ATMOSPHERIC DISPERSION MODELLING AND HEALTH IMPACT ASSESSMENT IN THE FRAMEWORK OF A CBRN-E TRAINING EXERCISE IN A COMPLEX URBAN CONFIGURATION

Patrick Armand[1], Christophe Duchenne[1], and Emmanuel Bouquot[2]

[1]CEA, DAM, DIF, F-91297 Arpajon, France
[2]CNCMFE NRBC-E, F-13090 Aix-en-Provence, France

Abstract: Training exercises are a great opportunity to improve the capabilities of the first responders and decision-makers to face potential CBRN-E release events. Moreover, AT&D modelling associated with health consequences evaluation is most often considered as a useful component of the emergency preparedness and management. Making use of the synopsis and data of a CBRN-E exercise, this paper describes the simulation of a fictitious terrorist attack implying a toxic chemical emitted with a dispersal device in a crowded public place of a large town. The chemical is released in an exhibition hall, and then goes outside through the venting system and the open gates of the building. The computations were carried out using CERES® CBRN-E, the emergency modelling and decision support system of CEA, with Parallel-Micro-SWIFT-SPRAY (PMSS) embedded inside to simulate the wind field and the dispersion. Health impact assessment indicates that in the studied scenario, irreversible effects would be encountered not only in the exhibition hall, but also in the public park around it, and even in some of the neighboring residential buildings and school. Eventually, this work shows how simulation can raise the realism of a training exercise (linking the noxious release and the sanitary consequences on the population and first responders) and may provide rescue teams, police or stakeholders with complementary information, likely to guide them in high-stakes decision-making.

Key-words: *CBRN-E exercise, crisis scenario, urban configuration, atmospheric dispersion, health consequences.*

INTRODUCTION

In case of fictitious or real releases of CBRN threat agents, atmospheric dispersion modelling followed by health consequences assessment are more and more often deemed by rescue teams and decision makers as an important component of emergency preparedness and crisis management and mitigation (Armand *et al*., 2013). Many countries have set up civilian and military training centers whose role is to improve the capabilities of the national authorities to face CBRN-E events. In their missions, the training centers have to create crisis scenarios and to organize exercises gathering actors likely to be involved in such situations (fire brigade, police, medical teams, experts, stakeholders, etc.). A great attention is paid to the necessary realism of the scenario in all its aspects, notably the evaluation of the affected area and the effects of the toxic material release on the population and first responders. However, when considered, the dispersion in the air of hazardous materials is very often only modeled by an angular sector of a fixed arbitrary length, even if the environment is complex with a significant relief or buildings (industrial site or urban district).

This paper presents a new approach to the modelling and simulation of a terrorist action exercise striking a public place (hall of exhibition) in a large town (in the South of France). All scenario data including the geometry of the buildings in the impacted area, the nature of the chemical, the amount of the release, and the meteorological conditions during the incident have been used to assess the 4D (meaning both space 3D and time) distribution of the toxic material and its potential health effects on the people present both at the exhibition center and in the nearby urban district. The computations have been done with CERES® CBRN-E modeling and decision support system developed by CEA. In this study, the flow and dispersion solver used inside CERES® was the parallel version of MSS suite (Parallel-Micro-SWIFT-SPRAY).

The paper is structured as follows: firstly, the main features of the attack scenario are presented restricting the information to what is useful for modelling; secondly, the modelling system and the assumptions of the study are described; thirdly, the principal simulation results and lessons learned are commented on.

SCENARIO OF THE CBRN-E ATTACK

In this exercise, the false terrorist attack is supposed to be triggered at 3:00 pm inside a big exhibition hall located near a stadium in a public park of a large city. At 3:06 pm, the site security manager informs the fire brigade that many people in the hall smell a very unpleasant odor and begin to get out of the building. More than 1,000 people gather on the plaza in front of the hall waiting for the rescue team which arrives at 3:12 pm. A sulphur-containing chemical is detected in the air at 3:18 pm while, at the same time, an empty dispersal device is found in the hall. The decision is taken to fully evacuate the hall and close the public park. At 3:22 pm, mustard gas (yperite) is identified while several people show more or less severe signs of contamination. The following of the synopsis is mainly dedicated to the application of medical treatment and security procedures in the public park and in the surrounding urban area. At 4:29 pm, the mobile laboratory of the fire brigade indicates that three more dispersal devices have been discovered in the exhibition hall where the average concentration of yperite is about 1 mg.m^{-3}.

