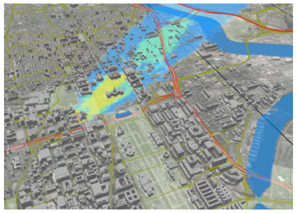
Radiological Dispersal Device (RDD) Modeling in Cities Using the QUIC Model

Los Alamos NATIONAL LABORATORY EST. 1943

Fall AGU Meeting 2007
LA-UR-07-3182

What is QUIC?

The Quick Urban & Industrial Complex (QUIC) dispersion modeling system

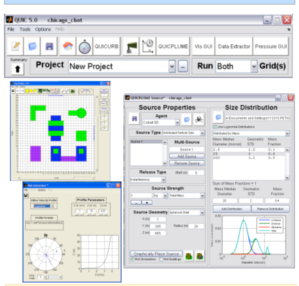


DC Mall tracer dispersion simulation

QUIC is comprised of:

* QUIC-URB
  produces 3D wind field around buildings using an empirical/diagnostic model
* QUIC-PLUME
  accounts for building-induced turbulence through a Lagrangian random-walk dispersion model
* QUIC-GUI
  graphical user interface for set-up, running, and visualization (QUIC-GUI)

The QUIC Graphical User Interface



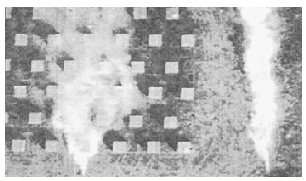
The QUIC-GUI allows for the user to easily set-up building layouts, specify the winds, choose a CBR agent type, and pick a release location.

2D and 3D visualization tools allow the user to rapidly display wind flow and plume dispersion patterns.

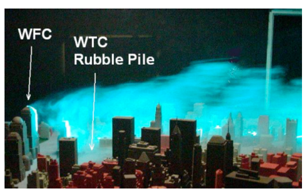
What is an RDD?

Radiological sources are commonplace at medical, research, and industrial facilities. There are concerns that a terrorist could steal the material and use high explosives to disseminate radioactive particles into the air. Long-term health impacts, clean-up, and relocation costs could be extremely severe.

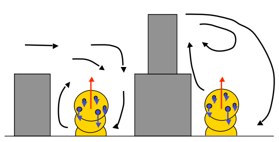
Why Buildings?



Buildings enhance lateral spread. Plan view of smoke dispersing over flat terrain (right) and going through an array of buildings (left). USEPA wind tunnel experiment.



Buildings enhance vertical spread. Side view of smoke being lofted high into the air by tall buildings. USEPA experiment from Heist et al. (2004).

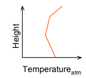


The consequences from an RDD in a city will depend on the interaction of the buoyant rise, building-induced winds and size-dependent particle gravitational settling.

Buoyant Rise Scheme

Initial Conditions

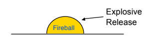
- **Layered atmosphere**
  (i.e., temperature gradients)



- **Hemispherical Source**

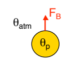
$$T_{plume}(t_0) = T_{fire}$$

$$r_{fire} = 3\left(HE_{mass}\frac{\rho_{atm}}{\rho_{fire}}\right)^{1/3}$$



Baker, W.E., Explosion Hazards and Evaluation, Elsevier, 1983.

Force Estimation



$$F_B = g\frac{\theta_p(t)-\theta_{atm}}{\theta_{atm}}$$

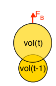
Note: θ is the potential temperature.

Temperature Evolution

$$\theta_p(t) = \theta_p(t-1) - F_{entrain}\cdot\left(\theta_p(t-1)-\theta_{atm}\right)$$

entrainment fraction

$$F_{entrain} = \frac{vol(t)-vol(t-1)}{vol(t)}$$



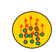
$$= \sigma_{xb}\sigma_{yb}\sigma_{zb}$$

Mean Upward Motion Due To Buoyancy

$$\overline{\Delta z}_{buoy} = \tfrac{1}{2}F_B\Delta t^2 + \overline{w}_B\Delta t$$

where $\overline{w}_B(t) = \left(vol_{t-1}/vol_t\right)\cdot\overline{w}_B(t-1)$

and $\overline{w}_B(0) = F_B\Delta t$



Δz_{buoy} applied to particles

Buoyancy-Induced Turbulence

memory term — random term

$$w'_B(t+\Delta t) = e^{-\frac{\Delta t}{tb_{scale}}}\cdot w'_B(t) + \left(1-e^{-\frac{\Delta t}{tb_{scale}}}\right)\cdot w'_{B\_ran}$$

