An attempt to introduce a resuspension model in MELCOR 1.8.6 for fusion applications

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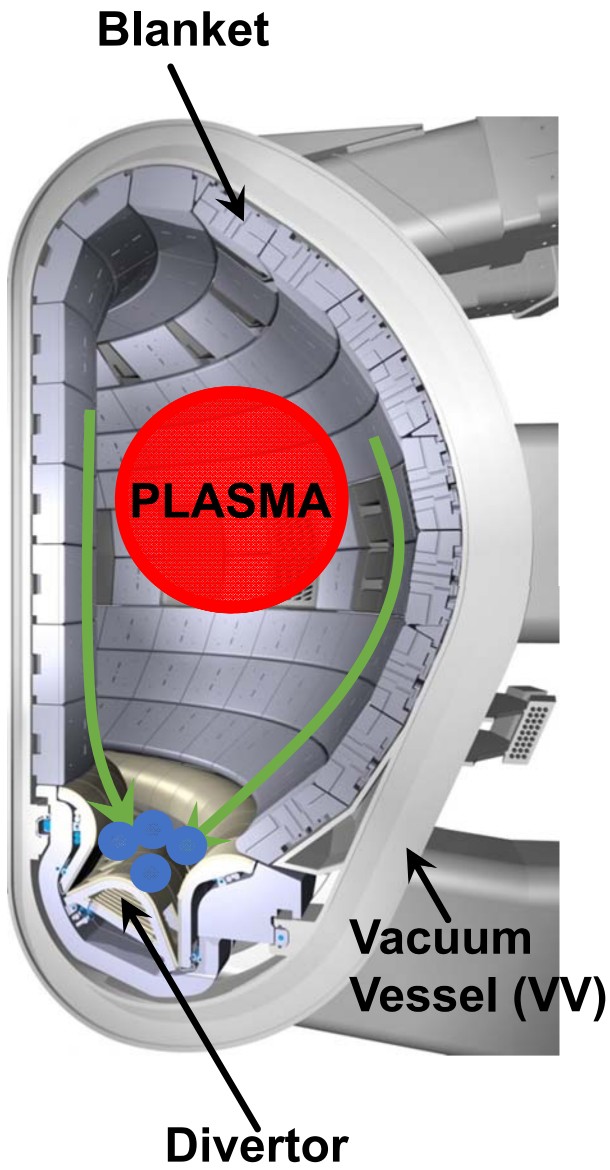
Content of the presentation

- Introduction – The problem;
- Selection of a resuspension model;
- The “ECART model”;
- Implementation in MELCOR - Limitations;
- Validation;
- Conclusions & Future perspectives.

Introduction – The problem

- During normal plasma operation the ***erosion*** of the "plasma facing components" occurs;
- The ***dusts*** formed tend to ***deposit onto the divertor surface***;
- In case of an ***In-vessel LOCA***, these dusts may resuspend;
- ***Resuspended dusts may be transported*** to the VV Pressure Suppression System (VVPSS);
- Define the ***maximum amount of mobilized dust*** is an issue of main concern;
- ***MELCOR v1.8.6 for fusion applications hasn't a resuspension model***;
- ***In MELCOR v2.2 for LWRs a resuspension is implemented (Force Balance Model);***
- ***An attempt to introduce a resuspension model in MELCOR was performed***.



Introduction – The problem

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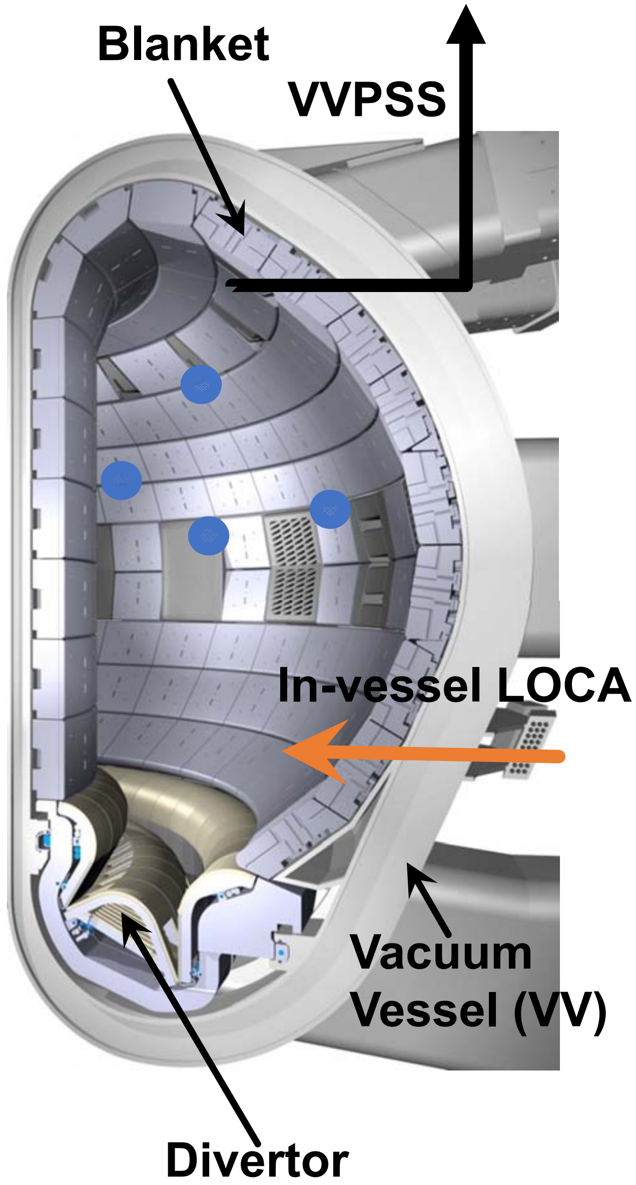


