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

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Abstract: On 20th June 2012, a "dirty bomb" crisis exercise was organized joining Paris Fire Brigade (BSPP) and the French Atomic and alternative Energies Commission (CEA). The fictitious explosion accompanied with a radioactive release was hypothetically located in a central district of Paris. CEA used its automated modelling chain of the meso-scale weather forecast over France downscaled to the whole Paris streets (at 3 m resolution) with PMSS and triggered a dispersion computation whose results were available 15 minutes after the beginning of the exercise and transmitted in real-time to BSPP. This was completed after radionuclide identification (30-45 min. later) by exposure assessment of the public and first responders. All results were forwarded by e-mail to the BSPP Operations Survey Centre (CSO) and to the Command Post Vehicle (VPC). So, the exercise demonstrated the operational capability and the significant help for Civil Security of new 4D modelling and decision support tools at the time when the crisis was occurring.

Key-words: *Crisis exercise, dirty bomb, Paris Fire Brigade, dispersion and impact assessment, results transmission.*

INTRODUCTION

It is more and more admitted that atmospheric dispersion modelling may be of great help for rescue teams and public authorities at least for preparedness before a crisis implying the release of hazardous materials, and also in the course of a real emergency. For such cases, advanced 4D (3D / time) simulations of the air flow and dispersion may provide the decision makers with a precise and realistic view on the event in terms of noxious gases or particles distribution and their health consequences. In this context, the French Atomic and alternative Energies Commission (CEA) and Paris Fire Brigade (BSPP) have proceeded to a fictitious "dirty bomb" crisis exercise on 20th June 2012. Computations of radionuclides dispersion and impact assessment were performed in real-time at CEA premises and the results transmitted to the BSPP Operations Survey Centre (CSO). This was achieved by using an operational chain of models, elaborated by CEA, comprising both the meso-scale weather forecast system MEDICIS and the micro-scale Parallel-Micro-SWIFT-SPRAY (PMSS) suite developed by ARIA Technologies, MOKILI, ARIANET, and CEA (Armand *et al*., 2011, SPRAY & SWIFT, 2008-2010). This paper presents the modelling chain process, atmospheric dispersion and radiological exposure results, time sequence of information forwarding to Fire Brigade, finally, lessons learned from the exercise and possible improvements of the simulation chain.

COMPUTATIONS CONDITIONS AND PROCESS

The exercise consisted in the false explosion of a "dirty bomb" containing a radioactive isotope of cobalt (^{60}Co). The attack was supposed to happen in Paris 8th district, a strategic area encompassing embassies, ministries, and the the French President residence (*Palais de l'Elysée*). The air flow inside all Paris streets was available before and during the exercise while atmospheric dispersion computations were launched at the time of the exercise. Moreover, post-processing allowed us to produce maps showing the radionuclide space and time distribution and the dreaded consequences expressed as radiological doses.

Calculation domain and geographical data

For the flow simulation, the domain was meshed horizontally at 3 m resolution with dimensions 4,050 m by 4,050 m and the vertical grid had 27 nodes from the ground to 1,000 m. The dispersion simulation results were projected on the same horizontal grid with a vertical meshing up to180 m. As this horizontal domain could not be handled by a single core, the large domain was divided in "tiles" distributed to multi-processors running in parallel. Topographical data are issued by the French Geographical Institute IGN BD ALTI® at a resolution of 25 m and interpolated on the 3 m grid. The 3D buildings description comes from IGN BD TOPO® and is processed to turn each building into a collection of triangular basis prisms.

