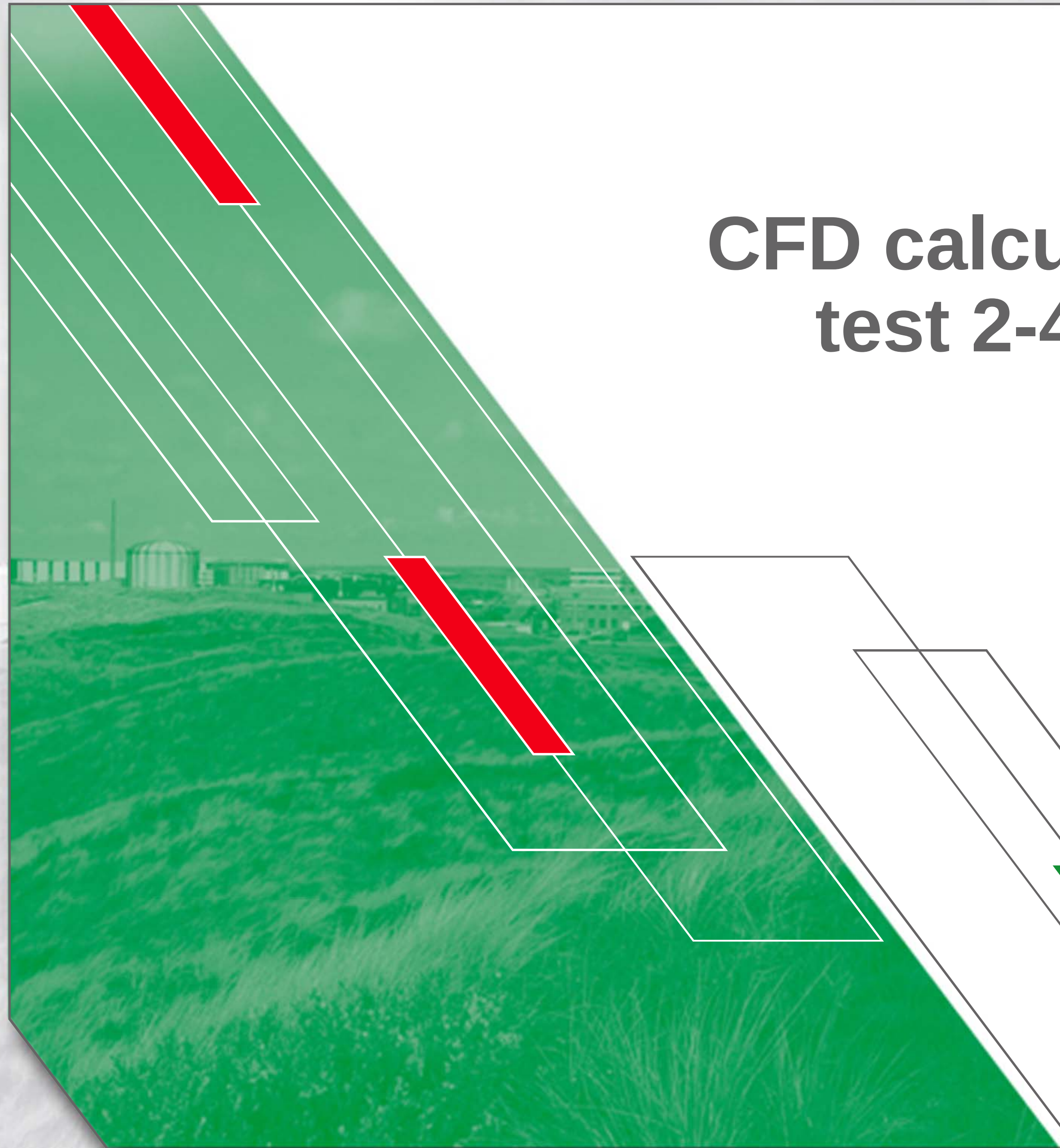


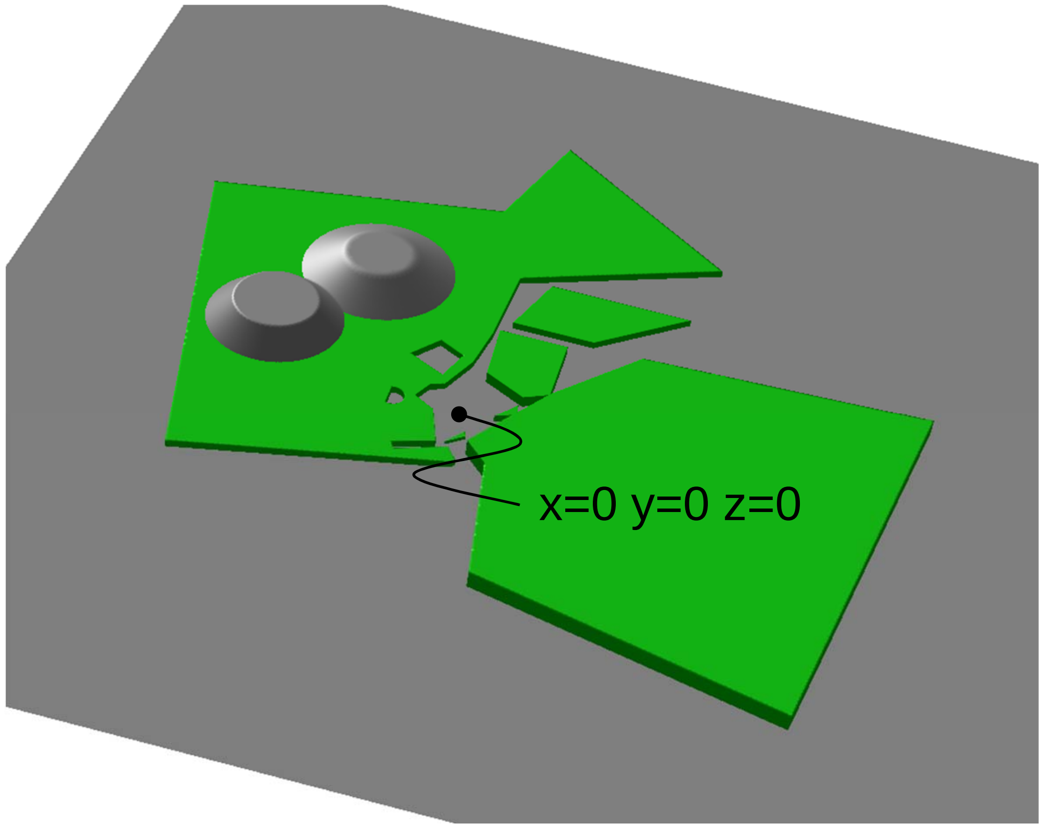
CFD calculations of the test 2-4 experiments

Author: G. de With

34. Model setup and boundary conditions

- Dimensions CFD model:
  x=1000m / y=100m / z=2000m.
- CFD Model:
  Transient simulation, with steady-state BCs.
- Simulation time:
  500-1000s, with a 1s time-step size.
- CFD Mesh:
  Polyhedral mesh elements.
- Turbulence model:
  k-ε RNG model.
- Temperature:
  Energy calculation.

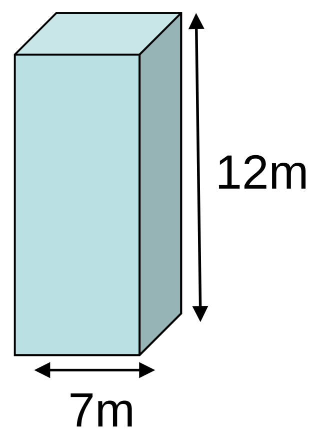
Geometry of the CFD model



35. Initial release of the aerosols

- The deposition velocity for the smaller aerosols is increased significantly.
- The initial cloud remains 12m × 7m × 7m.

Cloud shape



Deposition parameters **June 2010**

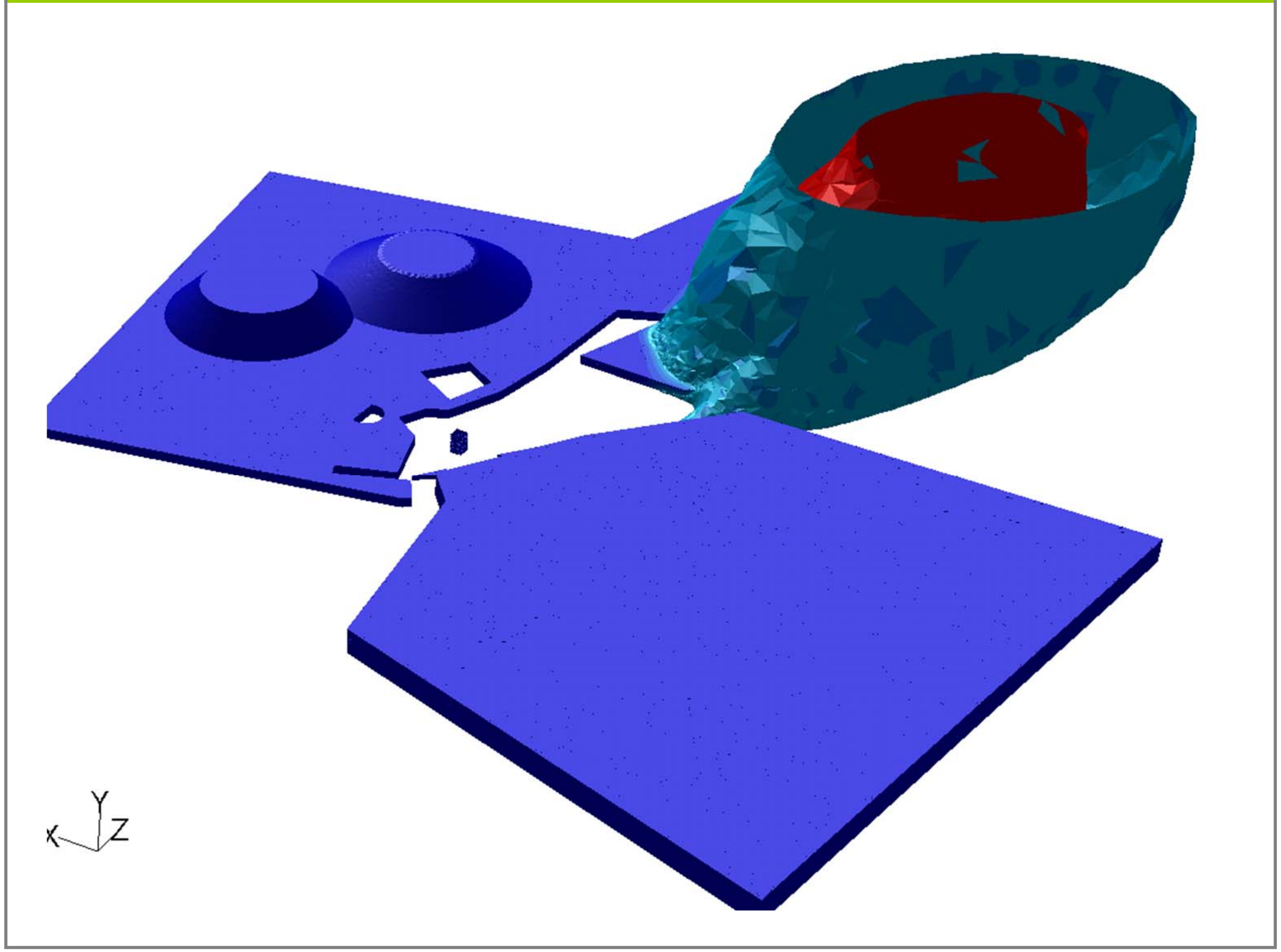
Droplet diameter (m)	Volume activity (%)	Deposition velocity (10^{-4} m/s)
$2 \cdot 10^{-5}$	10.0	70
$6 \cdot 10^{-6}$	46.6	10
$1 \cdot 10^{-6}$	15.0	0.5
$2 \cdot 10^{-7}$	28.4	0.01-0.02

Deposition parameters **January 2011**

Droplet diameter (m)	Volume activity (%)	Deposition velocity (10^{-4} m/s)
$2 \cdot 10^{-5}$	10.0	80
$8 \cdot 10^{-6}$	46.6	10
$1 \cdot 10^{-6}$	15.0	1.5
$2 \cdot 10^{-7}$	28.4	0.5