Drawn from Gaussian distribution with std dev σ_{wb}

where

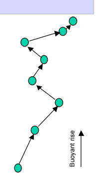
$$tb_{scale} = \frac{\min(\Delta_{zb},\sigma_{xb},\sigma_{yb})}{\overline{w}_B + F_B\Delta t} \quad \text{and} \quad \sigma_{ub} = \sigma_{vb} = \sigma_{wb} = 0.2\cdot(\overline{w}_B + F_B\Delta t)$$

Particle Movement

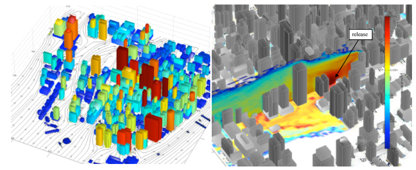
$$\Delta x_{total} = \Delta x_{random-walk} + u'_B\,\Delta t$$

$$\Delta y_{total} = \Delta y_{random-walk} + v'_B\,\Delta t$$

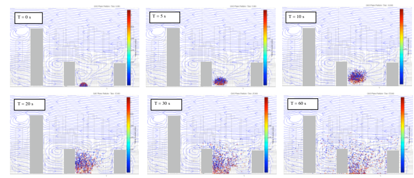
$$\Delta z_{total} = \Delta z_{random-walk} + w'_B\,\Delta t + \overline{\Delta z}_{buoy} - \Delta z_{grav\_set}$$



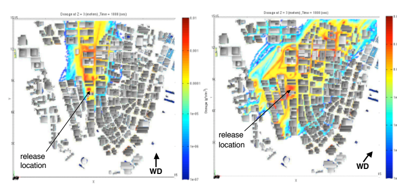
RDD Simulations



Left: streamlines computed by QUIC near the ground show complex flow patterns. Right: the horizontal and vertical slices of the time-integrated concentration for a ground-level RDD release in an open area between buildings illustrates significant lateral, vertical, and upwind transport of the radioactive material.

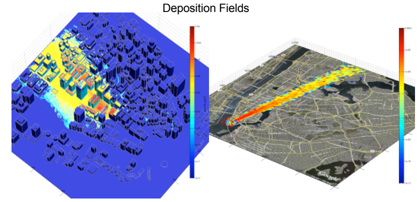


A side-view showing the evolution of the explosively released particles interacting with the building-induced flow. Lighter particles (blue) are generally lofted higher into the air, while the heavier particles (red) settle out near the ground.



Shifts in the prevailing wind direction cause unexpected changes in the spatial pattern of the airborne dosage field.

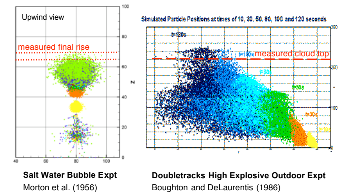
Deposition Fields

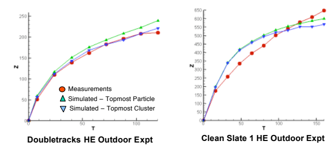


Left: deposition can be calculated on the ground as well on building walls and roofs. The mass of radiological agent on individual faces of buildings and by particle size can be provided in order to help estimate the magnitude of clean-up efforts. Right: deposition calculations can be carried out for longer distances on an outer grid.

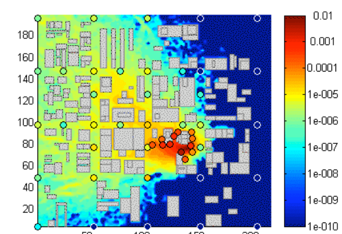
How accurate is QUIC?

QUIC has been tested against both field and lab tracer data, as well as buoyant rise experiments. QUIC will never give perfect answers, but it will account for the effects of buildings in an approximate way and provide more realism than non-building-aware dispersion models.





Validation of QUIC using laboratory and field buoyant rise experiments. The top of the model-computed buoyant puffs are close to the measurements.



Plume dispersion comparisons with Salt Lake City Urban 2000 field data (filled circles).

QUIC is a fast response urban dispersion model that runs on a laptop. Versions are available for Windows, Mac, and Linux OS's. CBR agent dispersion can be computed on building to neighborhood scales in tens of seconds to minutes.

The code is being used to assess the consequences of RDD releases in several US cities. It is being used to scope the magnitude of clean-up efforts, to develop rules-of-thumb for emergency responders, and to help determine economic impacts.

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