Selection of a resuspension model

Different models are available in literature, but they can be all subdivided into

TWO CATEGORIES

FORCE BALANCE models

The particles resuspend if the aerodynamic forces exceed the adhesion forces

- *ASTEC model*
- *ECART model*
- *MELCOR V2.2 model*

ENERGY TRANSFER models

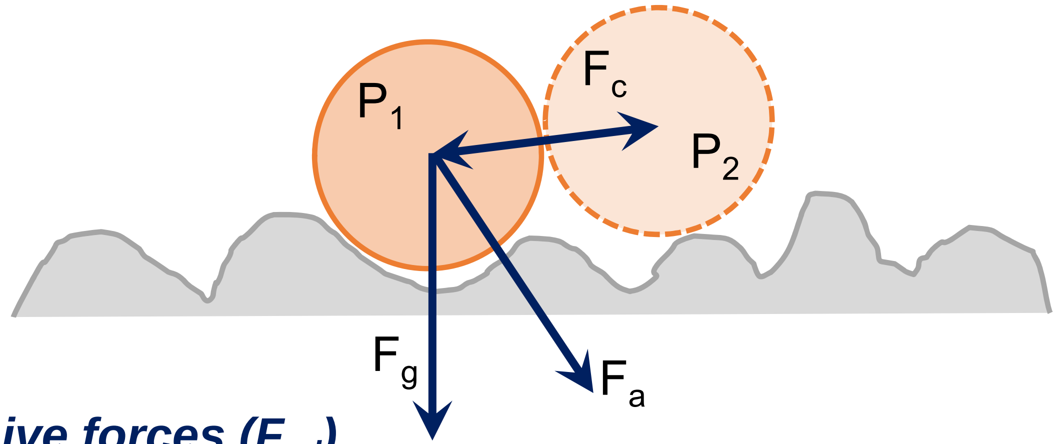
The particles resuspend if enough rotational energy is transferred by the fluid motion

- *Rock & Roll model and derivates*

The "ECART model"

- Why the ***ECART model***?
  - It is ***simple***;
  - It was ***already validated*** for fusion applications.
- How it works?

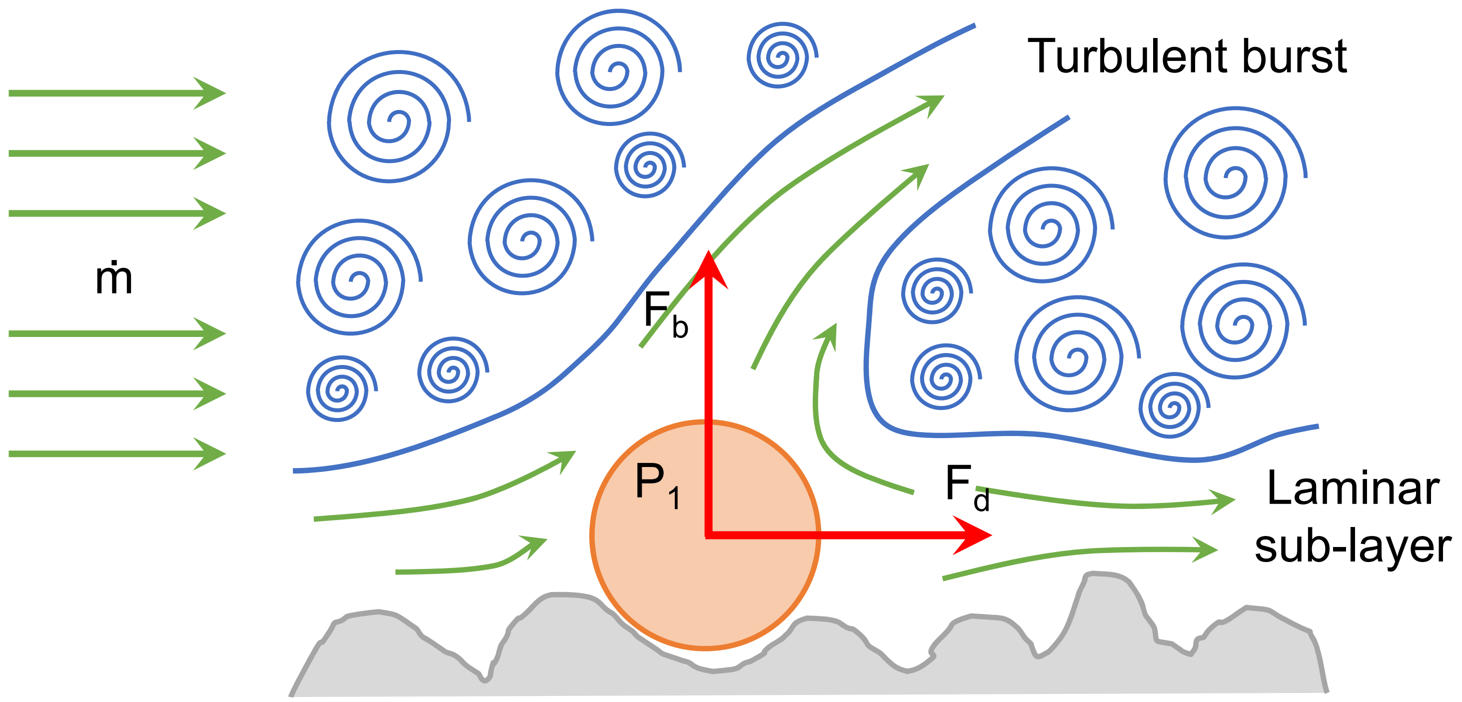
The "ECART model"



