SIMULATION OF THE PLUME GAMMA EXPOSURE RATE WITH 3D LAGRANGIAN PARTICLE MODEL *SPRAY* AND POST-PROCESSOR *Cloud_Shine*

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Outline of the presentation

- Context and objectives
- Description of *SPRAY 3.0* dispersion model
- Description of *Cloud_Shine* post-processor
- Validation of *Cloud_Shine* post-processor
- Examples of use of *SPRAY 3.0* and *Cloud_Shine*
- Conclusion and perspectives

Context and objectives

- Following a release of radionuclides in the atmosphere, the exposure rate assessment concerns regulatory requirements and health risk evaluation
- In the nuclear safety methodology, it is usually considered that…
  - the concentration in the plume is uniform and the plume extends semi-infinitely in all hemispheric directions over a flat terrain
  - a 'global' coefficient takes account of the gamma rays flux in the idealized semi-infinite geometry and factors to convert the activity flux into irradiation dose
- Nevertheless, in case of complex meteorological conditions and non-flat terrain with obstacles, a more precise approach is required to compute the plume shape and the radionuclides concentration distribution (*cf. Weng et al.*, 2003; *Raza and Avila*, 2001; *Ichikawa et al.*, 1981)
- In this work, a Lagrangian particle model is used to evaluate the gamma radiation of 3D continuous or transient radioactive plumes
  - The spatial distribution of discrete particles is computed with *SPRAY*
  - The plume exposure rate is evaluated with *Cloud_Shine* post-processor

Description of *SPRAY 3.0* dispersion model

- *SPRAY 3.0* is 3D Monte Carlo dispersion code developed by ARIANET and ARIA Technologies (*Tinarelli*, 2001)
- *SPRAY 3.0* is able to reproduce the advection, dispersion, dry deposition, wet deposition and radioactive decay of particles…
  - in complex meteorological conditions
  - at several spatial scales including the urban scale (*Moussafir*, 2004)
- The radionuclides release is represented by emitting packs of Lagrangian particles whose 3D trajectories in the turbulent flow are computed
- The velocity of the particles is characterised by:
  - a mean component (wind field prediction or diagnostic)
  - a stochastic component (calculated according to *Thomson*, 1987)
- Time history of *SPRAY* particles positions in the atmosphere is stored and used by *Cloud_Shine* to evaluate the direct gamma exposure rates

Description of *Cloud_Shine* post-processor (1)

- Gamma radiation : emission of photons in the energy range 0.01-10 MeV
- Equation of the gamma rays flux

$$\Phi(E) = \iiint \frac{C(r)\, B(E,\mu r)\, \exp(-\mu r)}{4\pi r^2}\, d^3 r$$

- Resolution of the equation of the gamma rays flux in a Lagrangian model

$$\Phi(E) = \sum_{particles\ i} \frac{B(E,\mu r_i)\, \exp(-\mu r_i)}{4\pi r_i^2}\, Q_i$$

Φ (*E*)	Gamma rays flux at the energy level E	$Bq.m^{-2}$
C	Radionuclide activity concentration	$Bq.m^{-3}$
B	Build-up factor (formula of Berger)	unitless
μ	Linear attenuation coefficient in the air	m^{-1}
r	Radial coordinate	m
Qi	Radioactivity of the particle *i*	Bq

Description of *Cloud_Shine* post-processor (2)

- Computation of the gamma exposure rate et the energy level E

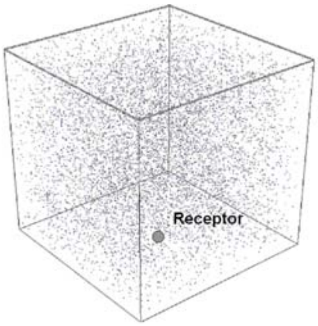
$$D(E) = C_b(E)\, I(E)\, E\, \mu_a(E)\, \Phi(E)$$

- Set of discrete values for the gamma energy range $D = \sum_{energy\ level\ j} D(E_j)$
- Threshold or 'cutting' distance corresponding to $D_{min} = 10^{-20}$ $Sv.s^{-1}$
- Parameters are interpolated into tabulated values of *Weng et al.* (2003)
- E.g. ^{133}Xe principal energy levels 79.61 keV and 80.99 keV

D (*E*)	Gamma exposure rate	$Sv.s^{-1}$
μ_a (*E*)	Mass coefficient of energy absorption in air	$m^2.kg^{-1}$
E	Energy level	MeV
I (*E*)	Gamma rays intensity	unitless
C_b (*E*)	Conversion factor (air to body tissues)	$Sv.Gy^{-1}$
Ej	Discrete value j of the energy	MeV

