set, high-quality meteorological observational data including high temporal and special resolution as well as high-quality tracer sampling data has to characterize the dataset. Finally it should describe a variety of meteorological conditions, such as different atmospheric stratifications and it has to be prepared in a harmonized form, to be easily used for testing purposes.
Following the group categories proposed in this paper the Tables 1a,b,c,d, were built. In these tables the datasets considered are listed and their accomplishments with former characteristics are highlighted. The choice of the datasets is based on their basic characteristics following our criteria for emergency model validation.

Table 1a: Group I - experiments in built-up areas and urban environments

Experiment (date)	**Dataset Description. (F-field experiment, L-Lab experiment, O-Obstucted, U-Unobstructed**	**References**
Birmingham (1999/2000)	F, O, real city, elevated plateau, complex configuration of buildings	Cooke et al. (2000) Technical Paper CUED/A-AERO/TR.27, Department of Engineering, Cambridge University.
URBAN 2000_Salt Lake City (2000)	F, O, real city, complex terrain, major urban tracer and meteorological field campaign (part of the DOE's Chemical and Biological National Security Program that focuses on countering the challenging threat of chemical and biological weapons attacks against civilian populations.	Allwine et al. (2002), *Bull. Am. Meteorol. Soc. 83, 521-536.* Chang et al. (2005), *J Appl Meteorol., Vol. 44 (4): 485-501*
Los Angeles (2001)	F, O, real city, satisfactory data, tall buildings	Rappolt (2001), Report number 1322, prepared for STI, Bel Air, MD, by Tracer Environ. Sci. and Tech., San Marcos, CA 92071. 33 pp. Hanna et al. (2003), Atmospheric Environment, Vol. 37: 5069-5082.
Barrio Logan (2001)	F, O, real city, single storey residences, Little specific information on the experimental details appears to be available.	Venkatram et al. (2002), 4th AMS Symposium on the Urban Environment, Norfolk, VA. Venkatram et al. (2004), Atmos. Environ., 38, 3647-3659.
London: DAPPLE programme (2003)	F, O, real city	Hanna and Chang (2012), Meteorol. Atmos. Phys. Britter, R.E. (2005), http://www.dapple.org.uk
Joint Urban 2003 (JUT)_Oklahoma City experiment: (2003)	F, O, real city, There is a web site that is openly accessible, Provide an archived data set that has been quality-controlled and consistency-checked based on a detailed data management plan.	DPG (2005), https://ju2003- dpg.dpg.army.mil Hanna and Chang (2012) Meteorol. Atmos. Phys.
Nantes field (1999)	F, Real city	Vachon et al (1999), 6th Int. Conf. on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes.
Kit Fox (1995)	F, O, artificial structures, Dense gas (CO2) was released at nearly constant rate	Hanna and Chang (2001), Atmospheric Environment, Vol. 35, 2231-2242. Hanna et al. (1999) Hanna Consultants Report No. P011F for the American Petroleum Institute, Washington, DC, 110pp.
Cardighton (1993)	F, O, artificial structures, The paper does not provide a clear database of the measurements.	Davidson et al. (1995), Atmospheric Environment, Vol. 29, 3245-3256.
UMIST ETC (1995)	F, O, artificial structures, conducted on a flat test, gas tracer of pure-grade propylene (C3H6) was released	Macdonald (1997), Report to DSTL on Agreement 2044/014/CBDE. Environmental Technology Centre, UMIST, UK
Dugway (2001)	F, O, artificial structures, not enough basic data are provided in this reference to allow effective use to be made of the experiment.	Venkatram et al. (2002), 4th AMS Symposium on the Urban Environment, Norfolk, VA, May 2002.
MUST (2001)	F, O, artificial structures, flat open terrain, Data were collected over a wide variety of wind and stability conditions, dataset includes extensive meteorological documentation within and around the test site, tracer gas (propylene)	Biltoft C.A. (2001), Customer report for Mock Urban Setting Test, DPG Document No. WDTC-FR-01-121 Yee and Biltoft (2004) Boundary Layer Meteorology, Vol. 111, pp.363–415.
Nantes (1999)	L, O, real city	Kastner-Klein et al. (2000), In Proceedings of 14th AMS Symposium on Boundary Layers and Turbulence, Aspen, CO, August 7-11, 2000.
Joint URBAN 2003_Oklahoma City experiment: (2003)	L, O, real city	Leitl et al. (2003), Final Report Phase I 08-2003, & Leitl and Schatzmann (2005), Final Report Phase II 07-2005, Meteorological Institute, Hamburg University, Bundesstrasse 55, 20146 Hamburg, Germany. https:// www.ju2003slc.org/,

