Predictive model of aerosol transport and deposition. Application and validation to the PWR reactor building

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Context

Accurate assessment of suspended contaminant particles amounts, which can be inhaled by an operator, is a major concern in the radiation protection field. Also, to improve workers and environment protection, the detection capabilities of measurement devices have to be correctly evaluated. This issue concerns essentially the industrials facilities such as nuclear buildings.

Objectives

Efficient prediction of contaminant transfer inside a ventilated room can help to optimize the location and setting of radiation protection devices, which are essential for risk management and for collective protection equipment choice. For that purpose, a predictive model of aerosols transport and deposition has been developed and validated on simple geometries and at reactor building scale.

Aerosols transport model *

- Transport equation :

$$\frac{\partial C}{\partial t}+\frac{\partial}{\partial x_i}\left\{\left[U_{f,i}+\tau_p g_i+V_{ele}-\tau_p\left(\frac{\partial U_{f,i}}{\partial t}+U_{f,k}\frac{\partial U_{f,i}}{\partial x_k}\right)\right]C\right\}=\frac{\partial}{\partial x_i}\left[\left(D_B\delta_{ik}+D^t_{p,ik}\right)\frac{\partial C}{\partial x_k}+C\frac{\partial}{\partial x_k}\left(D_B\delta_{ik}+\frac{\Omega}{1+\Omega}D^t_{p,ik}\right)\right]$$

- Boundary layer equation :

$$C(y^+)=\frac{J}{u^*\mathbf{V}^+.\mathbf{n}}\left\{1-\exp\left[\frac{\mathbf{V}^+.\mathbf{n}\,\sigma_t}{\kappa}\ln(y^+)+\mathbf{V}^+.\mathbf{n}\,\lambda(Sc_B,\tau_p^+)\right]\right\}$$

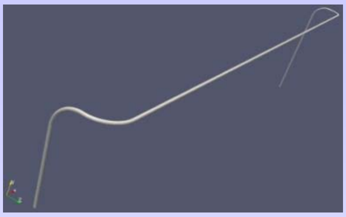
- V^+, dimensionless deposition velocity :

$$\mathbf{V}^+=\underbrace{\frac{1}{u^*}\left\|\tau_p\mathbf{g}\right\|}_{V_s^+}+\underbrace{\frac{1}{u^*}\left(\frac{-\mu_f C_u H}{\rho_f T}\left.\frac{dT}{dy}\right|_{y=0}\right)}_{V_{th}^+}+\underbrace{\frac{1}{u^*}\left(\frac{qE\,Cu}{3\pi\mu_f d_p}\right)}_{V_{ele}^+}$$

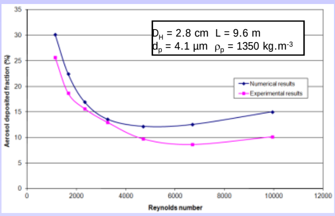
With V_s^+, V_{th}^+ and V_{ele}^+ are the dimensionless sedimentation, thermophoresis and electrophoresis velocities

Evaluation of aerosols deposition in sampling duct

Sampling duct

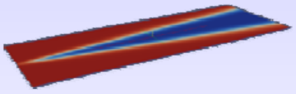


Sampling duct geometry. (Charuau et al. 1982)

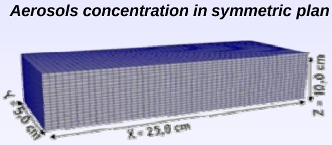


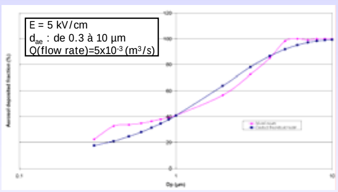
Aerosol deposited fraction according to Re. (Charuau et al. 1982)

