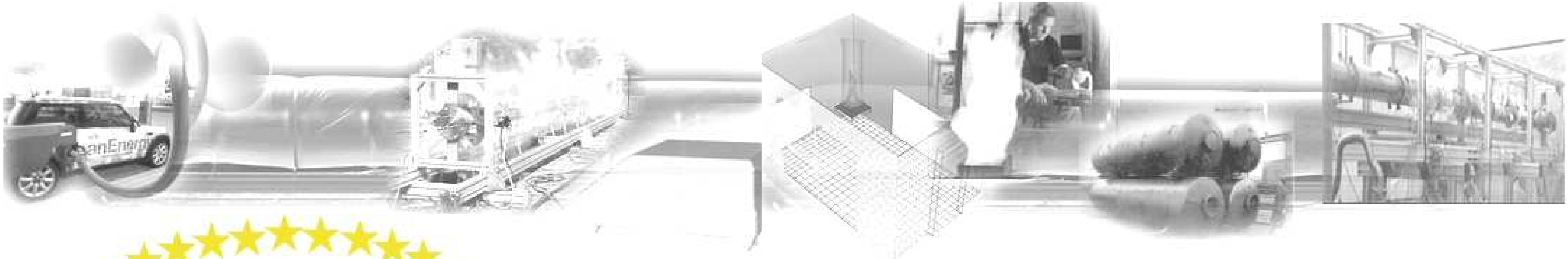

The European Network of Excellence for Hydrogen Safety

Estimation Of An Allowable Hydrogen Permeation Rate From Road Vehicle Compressed Gaseous Hydrogen Storage Systems In Typical Garages; Part 2: CFD dispersion calculations using the ADREA-HF code and experimental validation using helium tests at the GARAGE facility

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3rd International Conference on Hydrogen Safety
Ajaccio, Corsica (FR), 16-18 Sept. 2009

Scope

- For hydrogen assumed to be released by permeation from a typical automotive storage system in a garage-like facility
- Investigate whether homogeneous or stratified conditions develop within the facility, using CFD and experiments
- test the applicability of the simple model approaches in the case of permeation

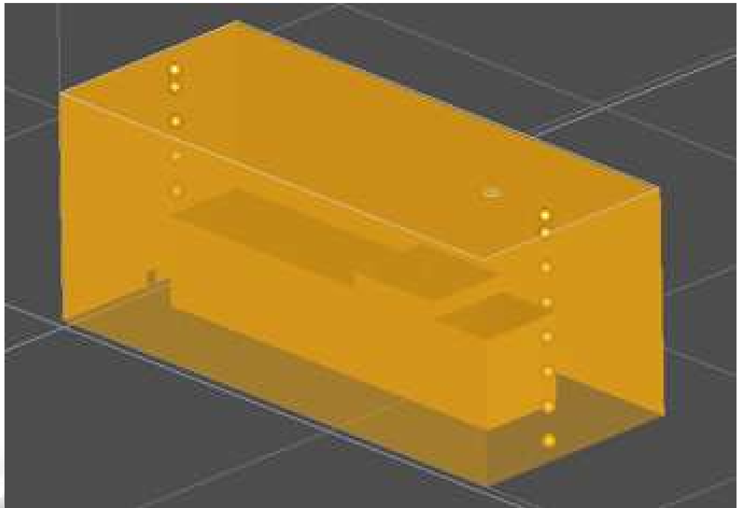
Scenarios

SAE draft: 75 NmL/min/car

CEA measured min ventilation

Scenario	Release rate (NL/min)	Released substance	Ventilation rate (ACH)	Source diameter (cm)	Source height (m)	Source gas mass fraction
Bus-1	1.087	H_2	0.001	15	3.5	1.0
Bus-2	1.087	H_2	0.03	15	3.5	1.0
CEA-1	1.0	He	0.01	7	0.0	1.0
CEA-2	0.03	He	0.01	7	0.0	1.0

Bus Garage dimensions 16×6.55×6.0 m



CEA garage dimensions 5.76×2.96×2.42 m
garage representing the part above bus

Homogeneous model (Lees, chap 10)