		Kastner-Klein et al. (2003), AMS Symp. on Urban Zone, Seattle, WA.
MUST (2001)	L, O, artificial structures	Bezpalcova, K. and Harms, F. (2005), EWTL Data Report
Cardighton WT (1993)	L, O, artificial structures	Macdonald et al. (1998), Atmospheric Environment 32, 3845-3862.
Porton Down WT	L, O, artificial structures	Macdonald et al. (1998) Atmospheric Environment 32, 3845-3862.

Table 1b: Group II - experiments from radiological studies for emergency preparedness and response

Experiment (date)	**Dataset Description. (F-field experiment, L-Lab experiment, O-Obstucted, U-Unobstructed**	**References**
MOL (2001)	F, U, flat terrain, Ar^{41} release, complete data information	Drews et al. (2002), Report of NKS project NKS/BOK-1 , ISBN 87-7893-109-6. Available from the NKS Secretariat,www.nks.org. Tsiouri et al. (2012a), Radiation Protection Dosimetry, Vol. 148 (1), 34-44.
ANSTO (2002-2003)	F, U, Complex terrain, radioactive noble gas Ar^{41}, release data along with concurrent meteorological measurements, valuable tool for evaluating emergency response models of radiological dispersion.	Dyer and Pascoe (2008), 12th Int. Conf. on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes. Tsiouri et al. (2012b), International Journal of Environment and Pollution 50 (1-4) , pp. 386-395

Table 1c: Group III - experiments concerning dense- light gas releases

Experiment (date)	**Dataset Description. (F-field experiment, L-Lab experiment, O-Obstucted, U-Unobstructed**	**References**
Burro and Coyote	F, U, dense gas (LNG) pool, Release quasi-continuous. lateral and temporal resolution: good	Koopman et al (1982), Burro series data report. LLNL/NWC 1980 LNG Spill Tests, UCID-19075 Goldwire et al. (1983), LLNL/NWC 1981 LNG phase transition, UCID-199953
Maplin Sands	F, U, dense gas(LNG,LPG), surface: water, Release: Both instantenous and continuous, type of release: boiling liquid, lateral resolution: marginal & temporal resolution: good	Puttock et al. (1984) TNER.84.046, Shell Research Ltd., Thornton Research Centre, Combustion Division.
Thorney Island	F, U, dense gas	Anfossi et al. (2010), Atmospheric Environment, 44 (6), 753-762. Nielsen and Ott (1996), Riso Report 845(EN), Risö National Laboratory Report 845 (EN)
Desert Tortoise and Goldfish	dense gas, 2-phase jet, flat area	Goldwire et al. (1985), Desert Tortoise series data report: UCID-20562, Lawrence Livermore National Laboratory, Livermore, CA, 1985
Hanford Kr85	F, U, radioactive, neutral cloud	Nickola et al. (1970), A volume of atmospheric diffusion data, BNWL-1272, UC-53, Battelle Pacific Northwest Laboratories
Prairie Grass	F, U, dense-gas release but neutral cloud	Barad (1958), Vol. I. AFCRC-TR-58-235 (I), AD 152572. AFGL, Hanscom AFB, MA 01731. Hanna et al. (1991), Report Nos. 4545, 4546, and 4547, 338 pp.
NASA_HySafe SBEP	F, U, Light gas, 2-Phase jet (Large LH2 release on flat ground with small circular ground fence around the spill dike)	Witcofski RD, Chirivella JE. (1984), Int J Hydrogen Energy 1984;9(5):425–35. Venetsanos and Bartzis (2007), Int. J. of Hydrogen Energy, 32 (13), 2171-2177
BAM	large-scale LH2 spill tests adjacent to buildings, accidental spills of cryogenic hydrogen in a residential area.	Marinescu-Pasoi and Sturm (1994), Reports R-68.202 and R-68.264; Venetsanos and Bartzis (2007), Int. J. of Hydrogen Energy, 32 (13), 2171-2177