Validation of *Cloud_Shine* post-processor

- In the ‘academic’ configuration of a semi-infinite cloud, gamma dose rate coefficients are available in the literature (*Eckerman and Ryman*, 1993)
- In *SPRAY 3.0* and *Cloud_Shine*, the calculation domain has been filled with particles to represent the uniform cloud of an irradiating radionuclide
- *Cloud_Shine* exposure rates due to an activity concentration of 1 Bq.m^{-3} in ^{133}Xe compare very well with *Eckerman and Ryman*



Calculation domain
(dimensions 50 m x 50 m x 50 m)

	Semi-infin. cloud	*Cloud_Shine*		
		Threshold 10^{-21} Sv.s^{-1}	Threshold 10^{-22} Sv.s^{-1}	Without threshold
Dose rate (x10^{-15} Sv.s^{-1})	1.56	1.48	1.49	1.49

Comparison of the gamma dose rate results with the semi-infinite cloud and Cloud_Shine

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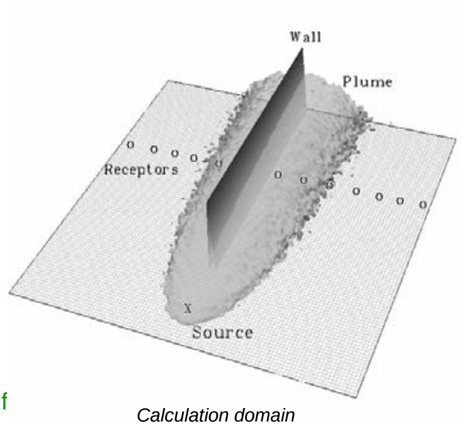
Case #1: Virtual wall along the axis of a plume (1)

- Calculation conditions:
  - source located at the ground level
  - release of 10^{13} Bq.d^{-1} in ^{133}Xe
  - wind velocity 5 m.s^{-1}
  - neutral atmosphere
- A virtual ‘gamma rays-proof’ wall (zero thickness) is superimposed along the plume axis
- The role of the virtual wall is to hide each half-domain from the other half of the total domain

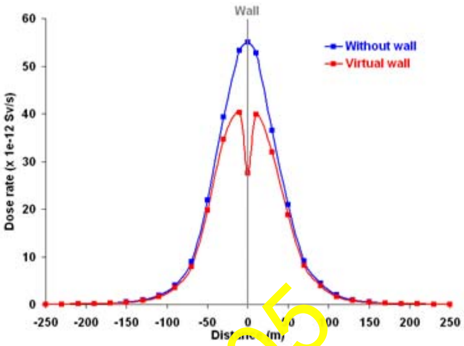


Calculation domain
(dimensions 500 m x 500 m x 250 m)

Receptors placed crosswise the plume axis, with central receptor at 250 m from the source

Case #1: Virtual wall along the axis of a plume (2)

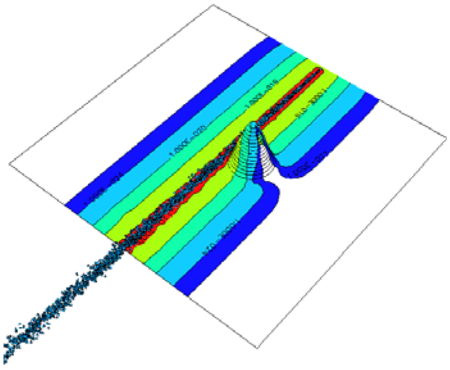
- With no wall, the maximum dose rate is obtained on the plume axis
- With the virtual wall, the maximum dose rate occurs off-axis where the radiation is the most efficient (gamma rays are ‘short range’)
- The exposure rate with the virtual wall is a factor of two of the dose rate without wall, only on the axis of the calculation domain
- When the crosswise distance to the wall increases, the gamma exposure rate tends to its value with no wall



Crosswise profiles of the exposure rate without wall and with the virtual wall

Case #2: Geometrical hill

- Calculation conditions:
  - source located at 20 m AGL
  - release of 10^{13} Bq.d^{-1} in ^{133}Xe
  - wind velocity 5 m.s^{-1}
  - neutral atmosphere
- Geometrical hill:
  - 1.8 km to the right of the plume axis
  - 2 km large at the ground level
  - 800 m high
- Modification in the gamma dose rate close to the ground level for points in the shadow of the relief
- Influence of the topography on the gamma exposure rate