Figure 1 shows the aerial view of the urban area where the event is presumed to occur. The exhibition hall submitted to the false event is circled in yellow. Figure 2 is a zoom of the district located north to the hall.

Figure 1. Satellite view of the area of interest.

Figure 2. Oblique view of the urban area north to the hall.

MODELLING SYSTEM AND COMPUTATIONS CONDITIONS

Albeit the toxic chemical is released inside the exhibition hall, part or all yperite is probably transferred out of the building due to both ventilation and the movement of people escaping from the exhibition hall. As the toxicity of yperite is high even with low concentration levels, many people are likely to be affected (not only the public in the hall, but the urban district inhabitants, and the first responders).

Calculations hypotheses

Derived from the chemical attack scenario, the principal conditions of the simulations are given hereafter:
1 – Wind blows from the south at 20 km.h^{-1}, at a height of 10 m above the ground level in an open area.
2 – The volume of yperite which is released is 4 L, inferred from the discovery of the dispersal device.
3 – As the suspicious smell occurs at 3:06 pm, the release is supposed to begin a bit earlier, circa 2:50 pm.

Indoor / outdoor transfer

Moreover, the release duration is less than 30 minutes as the dispersal device is found empty at 3:18 pm. In this study, no detailed CFD computation was carried out inside the building. We considered a uniform concentration in the hall (whose volume is around 100,000 m^3) evolving with time. The release rate of the yperite droplets from the dispersal device is estimated to be 3 g.s^{-1}. The aerosol is then transferred through the venting (turnover of 2 h^{-1}) and the gates of the hall (time constant of 1 h^{-1}). Figure 3 shows the history of the yperite mean concentration in the hall. It can be noticed that this numerical result is fully consistent with the concentration of 1 mg.m^{-3} measured at 4:29 pm by the mobile lab. Figure 4 presents the kinetics of the chemical release to the atmosphere. Two-thirds of the chemical exist through three outlets located on the roof of the exhibition hall while one-third is transferred through the 21 gates of the building. For these accesses, it is supposed that one-third of the chemical goes through the main entrance and the rest through the other doors (emergency exit, access for delivery…). The total number of point sources is 24.

Atmospheric dispersion and health impact assessment

Using the chemical source term as determined previously, the dispersion and health effects evaluation has been performed with CERES® CBRN-E. This new operational 4D modelling and decision support tool has been developed since 2008 by CEA in the framework of academic and industrial collaborations. It is devoted to assess AT&D, environmental impact and human health consequences of possibly deleterious, accidental or chronic, releases in the atmosphere. CERES® can cope with all categories of CBRN agents, explosions (E), and all kinds of natural (rural) or built (industrial plant, urban district...) environments.

CERES® can be utilized for both safety studies and emergency preparedness or handling. When applied in an emergency, it is committed to deliver directly exploitable results (e.g. danger zones) in less than 15 minutes whatever the situation, should it be a conventional accident, or a malevolent or terrorist action. CERES® is modular and flexible by design, offering the user multiple possibilities, especially regarding the meteorological data and the range of dispersion models (standard or urbanized Gaussian or LPDM).

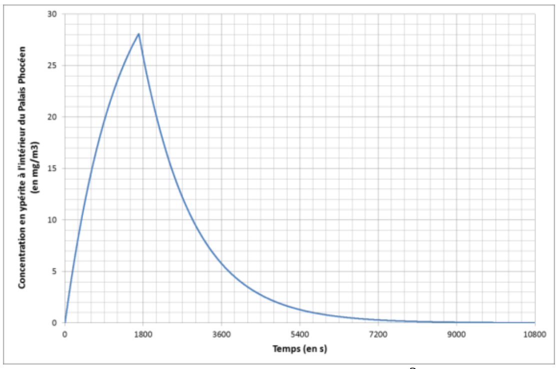

Figure 3. Yperite concentration (in mg.m^{-3}) evolution inside the exhibition hall.

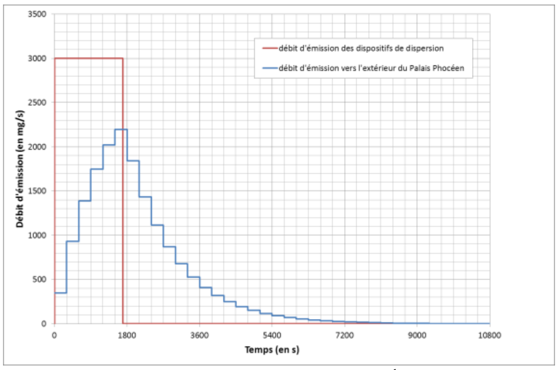

Figure 4. Yperite rate release (in mg.s^{-1}) within the dispersal device and to the atmospheric environment.