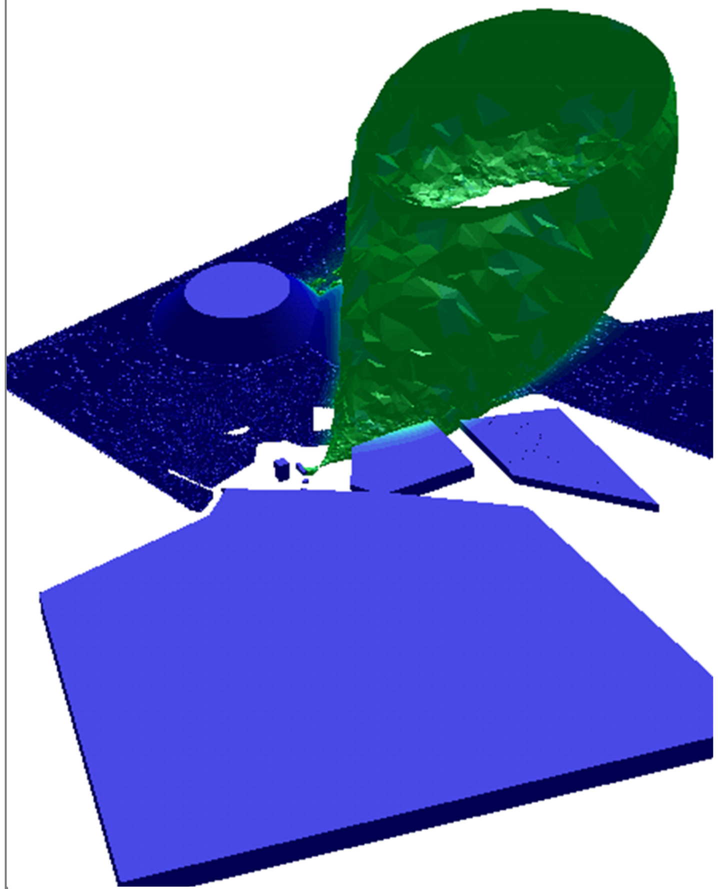
36. Dispersion of ^{99m}Tc Test 3

^{99m}Tc dispersion at t=100 s and 10 Bq/m^3

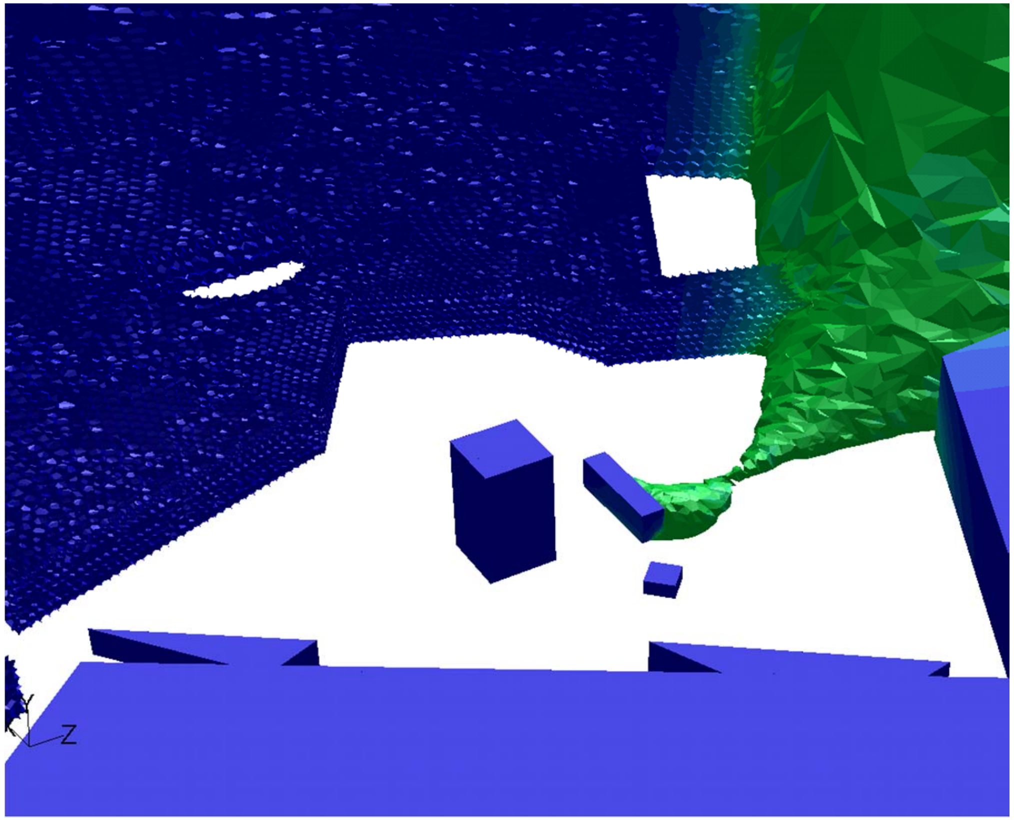


37. Dispersion of ^{99m}Tc Test 4 with bus

^{99m}Tc dispersion at t=1000 s and 5 Bq/m^3

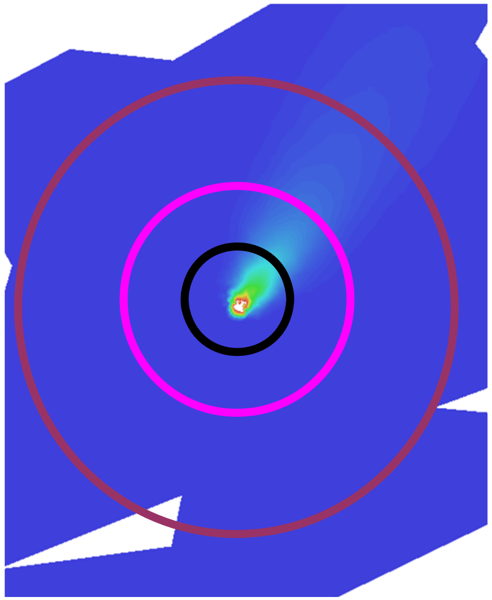


^{99m}Tc deposition zoom-in



38. ^{99m}Tc in the air and on the ground

^{99m}Tc contamination zones

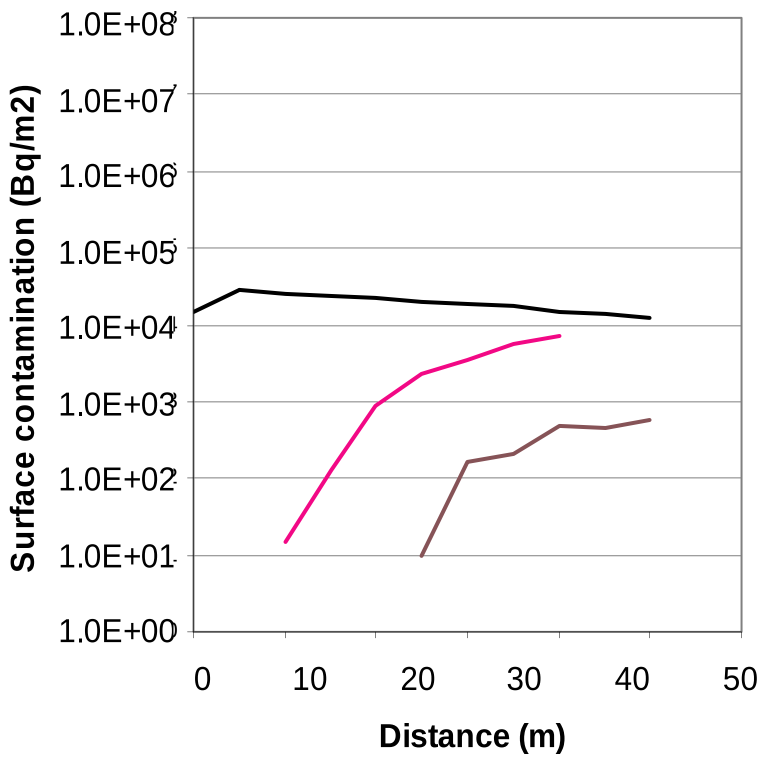


^{99m}Tc activity on the ground surface per diameter category

Droplet diameter (m)	R_{50} zone (m)	R_{75} zone (m)	R_{95} zone (m)
January 2010	7.4	16.6	42.1
June 2010	13.7	36.3	55.6
January 2011	13.8	36.5	55.7

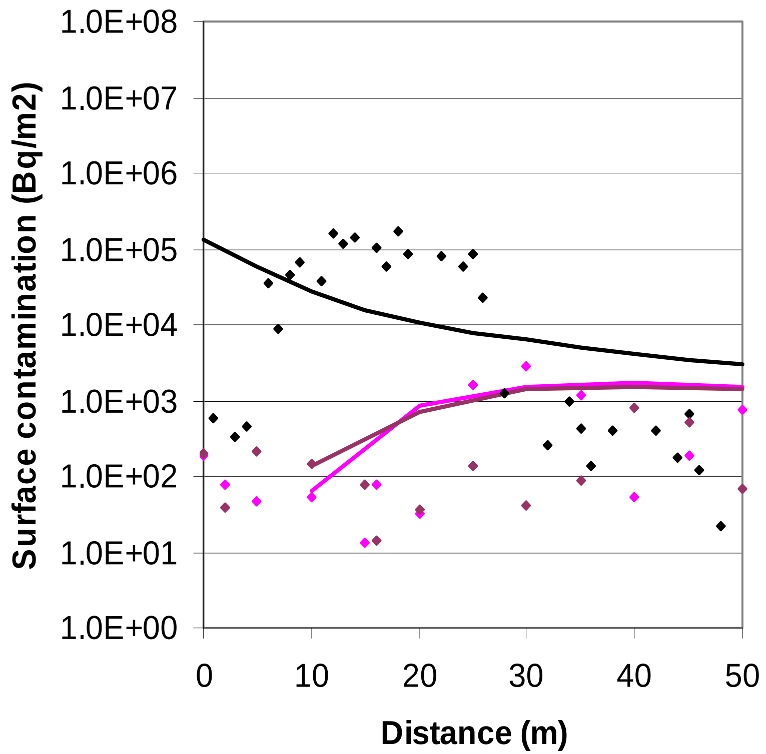
39. Deposition of ^{99m}Tc Test 2

Deposition parameters **January 2011**



Simulation

Deposition parameters **January 2010**

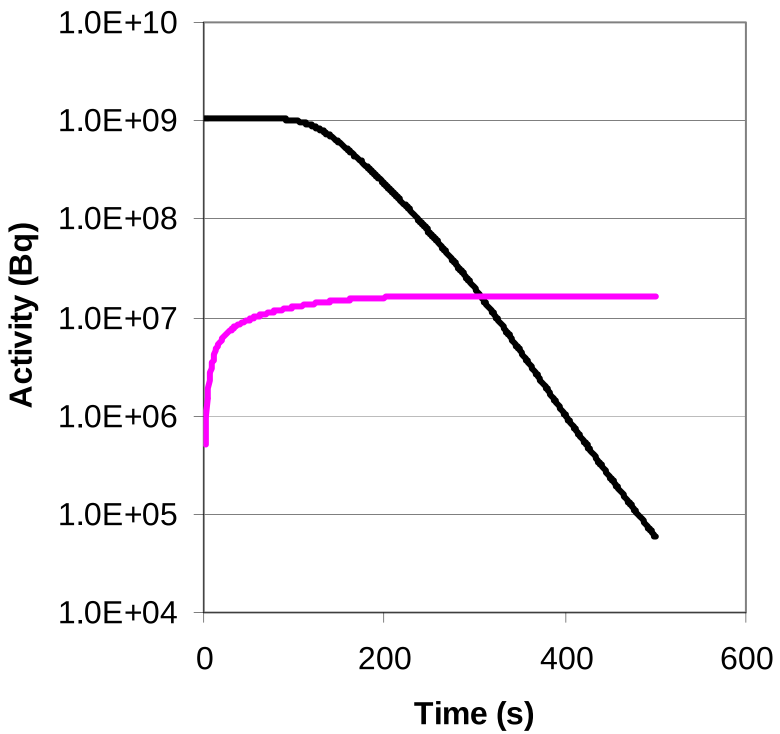


Simulation

Experiment

40. ^{99m}Tc in the air and on the ground

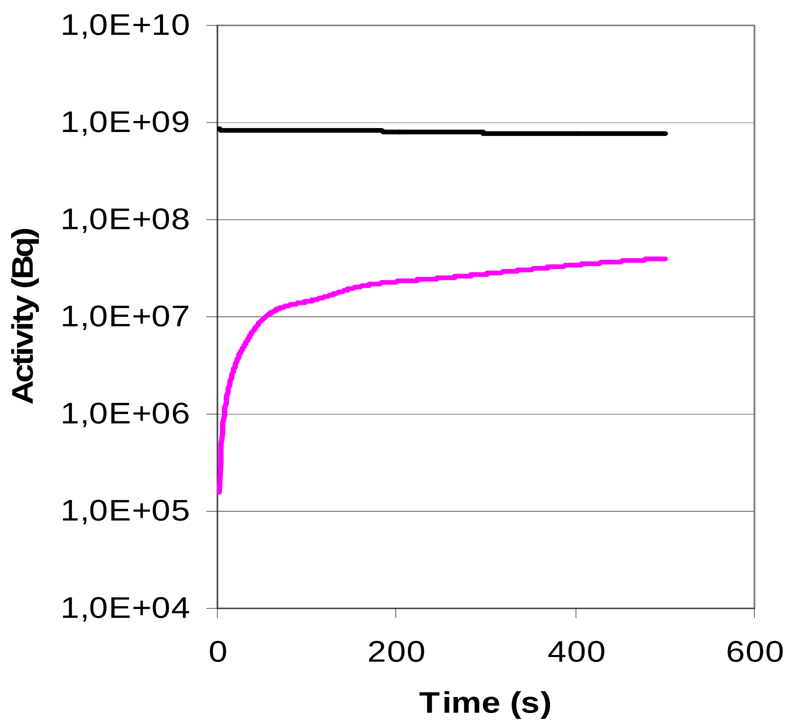
^{99m}Tc in the air and on the ground (**January 2010**)



^{99m}Tc activity in the air

^{99m}Tc activity on the ground

^{99m}Tc in the air and on the ground (**January 2011**)



^{99m}Tc activity in the air

^{99m}Tc activity on the ground

41. Conclusions January 2011 simulations

FINDINGS

- Despite the increase in deposition velocities the results from January 2011 are broadly similar to those presented in Seville.
- The deposition velocity for the smaller aerosols has less impact on the total deposition, due to the fact that the terminal velocity is comparatively low.
- The total amount of activity that is deposited onto the ground is increased from 1.6% (January 2010) to 4.7%. This is partly a results of the increase in the computational domain.

FURTHER WORK

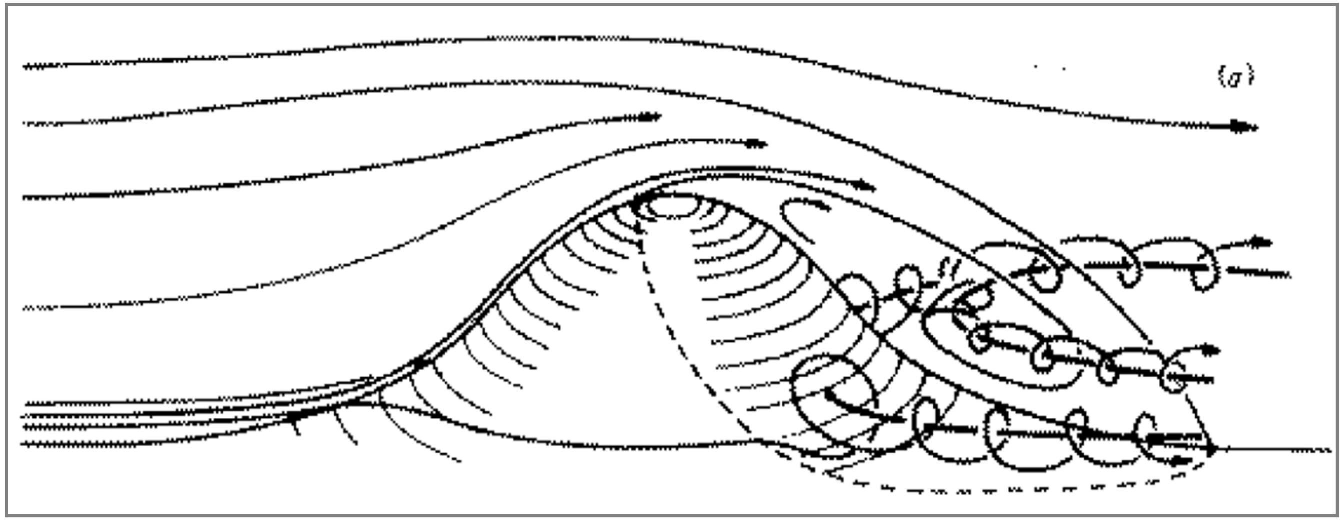
- Complete the simulation for test 4.

KEY CONSIDERATIONS

- i. Quality of the boundary conditions, ii. quality of the airflow predictions and iii. quality of the dispersion / aerosol models.

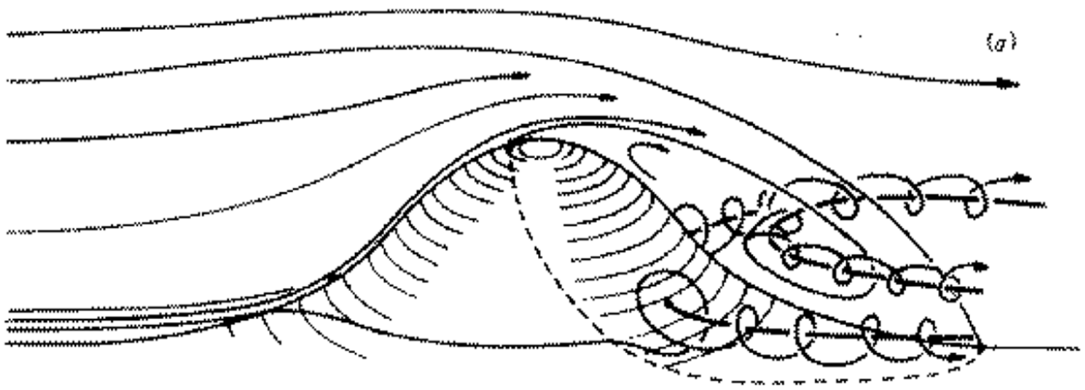
42. CFD validation against windtunnel experiments

- For validation of the simulation model experimental data published by Lawson et al. is used.
- Wind tunnel experiments are performed on the dispersion effects from terrain obstructions in a neutral atmospheric boundary layer.
- The experiments are performed in the meteorological wind tunnel of the US Environmental Protection Agency (EPA).
- In the wind tunnel an axi-symmetric hill-shaped object is placed as shown below.



