3D SIMULATION OF DISPERSION IN THE URBAN ENVIRONMENT IN CASE OF AN EXPLOSION, USING TESATEX PRE-PROCESSOR AND MICRO-SWIFT-SPRAY MODELLING SYSTEM

Patrick Armand[1], *Christophe Olry*[2], *Armand Albergel*[2],
and Christophe Duchenne[1]

[1] **Commissariat à l'Énergie Atomique,**
Département Analyse, Surveillance, Environnement, Bruyères-le-Châtel, France
[2] **ARIA Technologies, Boulogne-Billancourt, France**

Introduction and objectives

- Explosions occurring in case of an industrial accident or a malevolent action can bring out the sudden atmospheric release of noxious materials (RBC)
- The resulting pollutant cloud must be modelled in a way to adequately assess the dispersion and potential health impact of the release
- On the other hand, the source term modelling should be simple enough to be consistent with operational numerical tools fit for emergency response
- TESATEX module has been designed as a pre-processor dealing with the initial distribution in the cloud from explosion time to stabilisation time
- TESATEX is intended to be coupled with 3D Gaussian puff or Lagrangian dispersion codes (in this work, Micro-SWIFT-SPRAY) (ARIA Technologies)
- TESATEX is an evolution of SARRIM (ARIA Technologies and CNES) used to evaluate the impact of launchers trials or accidents (Cencetti et al., 2007)

  → *SARRIM was modified to deal with less energetic explosions and events happening in uneven terrain or constructed areas*
- TESATEX also uses the empirical mass distribution in the initial cloud as predicted by HOTSPOT Gaussian model (Homann, 1994)

Physical modelling in TESATEX – Cloud stabilisation

- The stabilized cloud is represented by a sphere on top of a cylinder with dimensions depending on the height reached by the cloud
- The stabilisation height depends on the atmospheric stability determined by the temperature profile (met’ mast, rawinsonde or weather prediction)
- In stable conditions, cloud stabilisation height z_{stab} is computed by solving iteratively the above equation while $z_{stab} > z_k$ with z_k altitude of the k-level
- In unstable conditions, the cloud stabilisation height is computed using a threshold value for the pot. temp. gradient in order to maximise the impact

$$z_{stab} = \left[\frac{8\, F_I}{\gamma_x\, \gamma_y\, \gamma_z\, s_k} \right]^{1/4}$$

$$F_I = \frac{3\, g\, H\, M_{exp}}{4\, \pi\, c_p\, T\, \rho_{sur}}$$

$$s_k = \frac{g}{T}\left(\frac{\Delta\, \phi}{\Delta\, z} \right)_k$$

F_I	Buoyancy term	T	Ambient air temperature
g	Gravity acceleration	ρ_{sur}	Air density near ground
H	Energy rel. by 1 g of TNT	$\gamma_x, \gamma_y, \gamma_z$	Coef. of air entrainment
M_{exp}	TNT eq. explosive mass	s_k	Stability parameter
c_p	Air specific heat	$\Delta\phi/\Delta z$	Virtual pot. temp. gradient

Physical modelling in TESATEX – Cloud displacement (1/2)

- To take account of the wind effect between explosion and stabilisation, the cloud is cut out in layers defined by the meteorological vertical grid
- The layers are moved using the local wind conditions known by observations or 3D model output according to the following algorithm…
- For each K-layer between z_{k-1} and z_k located under the stabilisation height z_{stab}, the cloud arrival time t_k at k-level is calculated with the relation:

$$t_k = \frac{1}{\sqrt{s}} \mathrm{Arc\cos}\left[1 - \left(\frac{s\,\gamma_x \gamma_y \gamma_z z_k^4}{4F_I}\right)\right]$$

- The K-layer displacement is computed between t_0 and t_k, then t_k and t_{stab}
  - Step 1 – Till t_k, the lower layer displ. is taken into account (by iteration)

$$\begin{cases} \Delta x_{t_0-t_k} = \Delta x_{t_0-t_{k-1}} - (t_k - t_{k-1}) \cdot VIT^K \cdot \sin DIR^K \\ \Delta y_{t_0-t_k} = \Delta y_{t_0-t_{k-1}} - (t_k - t_{k-1}) \cdot VIT^K \cdot \cos DIR^K \end{cases} \quad \text{with} \quad \begin{cases} \Delta x_{t_0-t_1} = -t_1 \cdot VIT^1 \cdot \sin DIR^1 \\ \Delta y_{t_0-t_1} = -t_1 \cdot VIT^1 \cdot \sin DIR^1 \end{cases}$$