Weather forecasting

For the exercise, the CEA meso-scale to micro-scale weather prediction system was used focusing on the calculation domain in Figure 1. At the end, the chain of models provides and refreshes every six hours the meteorological forecast at 3 m resolution in all streets of Paris. The micro-scale (or local scale) air fluxes are continuously computed by down-scaling the hourly results of MEDICIS meso-scale weather forecast over France operated routinely by CEA. MEDICIS which ran MM5 with a 9 km domain on France at the time of the exercise, is now updated with WRF at 5 to 1.6 km resolution on a better computation server. Figure 1 presents MM5 grid nodes where wind, temperature and humidity vertical profiles were extracted for the 3D mass-consistent PSWIFT diagnostic. When the exercise was launched on 20th June at 11:00, four hourly timeframes wind field (11:00 to 14:00 local time) were available. Figure 2 shows the meso-scale, *i.e.* without buildings influence, history of the wind modulus and direction near the ground level (at Figure 1 red dots) during the sequence. At a sufficiently high altitude over the town, weather conditions are quite unchanging with a 2.5 m.s^{-1} North wind varying less than 15°, and no precipitation in the period.

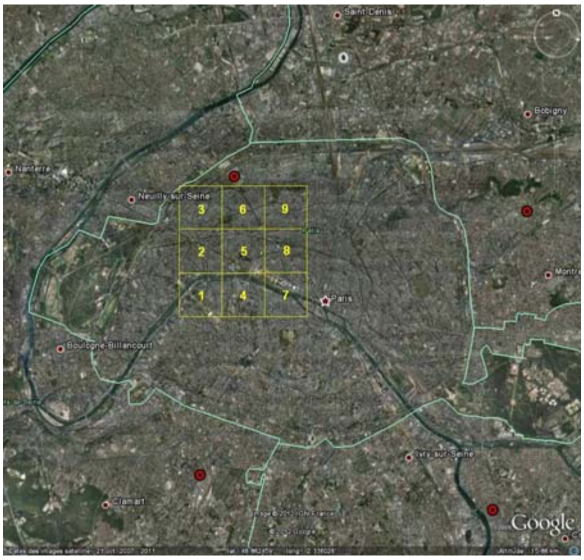


Figure 1. The computation domain is divided into 9 tiles. The four red dots represent the MM5 vertical profiles.

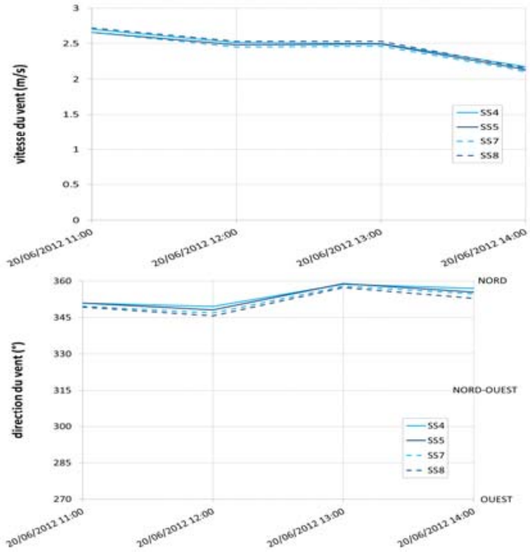


Figure 2. Time profiles of the wind modulus (in m.s^{-1}) and direction (in °) at four points of the meso-scale grid.

Release scenario description

The crisis scenario was chosen in agreement with the Fire Brigade. We considered the fictitious explosion of a dirty bomb placed inside a van parked in front of the post office in *La Boétie* street, near *Miromesnil* metro station (8th district). When the bomb blew up at 11:00, the explosion was moderate, however strong enough to disperse a radioactive aerosol in the air. The release was brief, lasting less than two minutes, producing a cylindrical plume of 10 m diameter, and rising up to 20 m. This initial approximate geometry was chosen to take account of the explosion blast effect. Later on, the radionuclide was identified as ^{60}Co.

Dispersion computation

The aerodynamic diameter of the aerosol is 1 µm, its density 2000 kg.m^{-3}, and its dry deposition velocity 5.10^{-3} m.s^{-1}. The numerical particles positions calculation time step is 1 s. The concentration is sampled every 10 s and the 3D average concentration field is stored every 60 s. In PSPRAY, 800,000 numerical particles were simulated: a high number providing very precise information on contamination distribution in the whole domain, near and far from the release. The calculation was carried out on a 16-core machine.