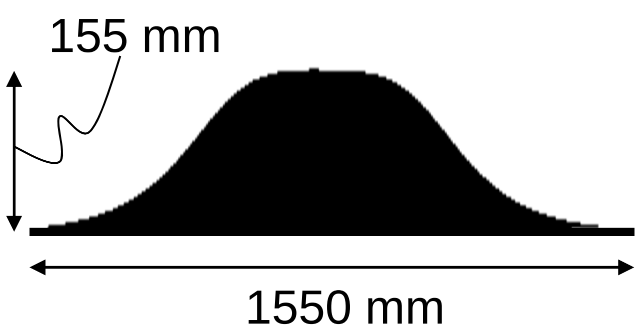
43.Sketch of the model geometry

Sketch of the model geometry



Geometry of the CFD model

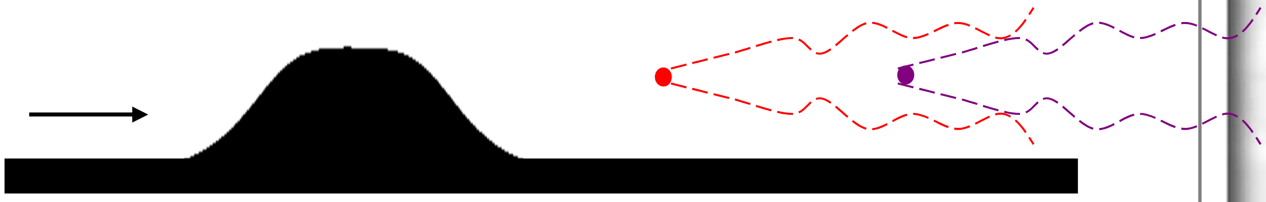
$$y(r) = \frac{y_h + c_h}{1 + \left(\frac{r}{L_h}\right)} - c_h$$



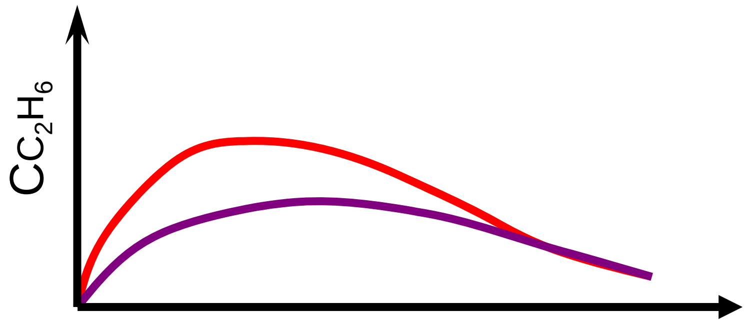
44. Release of ethane on the downstream side of the hill

- Release of ethane gas from 2 source points.
- Wind speed of 4 m/s.
- Atmospheric boundary layer is scaled.
- Ethane gas concentrations are measured near the ground and used for validation.
- Use of non-isotropic Reynolds stress turbulence model.

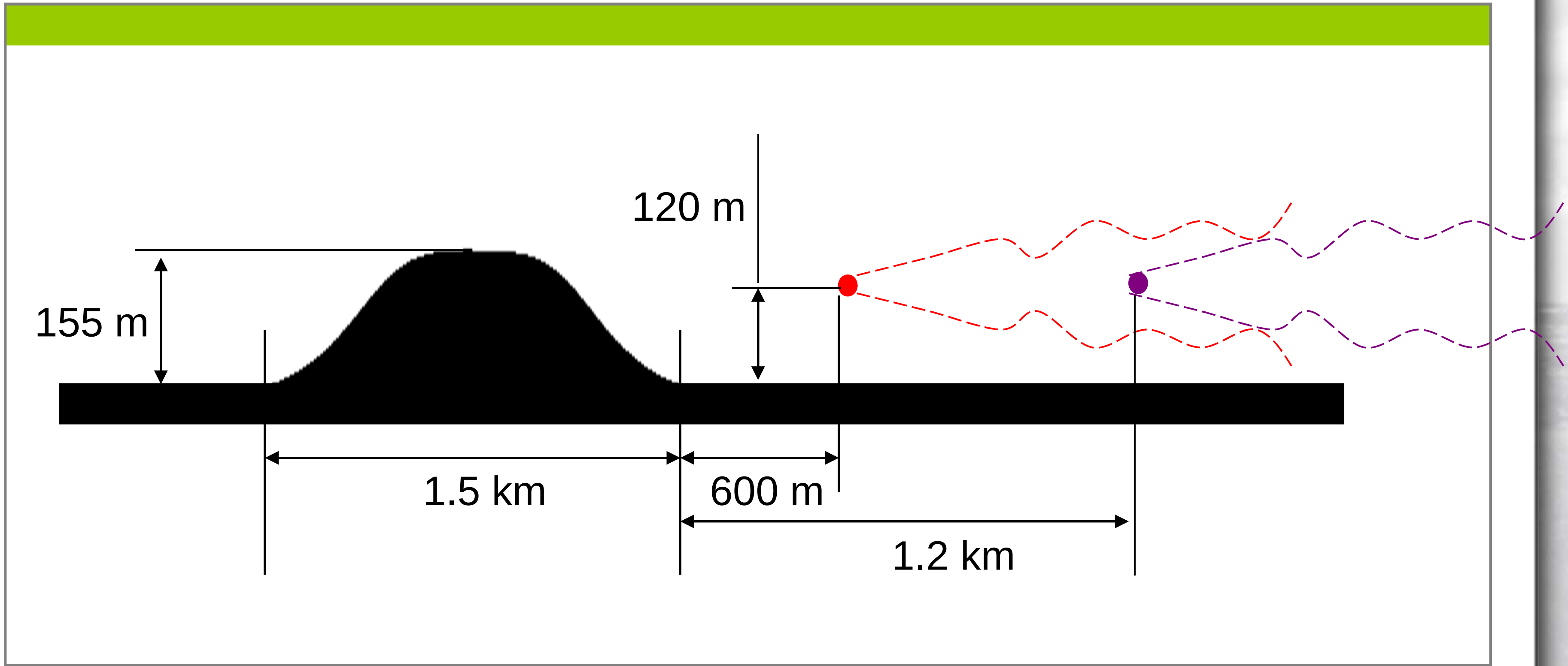
Geometry of the CFD model



Ethane concentration near the ground

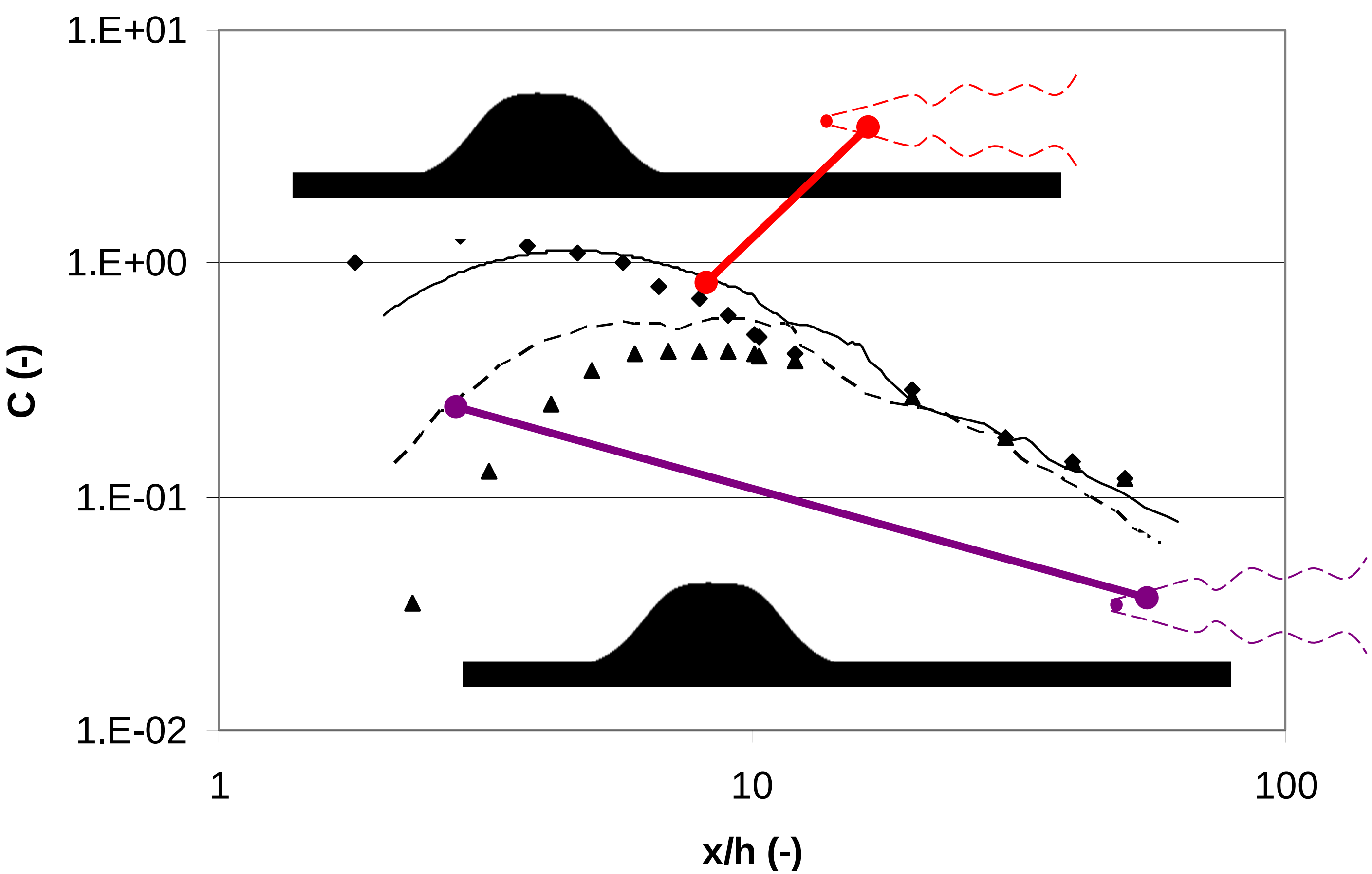


45. Geometry of the terrain objects put in context



46. Simulation results versus experiments

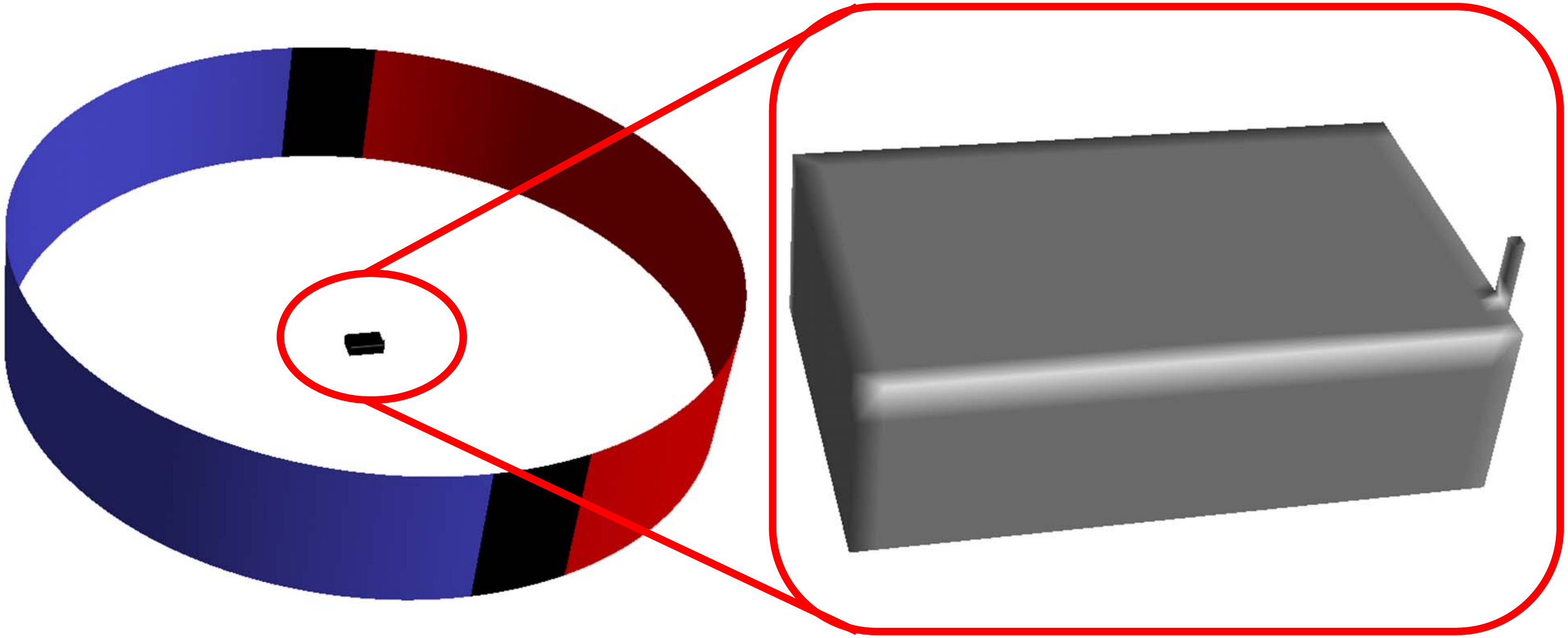
Normalised ethane concentration on the downwind side of the hill



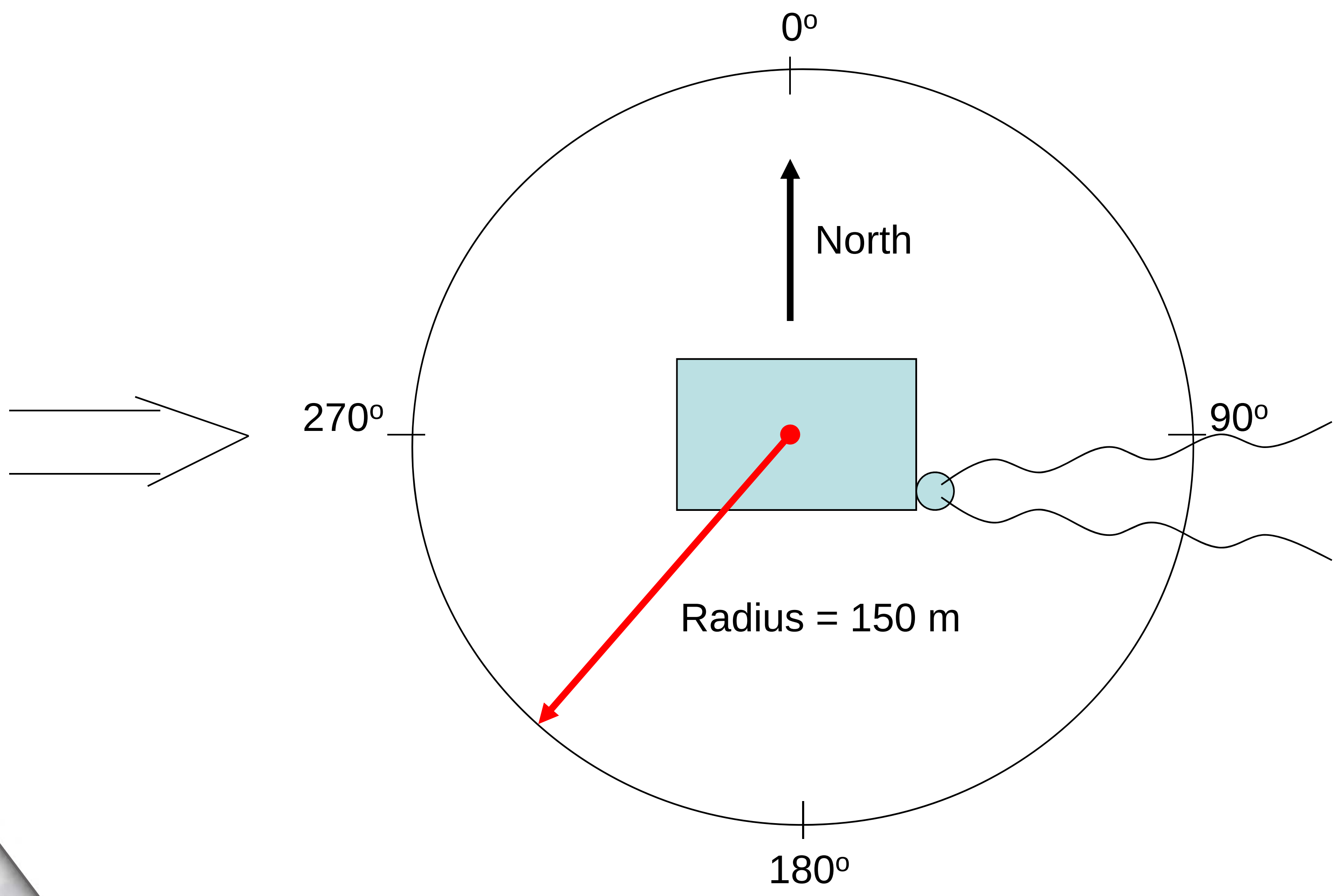
47. Conclusions from the validation runs

