

# DEVELOPMENT AND VALIDATION OF AGGLOMERATION MODEL FOR CFD SIMULATIONS OF AEROSOL DISPERSION DURING FUKUSHIMA FUEL DEBRIS RETRIEVAL

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# Content

Context (Fukushima-Dai-ichi)

Objective

DELIA facility description

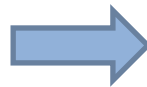
Aerosol dispersion and agglomeration modelling in ANSYS CFX

CFD simulations of agglomeration in DELIA facility

Conclusion



Fukushima Dai-ichi  
accident



Reactor core  
meltdown



Corium accumulation in  
the reactor pedestal

Fukushima reactors dismantling issue:

- Development by CEA of a laser technique for the fuel debris retrieval
- IRSN – CEA collaboration in a project led by ONET (and funded by the METI) to bring relevant elements to analyse the risk occurred by the dispersion of aerosols emitted by the dismantling operations

Evaluate the amount of aerosols likely to be deposited on the walls and those to be released into the environment is one of the key safety issues in the dismantling actions of reactors of Fukushima Dai-ichi

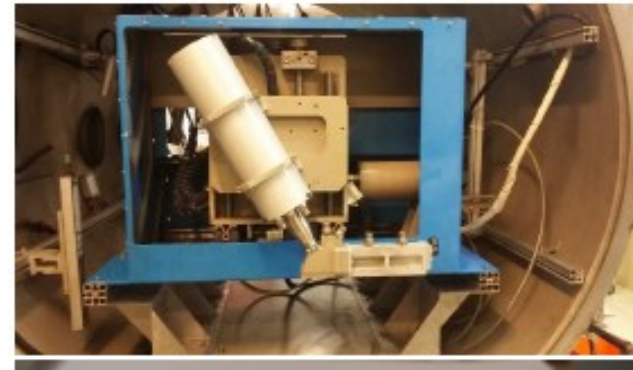
- ✓ In a first approach, CFD simulations of dispersion (including the transport, the deposition on the walls and the agglomeration) of aerosols emitted during laser cutting of non-radioactive fuel debris simulants have been carried out, by considering a lognormal fit of the experimental PSD
  - => for Ex-vessel simulant the comparison with experimental was not so good
- ✓ Improvements of the method are proposed here for better taking into account PSD different of lognormal monomodal ones and allowing to better approach the experimental results, in particular for Ex-vessel,

- Experimental platform dedicated to the laser cutting of non-radioactive fuel debris simulants

Exhaust for gas-particle mixing analysis  
(Concentration, Size)