Adhesive forces (F_{ad})

F_g	Gravitational
F_c	Cohesive (intermolecular attraction)
F_a	Friction adhesive (sliding and rolling resistance)

The "ECART model"



Adhesive forces (F_{ad})

F_g	Gravitational
F_c	Cohesive (intermolecular attraction)
F_a	Friction adhesive (sliding and rolling resistance)

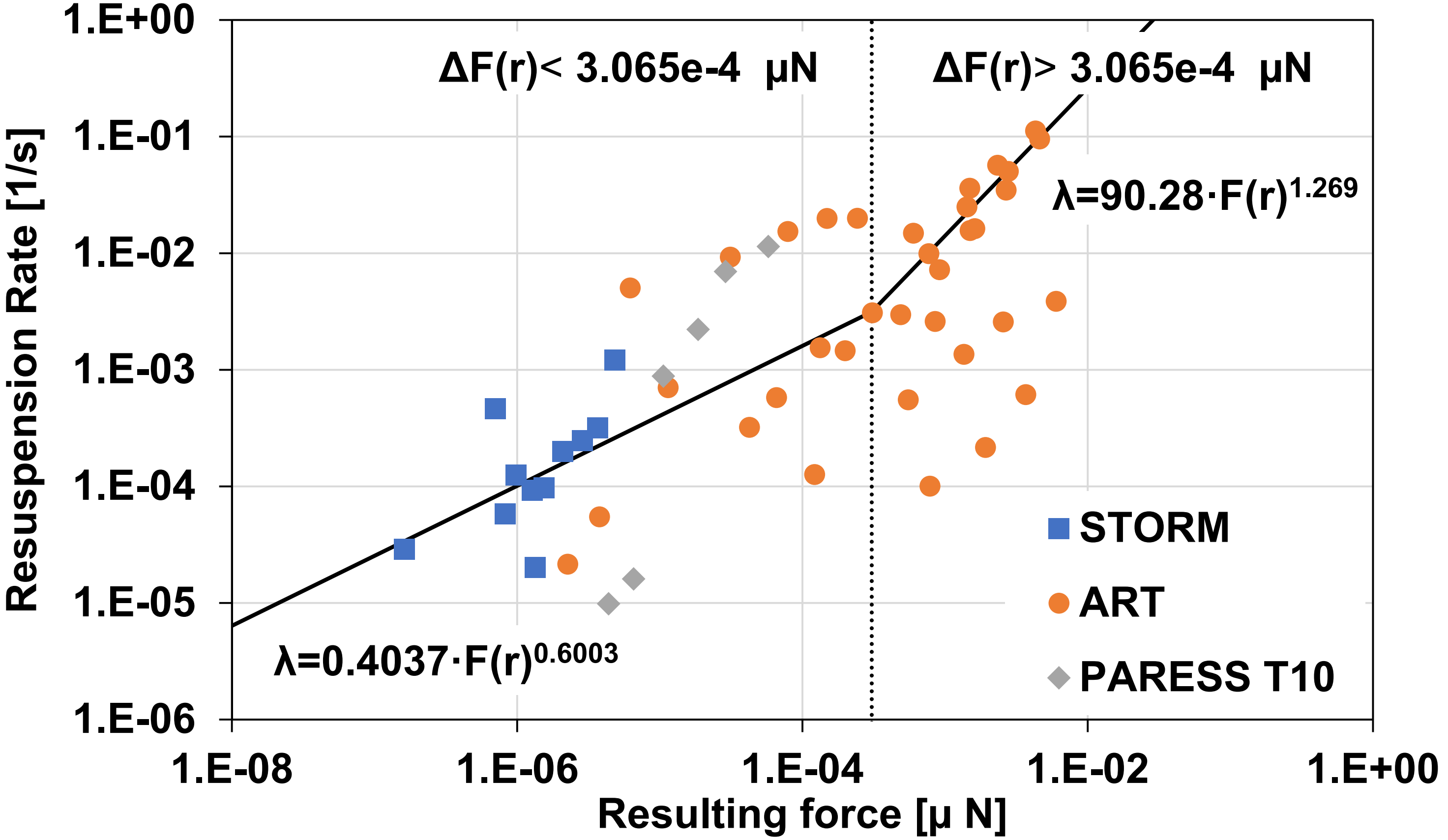
Aerodynamic forces (F_{ae})