- From 10 hill height onwards there is good agreement with the experimental data.
- Directly behind the release point up to 10 hill heights downstream the the effects from the turbulent flow field are visible, but the comparison with experimental data is moderate.
- Accurate modelling of the ethane dispersion requires good representation of the wake flow behind the hill.
- Use of a non-isotropic turbulence model was essential to reproduce the experimental results.
- The similarities with the Pribram experiments suggest that the lessons learned also apply to the Pribram runs. These are:
  - Apply non-isotropic turbulence model.
  - Apply higher mesh resolution, particular in the downstream region.
  - Apply high numerical accuracy to trigger instabilities in the flow-field

37. Comparison between CFD and the guassian based model NUDOS

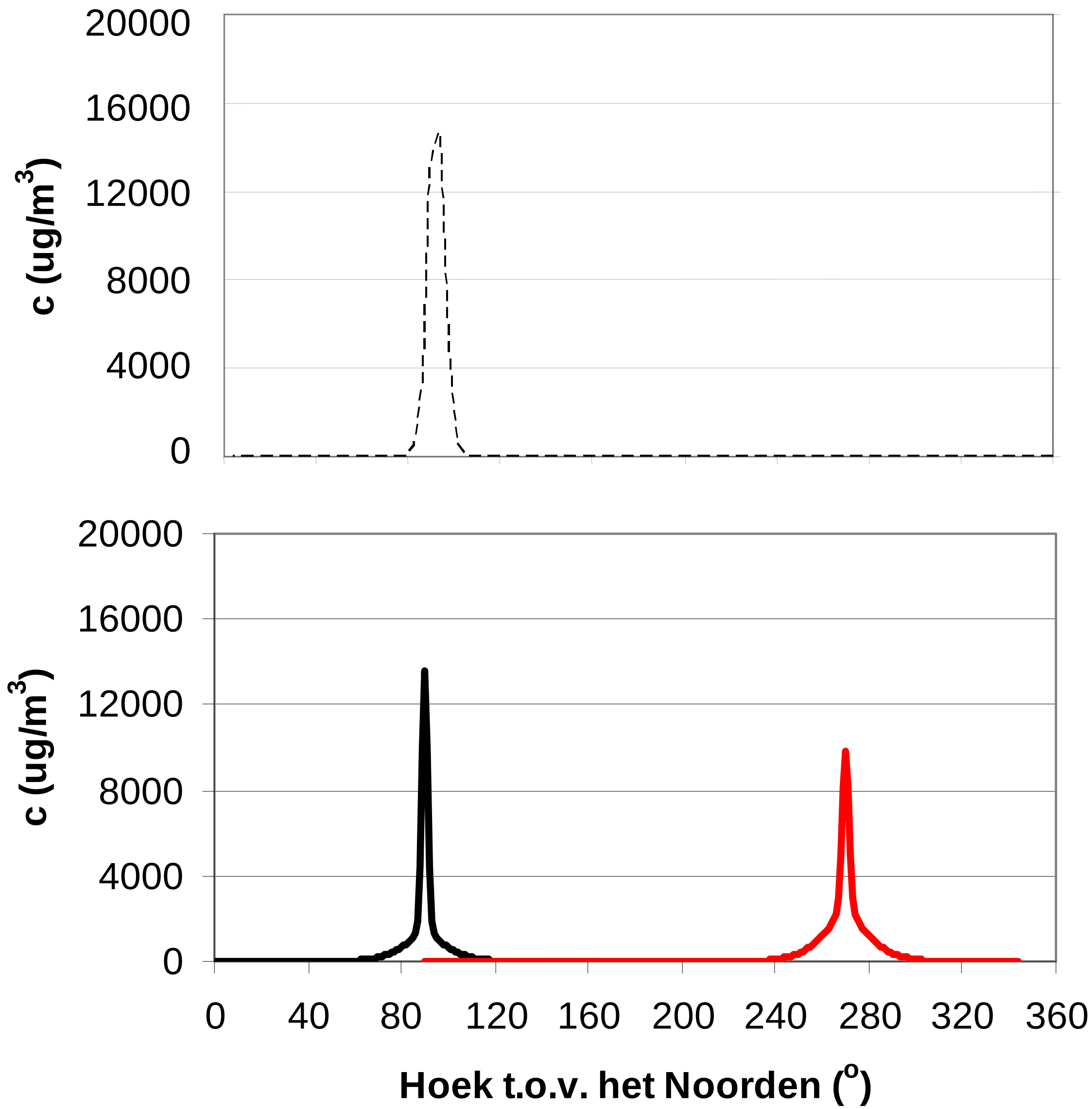


37. ^{99m}Tc in the air and on the ground

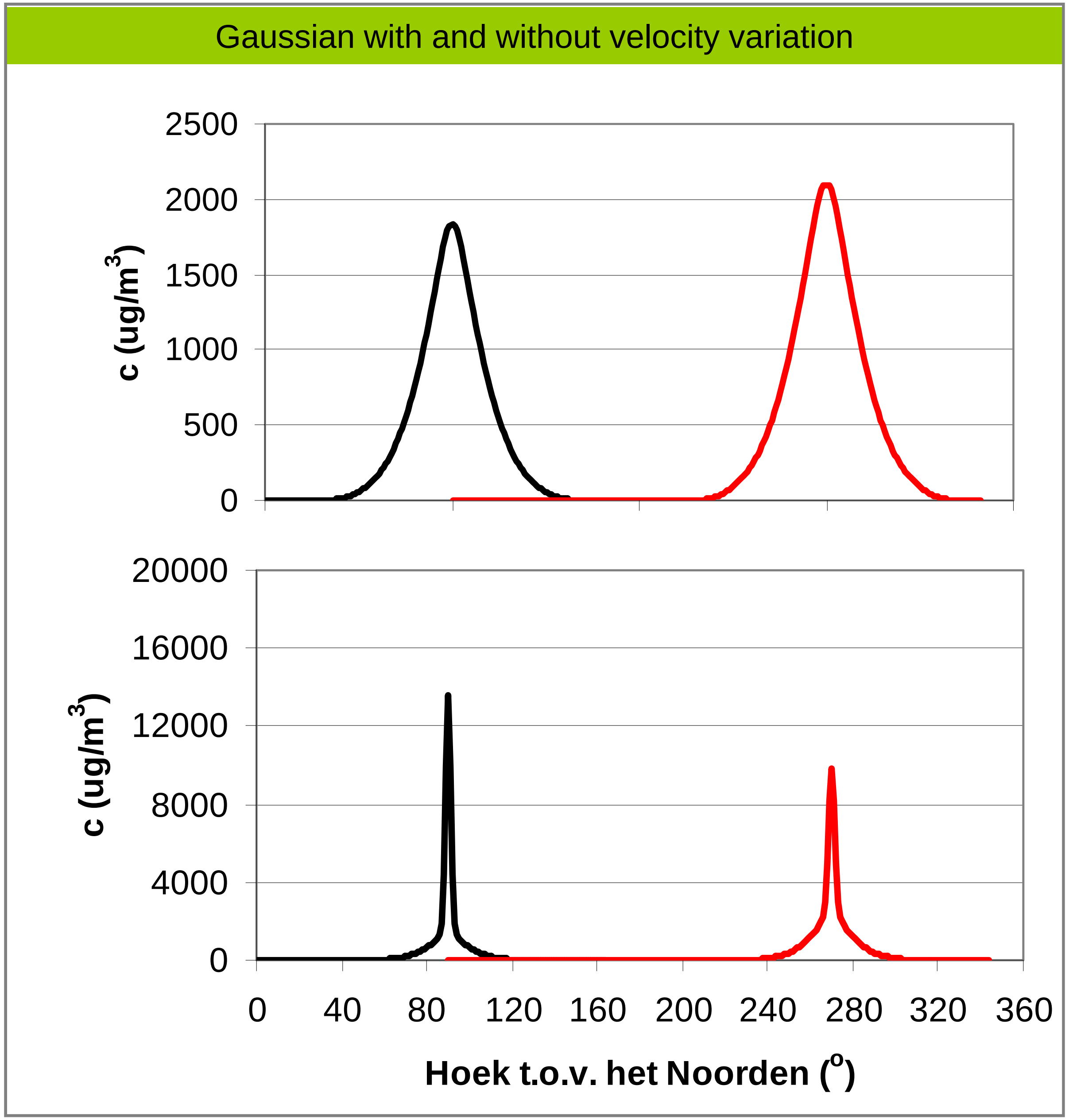


37.

CFD versus Gaussian model



37.



Gaussian with and without velocity variation
2500
2000
1500
1000
500
0
c (ug/m3)
20000
16000
12000
8000
4000
0
c (ug/m3)
0
40
80
120
160
200
240
280
320
360
Hoek t.o.v. het Noorden (o)

44. Conclusions from the validation runs

- From 10 hill height onwards there is good agreement with the experimental data.
- Directly behind the release point up to 10 hill heights downstream the the effects from the turbulent flow field are visible, but the comparison with experimental data is moderate.
- Accurate modelling of the ethane dispersion requires good representation of the wake flow behind the hill.
- Use of a non-isotropic turbulence model was essential to reproduce the experimental results.
- The similarities with the Pribram experiments suggest that the lessons learned also apply to the Pribram runs. These are:
  - Apply non-isotropic turbulence model.
  - Apply higher mesh resolution, particular in the downstream region.
  - Apply high numerical accuracy to trigger instabilities in the flow-field

CFD calculations of the test 2-4 experiments

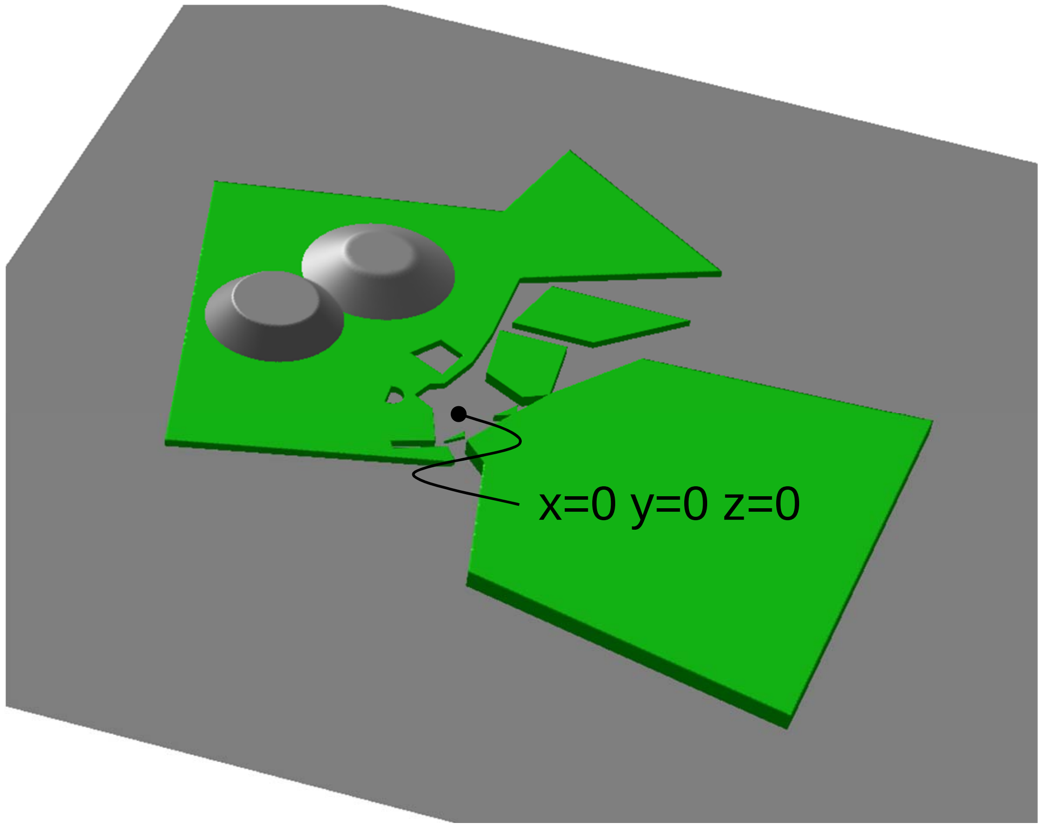
Author: G. de With

Seville, Spain

22. Model setup and boundary conditions

- Dimensions CFD model:
  x=1000m / y=100m / z=2000m.
- CFD Model:
  Transient simulation, with steady-state BCs.
- Simulation time:
  500-1000s, with a 1s time-step size.
- CFD Mesh:
  Polyhedral mesh elements.
- Turbulence model:
  k-ε RNG model.
- Temperature:
  Energy calculation.

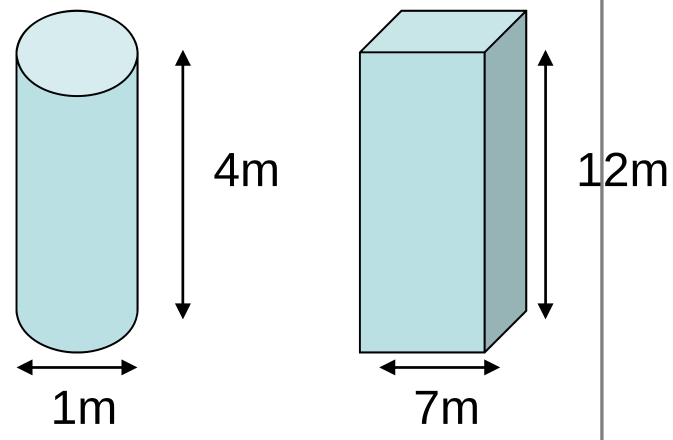
Geometry of the CFD model



23. Initial release of the droplets

- The starting point of the computation is a cylindrical or cubical formed cloud containing a uniform concentration of ^{99m}Tc.
- The explosion itself is not computed.
- The geometry of the cloud and its content are based on discussion with the WG9.
- The total activity as specified by in the start document.