Electrophoresis deposition



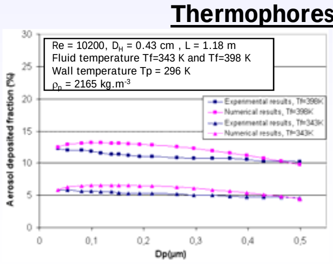
Aerosols concentration in symmetric plan



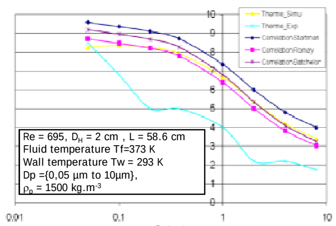


Aerosol deposited fraction according to particles diameter. (Park et al. 2002)

Thermophoresis deposition



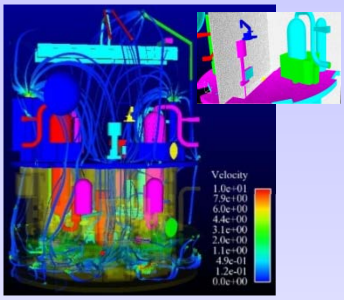
Aerosol deposited fraction according to particles diameter. (Lin et al. 2004)



Aerosol deposited fraction according to particles diameter. (Montassier et al. 1990)

Gas and aerosol transfer in reactor building (RB)

RB configuration and mesh

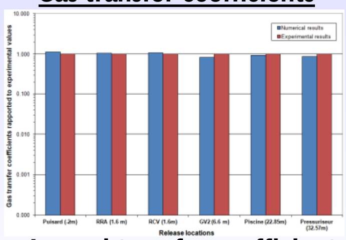


3D streamlines in RB fluid domain. Streamlines are colored by velocity magnitude.

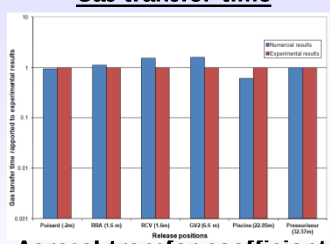
Simulations conditions

- Numerical and experimental comparison of **transfer coefficients** of gas and aerosol particles (1 µm, 5 µm) for different injection sources
- The flow field and aerosol dispersion in the RB geometry were simulated using Code_Saturne, a free CFD software developed by EDF R&D
- There are six gas release locations and two aerosol release locations. Air was sampled at six positions for each injection
- The sampling points are located at different levels in the RB (level -2m up to level 32m)
-Values presented below are the average values over all sampling locations

Gas transfer coefficients

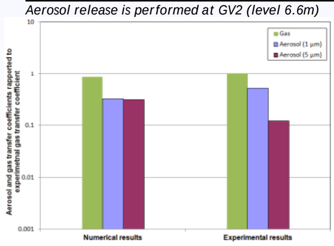


Gas transfer time



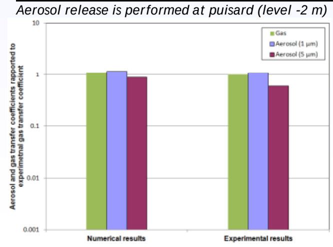
Aerosol transfer coefficients

Aerosol release is performed at GV2 (level 6.6m)



Aerosol transfer coefficients

Aerosol release is performed at puisard (level -2 m)



Conclusion

The transfer coefficients estimated numerically almost agree with the experiment results. The difference between numerical calculations and experimental results is about 12% for the gas transfer coefficients and it reaches 60% for the particle transfer coefficients. Due to the complexity of the geometry, this result can be regarded as a satisfactory result.

Ongoing research

- Acquire additional experimental results to enhance the **validation process** of the aerosols transport model
- **Solving the inverse problem**, in order to characterize and locate the pollutant contamination source inside the reactor building

(*) Nérisson, P., Simonin, O., Ricciardi, L., Douce, A., Fazileabasse, J. (2011) Improved CFD transport and boundary conditions models for low-inertia particles, Computers and Fluids, Vol 40, pp 79-91