F_d	Drag (shear stress on wall)
F_c	Burst (breaking of laminar sub-layer)

Resuspension occurs when:

Adhesive forces (F_{ad}) < ***Aerodynamic forces (F_{ae})***

If $\underline{\Delta F(r) = F_{ae} - F_{ad}}$, the resuspension rate (λ) can be expressed as shown



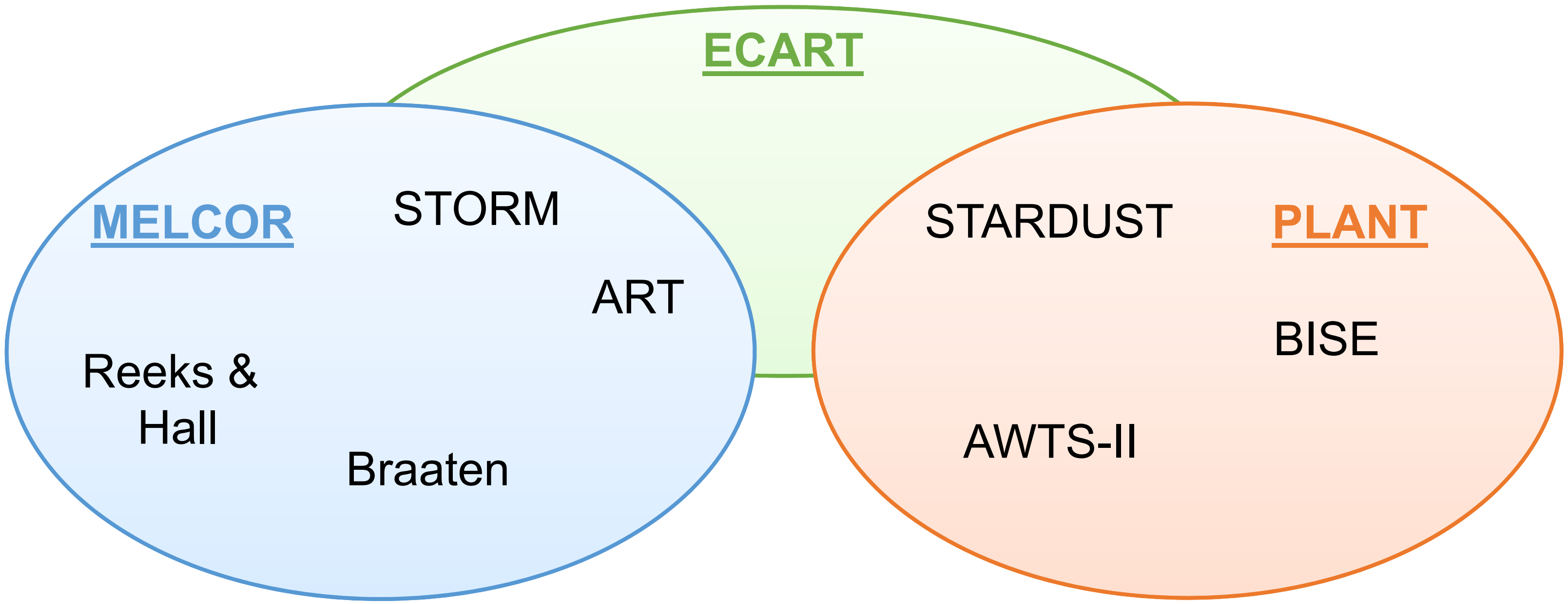
Implementation in MELCOR - Limitations

- The model was implemented through ***Control Functions (CFs)***;
- About ***200 CFs*** are needed for each CV;
- The model is ***not identical to the ECART one*** because correlations needing iterative calculations were substituted with explicit correlations;
- The aerosol population is subdivided into only ***5 groups***;
- ***The CFs calculate only the resuspension rate for each group, and the resuspended mass is computed at the end of the calculation through a dedicated Microsoft Excel ® file***;
- The model runs ***independently from the RN package***;
- Only the total amount of resuspended mass is computed. ***The fate of the resuspended particles is not tracked***.

Validation

Several tests were selected to be part of the validation matrix. The selection was based on:

- Tests employed to validate the model implemented in ***ECART***;
- Tests employed to validate the model implemented in ***MELCOR v2.2***;
- Tests referring to the peculiar "***plant conditions***".

