Numerical Modeling of Sampling Airborne Radioactive Particles Methods from the Stacks of Nuclear Facilities in Compliance with ISO 2889

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Introduction: The International Standard ISO 2889 focuses on monitoring activity releases of radioactive substances in air in stacks of nuclear facilities and sets the performance criteria and recommendations required for obtaining one point valid measurements. The criteria those guarantee the homogeneity of the air stream at the sampling locations are the following: **a)** absence of angular or cyclonic flow (the mean flow angle between the flow axis and stack axis should not exceed 20); **b)** symmetry of air velocity profile (the Coefficient Of Variation should be less than 20% on the centre two-thirds of the area of the stack); **c)** symmetry of gas concentration and particle profile, injected on the base of chimney (measured with the same principle of velocity profile). The main objective of this study is to verify the compliance of an ongoing nuclear facilities stack design with the ISO 2889 requirements, during normal and off-normal conditions.

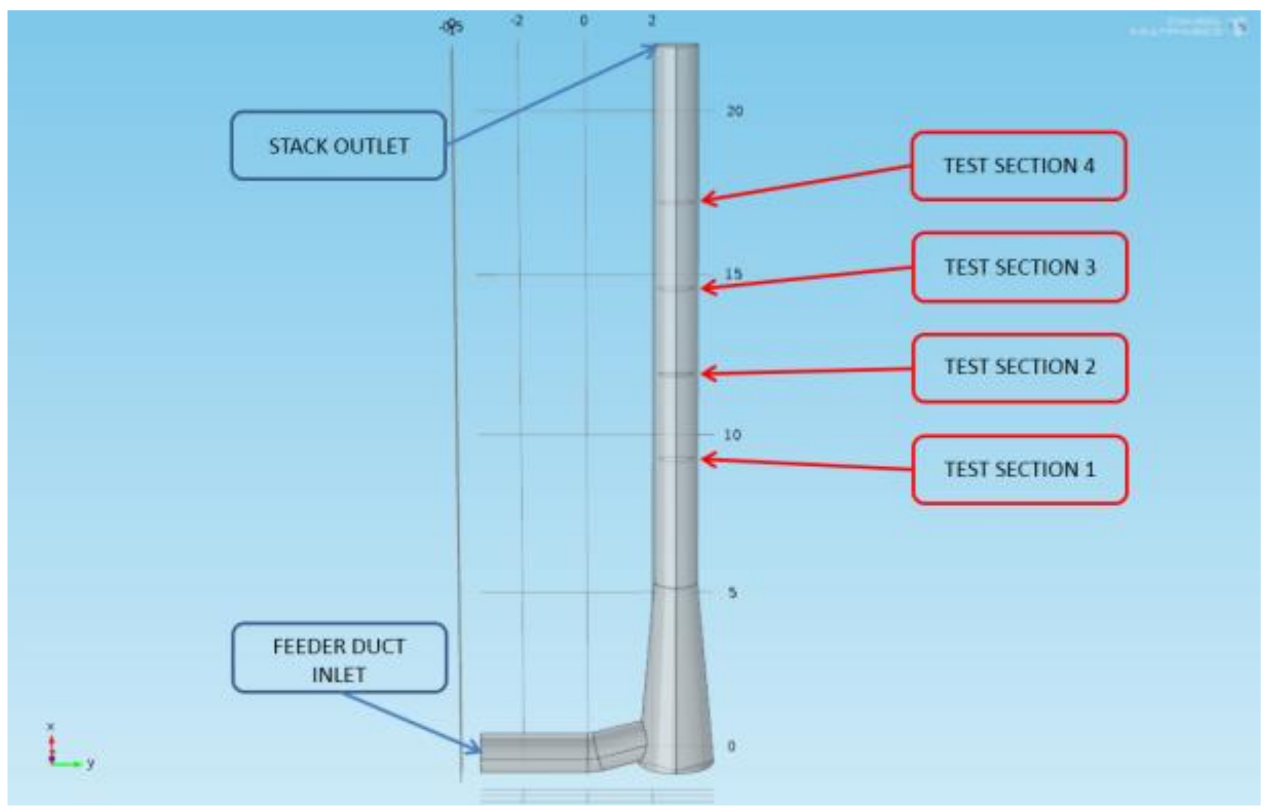


Figure 1. Geometry of the stack and test sampling sections positioning

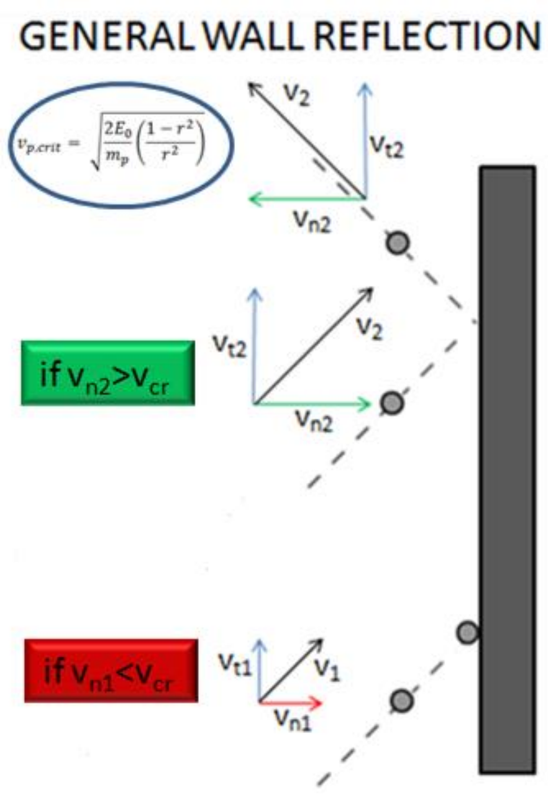
Computational Methods: The simulations are performed with Comsol Multiphysics® 4.4 – Heat Transfer and Particle Tracing Modules and are based on the following steps: 1) stationary fluid flow study (single phase incompressible turbulent k-eps closure model); 2) stationary transport of diluted species study (using the air velocity field obtained in the previous study); 3) time dependent particle transport study (using the air velocity field obtained in the first study).

$$\nabla \cdot \boldsymbol{u} = 0$$

$$\rho \frac{\partial \boldsymbol{u}}{\partial t} + \rho(\boldsymbol{u} \cdot \nabla)\boldsymbol{u} = \nabla \cdot [-p\boldsymbol{I} + \boldsymbol{\tau}]$$

$$\frac{\partial c}{\partial t} + \boldsymbol{u} \cdot \nabla c = \nabla \cdot (D \nabla c)$$

$$\frac{d}{dt}(m_p \boldsymbol{v}) = \left(\frac{1}{\tau_p}\right) m_p(\boldsymbol{u} - \boldsymbol{v}) + m_p \boldsymbol{g} \frac{(\rho_p - \rho)}{\rho_p}$$