In this study, it was decided to feature Parallel-Micro-SWIFT-SPRAY (PMSS) as the flow and dispersion solver inside CERES®. The interest to embed PMSS in CERES® is to combine a fast response simplified CFD module and CBRN-E impact models with the benefit of CEA expertise in this field and of a tried and tested ergonomic graphical interface fitting the needs of the rescue teams and decision makers.
PMSS is developed by ARIA Technologies, ARIANET, MOKILI and the CEA (see Tinarelli *et al*. 2013, Duchenne *et al*., 2011) and consists of the parallel versions of SWIFT and SPRAY. SWIFT is a 3D mass-consistent diagnostic model interpolating meteorological measurements and / or model results and taking into account the influence of the buildings on the wind field according to Röckle approach. SPRAY is a 3D Lagrangian dispersion model able to deal with the numerical particles bouncing off onto the buildings and, possibly, the deposition on all exposed surfaces (ground, façades, and roofs…).

MAIN RESULTS OF THE SIMULATION

This section presents and analyzes in three steps the sequentially obtained computational results.

Local-scale wind field

In this scenario, the meteorological conditions are supposed to remain unchanged during the simulation. Figure 5 shows the horizontal section of the wind field (vectors and modulus) at 2 m above the ground level. The flow is principally oriented from the south to the north what is observable in the areas not influenced by the buildings. North of the large buildings, low wind wake zones are clearly visible. In some densely built areas, the flow is complex with the channeling effect of streets not aligned with the wind direction.

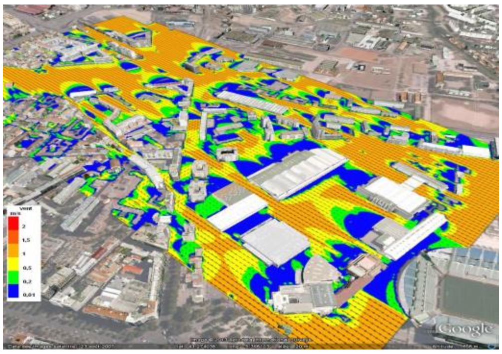

Figure 5. Wind field view at 2 m above the ground.

Toxic chemical atmospheric dispersion

From the chemical release rate in Figure 2, it appears that the yperite is emitted out of the exhibition hall in two hours. This is also the duration chosen for the dispersion simulation. Figure 6 presents the section of the toxic concentration field between the ground and a height of 2 m at six successive times (5; 15; 30; 60; 90; and 120 minutes) after the beginning of the release. The figure illustrates the chemical distribution which is complicated even for this simple meteorological condition and which predominantly depends on the buildings configuration. Distances at which different concentration levels are reached may be seen on the figure, e.g. 1 $mg.m^{-3}$ at some tens of meters around the exhibition hall; 0.3 $mg.m^{-3}$ on the opposite side of the street where the hall is located; and 0.1 $mg.m^{-3}$ at 600 m from the hall 45 min after the release start.