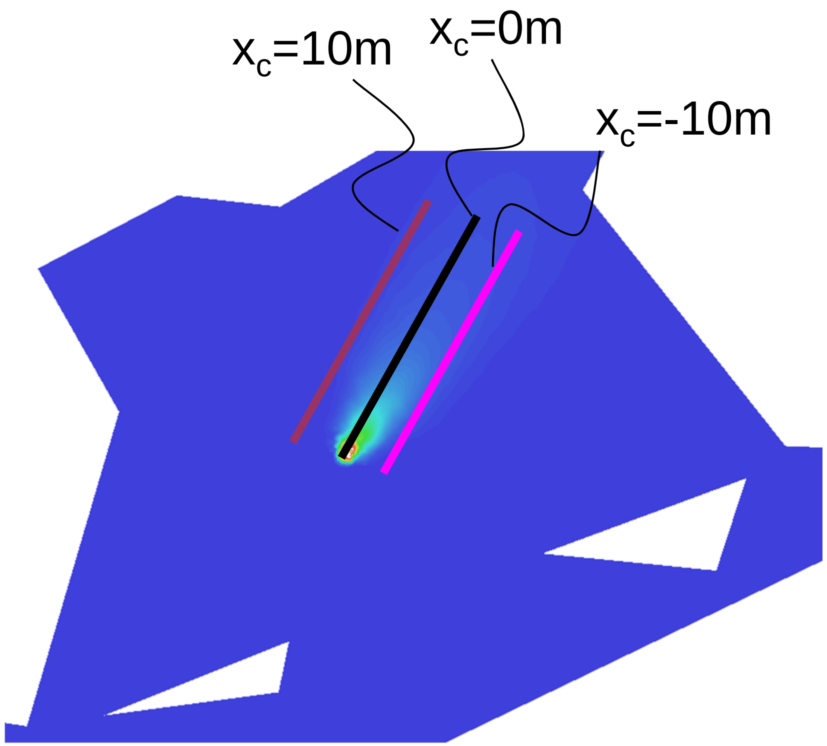
Shape of the initial cloud



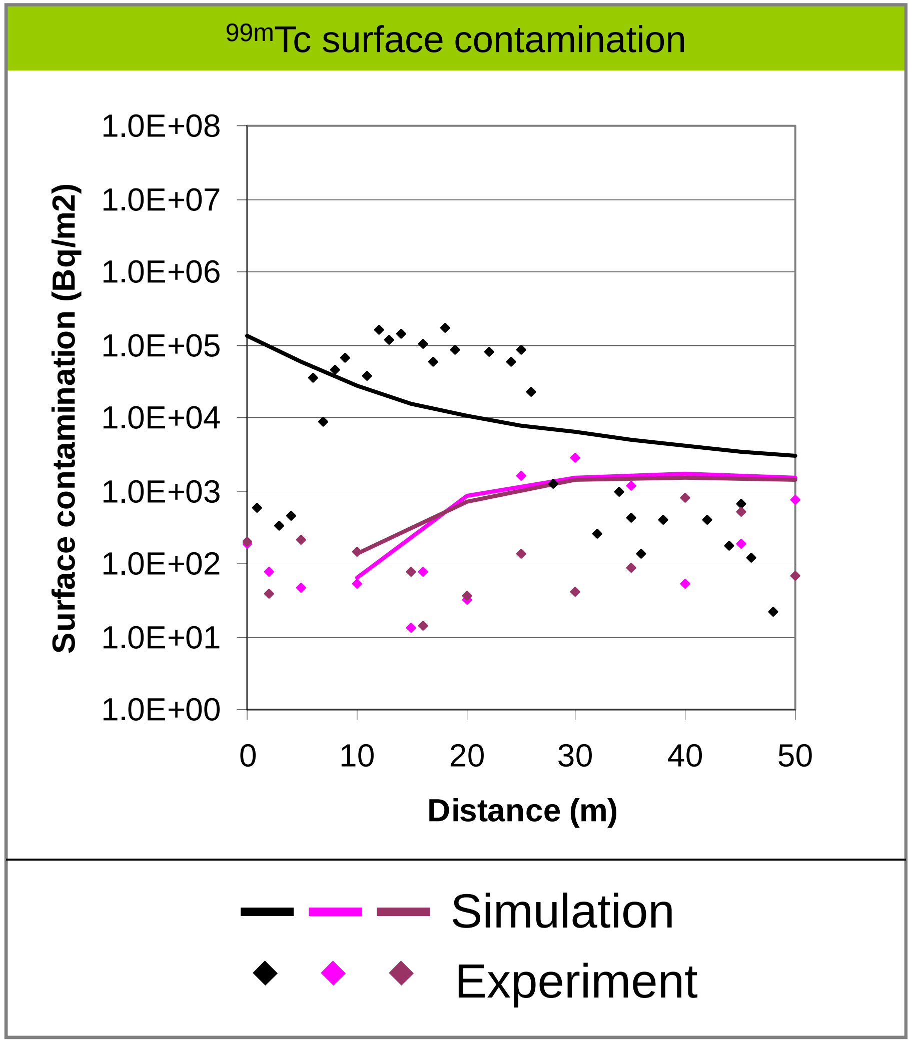
Dia. versus activity in the cloud

Droplet diameter (m)	Volume activity (%)
$2 \cdot 10^{-5}$	10.0
$6 \cdot 10^{-6}$	46.6
$1 \cdot 10^{-6}$	15.0
$2 \cdot 10^{-7}$	28.4

24. ^{99m}Tc surface contamination (January simulation)

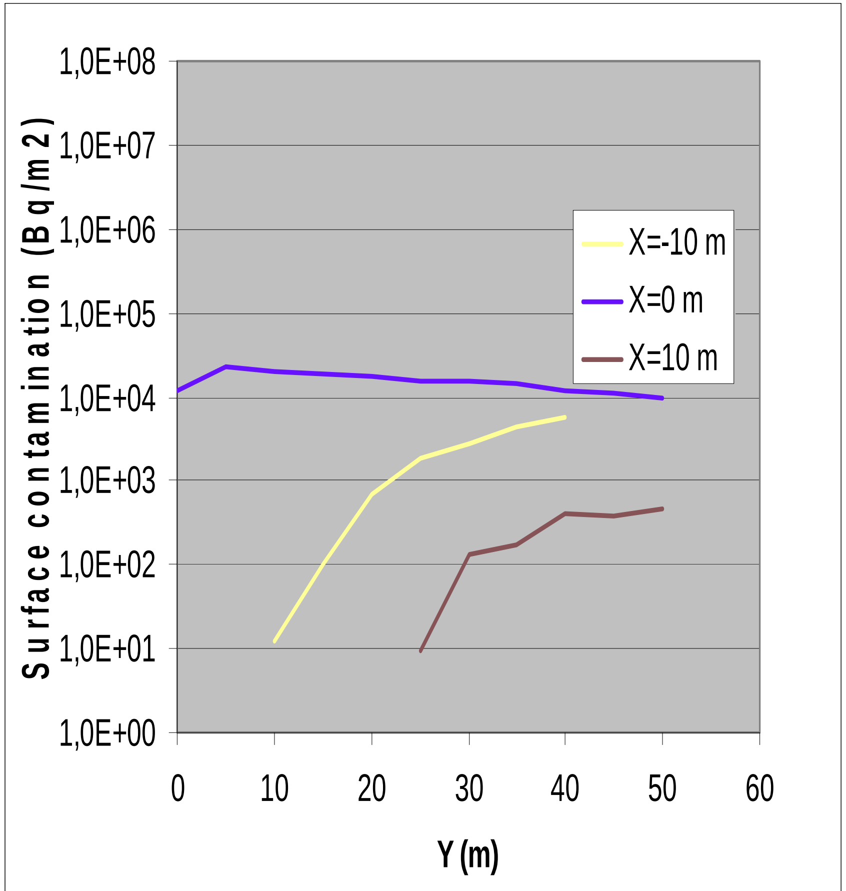


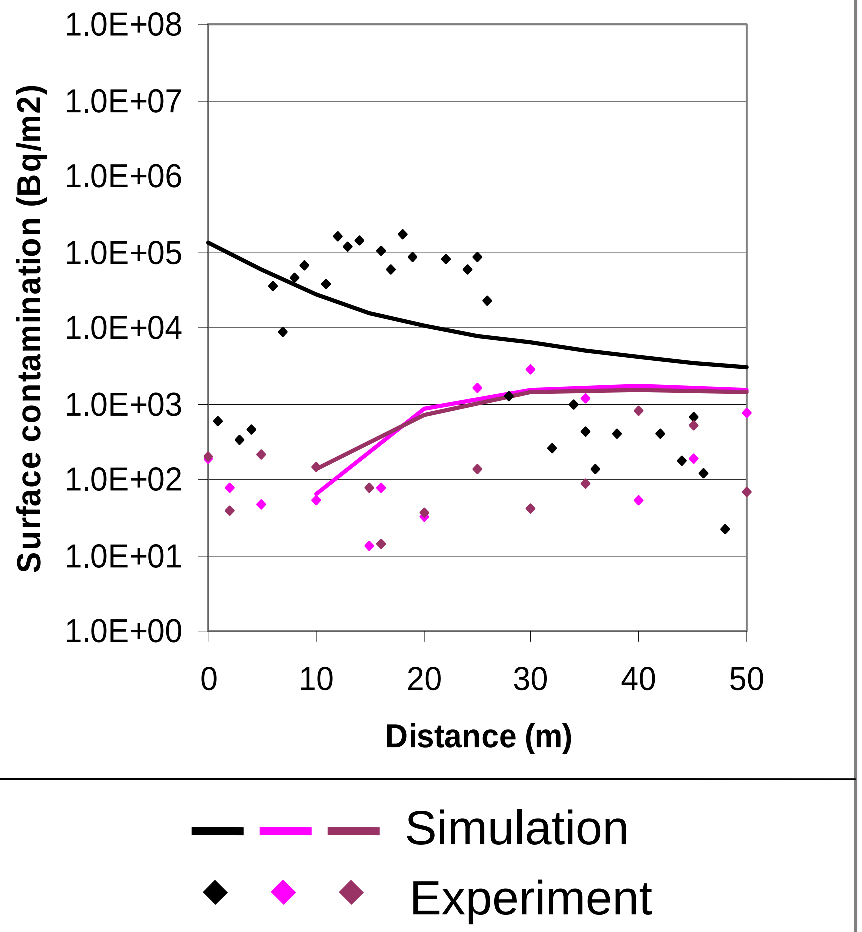
Position of the 3 lines in the graph relative to the explosion.



25. Deposition of ^{99m}Tc Test 2 (June simulation)

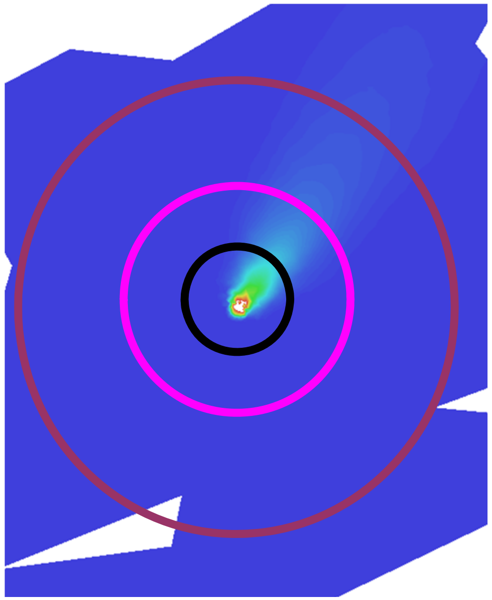
June simulation	January simulation





26. ^{99m}Tc in the air and on the ground

^{99m}Tc contamination zones

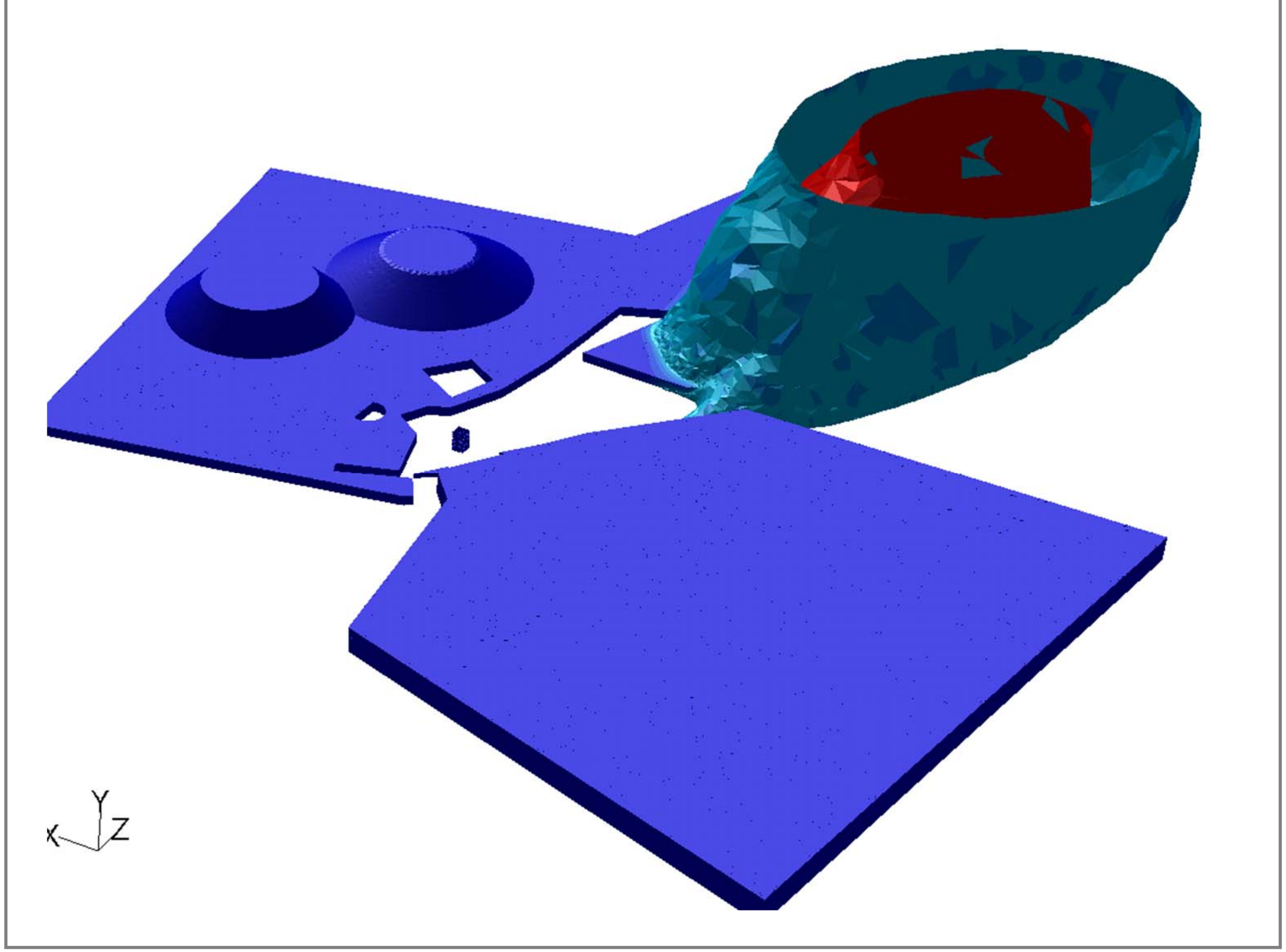


^{99m}Tc activity on the ground surface per diameter category

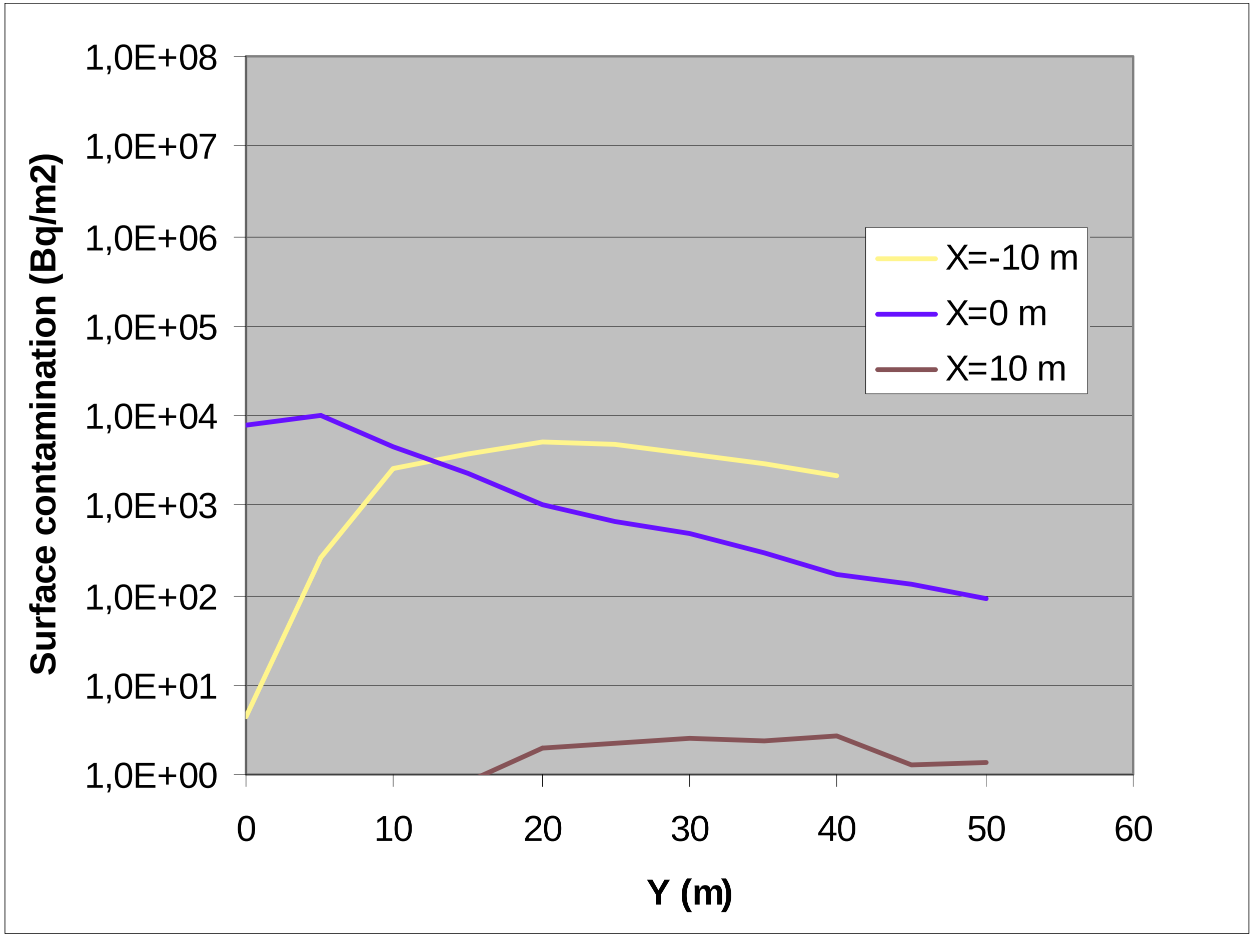
Droplet diameter (m)	R_{50} zone (m)	R_{75} zone (m)	R_{95} zone (m)
Jan. sim.	7.4	16.6	42.1
June sim.	13.7	36.3	55.6

