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REAL-TIME USE OF A CFD MODELLING SYSTEM IN THE FRAMEWORK OF "TOXIC 2014", A MAJOR CIVILIAN SECURITY EXERCISE AT A VERY COMPLEX URBAN SITE IN PARIS

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Abstract: On 22 May 2014, a civilian security exercise named "Toxic 2014" was organized in "La Defense" business district located west of Paris. It was a fictitious massive release of ammonia from a tanker-vehicle (after an accident or a terrorist attack). The French Atomic and alternative Energies Commission (CEA) was involved in "Toxic 2014" to provide in real time the Paris Fire Brigade and the "Prefecture" (local authority) with dispersion and danger zones results taking account of the buildings and the local meteorological conditions. The exercise showed that a modelling and decision-support system like CERES® developed by CEA fosters the understanding and a shared representation of the emergency situation as it facilitates the communication to the authorities. Thus, the exercise illustrated the role of advanced modelling in coordinating a crisis command centre and taking adapted population protection measures.

Key words: *advanced modelling, decision support, civilian security, CBRN-E crisis exercise, CERES®.*

INTRODUCTION

Explosions and toxic releases into the atmosphere may originate from accidental situations or malicious emerging threats. The social consequences of such events are increasingly feared and a great attention is paid to the prevention, provision, and managing of what are now called the "CBRN-E threats".

In the last decades, physical modelling and numerical simulation have experienced parallel considerable improvements (see Benamrane *et al.*, 2013, commenting on the evolution in the use of the models from Chernobyl to Fukushima). This is not only good and important for the scientist and the engineer. It is also an opportunity to change the status of the predictive computations performed in emergency preparedness and response to make them an effective support in the decision-making process. Built environments with, possibly, a complex topography and varying meteorological conditions are definitely the places where CBRN-E events may arise. Advanced modelling is now able to produce 2D and 3D detailed and realistic results directly useable by the civilian security to protect the population in a very limited amount of time (around 15-30 minutes) even for a very large urban simulation domain as shown in Oldrini *et al*. (2013).

The French Atomic and alternative Energies Commission (CEA) is committed to developing a modelling and decision support system called CERES® adapted to CBRN-E threats as illustrated in Armand *et al*. (2013) (2014) and (2015). In this respect, the present paper documents a major civilian security exercise called "Toxic 2014" which was hold in "La Defense" district near Paris and implied the fictitious release of a toxic industrial chemical. It is described how the exercise took advantage of CERES® capabilities.

THE DESIGN AND SCENARIO OF "TOXIC 2014"

Since 2012, the CEA has launched a research work aiming at evaluating the adequacy of the modelling and decision-support tools with the actual needs of the emergency players. In this framework, the CEA was associated to the organization of an exercise named "Toxic 2014" held on 22 May 2014 to test the safety procedures plan of "La Defense" business district (located North-West of Paris) in case of a toxic release. The partners were the Paris Fire Brigade, the public body in charge of "La Defense" security, and the "Prefecture" which is the local public authority in France.

The involvement of CEA in "Toxic 2014" exercise included contributions to the preliminary elaboration of the noxious release scenario and to the exercise itself by providing expertise and modelling regarding atmospheric dispersion and health impact assessment. In the following, details are given about these two phases and the simulations that have been produced for preparedness and response.

Proposal for scenarios

In September 2013, the CEA was asked by the Prefecture to develop realistic scenarios of a hazardous atmospheric dispersion fulfilling of a number of requests: releases should be chemicals as a "dirty bomb" exercise had been carried out the year before; meteorological conditions should be such that a large part of "La Defense" is affected towards Paris; and the danger zones should be quite large in order to simulate a serious event and to train the Fire Brigade first-responders and the Prefecture command centre.

Along with this, the CEA proposed several plausible CBRN-E events corresponding to either accidents or malevolent actions. In order to obtain a large panel of situations, different weather conditions, locations of the release, and toxic chemicals were presented as exemplified in Figure 1. For each possible place of the release, realistic scenarios and operating modes were built up (not reported in this paper).