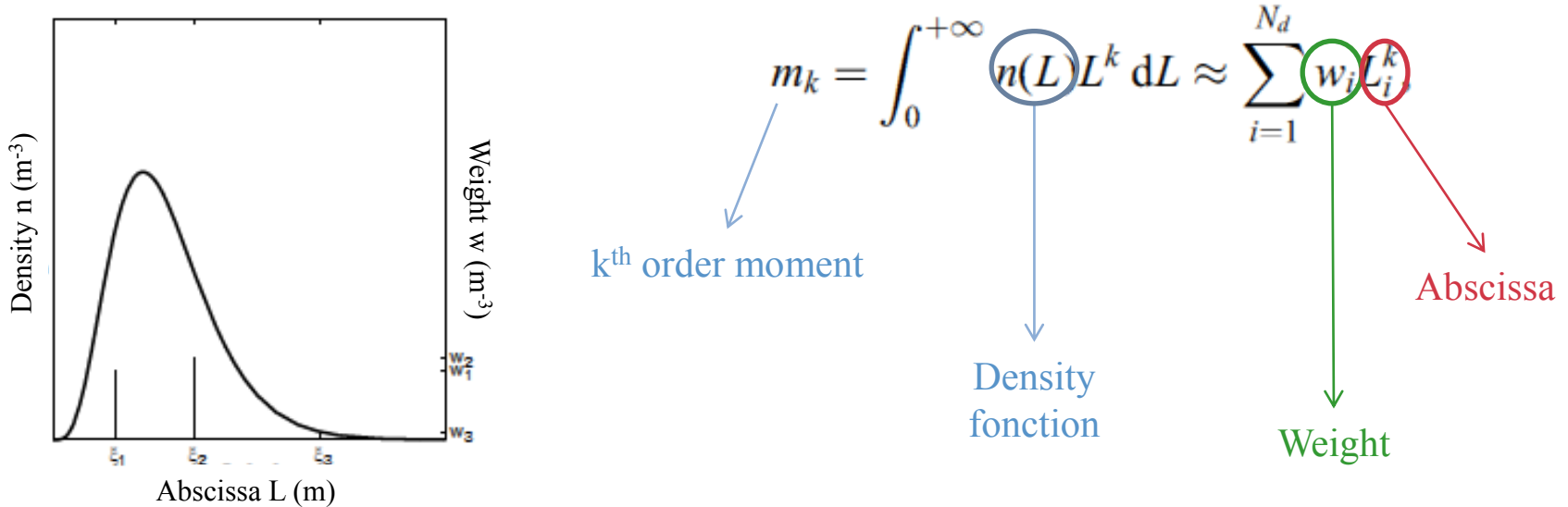
Laser cutting device into the vessel



**3 corium simulants cut**

In-vessel  
Ex-vessel  
Zr

## ➔ DQMOM method for population balance



$$\begin{aligned}
 \frac{\partial w_n}{\partial t} + \frac{\partial}{\partial x_i} \left( U_i + \tau_p(\xi_n) \left( g_i - \left( \frac{\partial U_i}{\partial t} - U_j \frac{\partial U_i}{\partial x_j} \right) \right) w_n \right) &= \frac{\partial}{\partial x_i} \left( (D_B + D_T) \frac{\partial w_n}{\partial x_i} \right) + a^n \\
 \frac{\partial \zeta_n}{\partial t} + \frac{\partial}{\partial x_i} \left( U_i + \tau_p(\xi_n) \left( g_i - \left( \frac{\partial U_i}{\partial t} - U_j \frac{\partial U_i}{\partial x_j} \right) \right) \zeta_n \right) &= \frac{\partial}{\partial x_i} \left( (D_B + D_T) \frac{\partial \zeta_n}{\partial x_j} \right) + b^n
 \end{aligned}$$

advection      sedimentation      particle deviation      diffusion      source terms

## ➤ Particle wall deposition modelling

### Source term of wall deposition flux $J$

$$J = V_d^+ u^* C_M \quad (\text{Nerisson, 2014})$$

Where  $u^*$  is the friction velocity,  $C_M$  is the particle mass concentration in the first cell close to the wall) and  $V_d^+$  is the non-dimensional deposition velocity taking account the major deposition phenomena (sedimentation, diffusion and inertia).