(VIT^K local velocity and DIR^K direction of the wind in the K-layer)

Physical modelling in TESATEX – Cloud displacement (2/2)

  - Step 2 – The total displ. till t_{stab} of each K-layer is given by following relation

$$\begin{cases} \Delta x_K = \Delta x_{t_0 - t_k} - \left(t_{stab} - t_k\right) \cdot VIT^K \cdot \sin DIR^K \\ \Delta y_K = \Delta y_{t_0 - t_k} - \left(t_{stab} - t_k\right) \cdot VIT^K \cdot \cos DIR^K \end{cases}$$

- Finally, the displ. of the stabilisation layer K_{stab} and upper layers verifies:

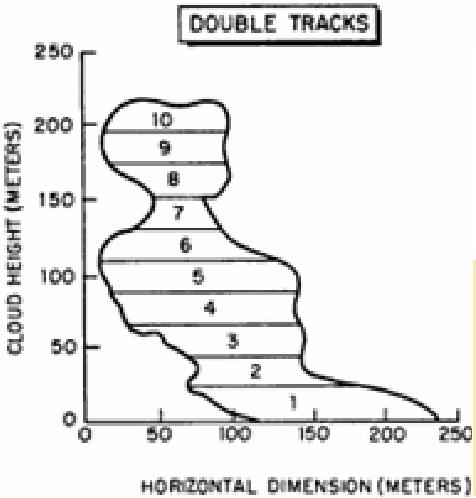
$$\begin{cases} \Delta x_K = \Delta x_{t_0 - t_{K_{stab}-1}} - \left(t_{stab} - t_k\right) \cdot VIT^K \cdot \sin DIR^K \\ \Delta y_K = \Delta y_{t_0 - t_{K_{stab}-1}} - \left(t_{stab} - t_k\right) \cdot VIT^K \cdot \cos DIR^K \end{cases}$$

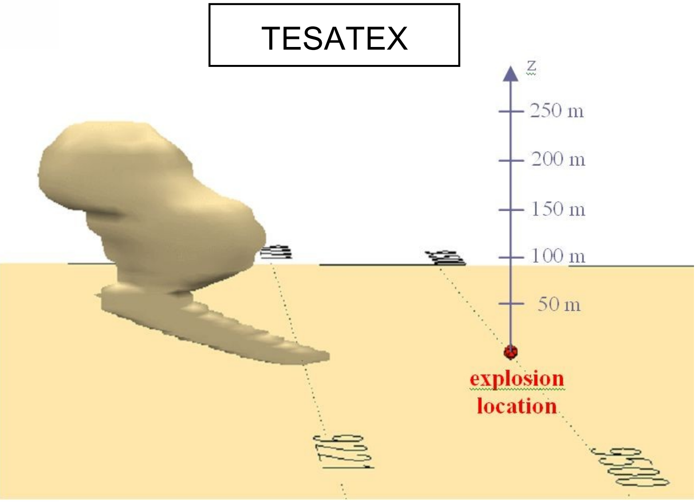
- This method can be applied wit 3D computed met' fields. In this case, cloud displ. with the wind is obtained using a 3rd order Runge-Kutta algorithm
- The displacement takes into account the topography and the presence of obstacles as the 3D wind field integrates these effects

Experimental validation in an open-field trial (1/2)

- TESATEX – MSS were validated using the data of the ‘Double Tracks’ trial (‘Operation Roller Coaster’ at Tonopah Range test site – Nevada – 1963)
- Open-air detonation of an edifice containing plutonium and 53,5 kg of TNT (experimental results were normalized to 1 kg of initial mass of plutonium)
- In the trial, met’ conditions, particles distribution, activity concentration in the atmosphere and activity deposition on the ground were measured
- TESATEX was run with Micro-SWIFT computed 3D wind field

	TESATEX	Meas.
Stabilisation time	118 s	105 s
Stabilisation height	199 m	210 m
Cloud top height	243 m	





Stabilized cloud configuration determined by TESATEX (taking into account the wind influence) compares very well to the observed cloud geometry

Experimental validation in an open-field trial (2/2)