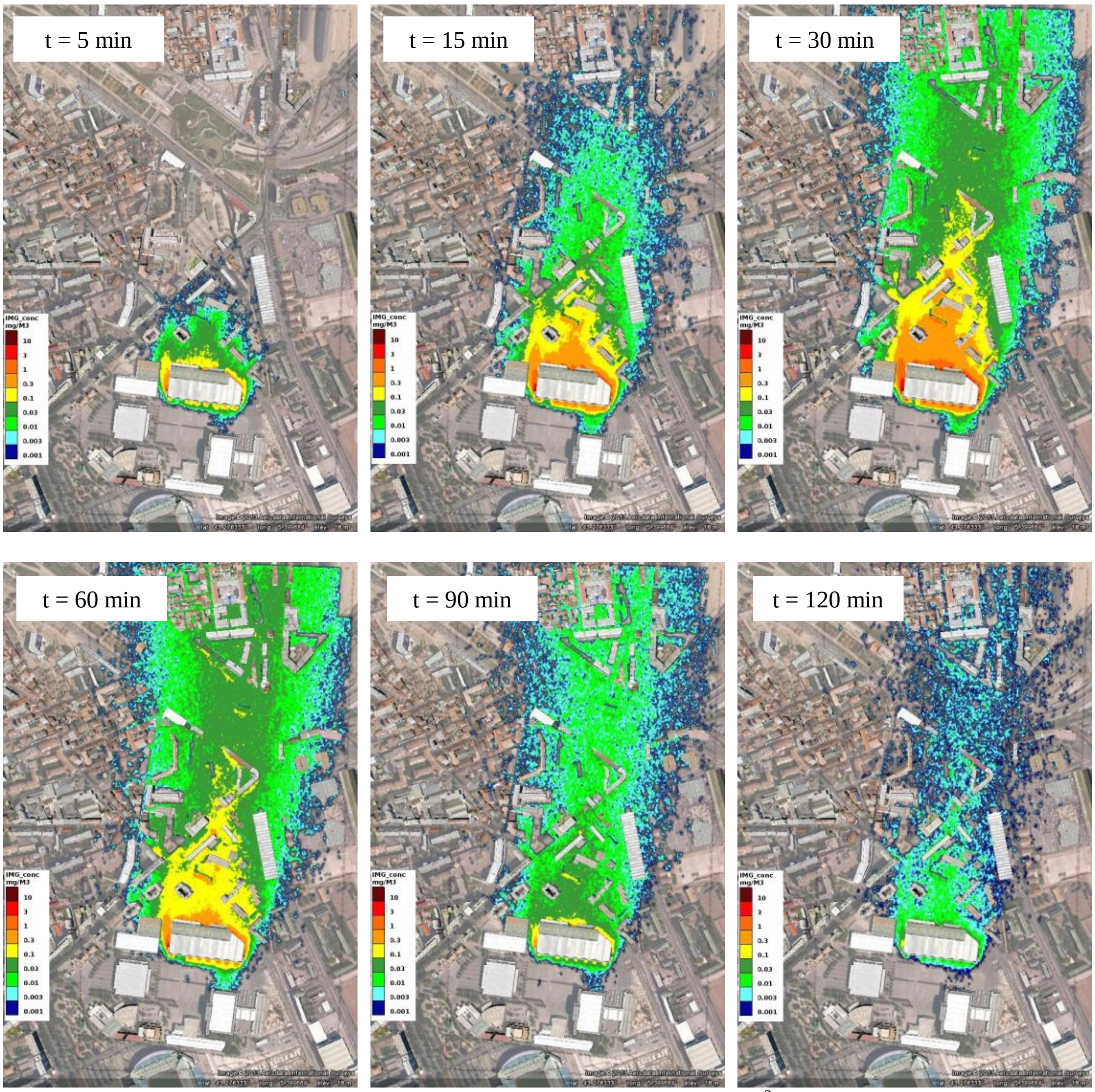

Figure 6. Section at 2 m above the ground of the yperite concentration (in $mg.m^{-3}$) in the urban district at six instants after the start of the chemical release.

Health impact assessment

The concentration levels and the exposure duration are the relevant information to infer the health effects of the deleterious dispersion. In this study, we have used the Acute Exposure Guideline Levels published by the US EPA Advisory Committee for the development of AEGL for hazardous substances. The AEGL are guidelines to help national and local authorities as well as private companies to deal with emergencies involving spills, or other catastrophic events. They are applicable to all categories of population including sensitive people. There are three levels of AEGL (1, 2, and 3) corresponding respectively to reversible, irreversible, and possibly lethal consequences, defined for various exposure durations (10 min to 8 hr).

Figure 7 shows the danger zones for the yperite scenario. At each location, AEGL have been determined using the most adapted value to the effective duration of the plume going by. From this figure, AEGL 3 is limited to a small area in front of the exhibition hall; AEGL 2 is passed over not only around the building, but also locally in some streets; AEGL 1 concerns a quite large urban area, and also an elementary school.