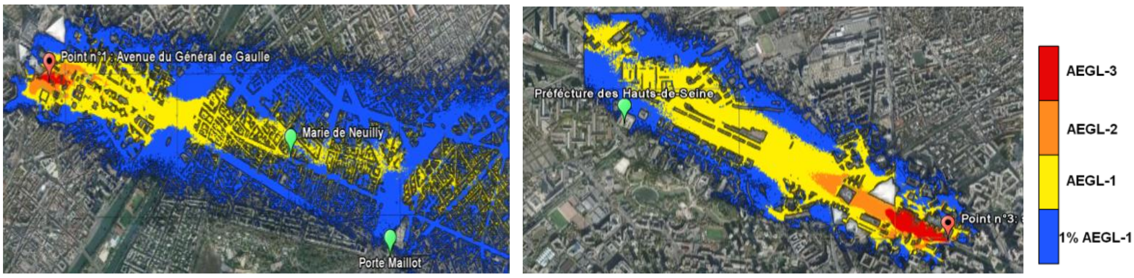

Figure 1. Distribution of a toxic chemical released in "La Defense" district (results given for two release locations). The danger zones have warm colours. They were determined using the AEGLs of the US-EPA.

Choice of the exercise scenario

In December 2013, the CEA presented the modelling results of various fictitious releases and potential consequences on the population to the players implied in the future exercise (Prefecture, municipalities, fire-fighters, police, health service, public transport operators...). Considering the aims of the exercise, the chosen scenario was a hypothetical hazardous material transport accident. More precisely, it was a breach in a tanker-vehicle containing liquefied ammonia. This event was considered as appropriate by the players as ammonia is a usual chemical compared to other proposed species. Moreover, it could be related to both an accidental event and a malevolent action (like a tanker hijacking). The location was taken on the circular boulevard, west of the district, quite aligned with the esplanade of "La Defense".

The final scenario was featured by CEA choosing it as realistic as possible, respecting the protocols and intervention times of the fire-fighters and making the Prefecture command centre work in anticipation. As a matter of fact, it was decided to have a change in the wind direction during the release, thus a variation of the impacted areas that could be predicted in the course of the exercise.

Chosen inputs for "Toxic 2014"

In March 2014, the CEA presented the detailed conditions of the scenario (Table 1) to the exercise teams.

Table 1. Main features of "Toxic 2014" exercise.

Meteorological conditions	Wind blowing first from northwest then from southwest
Source term	~10 tons of ammonia with 15% instantaneously released and 85% evaporating in 45 min
Mock-up of the district	Includes the topography, the explicit description of the buildings at 1 m resolution and a rugosity length for the small elements (bus shelters, booths…) not described in the obstacles files

THE TIME SEQUENCE OF "TOXIC 2014" (IN BRIEF)

The exercise began on 22 May 2014 at 1 pm. The Prefecture was alerted at 1:15 pm to an accident in "La Defense" implying a tanker-vehicle. The command center and the security procedures plan were activated at 1:25 pm simultaneously with the information about the victims and the plausible chemical risk.

The CEA involvement in the exercise had been predetermined with the Prefecture and Paris Fire Brigade. The CEA was informed at 1:30 pm by the Fire Brigade and received the first input (place of the event and gross estimate of the source term) necessary to begin with a real time simulation of the event. Dispersion results taking account of the buildings were obtained in about 20 minutes and sent by e-mails both to the Fire Brigade operational center in Paris and to the command center of the Prefecture. Meanwhile, a CEA expert was requested to join the command center and arrived there at 2:00 pm.

Phase 1 – Beginning of the exercise

The question of the population sheltering or evacuation arose very quickly. It was discussed by the Fire Brigade, the medical emergency team, the Prefecture, and the expert using the map views of the complex dispersion pattern (see Figure 2) displayed on the computers terminals of the command center.

At 2:03 pm, the Fire Brigade recommended the skyscrapers confinement rather than their evacuation; as a precaution, the Prefecture decided to confine the whole district waiting for a more accurate assessment.

At 2:23 pm, the CEA debated the plume dispersion simulation with the Fire Brigade. From a video, it was clear that at this time, the release was over and the plume diluted with concentrations below any adverse effects on the human health. Then, the map of the toxic load (presented after the plume crossed all the area) was used to delimitate the health consequences zones (see Figure 3). While the most severe effects were limited to "La Defense" esplanade, it was probable that due to a low olfaction threshold, numerous people may have detected the abnormal presence of the ammonia in many localities at the north of the district. This was considered as a very important information by the Fire Brigade.

Phase 2 – First update of the situation

At 2:39 pm, the Prefecture cabinet director arrived triggering the first situation update. The Fire Brigade indicated with a map the presence of the rescue teams on the spot and the measures taken to confine the population. The CEA presented the simulation of the plume dispersion on a video and the assessment of the health consequences (cumulated from the beginning of the release). The Fire Brigade explained that at this time, the risk did not evolve anymore and that a confirmation was expected from the field.