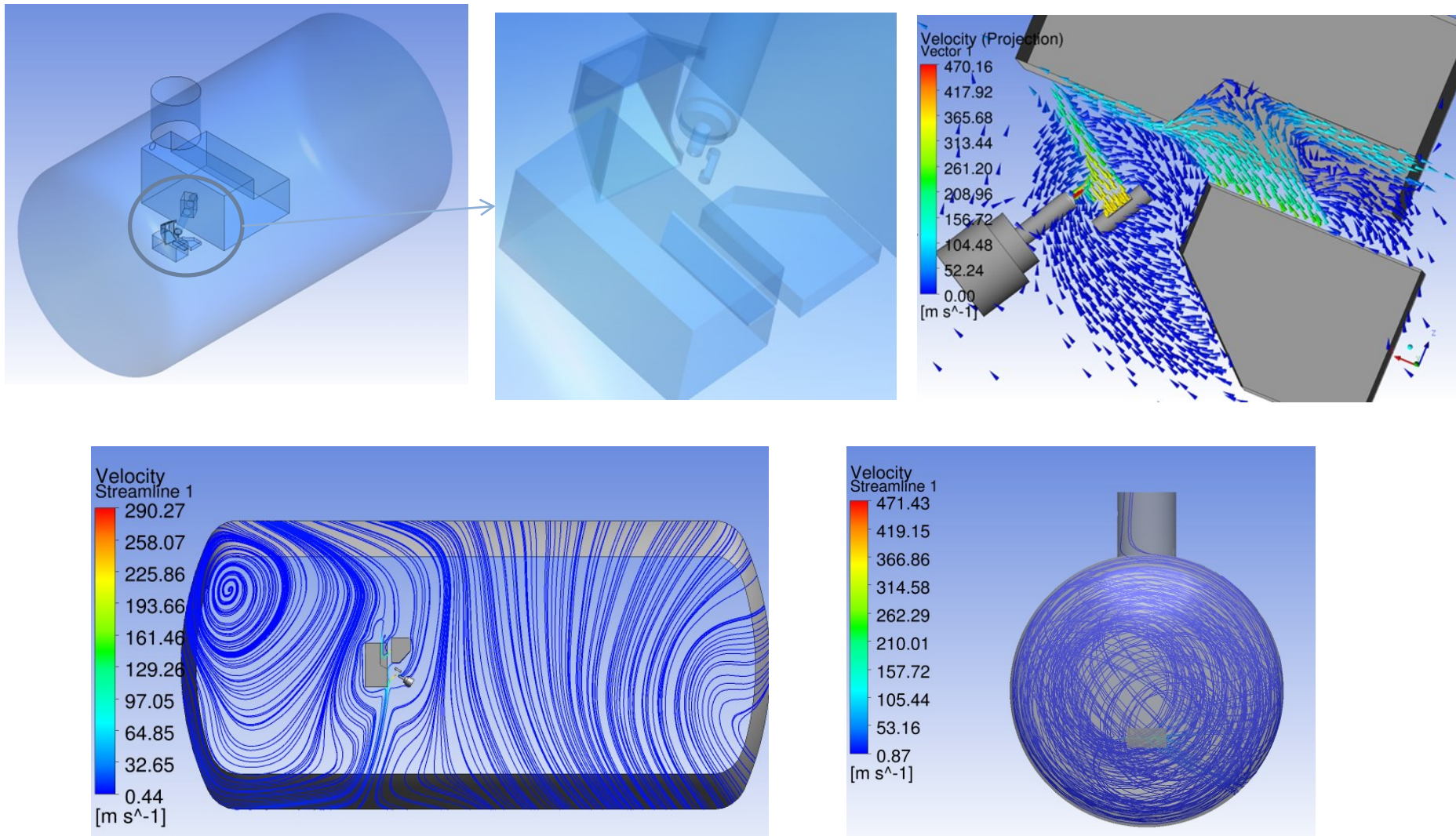
## ➤ Agglomeration modelling by using external FORTRAN routine

Source terms ( $a_n, b_n$ ) added to the weight and abscissa transport equations

$$(1 - k) \sum_{i=1}^n L_i^k a_i + k \sum_{i=1}^n L_i^{k-1} b_i = S_k^n \quad \Longrightarrow \quad A \begin{pmatrix} a_n \\ b_n \end{pmatrix} = S \quad \Longrightarrow \quad \begin{pmatrix} a \\ b \end{pmatrix} = A^{-1} S$$