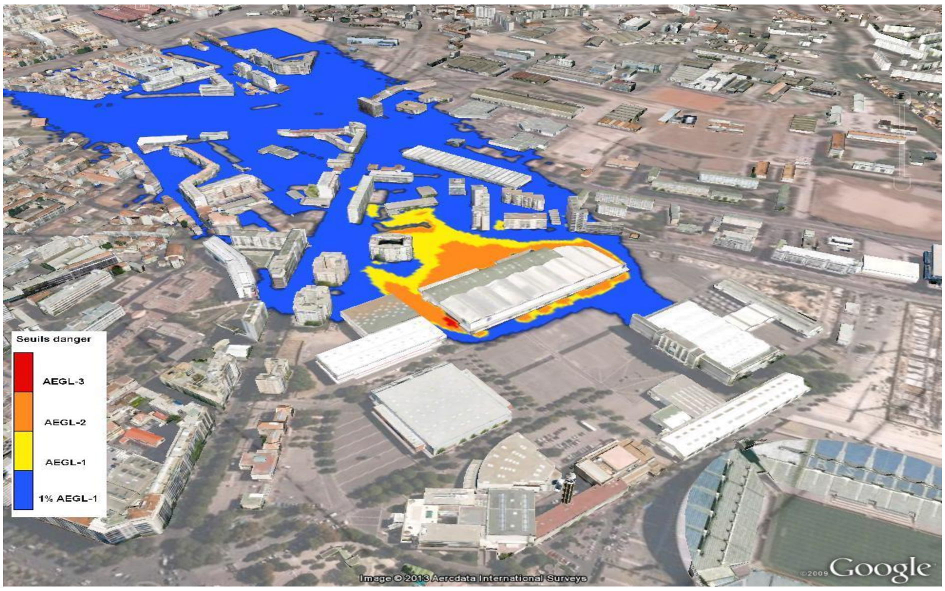

Figure 7. Danger zones corresponding to the AEGL thresholds.

CONCLUSION

In this paper, the synopsis and data of a CBRN-E training exercise have been used to develop the physical model and numerical simulation of this crisis scenario. The exercise consists in a fictitious terrorist attack implying a toxic chemical emitted with a dispersal device in a crowded public place of a large town. The chemical (yperite) is released inside an exhibition hall where it diffuses and is transferred outside through the ventilation and the gates of the building. The computations were carried out with CERES® CBRN-E, the emergency modelling and decision support system of CEA, featuring Parallel-Micro-SWIFT-SPRAY (PMSS) for the flow and dispersion simulation. Given the nature and quantity of the release, the health impact assessment clearly indicates that irreversible effects would be observed not only in the exhibition hall, but also in the public park around it, and even in some of the neighboring residential buildings.
Finally, this study confirms our capability to precisely and quickly simulate the distribution and effects of CBRN agents which could be accidentally or intentionally released in a built environment as complex as an urban district or an industrial site. It also demonstrates the role and the actual help that modelling can bring to crisis preparedness and management. Used to elaborate scenarios, simulation contributes to raise the realism of the exercises, especially the correlation between the noxious release and its consequences on the population and first responders. Used during an exercise or in the course of a real event, simulation could provide rescue teams, police and / or stakeholders with additional information, likely to guide them in high-stakes decision-making.

REFERENCES

Armand, P., C. Duchenne, Y. Benamrane, C. Libeau, T. Le Nouëne, and F. Brill. Meteorological forecast and dispersion of noxious agents in the urban environment – Application of a modelling chain in real-time to a fictitious event in Paris city. *15th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, HARMO'15*, May 6-9, 2013, Madrid, Spain, 724-728.

Duchenne, C., P. Armand, O. Oldrini, C. Olry, and J. Moussafir. Application of PMSS, the parallel version of MSS, to the micro-meteorological flow field and deleterious dispersion inside an extended simulation domain covering the whole Paris area. *14th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, HARMO'14*, Oct. 2-6, 2011, Kos, Greece, 679-683.

Oldrini, O., M. Nibart, P. Armand, C. Olry, J. Moussafir, and A. Albergel. Multi-scale build-up area integration in Parallel SWIFT. *15th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, HARMO'15*, May 6-9, 2013, Madrid, Spain, 485-489.

Patryl, L., C. Duchenne, P. Armand, L. Soulhac, and G. Lamaison. Validation of the urban modelling in CERES® CBRN by comparison with a Lagrangian code for complex cases. *NATO / SPS International Technical Meeting on Air Pollution Modelling and its Application, ITM 2013*, August 26-30, 2013, Miami, Florida, USA.

Tinarelli, B., S. Trini-Castelli, G. Carlino, J. Moussafir, C. Olry, P. Armand, and D. Anfossi. *Review and validation of Micro-SPRAY, a Lagrangian particle model of turbulent dispersion*. In Lagrangian Modeling of the Atmosphere, Volume 200, AGU Journal of Geophysical Research, May 2013 (ISBN: 978-0-87590-490-0).