- Micro-SPRAY computations were carried out using TESATEX source term
- Micro-SPRAY results obtained along the cloud axis were compared with ‘Double Tracks’ measurements, and with HOTSPOT numerical results
- Figure A: plutonium integrated activity concentration in the air (only inhalable)
  - Peak observed at a few 100 m in Micro-SPRAY results (not with HOTSPOT)
  - In far field, both models give similar results near ‘Double Tracks’ measurements
- Figure B: plutonium activity deposited on the ground (both inhalable and not)
  - At distances less than 1 km, Micro-SPRAY results agree with ‘Double Tracks’
  - Exp. max. observed 2 km away from the test location predicted by Micro-SPRAY

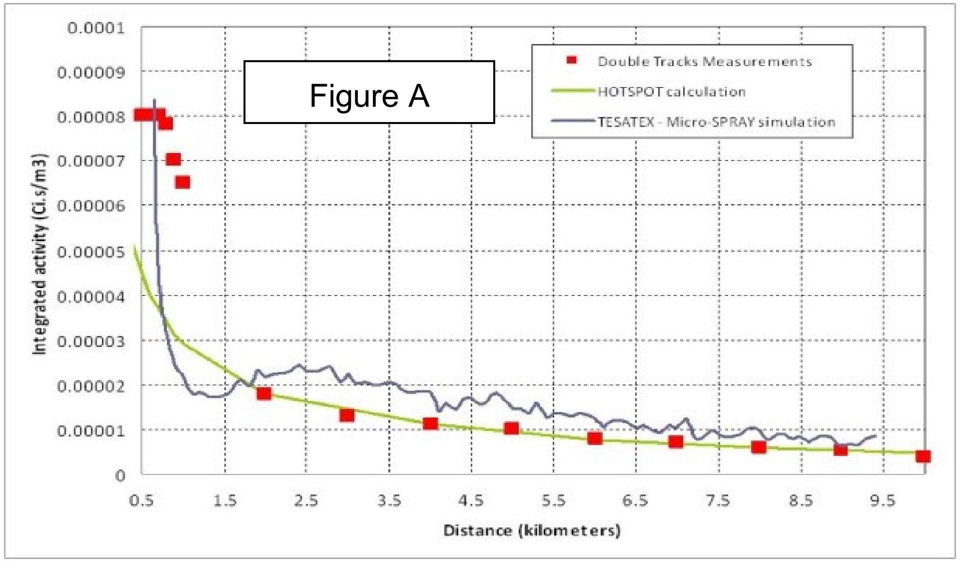


Figure A

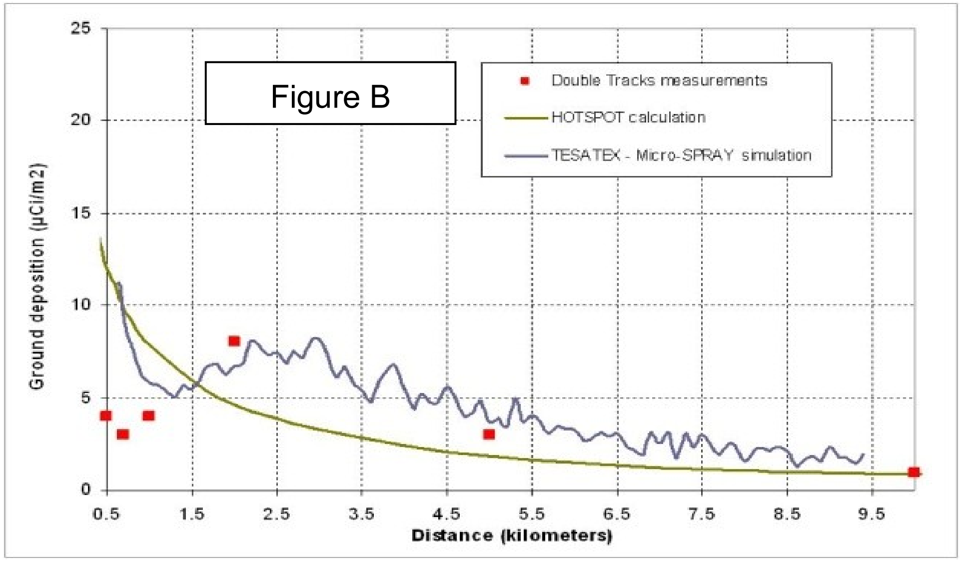
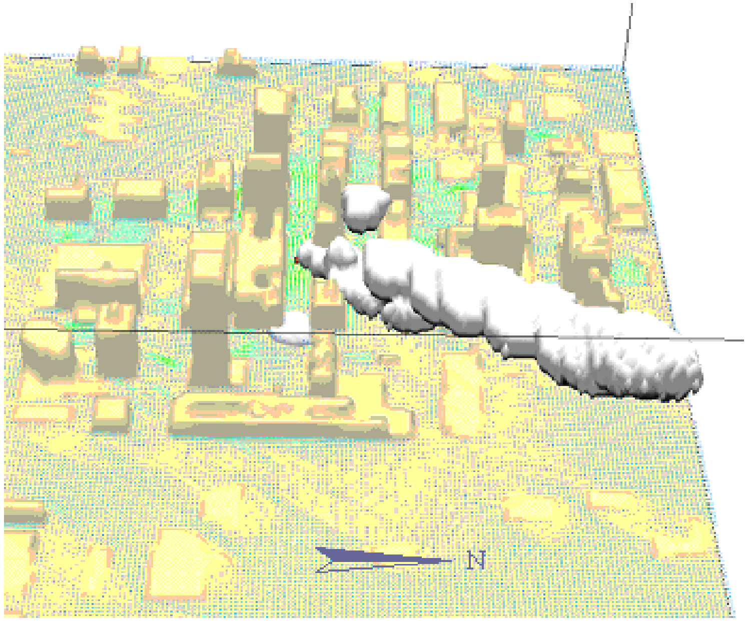