AIR FLOW AND DISPERSION RESULTS

Air fluxes in the streets network

Figure 3 illustrates the wind modulus at 2 m AGL on 20th June at 11:00 in a part of the domain including the release location. In the "free from buildings" areas (*e.g.* Seine River or *Concorde* square), the velocity is a bit less than 3 m.s^{-1}, consistent with the meso-scale prediction. On the contrary, in the "influenced by the buildings" areas, wind velocity is weaker, around 1 m.s^{-1}, except in the N-S oriented streets parallel to the wind where the velocity can reach more than 4 m.s^{-1} (because of the wind channeling). Figure 4 is a horizontal section at 2 m AGL of the 3D wind vector. This zoom near the place of the explosion shows the flow complexity inside the streets, especially for streets perpendicular to the wind axis where the air flux near the ground is opposed to the wind N-S main direction due a vortex forming induced by the flow above the roof level (spiral motion of the air in these W-E streets).

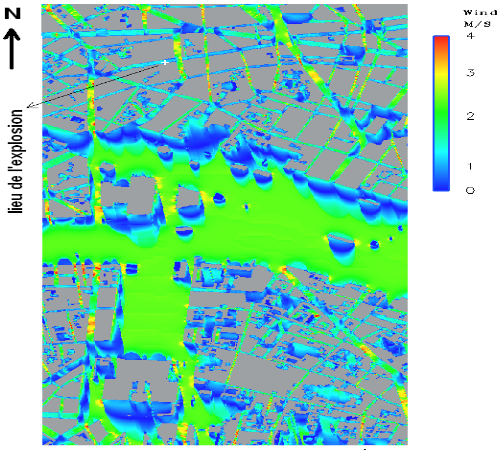


Figure 3. Wind velocity (in m.s^{-1}) near the ground in a part of the simulation domain.

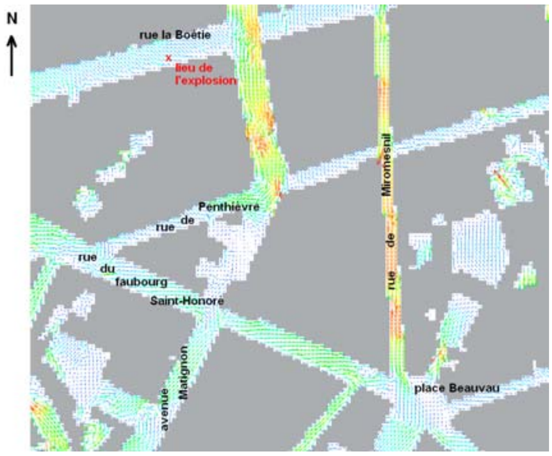


Figure 4. Wind vector field at 2 m above the ground. Detail near the place of the release.

Dispersion computation

At the fictitious news that a bomb had blown up in Paris (20th June at 11:00), very few information was available for modelling, except the news of a moderate explosion in a critical Paris area. Of course, it was not obvious that the bomb was accompanied by radioactive materials which, if any, were not identified. However, a radiological event could not be excluded. Models and computational resources permitting, it was thus decided to do a unit release dispersion calculation (1 TBq). Figure 5 illustrates the concentration field at successive times after the explosion (1, 2, 5, 10, 15, and 25 min) in the vertical air layer just above the ground (height of one to two buildings floors). At the time of the bomb attack, the wind blew N to S. The plume reached the corner of *Matignon* avenue and *Saint-Honoré* street, 200 m from the release point, at 11:02, the *Petit Palais* (exhibition place) (800 m) at 11:05, and *Invalides* boulevard (2 km) at 11:10. At 11:15, as a part of the plume already left the domain, a significant amount of radioactive materials was still trapped in *La Boétie* street. At this time, the plume spread 3 km downwind and 1 km crosswind.