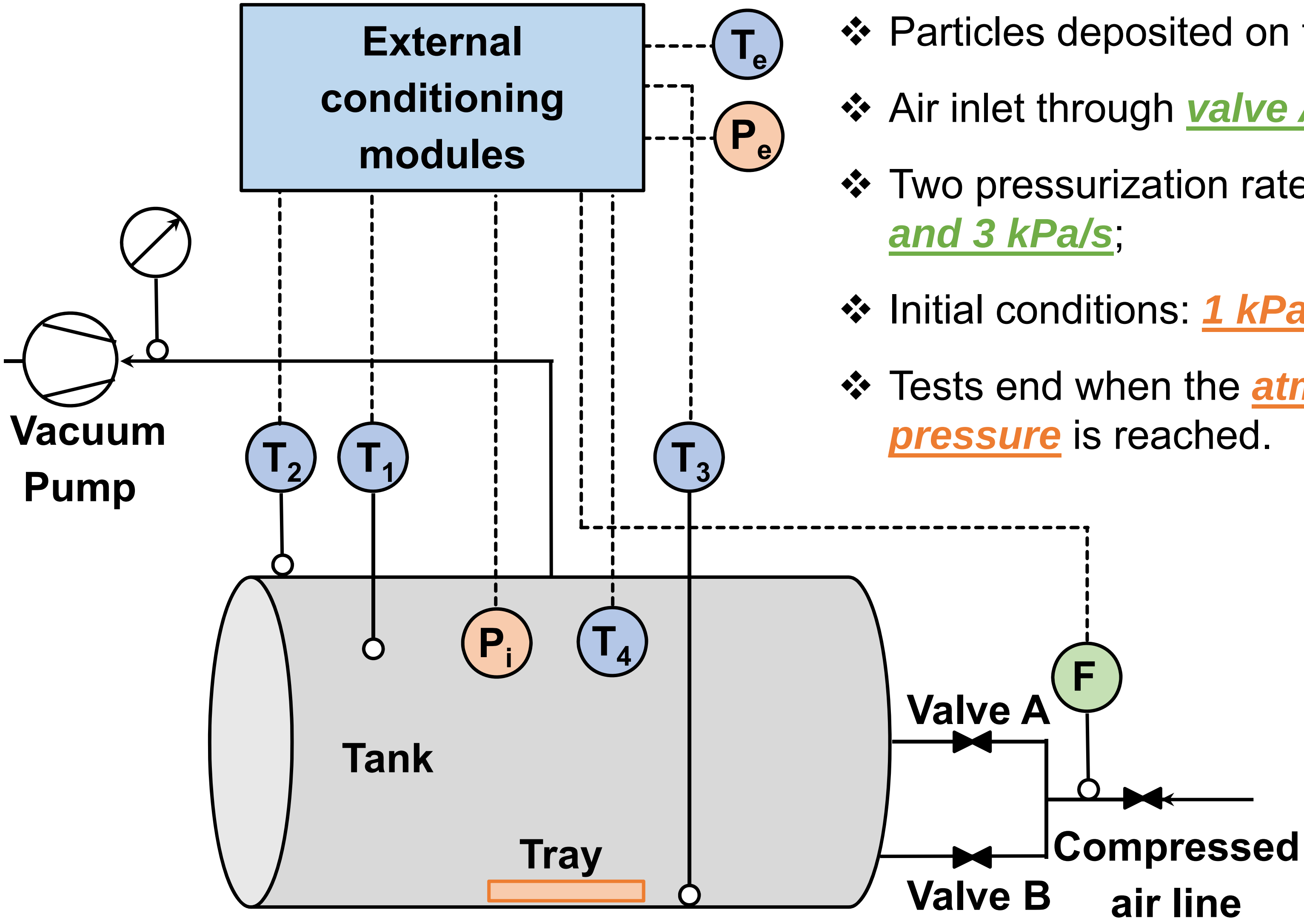


Validation

	EC.	MEL.	PL.	N° of tests	Tests characteristics	Ref.
STORM	✔	✔		5	- Atmospheric pressure - Multi-layer deposit	[1] [2] [3]
ART	✔	✔		7	- Atmospheric pressure - Multi-layer deposit	[1] [4]
Reeks & Hall		✔		7	- Atmospheric pressure - Monolayer deposit	[1] [5]
Braaten		✔		141*	- Atmospheric pressure - Monolayer deposit	[1] [5]
STARDUST	✔		✔	41*	- Pressure increasing from 1 kPa to 100 kPa - Multi-layer deposit	[6] [7]
AWTS-II			✔	5	- Pressure below atmospheric one (constant) - Multi-layer deposit	[8]
BISE			✔	30	- Atmospheric pressure - Mono-layer deposit (?)	[9]
			TOTAL	**236**		

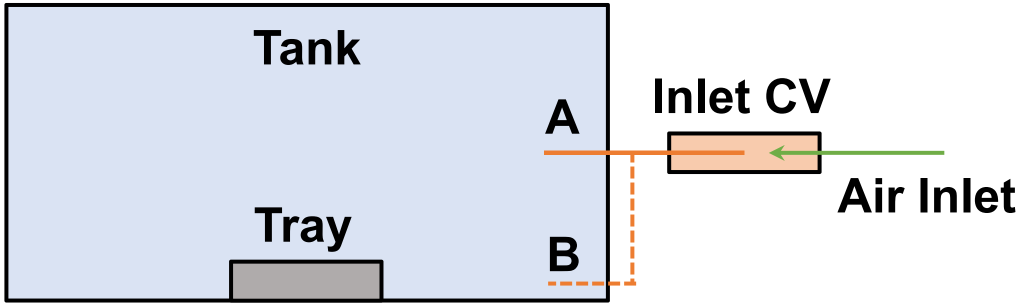
* Several tests were executed with the same boundary conditions.