Without ventilation (0 ACH)

$$V\frac{dc}{dt} = Q_s \Rightarrow \mathrm{c} = \frac{Q_s}{V}t$$

V facility volume

Q_s source vol. flow rate

t time

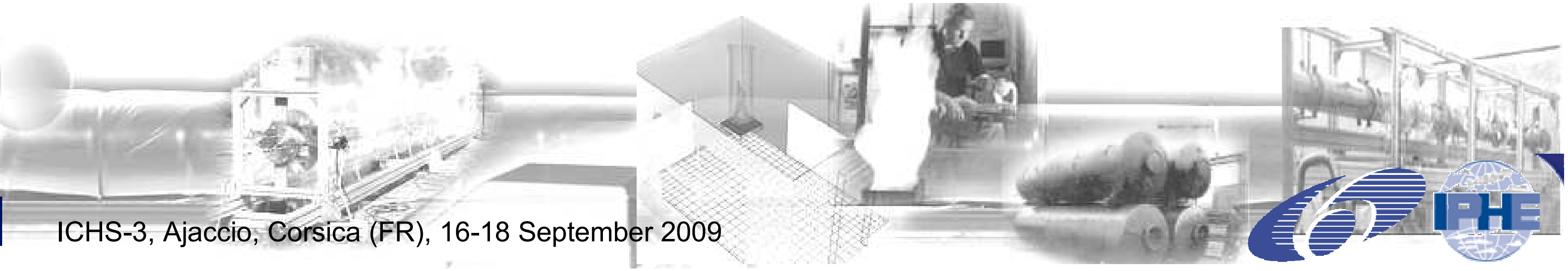
c vol. fraction

Q_{in} fresh air inflow vol. rate

With Ventilation

$$V\frac{dc}{dt} = Q_s - c\left(Q_s + Q_{in}\right) \Rightarrow$$

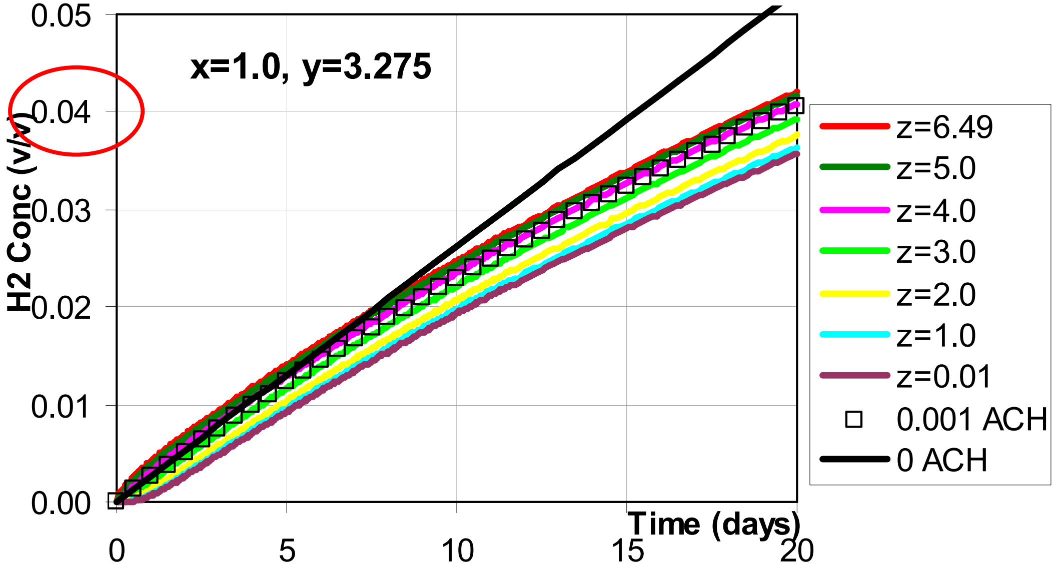
$$\mathrm{c} = \frac{Q_s}{Q_s + Q_{in}}\left(1 - \exp\left(-\frac{Q_s + Q_{in}}{V}t\right)\right)$$