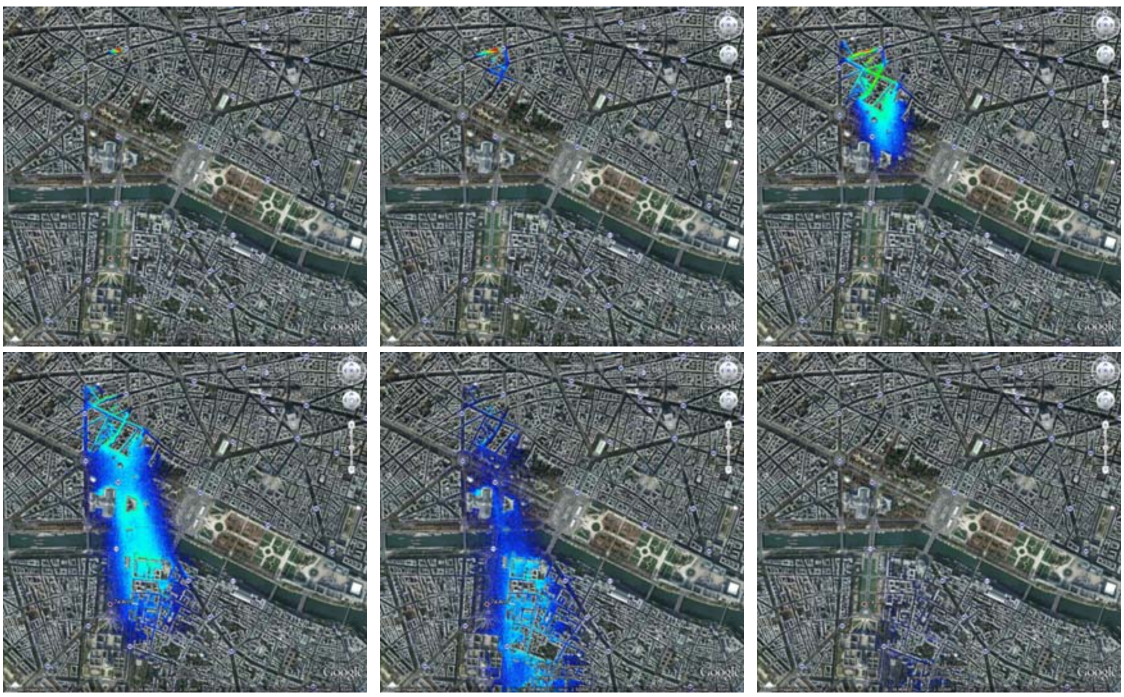
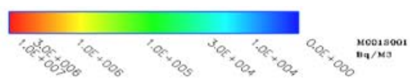


Figure 5. Radionuclide activity concentration (in Bq.m^{-3}) near the ground at six instants after the explosion.



Finally, the plume came out of the domain quite entirely at 11:30 what did not mean that there was no more radioactivity as it was transported on aerosol particles depositing on all accessible surfaces. Figure 6 shows the deposition on the ground and buildings façades and roofs after the plume finished to cross the domain. In the exercise, we did not evaluate infiltration inside the buildings although PSPRAY can do it. Obviously, it is the most important where deposition on façades is the highest.

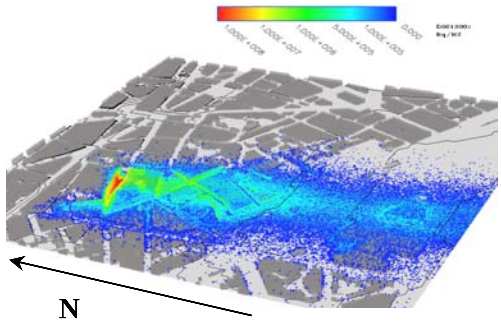


Figure 6. Radionuclide deposition on all surfaces after the plume crossed the domain (after 11:30).

HEALTH IMPACT ASSESSMENT

In case of a radiological emergency, it is crucial and mandatory to estimate the exposure of the population and first responders. For short-term doses, impact assessment considers inhalation and irradiation due to cloud shine and ground shine. Moreover, counter-measures are taken depending on the exposure level. In France, sheltering (evacuation) is considered if total effective dose equivalent exceeds 10 mSv (50 mSv). Otherwise, the regulation requires a 1 mSv per year limit of the population exposure to nuclear activities.