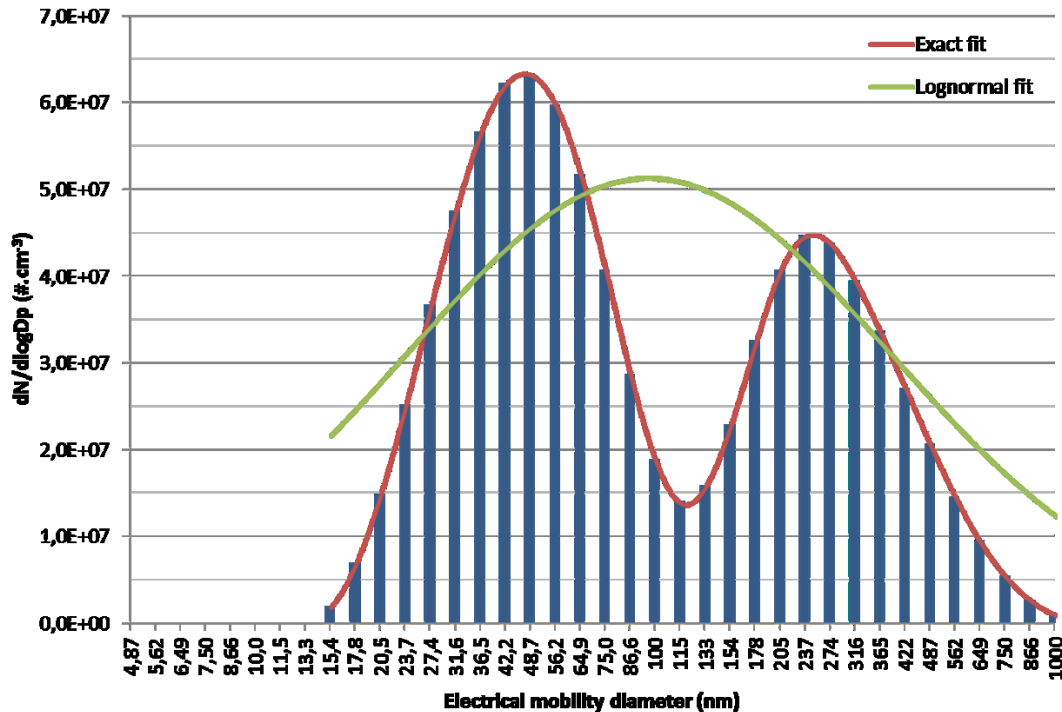
With  $S_k^n = \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n \beta_{ij} (L_i^3 + L_j^3)^{k/3} w_i w_j - \sum_{i=1}^n \sum_{j=1}^n \beta_{ij} L_i^k w_i w_j$  and  $\beta$  the agglomeration kernel  
(Guichard, 2013)

## ➤ Simulation of the airflows induced by the laser head in DELIA facility





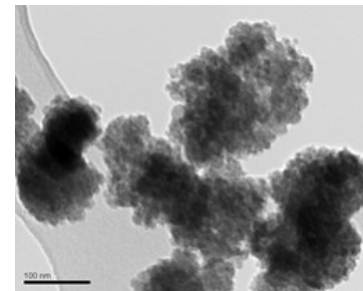
## Example of fit for Ex-vessel PSD



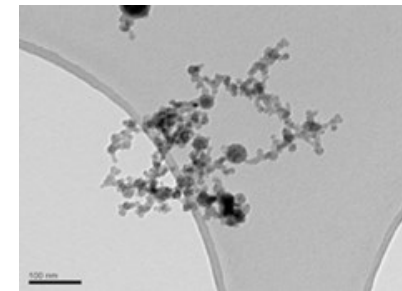
## Simulation execution

$$M_k = \int_0^{\infty} f(d_g) d_g^k dd_g$$

Moment order	Moments values	
	VF03 Log	VF03 Exact
0	1	1
1	1	1
2	1.484	2.042
3	2.9692	5.8691
4	7.1187	20.4436
5	18.9741	81.3311