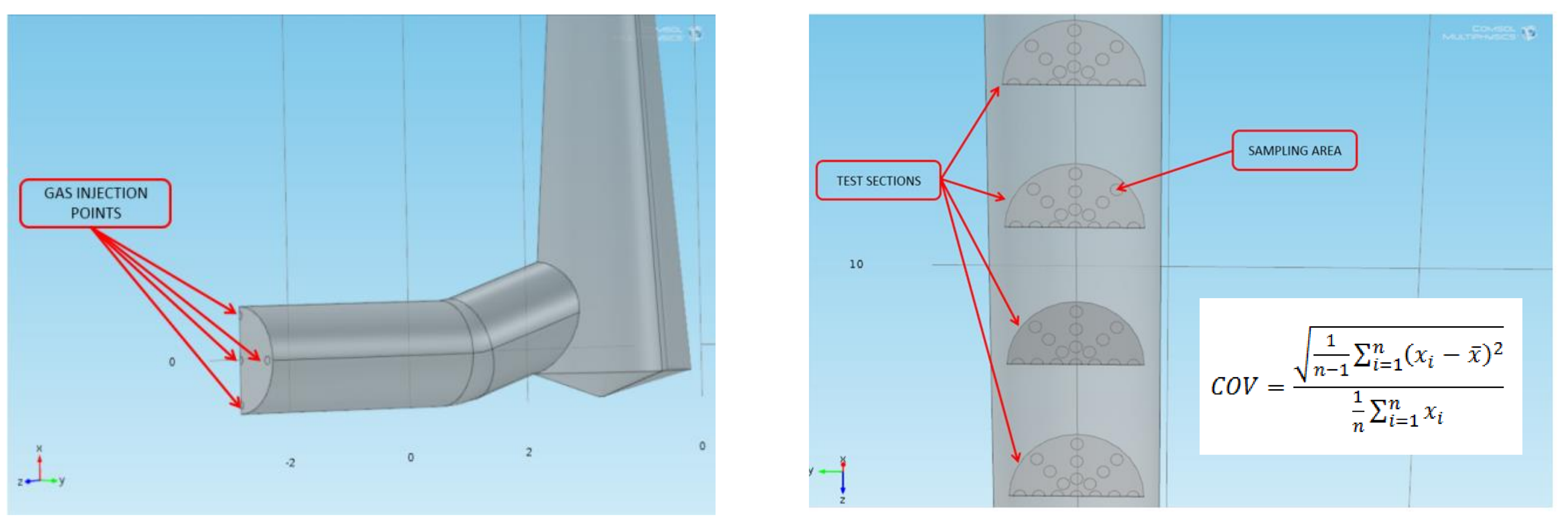


Figure 2. Boundary conditions details

Results: with the numerical simulations, they have been identified well-mixed sample locations along the chimney and the compliance with the ISO 2889 requirements as result of stack flow rate and airborne particle aerodynamic diameter modifications (fire scenario and HEPA filter disruption). For each test section analyzed, during the particle tracing simulation, is used the stick surface condition in order to calculate the COV (the particle which trajectory meets the section analyzed sticks on it)

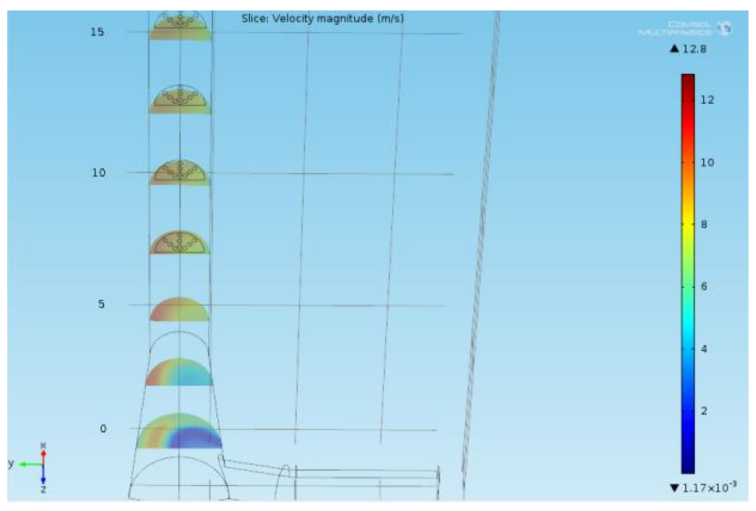


Figure 3. velocity field (100% flow)

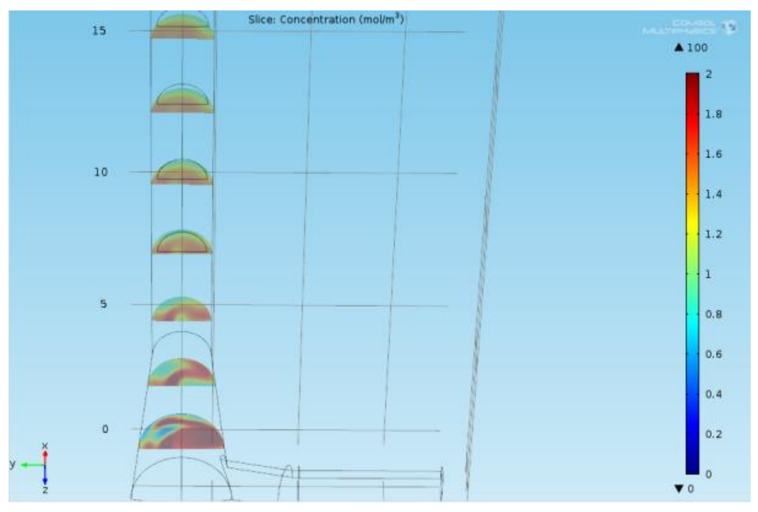


Figure 4. gas concentration field (100% flow)