Figure B

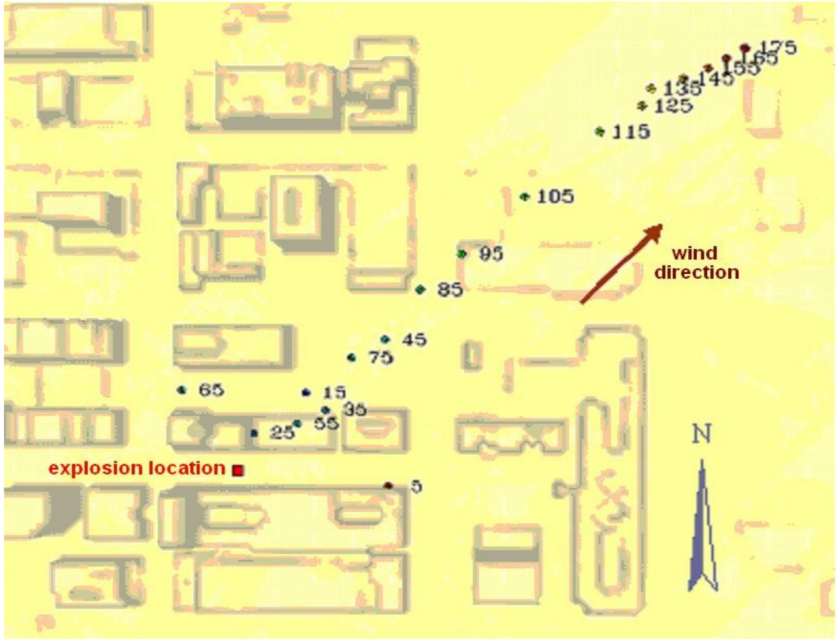
Application cases in Oklahoma City and Paris (1/3)

- TESATEX – MSS have been used to simulate hypothetical explosion and dispersion events in Oklahoma City (USA) and in Paris (France)
- The met' conditions and explosion locations (narrow street, broad street or large square) were varied to enlighten differences in cloud shape, atmos. distribution, dry deposition, and the potential impact of simulated events