During the exercise, impact assessment was carried out by post-processing PSPRAY atmospheric activity concentration (in $Bq.m^{-3}$) and deposition (in $Bq.m^{-2}$) results and simply using ^{60}Co dose coefficients. Note that SPRAYSHINE post-processor could have been used for a more precise assessment of the irradiation.

Dose by inhalation

Figure 7 presents the inhalation dose for an adult (supposed not to move during the plume crossing) and assuming a ^{60}Co source term of 1 TBq. The exposure is beyond 50 mSv only near the release in *La Boétie* street. The threshold of 10 mSv is overpassed in a part of this street, in the courtyards of some buildings between *La Boétie* and *Penthièvre* streets, and at some points in *Penthièvre* street and *Matignon* avenue with high ^{60}Co concentrations. The exposure is more than 1 mSv in many streets near the release location, but not farther than 400 m. At the beginning of a crisis, the released quantity of hazardous materials is not known or not precisely. It is better identified when information gradually comes from the premises. In general, it is necessary to re-evaluate many times the sanitary consequences. In this exercise, we did not need any new dispersion computation, but just had to re-estimate the dose with a modified source term (see Figure 8 drawn with a ^{60}Co source term of 10 TBq and appreciate the difference with Figure 7).

Dose by irradiation

The external exposure due to cloud and ground shine was also computed during the exercise. Immersion in the plume leads to doses much less than those by inhalation. Ground shine depends on the presence over the contaminated areas. Hypothesizing a 6-hour exposure for the rescue teams, the integrated ground shine dose (11:00 to 17:00) is much less than the inhalation dose. However, even if the ground shine goes beyond 1 mSv only in *La Boétie* street, some places in the district exhibit a dose higher than 0.1 mSv demonstrating that a longer exposure duration would imply the exceeding of the 1 mSv threshold value.

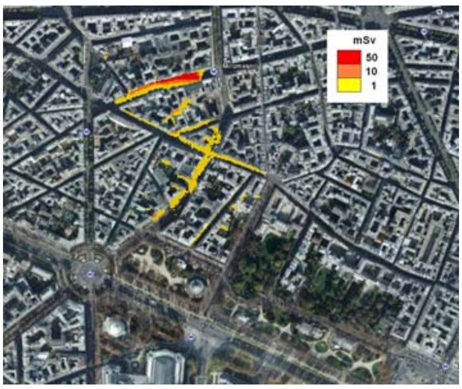


Figure 7. Dose by inhalation after the plume has gone through the area for a ^{60}Co release of 1 TBq.

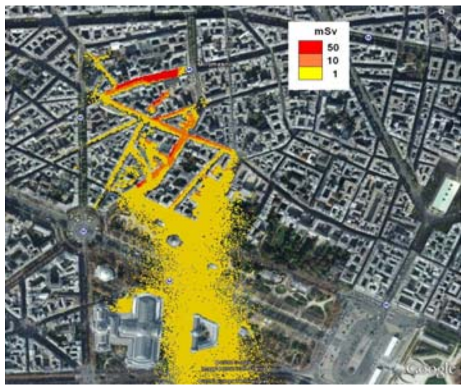


Figure 8. Dose by inhalation after the plume has gone through the area for a ^{60}Co release of 10 TBq.