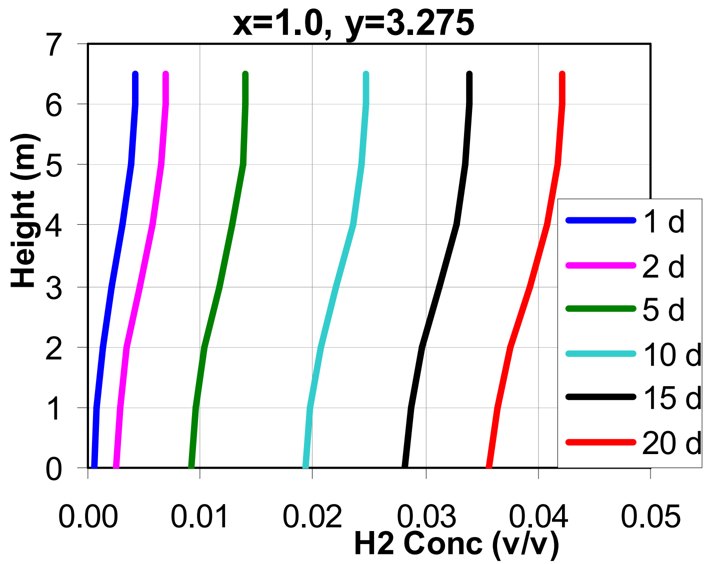


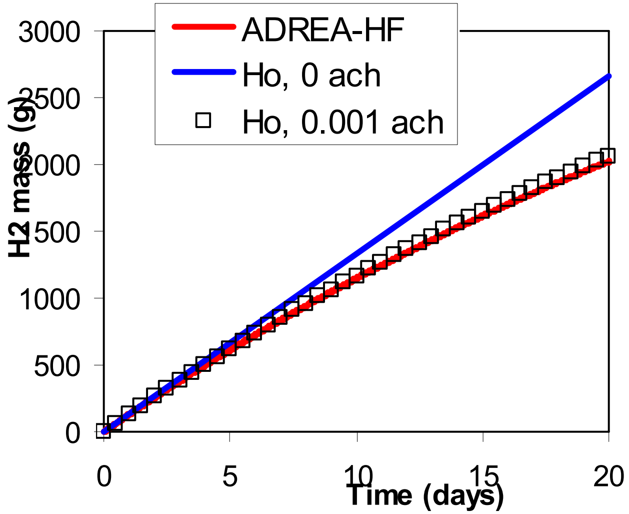
3d CFD modelling

- ADREA-HF CFD code
- k-ε turbulence model
- Maximum CFL = 5
- Max horizontal grid expansion ratio 1.12
- Bus-1 and 2
  - 36x23x32 (26496) grid cells in X,Y,Z (length, width, height)
  - Min cell size 0.15 m
- CEA-1 and 2
  - 27x19x25=12825 grid cells in X,Y,Z (length, width, height)
  - Min cell size 0.1 m

ADREA-HF Bus-1 (1.087NL/min, 0.001 ACH)