27. Dispersion of ^{99m}Tc Test 3

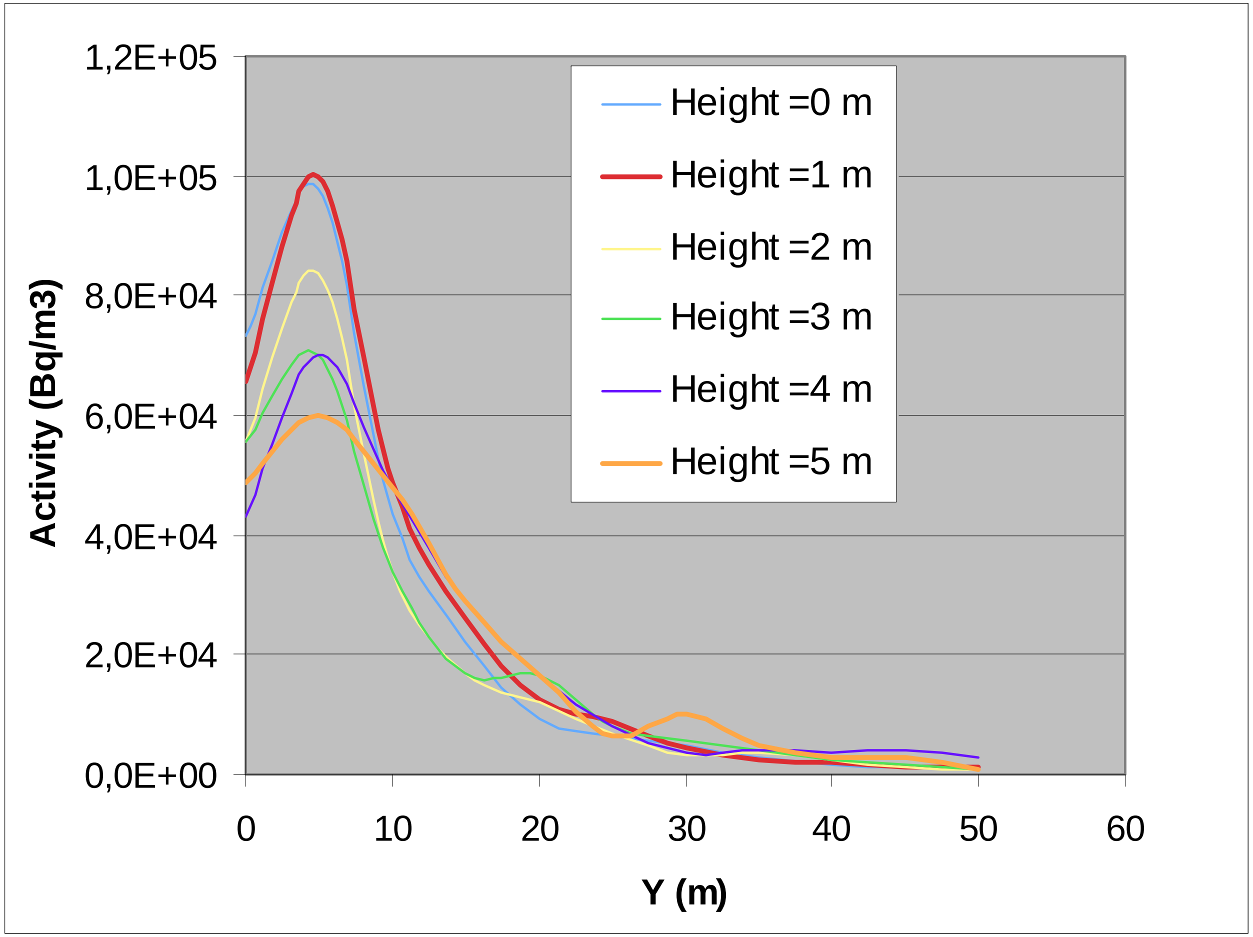
^{99m}Tc dispersion at t=100 s and 10 Bq/m^3



28. Deposition of ^{99m}Tc Test 3 (June simulation)

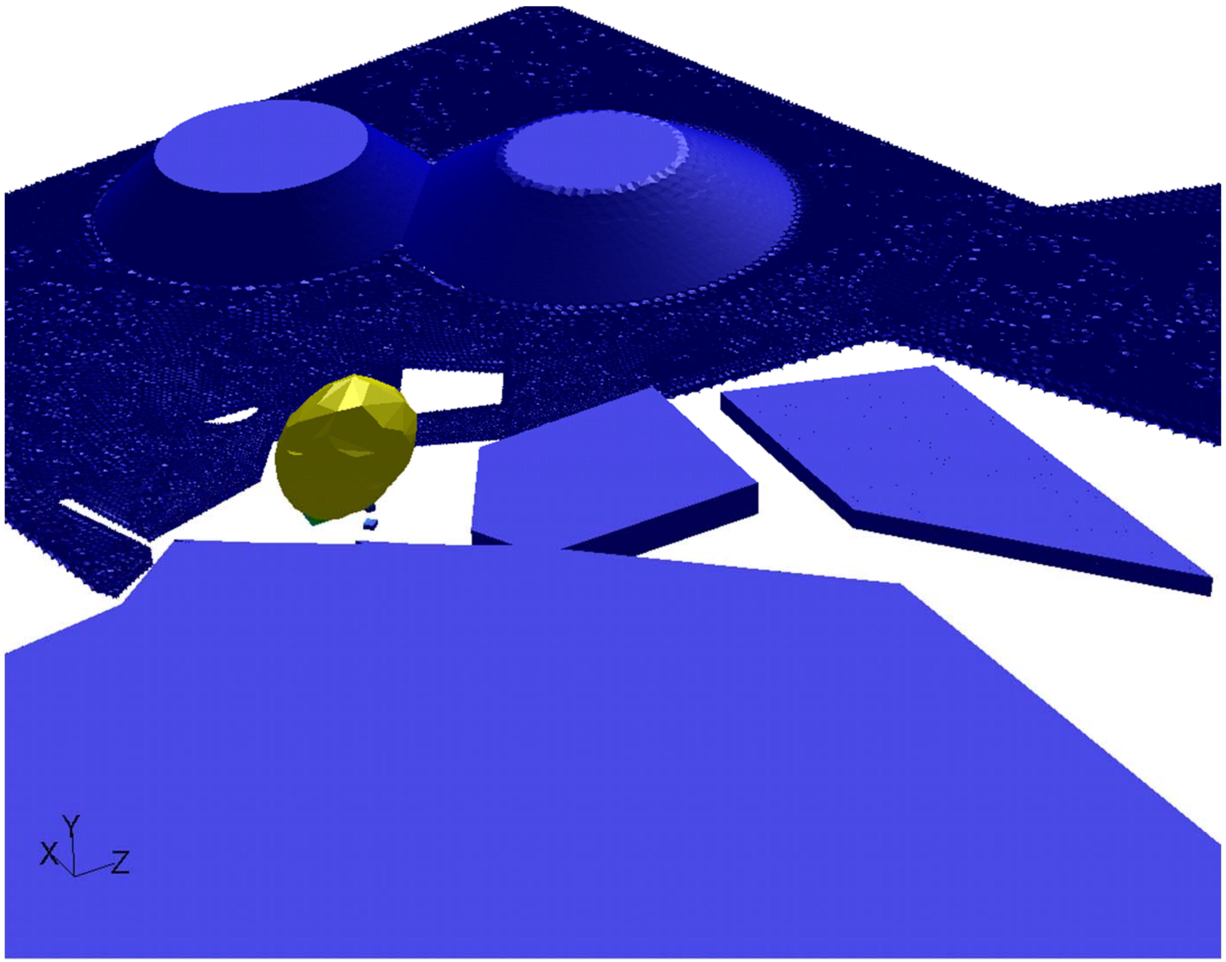


29. Dispersion of ^{99m}Tc Test 3 (June simulation)



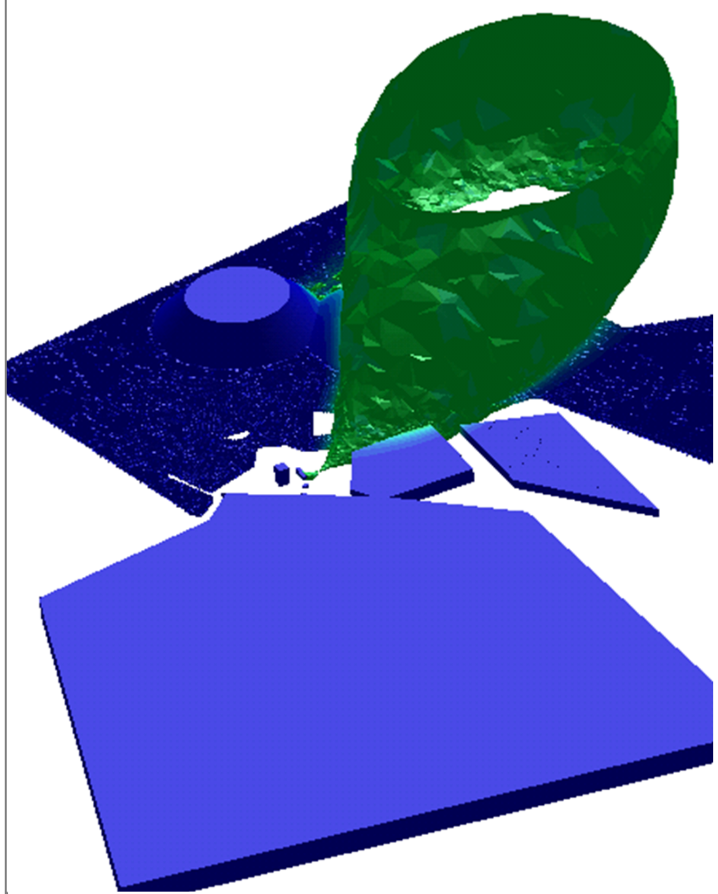
30. Dispersion of ^{99m}Tc Test 4 with bus

^{99m}Tc dispersion at t=100 s and xx Bq/m^3

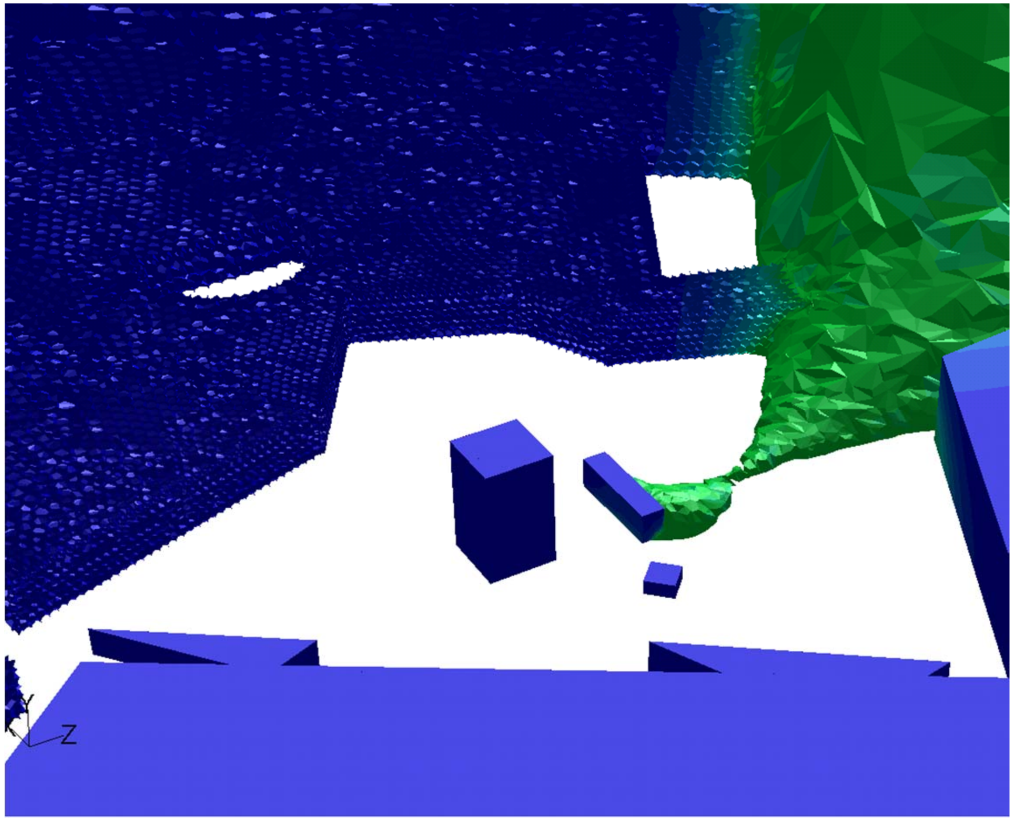


31. Dispersion of ^{99m}Tc Test 4 with bus

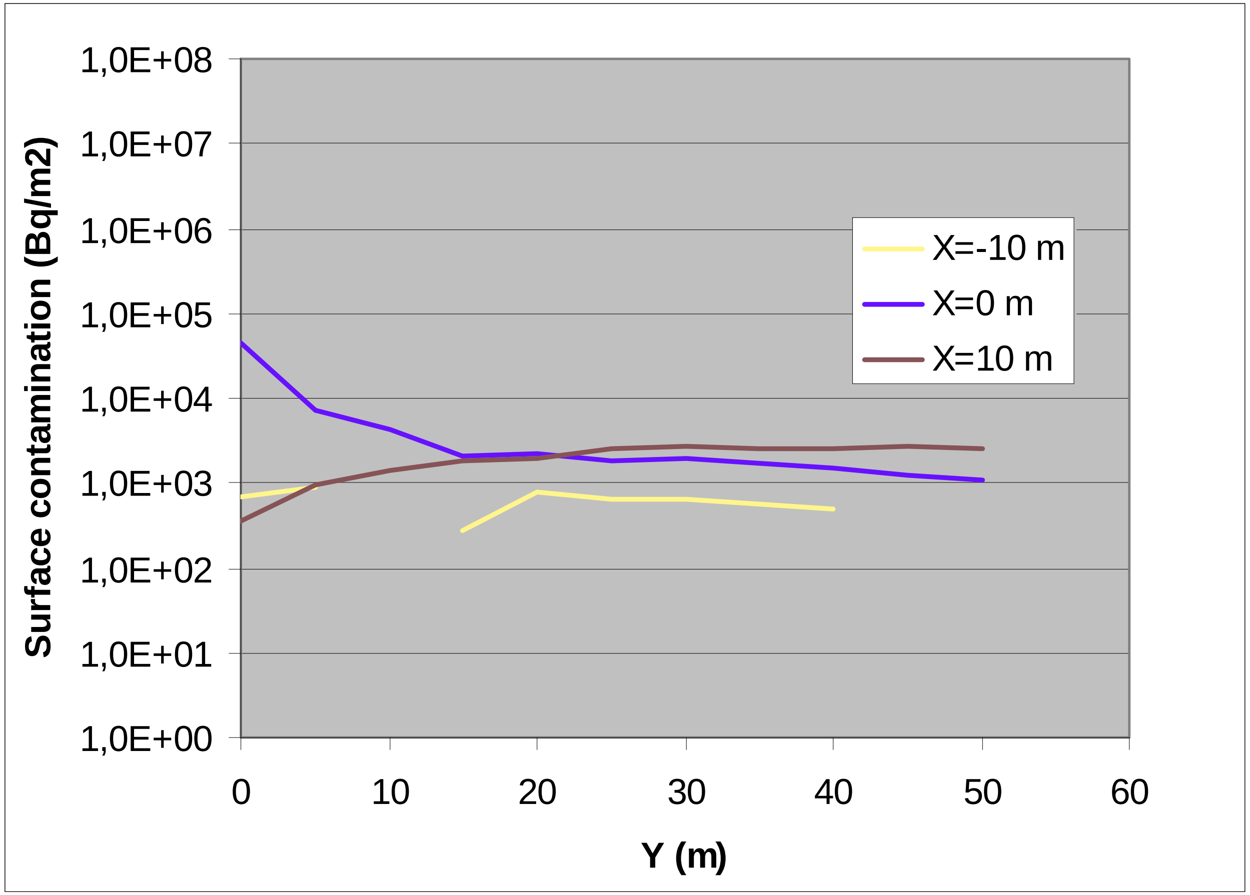
^{99m}Tc dispersion at t=1000 s and 5 Bq/m^3