Validation – STARDUST tests



- ***W***, ***C***, or ***SS*** particles;
- Particles deposited on the ***tray***;
- Air inlet through ***valve A or B***;
- Two pressurization rates: ***0.3 kPa/s and 3 kPa/s***;
- Initial conditions: ***1 kPa*** and ***110 °C***;
- Tests end when the ***atmospheric pressure*** is reached.

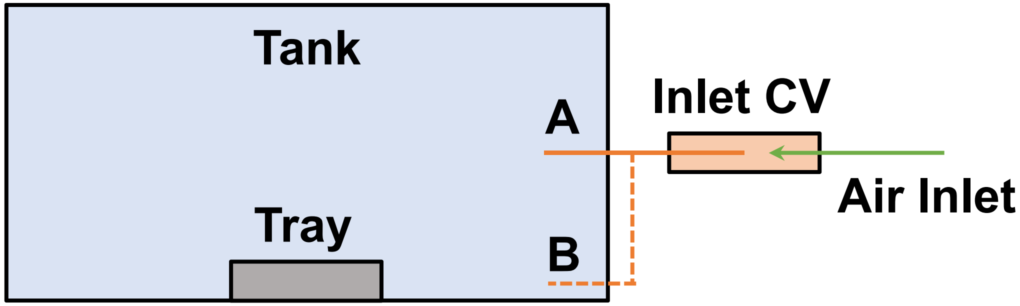
Validation – STARDUST tests



- ***Simple nodalization***;
- Only ***W tests*** will be discussed here;
- Range of ***velocities*** impacting the tray calculated through ***CFD calculations***;
- Flow velocity tuned through the ***cross-sectional flow area of the tank***.

Inlet	*Pressurization rate [kPa/s]*	*Range of velocities impacting the tray [m/s]*	*Velocities investigated [m/s]*
A	0.3	1 – 5	1 – 2.5 – 5
A	3	5 – 10	5 – 7.5 – 10
B	0.3	50 – 100	50 – 75 – 100
B	3	200 – 300	200 – 250 – 300