In-vessel simulant



Ex-vessel simulant

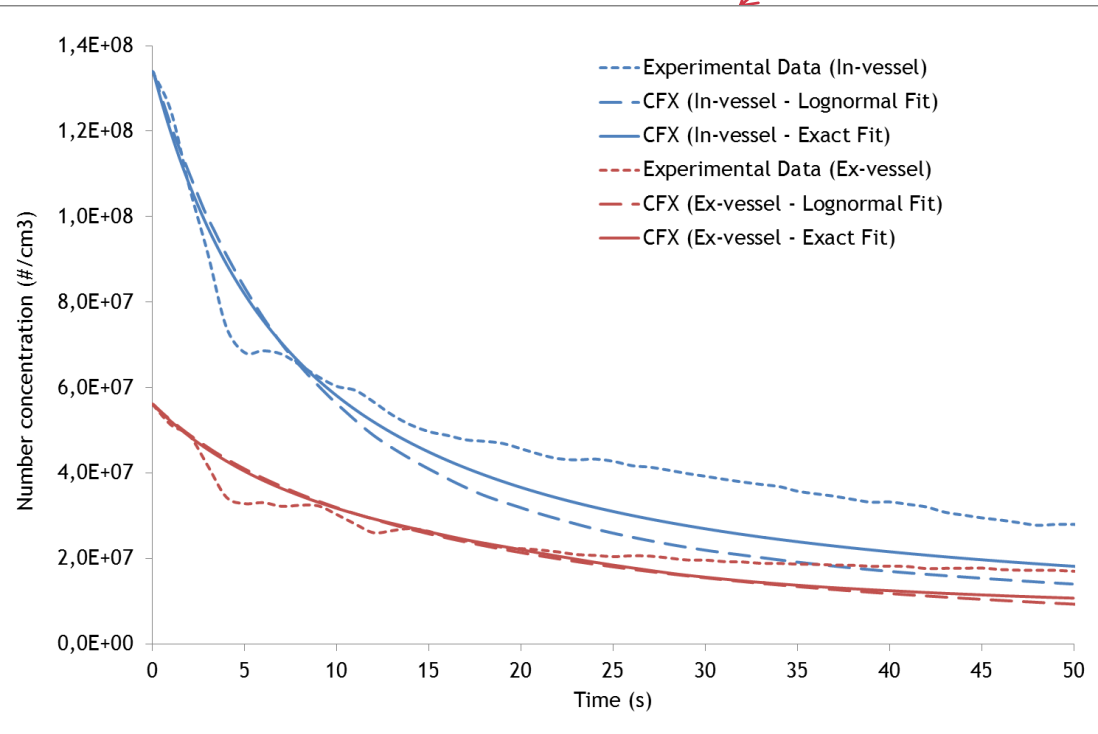
⇒ Implementation of the six first moments in the dataset of CFX

⇒ Calculation of the distribution weights and abscissa

⇒ Transport of weights and abscissa taking into account source terms of agglomeration