The medical emergency team updated the number of casualties and the hospitals taking care of them. It also stressed the saturation problem which could happen if people smelling the ammonia headed to the hospitals (see the olfaction area on Figure 3). Finally, the measures taken in the municipalities at the north of La Defense were further examined. It was noticed that buildings aeration could be advised as the plume had left the sector. Moreover, measurements in the field indicated that the concentration levels were very low consistently with the modelling.

Phase 3 – Second update of the situation

At 4:00 pm, the Prefect arrived at the command center triggering the second situation update. The nature of the event and the population protection measures were enlightened as the progressive annulment of the confinement measures. To supplement the Fire Brigade and health emergency service reviews, the CEA was requested to present the ammonia dispersion simulation and the consequences assessment. The full termination of the security measures all over "La Defense" district was declared at 4:30 pm.

NUMERICAL SIMULATIONS IN "TOXIC 2014"

The simulations were performed with PMSS, one of the dispersion solvers set up in CERES® modelling and decision-support tool. PMSS is developed by the CEA, ARIA Technologies, and MOKILI (Tinarelli *et al*., 2013). It is devoted to research and advanced modelling solutions testing. PMSS is nested in a meso-scale weather forecast system based on WRF and operated routinely by the CEA (resolution of 5 km above France and 1.6 km over the Paris region). Then, PMSS solves the 3D local urban flow and dispersion at a resolution of 1 to 5 meters.

PMSS simulations were carried out on a domain with dimensions 4.2 km x 6.3 km and a horizontal mesh size of 3 meters. This large domain was sub-divided in 24 tiles of 351 x 351 points. The vertical meshing had 37 levels from the ground to a height of 800 m. The flow was run with P-SWIFT on 25 processors and the dispersion with P-SPRAY using a maximum number of 64 processors. All the simulations were carried out in less than 15 minutes (a duration which is consistent with the emergency management).

Assessment of the toxic loads

The health consequences of the release were evaluated on the basis of the reference toxicological values applicable in France (given by the INERIS for common industrial gases) in case of an accidental acute exposure by inhalation. As the concentration was not time constant, the toxic load was evaluated at each point of the simulation domain and compared to threshold values.

The ammonia sensorial perception (SP) by olfaction was also considered. This is a concentration which is between 3.5 and 35 $mg.m^{-3}$ depending on the individuals, does not result in any health effect and it is not associated with a duration. The maximum concentration at each point was compared to the SP to identify the area where the olfaction threshold was exceeded.

Numerical results

Figures 2-a) to 2-d) illustrate the plume propagation and the volumetric concentration near the ground at successive moments after the beginning of the hypothetical release. The ammonia concentration field is presented with a gradual fading of the same color to avoid any confusion between the concentration and health consequences when providing the Fire Brigade and Prefecture command centers with maps.

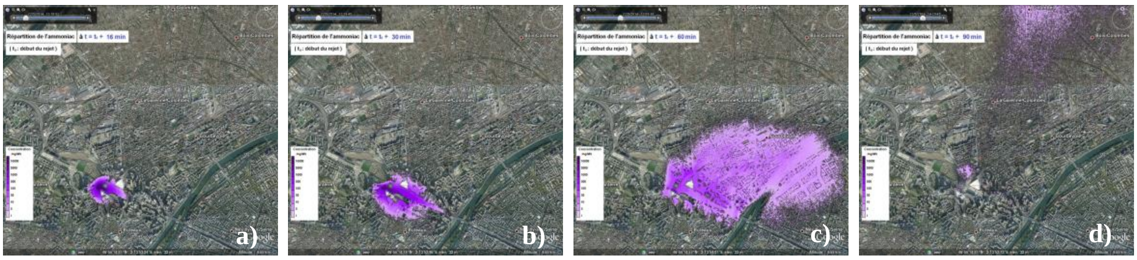

Figure 2. Ammonia volumetric concentration distribution at t_0 + 15 min (a), 30 min (b), 60 min (c), and 90 min (d).