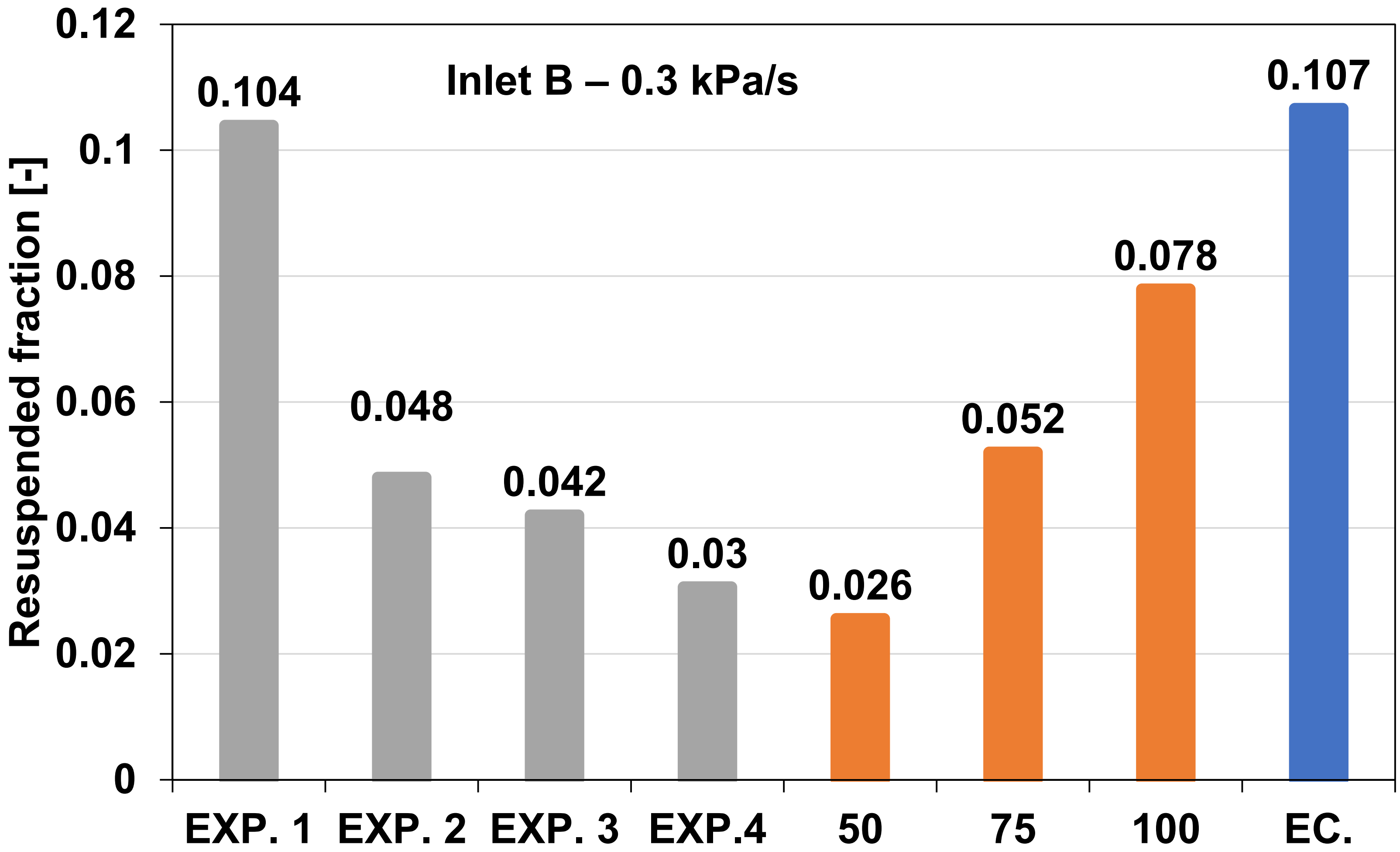
Validation – STARDUST tests



- ***Simple nodalization***;
- Tank is ***adiabatic***;
- Range of ***velocities*** impacting the tray calculated through ***CFD calculations***;
- Flow velocity tuned through the ***cross-sectional flow area of the tank***.

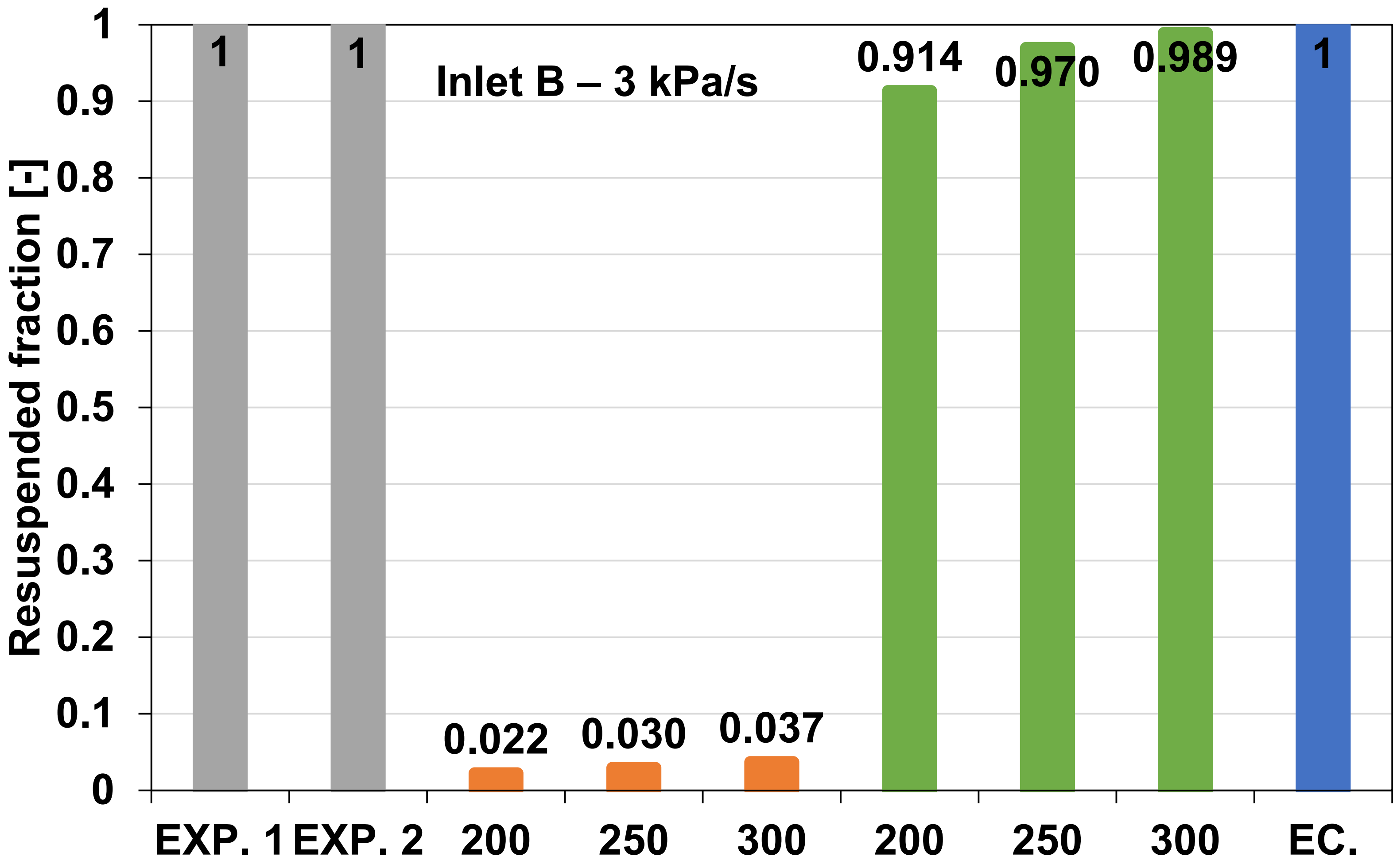
Group	*GMD [m]*	*Normalized W mass*
1	2.15e-7	0.009
2	3.22e-7	0.104
3	4.30e-7	0.257
4	5.37e-7	0.329
5	6.45e-7	0.300