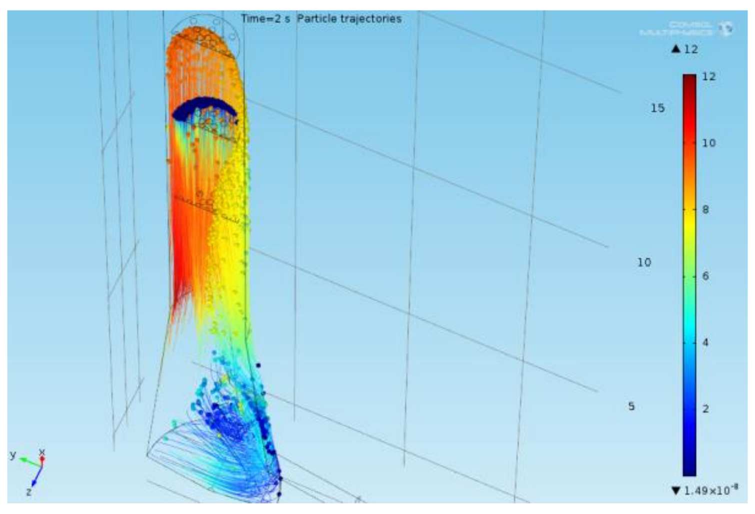


Figure 5. Particle trajectories at time t=2s for 10 micron particle and nominal flow rate (test section n.1)

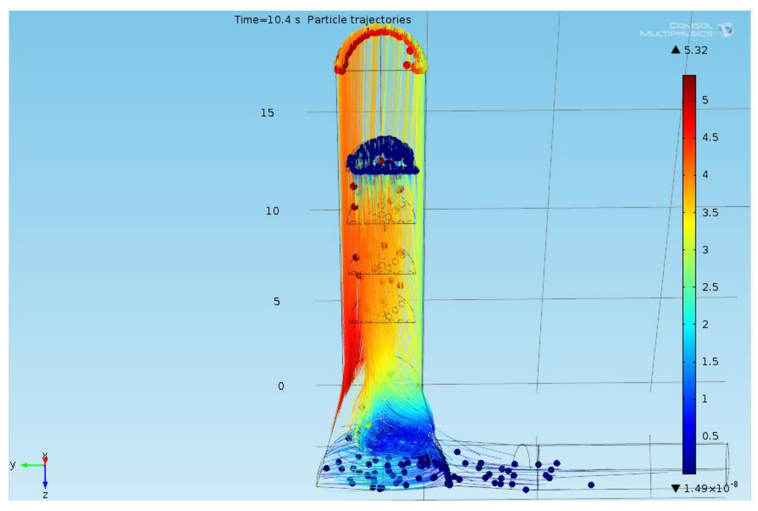


Figure 6. Particle trajectories at time t=10,4s for 100 micron particle and reduced flow rate (test section n.4)