^{99m}Tc deposition zoom-in



32. Deposition of ^{99m}Tc Test 4 (June simulation)



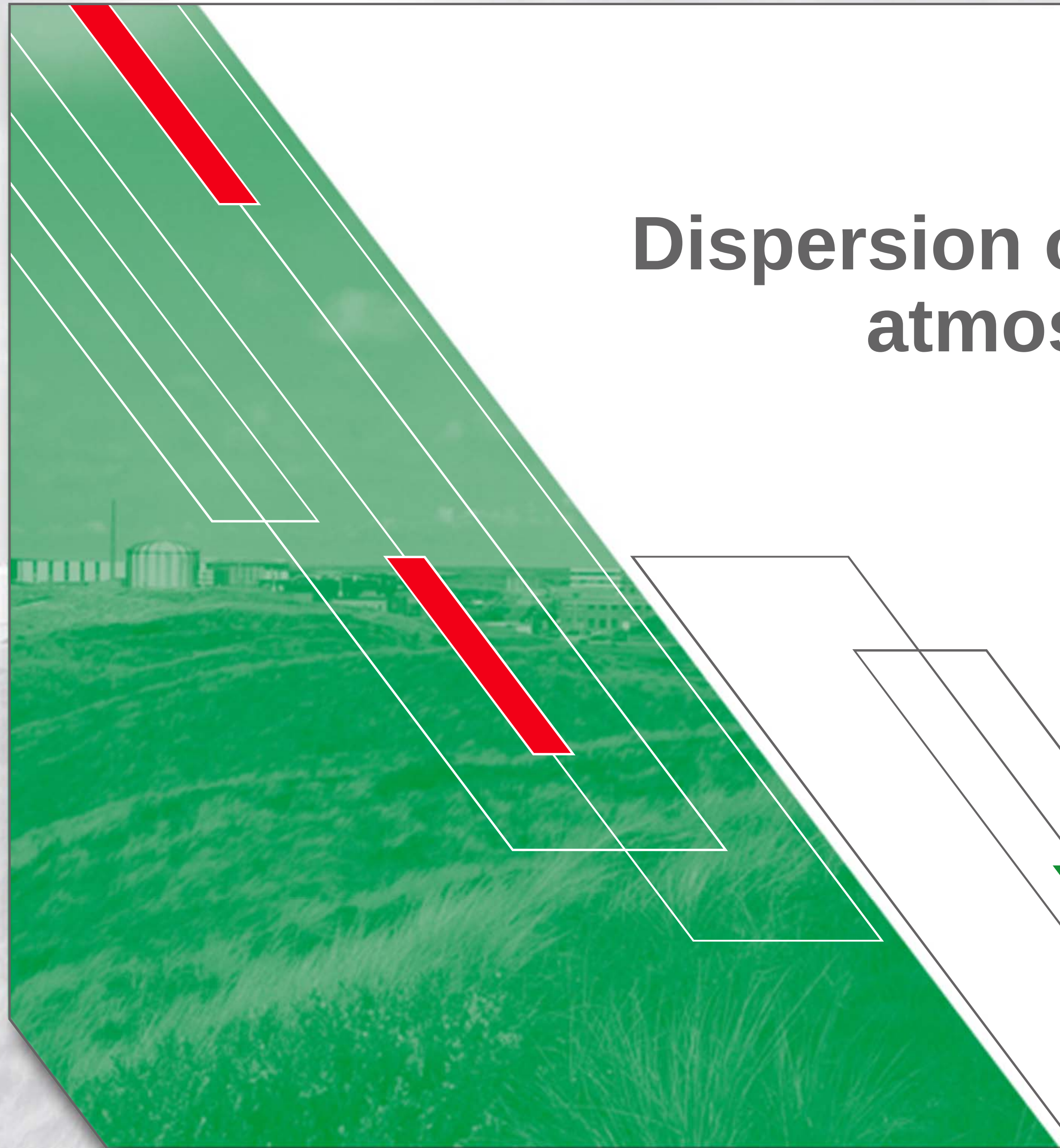
33. Conclusions

CONCLUSIONS

- Initial plume conditions have a considerable effect on the deposition
- The deposition are not symmetric across the centreline for test 2 and test 3.
- Asymmetric results are mainly a result of the chosen wind direction.
- The chosen wind speed for test 4 is 0.3 m and is a rough estimate.

FURTHER WORK

- Validation of the dispersion calculations using windtunnel data from the ERCOFTAC database.
- Incorporating atmospheric instability into the simulation



Dispersion of ^{99m}Tc in the atmosphere from a detonation

Author: G. de With

Contents

1. Introduction

- Field experiments at NINCBS in Pribram
- Explosion of ^{99m}Tc in the atmosphere
- Explosion carried out on a helicopter landing side surrounded by forest
- Tests side is surrounded by forest and hills.

- Measurements include:
  - Atmospheric conditions e.g. wind speed, direction temperature etc.
  - Droplet specifications, like droplet size and volume activity.
  - Surface contamination and subsequent dose rates.:
  - Radioactive concentrations in the air.

Test side at NINCBS in Pribram

2. Mathematical background

- Computational Fluid Dynamics (CFD)

  The calculations are based on the CFD software Fluent©, in-house algorithms are included to take account of nuclear decay, deposition and dispersion.

- Navier-Stokes equations

  The atmospheric flow is modelled using conservation equations for mass, momentum and energy.

- Dispersion and deposition of droplets

  Dispersion and deposition is modelled within an additional conservation equation.

- Pollution modelling

  Dispersion of the ^{99m}Tc pollutant is based on atmospheric and thermal flow features.

3. CFD conservation equations

- The CFD computation is based on conservation equations for mass, momentum and energy.
- Turbulent motion is take into account with a k-ε turbulence model.
- Forest patches are considered with an extra sink term.
- A logarithmic boundary model with roughness height is applied to the ground.

CFD conservation equations

$$\rho\left(\nabla \cdot u_k\right) = 0$$

Mass conservation equation

$$\rho\left(\frac{\partial(u_k)}{\partial t} + \nabla \cdot (u_k u_l)\right) = -\nabla P + \nabla \cdot \left(\mu_{eff} \nabla u_k\right) + S_{u,k}$$

Momentum conservation equation

$$\mu_{eff} = \mu_l + \mu_t$$

Turbulent viscosity

$$S_{u,k} = -\rho C_d a_l U^2 = -\frac{1}{2}\rho C_n U^2$$

Forest patches

$$\frac{\partial \rho E}{\partial t} + \nabla \cdot \rho u_k E = -\nabla u_k P + \nabla \cdot \left(\Gamma_T \nabla T\right)$$

Energy conservation equation

4. Dispersion modelling of ^{99m}Tc

- The activity from ^{99m}Tc is based on an additional conservation equation.
- Turbulent diffusion is based on the k-ε turbulence model.
- Brownian diffusion, terminal velocity and nuclear decay are considered.
- For each droplet diameter a separate conservation equation is required.
- Evaporation is not included.

Dispersion of ^{99m}Tc	
$\frac{\partial C_m}{\partial t} + \nabla \cdot \left[\left(u + v_{s,m} \right) C_i \right] = \nabla \cdot \left[\left(\Gamma_m + D_m \right) \nabla C_m \right] + S_{C,m}$	Droplet conservation equation
$\Gamma_m = \mu_{eff} / \rho$	Turbulent diffusion
$D = \frac{k_B \, T \, Cu}{3\pi \, \mu_l d_p}$	Brownian diffusion
$v_s = \frac{\rho_d g d_d^2}{18 \mu_a}$	Terminal velocity
$S_C = -\lambda C$	Nuclear decay

5. Modelling of droplet deposition

- Deposition is applied as an extra sink term to the elements adjacent to the ground.
- The sink term is a function of the deposition velocity and concentration ^{99m}Tc in the numerical element.
- Only dry deposition is considered.
- Dry deposition considers: gravitational settling, turbulent motion and Brownian diffusion.
- Deposition due to rainfall is not considered, but can be applied.

Deposition of ^{99m}Tc

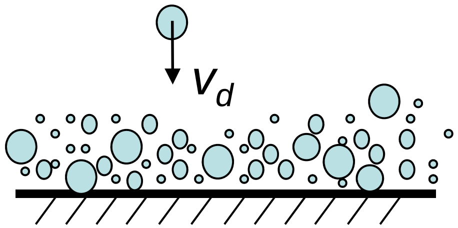
$$J_d = v_d \cdot C_b$$

Deposition flux

$$v_{dd} = \frac{v_s}{1 - \exp\left(-\frac{v_s I}{u^*}\right)}$$

Deposition velocity

Sketch of the droplet deposition



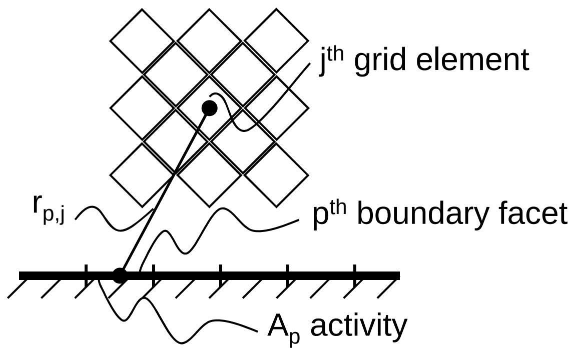
6. Radiation exposure from ^{99m}Tc

- The dose rate in each element is computed at the end of the time-step and is based on the accumulated droplet deposition.
- The activity at each boundary facet is considered a point source.
- The dose rate is based on the air Kerma rate constant for ^{99m}Tc in air.
- The air Kerma rate constant (Γ_a) is 0.018 μGy·m²MBq⁻¹h⁻¹.

Calculation absorbed dose rate

$$\dot{K}_{a,j} = \Gamma_a \sum_{p=0}^{p=P_b} \frac{A_p}{r_{p,j}^2}$$

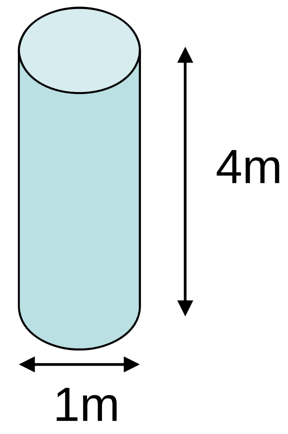
Sketch of the absorbed dose rate



8. Initial release of the droplets

- The starting point of the computation is a cylindrical formed cloud containing a uniform concentration of ^{99m}Tc.
- The explosion itself is not computed.
- The geometry of the cloud and its content are based on data provided by the NRPI.
- Possibilities for an explosion model are feasible and need to be discussed in a technical forum.
- The total activity in the cloud is 1,058MBq.

Shape of the initial cloud



Dia. versus activity in the cloud

Droplet diameter (m)	Volume activity (%)
$2 \cdot 10^{-5}$	10.0
$6 \cdot 10^{-6}$	46.6
$1 \cdot 10^{-6}$	15.0
$2 \cdot 10^{-7}$	28.4

9. Velocity boundary conditions

- Profiles for wind speed, kinetic energy and dissipation are based on a neutral atmospheric boundary layer.
- The wind speed is 4 m/s at 10m above ground.
- The turbulent kinetic energy is 0.27 m^2/s^2.
- The dissipation is inverse linear with the height from the ground.

Velocity boundary conditions

$$U(y) = u^*_{ABL} \ln\left(\frac{y + y_0}{y_0}\right)$$

Logarithmic velocity profile

$$k(y) = \frac{u^{*2}_{ABL}}{\sqrt{C_\mu}}$$

Turbulent kinetic energy profile

$$\varepsilon(y) = \frac{u^{*3}_{ABL}}{\kappa(y + y_0)}$$

Turbulent dissipation profile

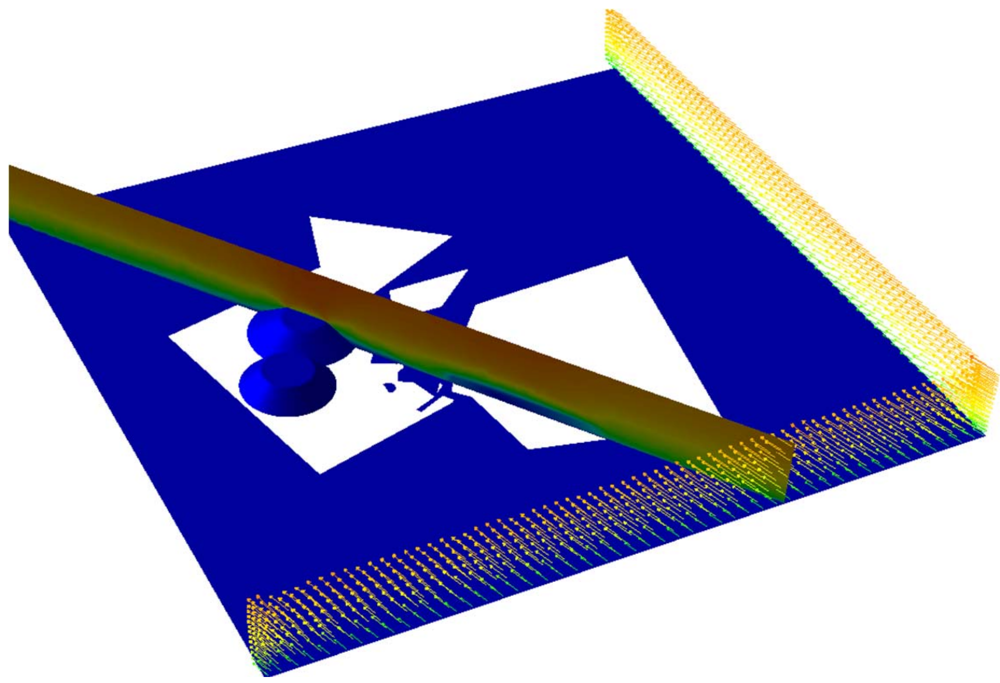
10. Simulation results

- Simulation process:
  - 1. Performed sensitivity simulations, 2. Fine-tune & calibrate simulation setup, 3. Performed final simulation
- Performed simulations include:
  - 1 final simulation with droplet spectrum
  - 10 simulations as part of the sensitivity analysis
- Simulations are benchmarked *only* against test 2 (15th May 2008) from the NRPI

11. Simulated atmospheric flow field

- Sustainable atmospheric flow
- Spatial variations in the grid resolution effect the sustainability of the flow field.
- Mesh sensitivity analysis was performed.
- Reduced wind speed in the forest patches
- Flow field is sensitive to wind speed, direction and forest settings
- Vortex formation in the wake area behind the forest