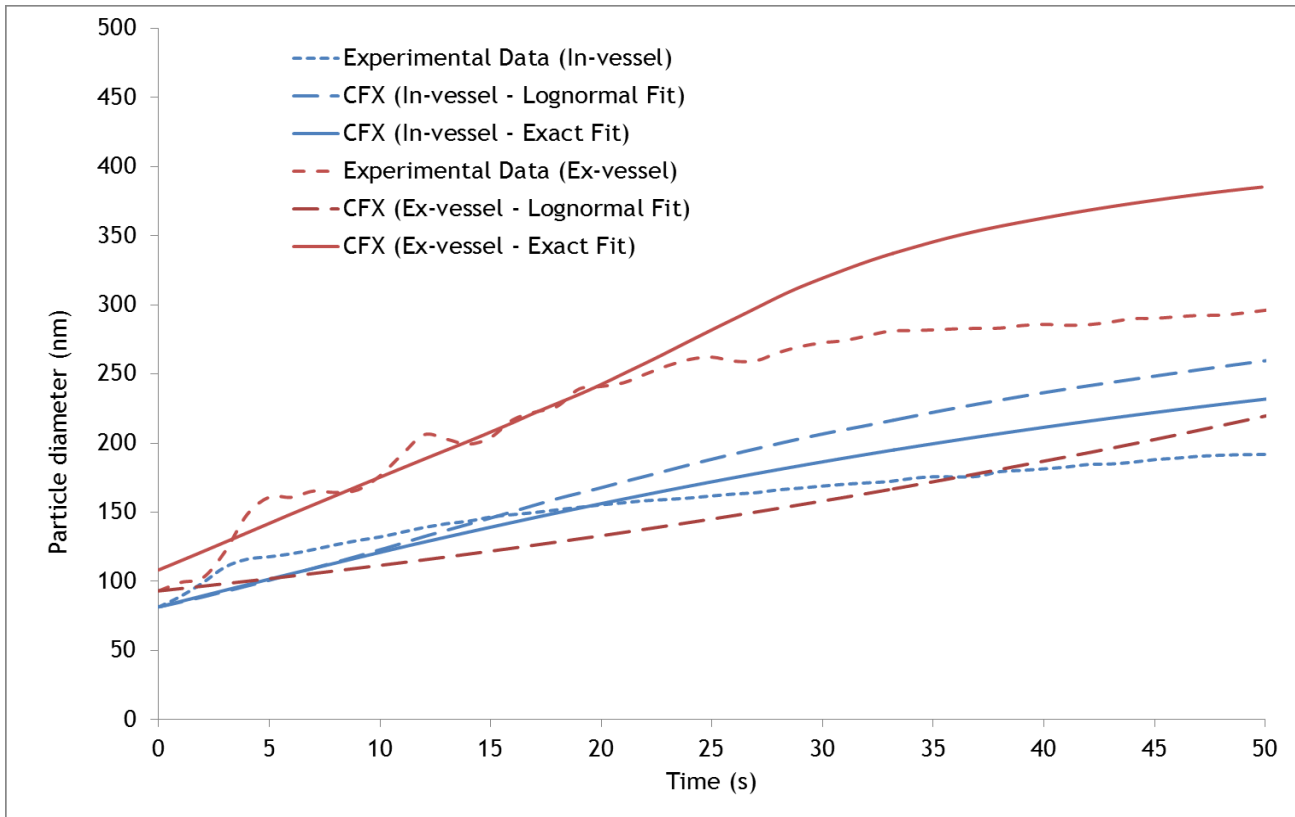
Monitoring of particle moments allowing to calculate the main particle parameters

Moment or moment combination	Physical mean
$M_0$	Total particle number concentration (#.m <sup>-3</sup> )
$\frac{M_1}{M_0}$	Mean number diameter (m)
$\pi M_2$	Total particle surface in aerosol (m <sup>2</sup> )
$\frac{\pi}{6} M_3$	Particle volume fraction (-)
$\frac{\pi \rho_p g}{72 \mu_f} M_4$	Particle deposition rate by sedimentation on a horizontal surface (s <sup>-1</sup> )
$\frac{\pi \rho_p^2 g}{108 \mu_f} M_5$	Particle mass flux by sedimentation (kg.m <sup>-2</sup> .s <sup>-1</sup> )