Validation – STARDUST tests



EXPERIMENTAL – MELCOR v1.8.6 – ECART

Validation – STARDUST tests



EXPERIMENTAL – MELCOR v1.8.6 – MELCOR v.1.8.6 (10 GMD) – ECART

- At the end of the tests, large tungsten agglomerates were found;
- Probably, tungsten agglomerates while rolling onto the tray;
- Increasing the tungsten size of 10 times improves the MELCOR predictions.

Conclusions & Future perspectives

- An attempt to introduce a ***resuspension model in MELCOR 1.8.6*** for fusion applications was shown;
- The model was derived from the model implemented in the ***ECART code***;
- The model was implemented by mean of ***CFs;***
- Small variations were introduced to ***avoid iterative calculations***;
- The model was ***validated*** against several tests;
- For the ***STARDUST tests***, the model showed a ***good agreement*** with the experimental data, ***but not all the phenomena that may occur during resuspension are simulated by the model***;
- For almost all the ***other validation tests***, the model showed ***conservative estimations***.

Conclusions & Future perspectives

- ***Improve the model***:
  - Reduce the ***CFs*** needed. Some CFs are now employed for diagnostic purposes;
  - Introduce an ***agglomeration model*** in function of the “Drag-Burst forces” ratio;
  - Increase the ***aerosol groups to 10*** (instead of 5);
  - Create CFs for the ***calculation of the resuspended mass*** (avoid Microsoft Excel ® file);
  - ***Coupling with the RN package***: ***Inject the resuspended mass*** during the time step Δt_n as an aerosol source during the time step Δt_{n+1};
  - If needed, further expand the ***validation matrix***.

Thank you for your attention

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References and additional slides

For further information on the ECART model see: ECART User's Manual Part 2 – Code Structure and Theory.

[1] M.F. Young, "Liftoff Model for MELCOR", *report n° SAND2015-6119*, Sandia National Laboratories, 2015.

[2] A. Bujan, L. Ammirabile, A. Bieliauskas, B. Toth, "ASTEC V1.3 code SOPHAEROS module validation using the STORM experiments", *Progress in Nuclear Engineering*, vol. 52, 2010, pp 777 – 788.

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[5] M. W. Reeks, D. Hall, "Kinetic model for particle resuspension in turbulent flows: theory and measurements", *Aerosol Science*, vol 32, 2001, pp 1 – 31.

References and additional slides

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References and additional slides

Adhesive forces (F_{ad})

F_g	Gravitational	$F_g = \frac{4\pi r_p^3}{3}\rho_p g$
F_c	Cohesive (intermolecular attraction)	$F_c = 2Hr_p\gamma$
F_a	Friction adhesive (sliding and rolling resistance)	$F_a = 0.2\left(F_g\gamma^3 + F_c\right)$

Aerodynamic forces (F_{ae})

F_d	Drag (shear stress on wall)	$F_d = \tau_0\pi r_p^2\chi^{2/3}$
F_b	Burst (breaking of laminar sub-layer)	$F_b = 4.21\rho_g\chi\nu^2\left(\frac{d_p\rho_g U^*}{\mu}\right)^{2.31}$

References and additional slides

- r_p, d_p, and ρ_p - particle radius, diameter, and density, respectively;
- γ and χ - collision and the aerodynamic shape factors, respectively;
- H - empirical coefficient: 10^{-6} N/m;
- v_f (often called v), μ, and ρ_g - flow velocity, the dynamic viscosity of the fluid, and the fluid density, respectively.
- $\boldsymbol{\tau}_0$ - shear stress at the wall: $\tau_0 = 0.125\lambda\rho_g v_f^2$
- λ - flow resistance coefficient:

$$\frac{1}{\sqrt{\lambda}} = -0.6\log_{10}\left(\left(\frac{\varepsilon}{3.7D}\right)^{3.33} + \left(\frac{6.9}{Re}\right)^{3}\right)$$

- D - hydraulic diameter;
- ε - surface roughness;
- U^* - friction velocity, calculated as: $U^* = \sqrt{0.125\lambda\rho_g v_f^2 / \rho_g}$