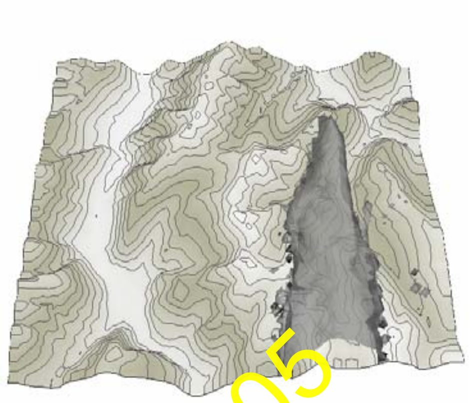


Calculation domain (horizontal dimensions 10 km x 10 km)

Exposure rate near the ground level

Case #3: Real topography (1)

- Calculation conditions:
  - ‘real’ topography
  - source located at 100 m AGL
  - release of 10^{14} Bq.s^{-1} in ^{133}Xe
  - dom. dim. 30 km x 30 km x 10 km
- Opposite figure: 3D view of the ^{133}Xe plume extending over the considered relief

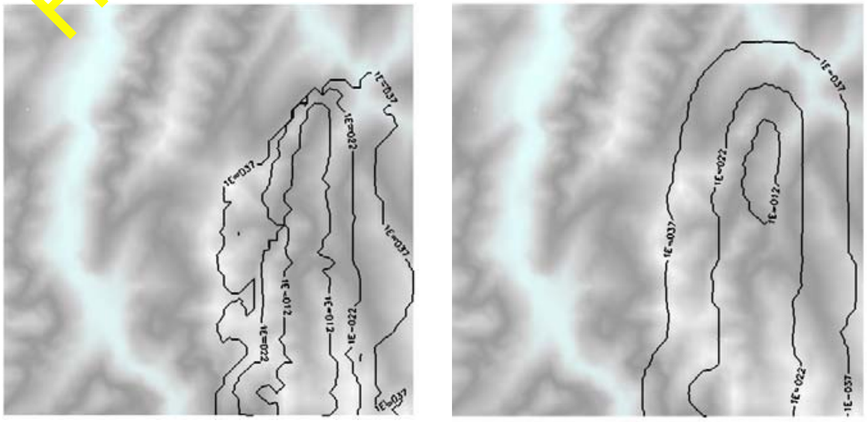


Atmospheric dispersion of the ^{133}Xe plume

Contour lines of the topography

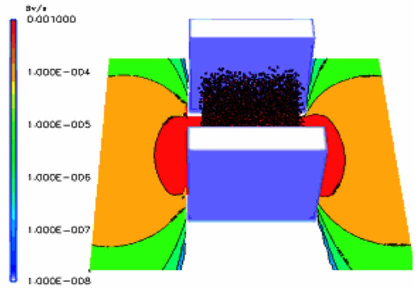
Case #3: Real topography (2)

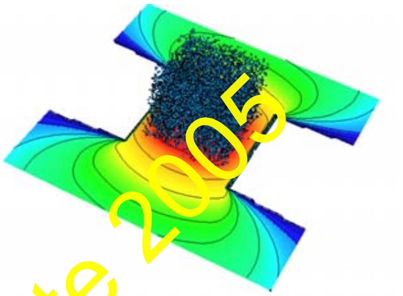
- For the same distribution of particles, the left fig. addresses the topography effect on the dose rate whereas the right fig. ignores the terrain configuration
- The ridge separates the ‘leeward’ part of the topography from the rest of it
- Shielding from the radiation of some places due to the mountainous terrain



Case #4: Influence of buildings on the gamma exposure rate

- Calculation conditions:
  - particles trapped in a cubic box (edge 30 m - 10^{17} Bq in ^{133}Xe)
  - two buildings (40 m long x 10 m large x 40 m high)
  - dom. dim. 100 m x 100 m x 200 m
- On lateral sides of the buildings, the dose rate is not zero even though there aren't any particles
- In two large areas in the shadow of the buildings, the gamma exposure rate is none
- Work at this scale still in progress...





Conclusion and perspectives

- In this work the gamma exposure due to 3D radioactive plumes is computed using the Lagrangian model *SPRAY 3.0* and *Cloud_Shine* post-processor
- In the case of a radionuclide uniform distribution over a flat terrain, *SPRAY 3.0* and *Cloud_Shine* results are directly comparable with the semi-infinite irradiation dose coefficients tabulated in the literature (*Eckerman et al.*, 1993)
- Several configurations have been studied to illustrate the shadow effects of the relief or the obstacles located on the trajectories of radioactive plumes
- The plumes impingement on the obstacles clearly modifies the exposure rates at the both sides of an artificial wall, in the leeward of an academic hill or a real topography, and behind the protected sides of buildings and streets
- A routine algorithm to compute gamma dose rate in acceptable CPU time is of interest to assess the impact of radioactive releases in the urban context
- This work should also be relevant to improve the inverse algorithm used to determine a source term from available gamma exposure measurements