Good agreement between CFX and experimental results

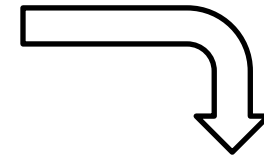
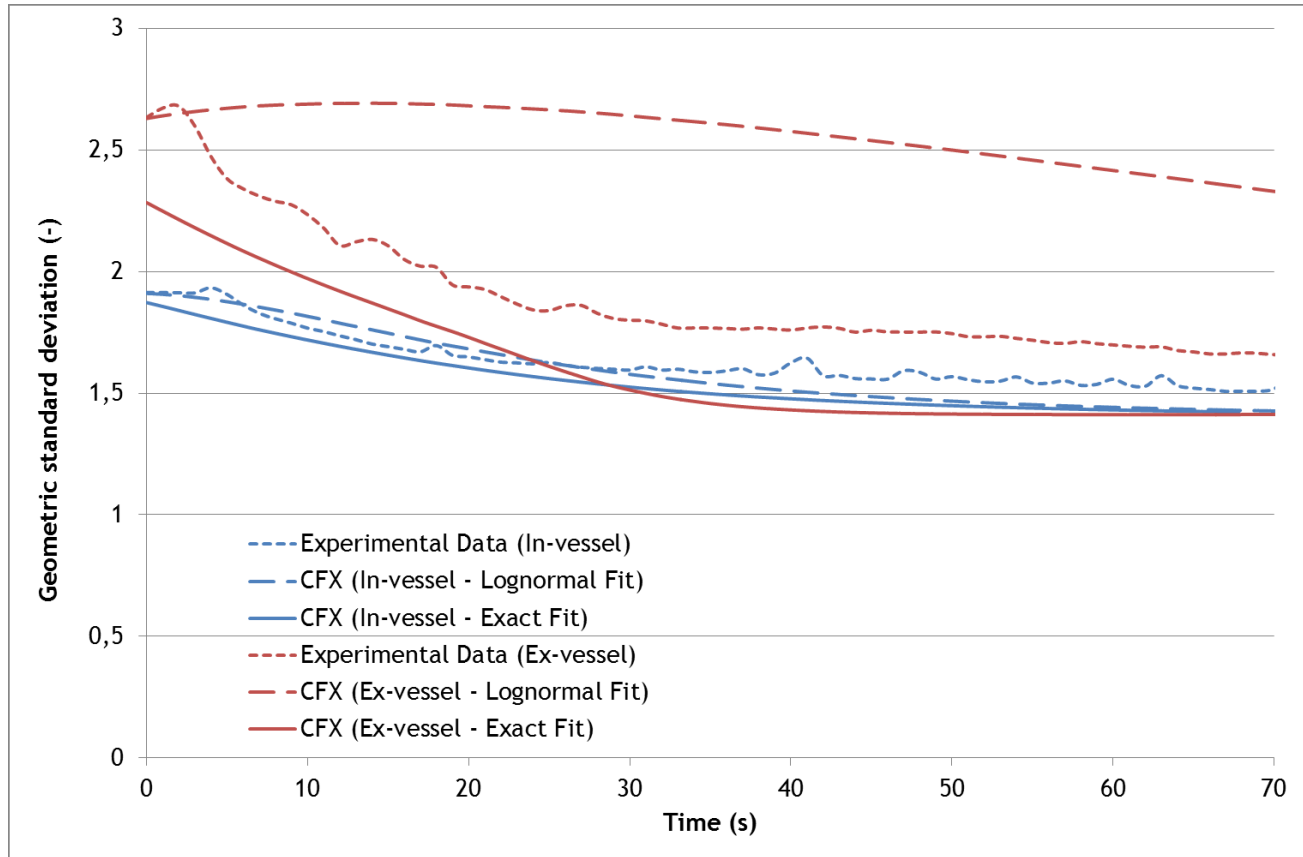
Sensitive improvement with the use of an exact fit, but very moderate for the number concentration



$$D_g = \frac{M_1}{M_0 \sqrt{\frac{M_0 M_2}{M_1^2}}}$$

Satisfactory agreement between CFX and experimental results for the particle diameter

Obvious improvement, in particular for Ex-vessel, highlighting the influence of the input data (use of an exact fit for the PSD)