Stabilized cloud shape in case of an explosion downtown Oklahoma City



Location of the layers setting up the stabilized cloud



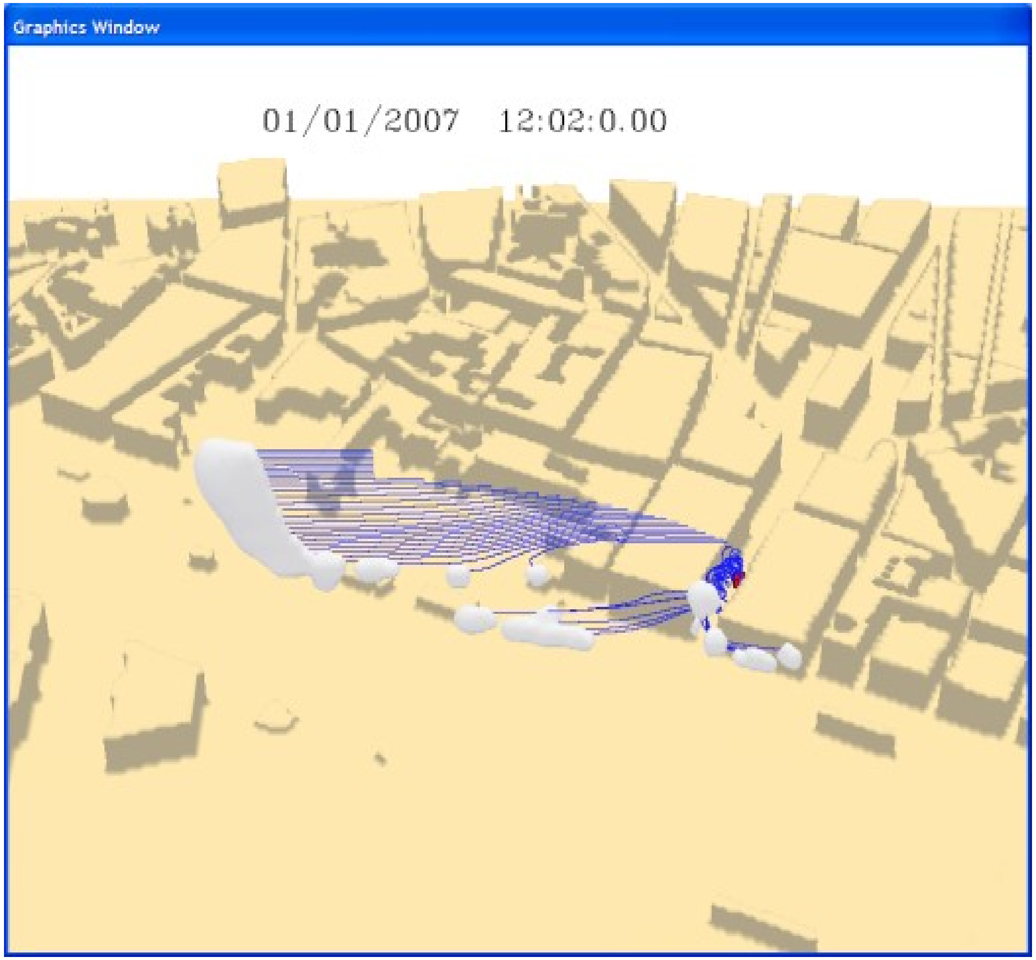
The displacement of the cloud lower part depends on the channelled flow in the urban canopy while, above the buildings, the cloud is advected by the wind

Application cases in Oklahoma City and Paris (2/3)

Virtual explosion of a RDD in Paris near Concorde square

At the time of the event, wind blows from the East

- The figure on the right shows layers trajectories till the stabilisation time and the shape of the stabilized cloud
  - The complicated wind field and cloud rise are strongly influenced by buildings
  - Despite wind direction is transverse to the street in which explosion happens, lower part of the cloud travels along the street and reaches Concorde square



Application cases in Oklahoma City and Paris (3/3)

- Micro-SPRAY dispersion results were post-processed to evaluate the radiological exposure due to the RDD
- Figures C and D present the total effective dose (inhalation and external irradiation by the cloud and by deposition) computed with the explosion source term issued by TESATEX (C) or supposed to be punctual (D)