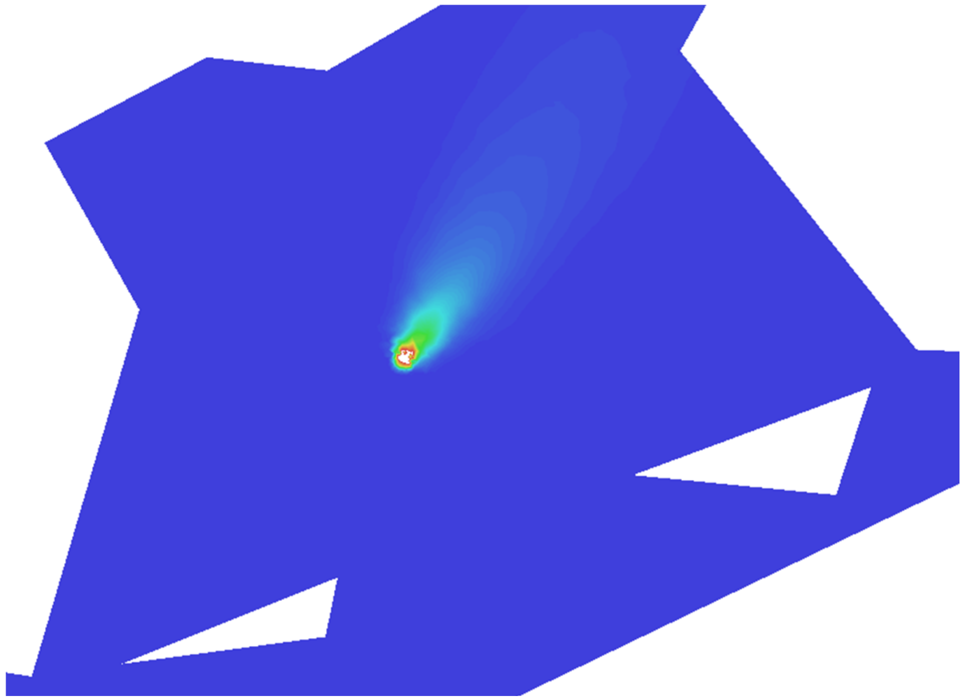
Prediction of the flow field



12. Deposition of ^{99m}Tc on the ground surface

^{99m}Tc deposition

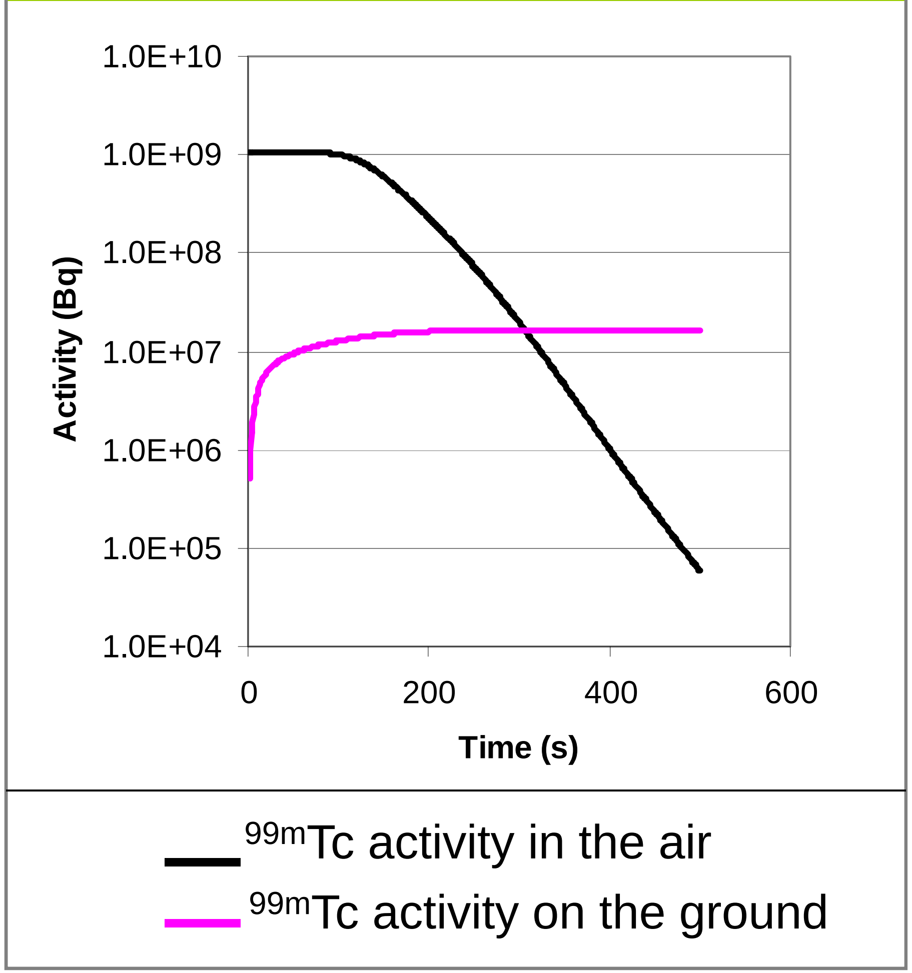
^{99m}Tc deposition zoom-in



13. ^{99m}Tc in the air and on the ground

- The total deposition of ^{99m}Tc on the ground 500s after the explosion is 1.6%.
- After 200s there is no further increase in ^{99m}Tc surface contamination.
- After 150-200s ^{99m}Tc reaches the outer edges of the computational domain.
- After 400s there is no significant concentration of ^{99m}Tc in the air.

^{99m}Tc activity in the air and on the ground

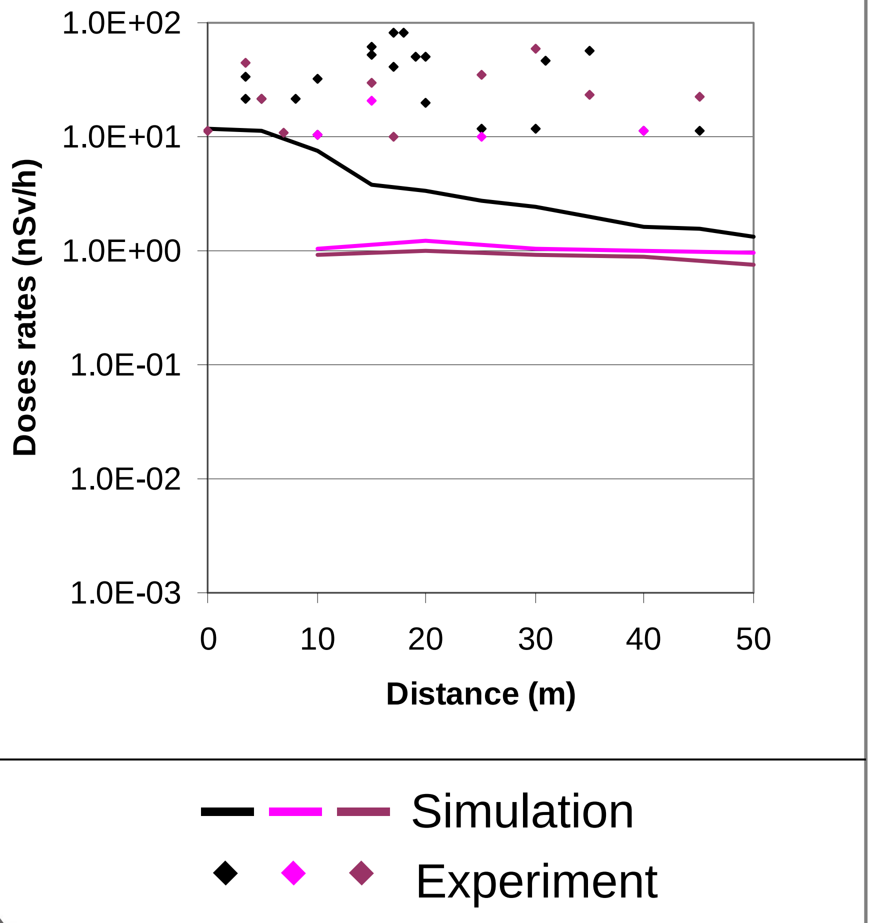


14. ^{99m}Tc in the air and on the ground

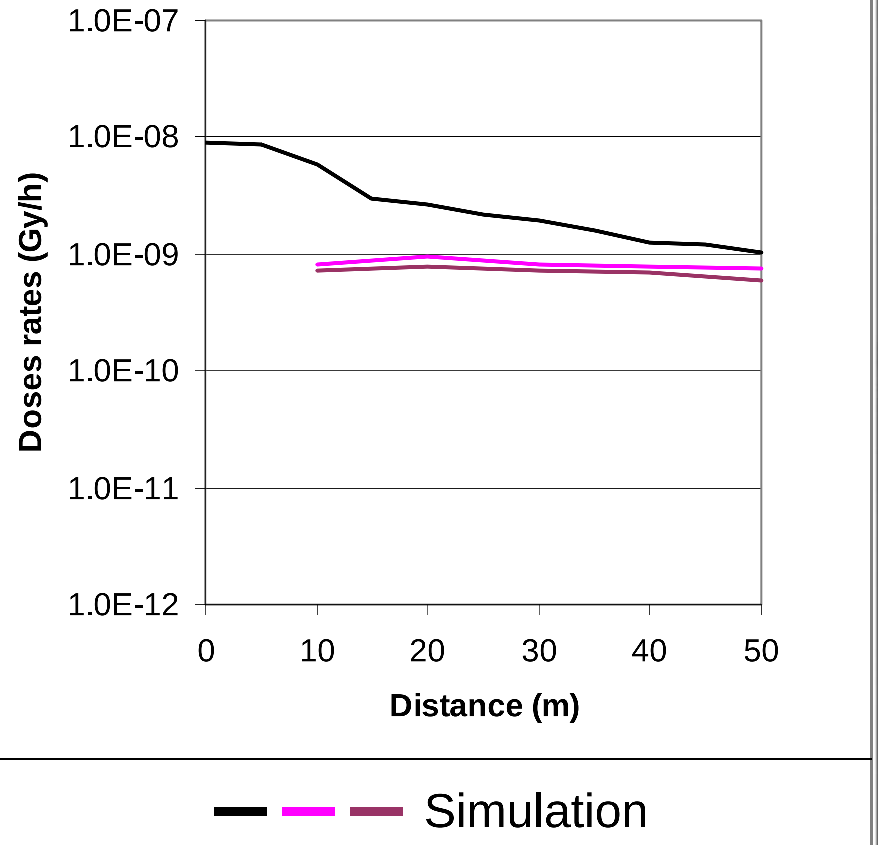
^{99m}Tc activity on the ground surface per diameter category			
Droplet diameter (m)	**Released activity (Bq)**	**Deposition (Bq)**	**Percentage deposition (%)**
$2 \cdot 10^{-5}$ / $2 \cdot 10^{-7}$	$1.06 \cdot 10^{9}$	$1.65 \cdot 10^{7}$	1.6

17. ^{99m}Tc dose rates at 1m above ground

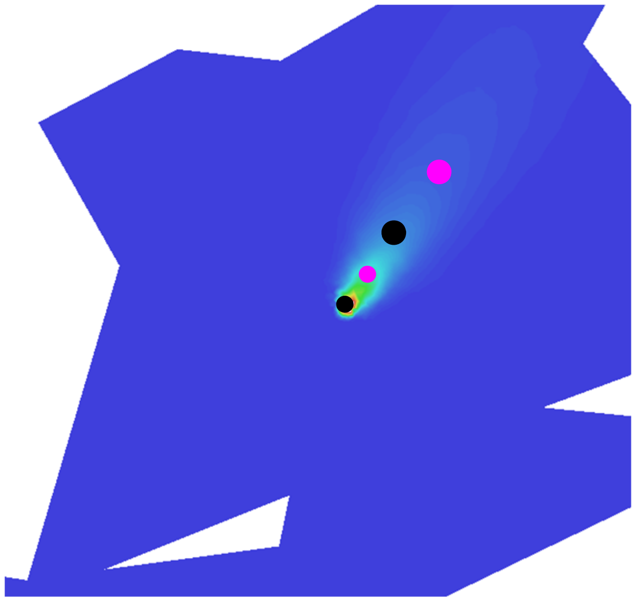
^{99m}Tc equivalent dose rates at 1m above ground

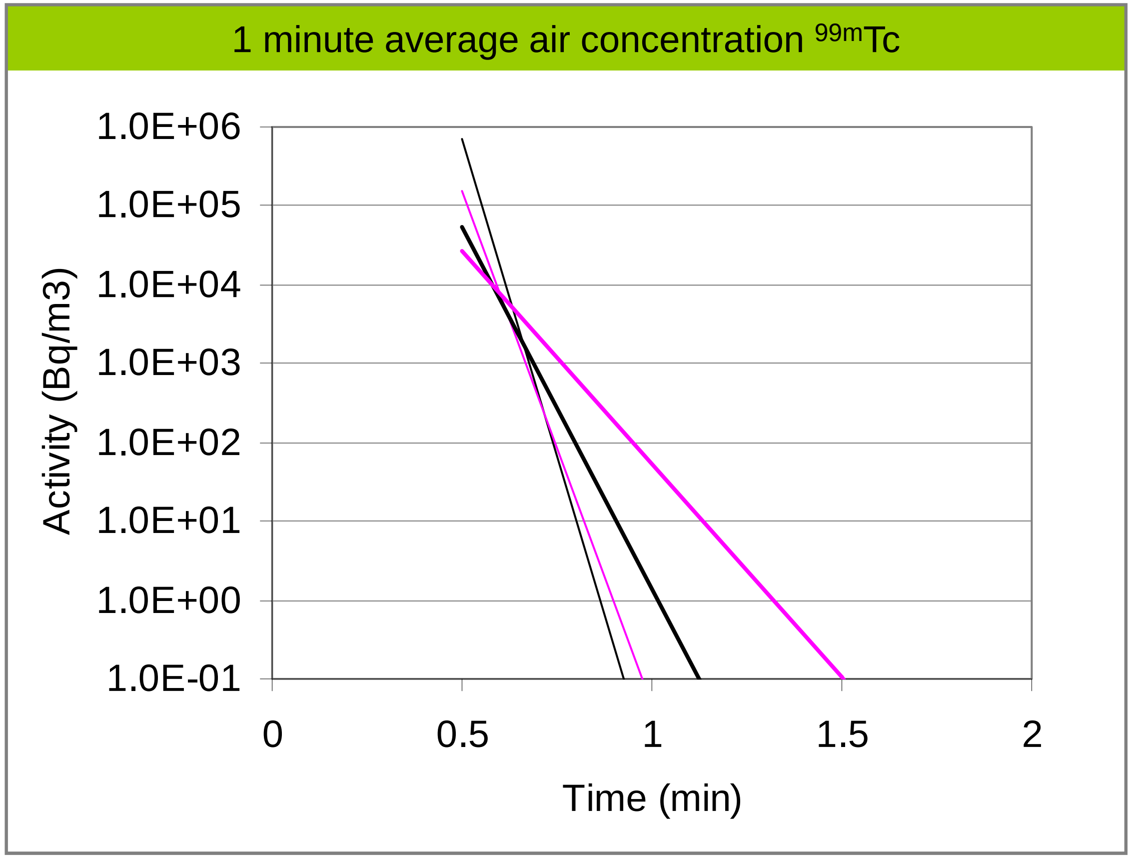


^{99m}Tc absorbed dose rate at 1m above ground



18. ^{99m}Tc concentrations in air





Graph with average concentrations as function of time for 4 positions.
The location of the 4 positions is shown in the adjacent picture.

19. Results from the sensitivity analysis

^{99m}Tc activity on the ground surface per diameter category					
Simulation	**Input parameter**	**Released activity (Bq)**	**Deposition (Bq)**	**Percentage deposition (%)**	**R_{95} zone (m)**
Default model input	**Default**	**$1.06 \cdot 10^{9}$**	**$9.16 \cdot 10^{6}$**	**0.9**	**38.4**

20. Conclusions

CONCLUSIONS

- CFD simulations give interesting qualitative results
- Effects from atmospheric conditions on the surface contamination are shown.
- CFD simulation results are very sensitive to atmospheric boundary conditions and initial cloud conditions.
- To reproduce the experimental results good climate data at the time of the experiment is required.

FURTHER WORK

- Incorporate a suitable algorithm to simulate the initial stages of the explosion
- Run a simulation for the final blind-test performed by the NRPI
- Other things that are of interest are: evaporation, wet-deposition & solar irradiation, LES calculation, automated topography

END