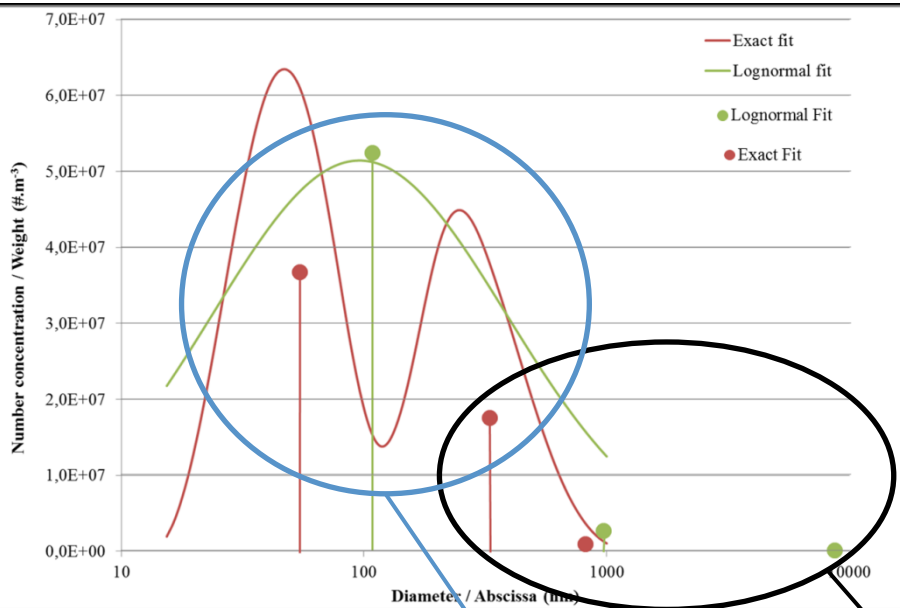


$$\sigma_g = e^{\sqrt{\ln \frac{M_0 M_2}{M_1^2}}}$$

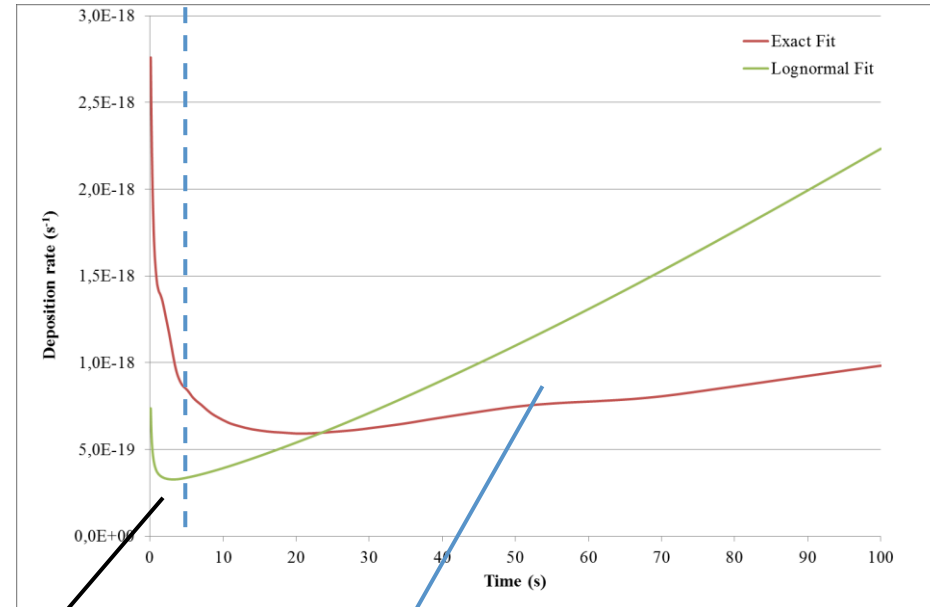
Satisfactory agreement between CFX and experimental results for the standard deviation, considering the exact fit for Ex-vessel simulant

## Fit influence on the deposition

### Weight and abscissa according to the fit



### Deposition according to the fit



Great difference between the distribution parameters of both fits which consolidates the use of exact fit

Gravitational and inertial deposition

Diffusional deposition

Strong influence of the fit on the deposition amount and kinetics

CFD simulations of agglomeration could be improved by a change in the way for implementing the moment input data

- ✓ It allows to take into account bimodal PSD (not possible with a lognormal fit) and to better approach experimental results, in particular for Ex-Vessel
- ✓ It allows also a better prediction of the evolution of the size of aerosol emitted during laser cutting.
- ✓ It is therefore an important key for the prediction of the aerosols dispersion and deposition in the real site, in order to develop countermeasures such as spray systems