TIME SEQUENCE OF RESULTS FORWARDING

Course of the exercise

The exercise was carried out on 20th June 2012, 11:00 to 12:25, simultaneously at the Operations Survey Centre (CSO) of Paris Fire Brigade (BSPP) and at CEA DAM Île-de-France where the computations were operated and the images presenting the results produced. Files were transmitted by e-mail to the CSO (24 / 7 vigil) which in turn sent the information to the Command Post Vehicle (VPC). At the rear, the VPC is equipped with a large screen which was unfolded during the exercise to visualize the results forwarded by CEA. In case of a "real" emergency handling, the VPC would be fully implied and placed near the event location which was not the case for this exercise. The exercise began with a phone call (t_0) from BSPP to CEA in order to warn about a fictitious explosion in *La Boétie* street. As a "dirty bomb" attack could not be excluded, a dispersion computation was launched on a 16-core machine (3.16 GHz) with PSPRAY model. Using 800,000 numerical particles, results were obtained in 15 minutes, and then post-processed to provide geo-referenced images of the 2D concentration near the ground at successive instants. The results were formatted to be directly used in the GIS of the BSPP and forwarded to CSO (t_0 + 30 min). In order to respect a realistic scenario of the crisis, it was decided to wait 25 minutes more before evaluating the doses, then elaborating and sending geo-referenced images of the exposure. In real life, this time lapse would be utilized to raise doubts about the radiological nature of the event and identify the radionuclides. One hour after the beginning of the exercise, the source term was re-evaluated and an updated exposure computation was done and transmitted to BSPP. In a real situation, one would keep doing this iterative process exploiting all information coming from the terrain, especially measurements of the radioactivity.

Comments and lessons learned

1 – The CEA micro-scale weather forecast system is now operational and provides every six hours the air flux prediction in all or any part of the streets of Paris. Dispersion computation can be launched given at the minimum the location of the release, later specifying the nature, quantity and history of the release.

2 – The dispersion results are post-processed to visualize the concentration field and determine the doses. The produced files are in formats fully consistent with the GIS of the BSPP. More automation of this final part of the modelling system, not available at the time of the exercise, is now in progress.

3 – During the exercise, sending e-mails to BSPP was done manually. Automation and dedicated e-mail boxes would help to spare time in the results transmission (even if it gives already satisfactory).

4 – In real life, performances would be a bit decreased as it could be harder to decide a first source term.

CONCLUSION

This paper describes a crisis exercise carried out on 20th June 2012 by Paris Fire Brigade and CEA DAM Île-de-France, consisting in the fictitious explosion of a dirty bomb in a Paris central and critical district. Atmospheric dispersion and radiological impact assessment were performed at CEA premises and results transmitted in real-time to the Operations Survey Centre (CSO) and Command Post Vehicle (VPC) at the rear of which they were visualized on a large screen. The method operated by CEA is to continuously run a meso-scale weather prediction modelling system over France, downscale the results to the micro-scale inside the streets of all Paris city (3 m resolution taken account of all buildings), then trigger dispersion computation where and when it is necessary. A very precise space and time mapping of the contaminant was sent to BSPP less than 30 minutes after the beginning of the exercise. All computations were done on a quite powerful, but not exceptional server. By convention, the radionuclide (^{60}Co) in the dirty bomb was supposed to be identified 30 to 45 minutes after the exercise launching. At this time, a first estimate of the radiological exposure by inhalation and irradiation was transmitted to BSPP showing urban areas where doses exceeded 1, 10 or 50 mSv. New computations of the doses were done using refined source term evaluations till exercise ended. *In fine*, the exercise demonstrated both the capability to numerically assess the dispersion and consequences of noxious releases with complex 4D models in a time consistent with crisis management and the interest of Civil Security services as Paris Fire Brigade to be provided with precise and practical impact assessment results visualized in real-time in GIS to help decision making.

REFERENCES

Armand, P., C. Duchenne, O. Oldrini, C. Olry, J. Moussafir, and A. Albergel. Simulation with PMSS of the wind field and potential dispersion in the streets of Paris. *15th Annual George Mason University Conference on Atmospheric Transport and Dispersion Modeling, GMU 2011*, July 12-14, 2011, Fairfax (VA) USA.

SPRAY 5 – General description and user's guide. ARIANET Report, 2010.

SWIFT Diagnostic wind field model version 1.6 – General design manual. ARIA Report, March 2010.

SWIFT Diagnostic wind field model version 1.6 – User's manual. ARIA Report, 2008.02.