Figure 3 presents the danger zones corresponding to the health effects of the toxic plume as the release is over and the plume has crossed the whole simulation domain (90 min after the triggering of the release). The zone of the significant lethal effects (5% of the population) (SELS) is in dark red; the zone of the first lethal effects (1% of the population) (SPEL) is in red; the zone of the irreversible health effects (SEI) is in orange and the zone of the reversible effects (SER) is in yellow. The area in which ammonia smelling may have been detected by the population from the beginning of the release to the considered time frame is colored in blue. It covers an extended area around four municipalities east and north of "La Defense".
Figure 3 also compares the results issued by CERES® and ALOHA (smooth ellipses) which is the hazard software of the CAMEO modelling system developed by the US-EPA (Jones *et al*. 2013). ALOHA is a Gaussian dispersion model not taking account of the topography and the buildings. It is widespread in the USA with the firemen and also popular in France. Given this model limitations, ALOHA results are quite consistent with PMSS results. The main difference is that the plume progression is contained by the

buildings what can be predicted by PMSS and not by ALOHA. Thirty minutes after the beginning of the release, the wind changes direction with the eastern part of “La Defense” not affected by the plume. This is predicted by PMSS and not foreseen by ALOHA. Finally, due to the complicated meteorological conditions and the air flow in between the buildings, only PMSS can predict contaminated areas upwind.

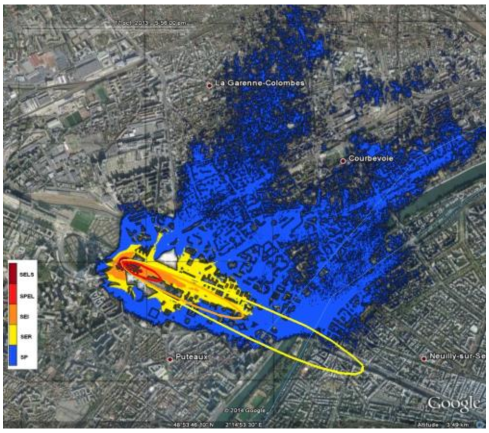

Figure 3. Comparison of the danger zones predicted by PMSS and ALOHA.

LESSONS LEARNT FROM “TOXIC 2014”

The toxic release exercise revealed two essential benefits in providing real time modelling expertise:

1. Simulation is relevant to enhance a common understanding of the space-and-time distribution of the chemicals what helps in making decisions and taking adapted measures for the population protection.
2. Simulation may be used to facilitate the communication to the authorities and all players what helps in generating a shared representation of the situation and an optimal coordination of the command center.

The main lesson was the complementarity between the first actions taken by the rescue teams in case of a short or medium duration release and the simulations aiming at diagnosing and anticipating the situation. Even if the performance in real life would be diminished as it is uneasy to determine the source term, the early visualization of the plume dispersion pattern is clearly of interest to support the response first phase.

The integration of modelling activities in the preparation of the exercise had triple benefits:

1. The better mutual knowledge of the scientific tools’ developers and the civilian security services;
2. The full CBRN risk analysis of events targeting “La Defense” with a much better apprehension of the human and organizational impact (to our knowledge, a “premiere” for a business district);
3. The development of a technically more precise than the usual practices, realistic and relevant scenario which allowed the state services to work in-depth the time sequence of the exercise;

The involvement of modelling expertise in the course of the exercise had also triple interests:

1. The effective use of the modelling by the services in charge of the population protection to identify the dispersion processes, adapt the first actions of the rescue teams and anticipate the event follow-up;
2. The static and dynamic presentation of the results (the CEA maps were used all along the exercise for communication purpose and to help in sharing a collective view during the situation updates);
3. For the CEA, the improvement and adaptation of the results provided by the computational tools to better fit the needs and the missions of the civilian security organization.

CONCLUSIONS

The paper addresses the promising capacities of up-to-date dispersion modelling and health consequences assessment applied to CBRN-E emergency preparedness and response. A civilian security exercise hold on 22 May 2014 in “La Defense” business district near Paris, named “Toxic 2014”, was the test bed for CERES® modelling and decision-support system. Flow and dispersion simulation taking account of both the buildings and local meteorological conditions were produced in around 20 minutes at 3 m resolution, post-processed to deduce the danger zones and transmitted to the Paris Fire Brigade and the “Prefecture”. The modelling was actually utilized by the services in charge of the population protection and contributed to identify the dispersion processes in the built environment, adapt the first actions of the rescue teams and anticipate the event follow-up. Finally, “Toxic 2014” was a good opportunity to work collaboratively with practitioners and make the CEA computational tools better fit their actual needs and missions.

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