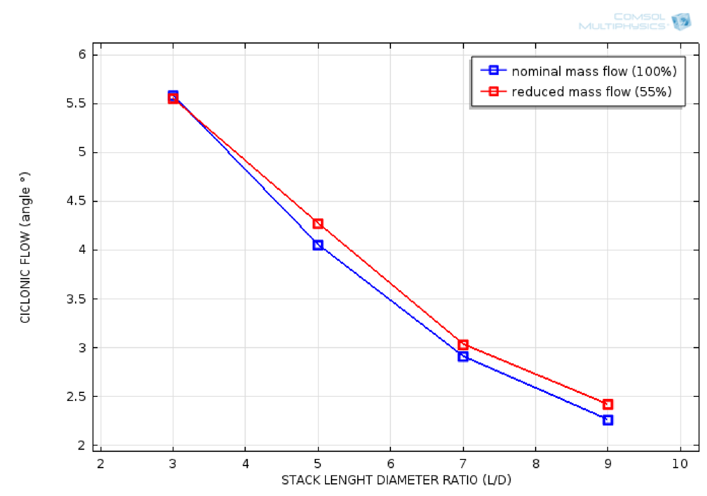


Figure 7. Cyclonic flow magnitude for different flow rate

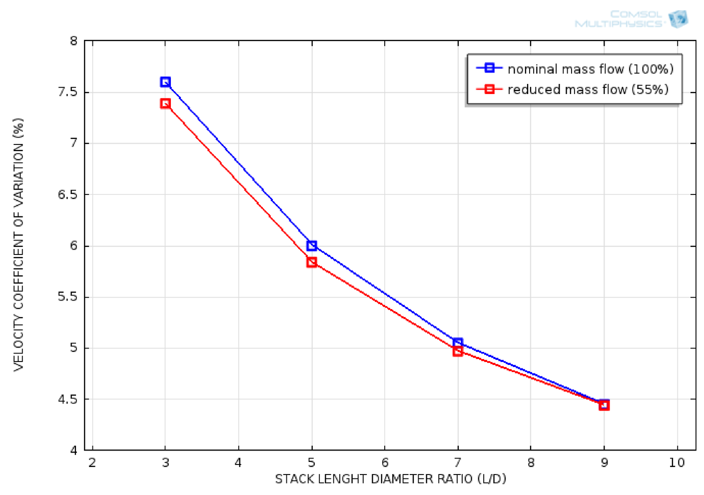


Figure 8. Velocity COV for different flow rate

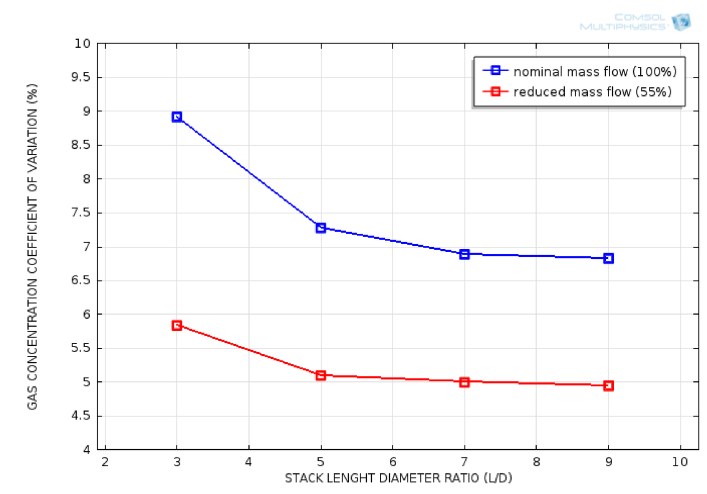


Figure 9. Gas concentration COV for different flow rate

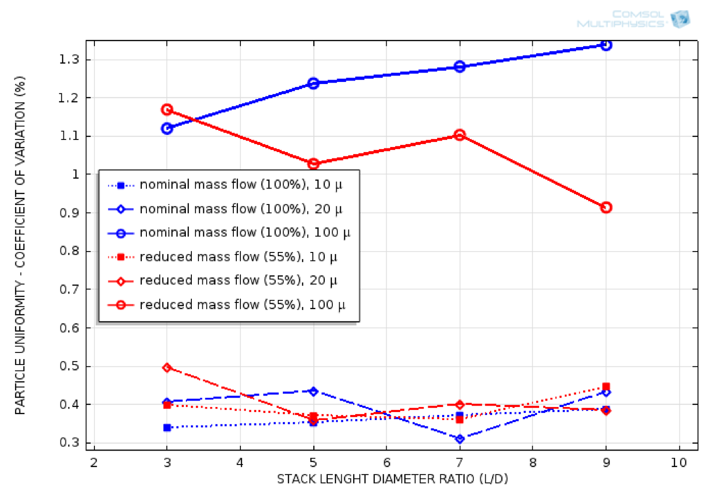


Figure 10. Particle COV for different flow rate and aerodynamic diameter

Case study	Stick particles	Sampling particles	Other
100% flow, 10 µ	4,2%	63.9%	31,9%
100% flow, 20 µ	4,9%	62,1%	33,0%
100% flow, 100 µ	32,5%	31,8%	35,7%
55% flow, 10 µ	4,5%	63,4%	32,1%
55% flow, 20 µ	5,3%	62,6%	32,1%
55% flow, 100 µ	44,2%	31,9%	23,9%

Table 1. Percent of particles those stick on the boundaries and pass through test section n.4 for different flow rate and aerodynamic diameter

Conclusions: In this study the capabilities of Comsol Multiphysics® for solving three-dimensional fluid flow problem is shown. The study allowed us to understand if ISO 2889 requirements are met and give at the same time some indications to improve the preliminary stack design (modification of feeder duct angle).