Figure C

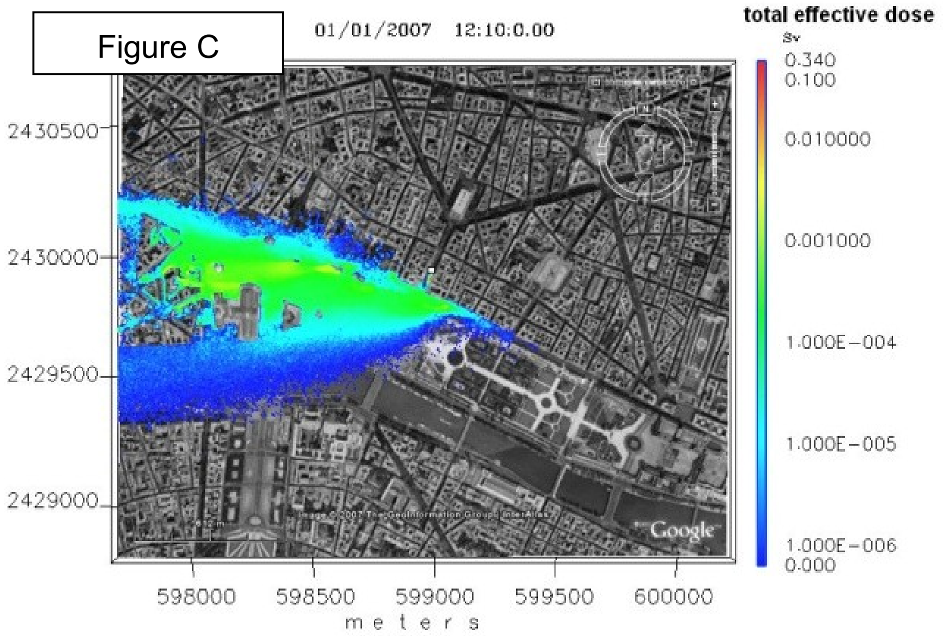
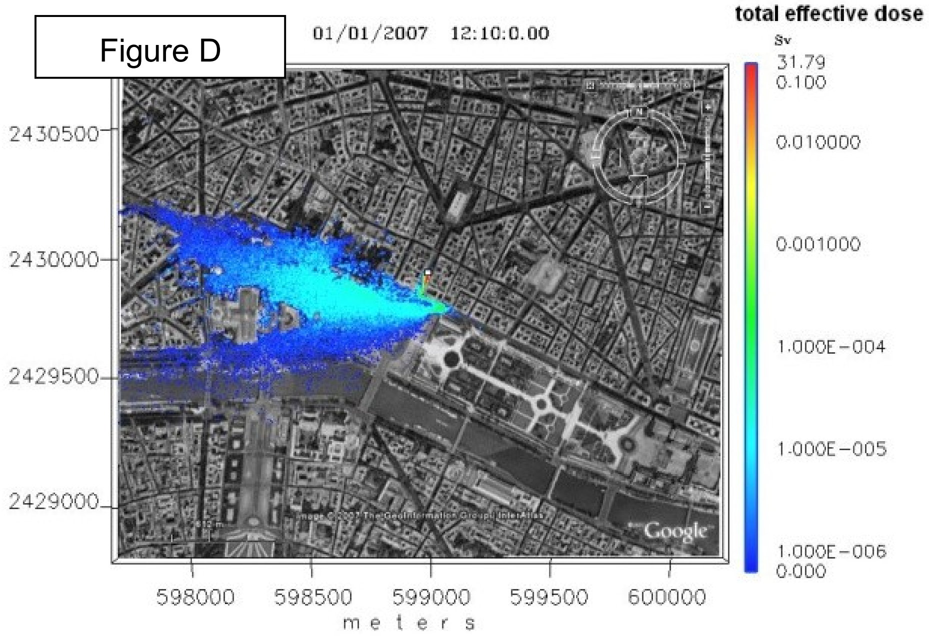


Figure D



With TESATEX, doses are lower near the source and contaminated area is larger. This is explained by the ascent and the transport of the cloud above the buildings while the pollutant remains in urban canopy in the other case

Dispersion of a noxious cloud at ‘La Défense’ business district (Paris)

Conclusion and perspectives

- TESATEX was designed as a pre-processor needed to model the source term generated by an open-air explosion in the urban environment
- TESATEX takes into account the wind field, possibly influenced by buildings, in the initial cloud development which is not depending on any dispersion code
- TESATEX modelling sounds a satisfactory compromise between accuracy in physical description and quick computing requirement
- TESATEX – Micro-SPRAY were validated with ‘Double Tracks’ trial and gave better results than HOTSPOT model (nuclear weapon radiological accidents)
- Virtual explosions of Radiological Dispersal Devices (RDD) have been simulated in Oklahoma City (downtown) and Paris (Concorde square district)
- Taking adequately buildings effects into account leads to more realistic results not only concerning the pollutant distribution, but also in terms of health impact assessment, and possibly counter-measures to carry out
- Further applications of TESATEX – MSS could concern the impact assessment of accidental events or malevolent actions in industrial sites or in the urban env.