Table 1d: Group IV - real accidents

Accidents (date)	**Description. (F-field experiment, L-Lab experiment, O-Obstucted, U-Unobstructed**	**References**
FESTUS (2002)	F, O, dense gas. Chlorine accident at a chemical processing plant in Festus, Missouri (took place while a railcar was offloading chlorine at a chemical processing facility).	Hanna S.R (2007), Report Number P082, prepared for RFHEEE, Arlington, VA, 58 pp. Hanna et al. (2009), Atmos Environ. 43, 262-270.
Macdona (2004)	F, U, dense gas. A filled 90-ton chlorine railcar was breached releasing 60 tons of chlorine as of three days after the accident.	Hanna S.R (2007), Report Number P082, prepared for RFHEEE, Arlington, VA, 58 pp.

Graniteville (2005)	F, O, dense gas. The collision derailed both locomotives and 16 of the 42 freight cars of train 192. Among the derailed cars from train 192 were three tank cars containing chlorine, one of which was breached, releasing chlorine gas.	Railroad Accident Report NTSB/RAR-05/04. Washington, DC. Hanna et al. (2009), Atmos Environ. 43, 262-270.
Stockholm (1983)	F, O, light gas. Hydrogen gas explosion	Venetsanos et al (2003), Journal of Hazardous Materials 105 (1-3) , pp. 1-25

As a result of the analysis of Table 1, a preliminary attempt to rank the datasets, focusing on the characteristics that make them more suitable for emergency-response applications, is presented. 'Primary' groups of datasets can be particularised as those including datasets that have a greater potential for testing models. Among the ones listed in the tables, as first screening we identified as possible candidates to enter the 'primary group' experiments the URBAN 2000 and Joint Urban 2003 for urban-scale and building-scale. URBAN 2000 used to evaluate and improve the hierarchy of atmospheric models being developed for simulating toxic agent dispersal from potential terrorist activities in urban environments and provide a dataset that resolves interacting scales of motion from the individual building up through the regional scale under the same meteorological conditions. For Joint Urban 2003 tracer and meteorological data a web site is openly accessible and provides an archived data set that has been quality-controlled and consistency-checked based on a detailed data management plan. It is a valuable dataset for evaluation and improvement of existing dispersion models. ANSTO Experiment from radiological studies for emergency preparedness and response could also be included to the 'primary' list. Routine airborne release data from nuclear research reactor of the radioactive noble gas Ar41 provides a valuable tool for evaluating emergency response models of radiological dispersion and evaluation of data assimilation algorithms for estimating the unknown emission rate of radionuclides in the atmosphere. The large datasets from the gamma monitoring network are valuable for model evaluation studies. It is a challenging test for models to predict flow in complex terrain.
We mention that in the frame of the Action, dedicated wind-tunnel experiments, reproducing the flow and tracer dispersion in a typical urban European site, have been carried out. At present, model simulations are running in order to perform a first model evaluation and intercomparison in two case studies related to these experiments, an open and a blind test. These first controlled studies allow assessing possible limitations and problems in the different modelling approaches. In a second phase, other experiments and real field campaigns will be selected, focusing on the performances of the modelling tools in situations closer to possible emergency scenarios.

CONCLUSIONS

In the present paper the available data-sets for the quality assurance of dispersion models together with a preliminary classification of the datasets, focusing on the characteristics that make them more suitable for emergency-response applications were presented. Data-sets that shall be used for the validation of hazmat dispersion models specifically prepared for different phases of emergency response, as well as for pre- and post-accident analysis were proposed. A parent classification that 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 was elaborated. 'Primary' groups of datasets were particularised. The data that are important for the validation of hazmat dispersion models is one of the objectives of the COST Action ES1006 (Evaluation, improvement and guidance for the use of local-scale emergency prediction and response tools for airborne hazards in built environments) and the proposed data-sets that fulfil the requirements will be identified and put into an easy-to-use data base. The dispersion models implemented in emergency response systems are a key element for the prediction of danger zones and health effects; therefore quality assurance of the dispersion models' predictive capabilities is absolutely necessary and high quality experiment dataset for emergency-response applications should be promoted with high priority.

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