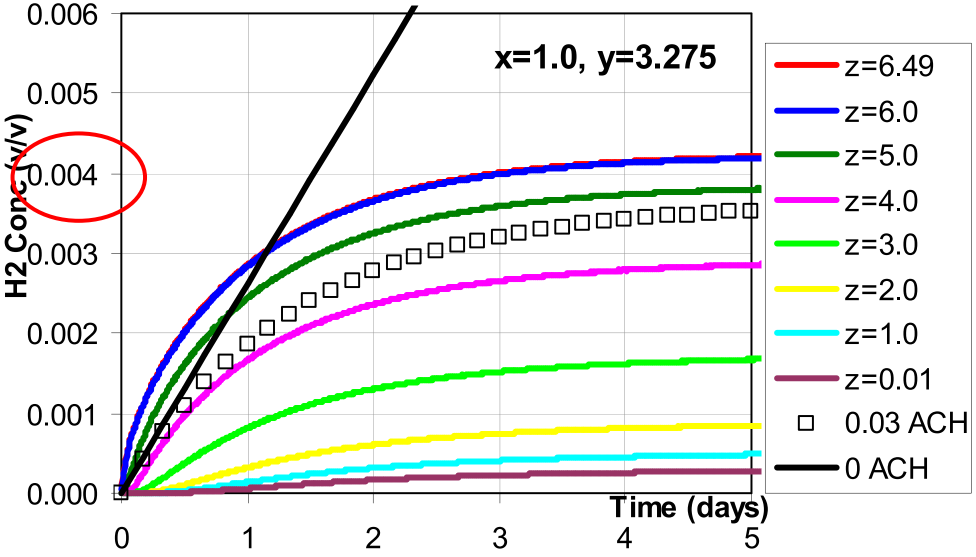


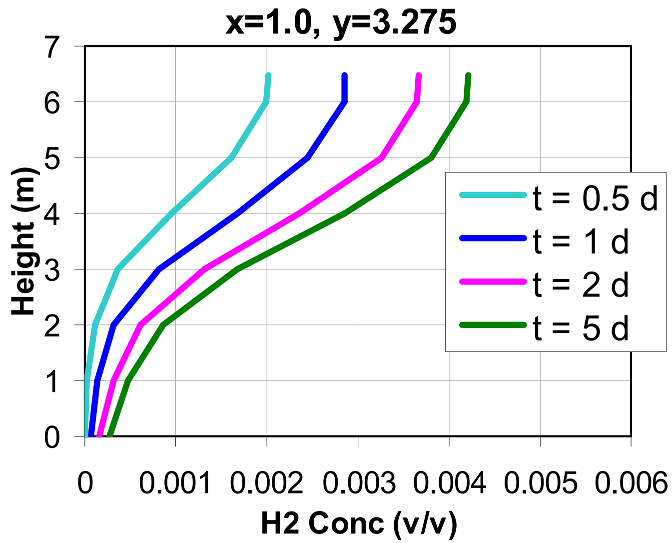


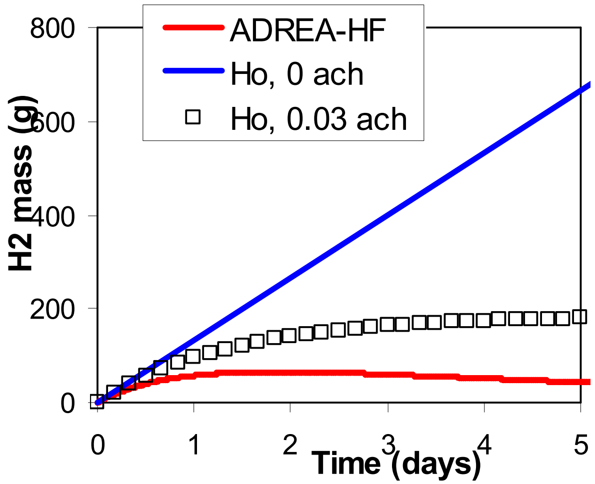


0.5% vertical concentration difference

ADREA-HF Bus-2 (1.087NL/min, 0.03 ACH)

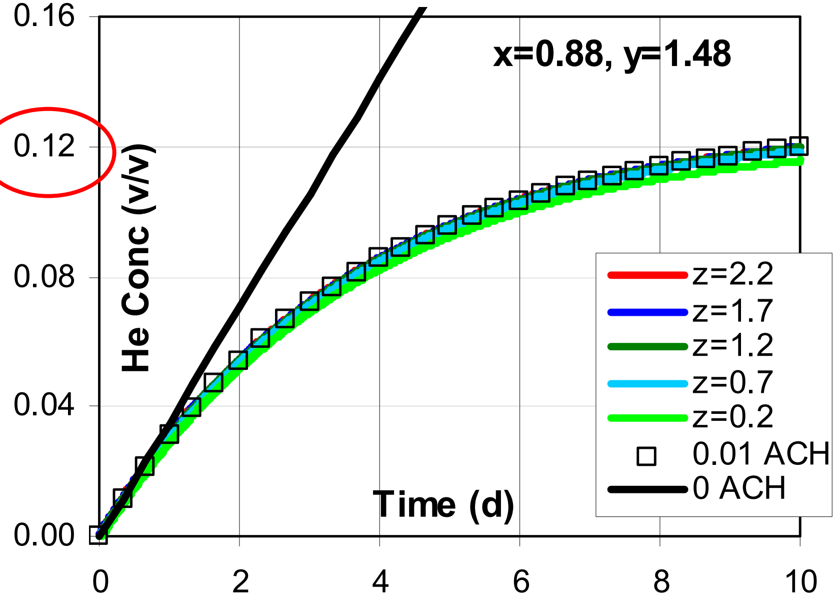


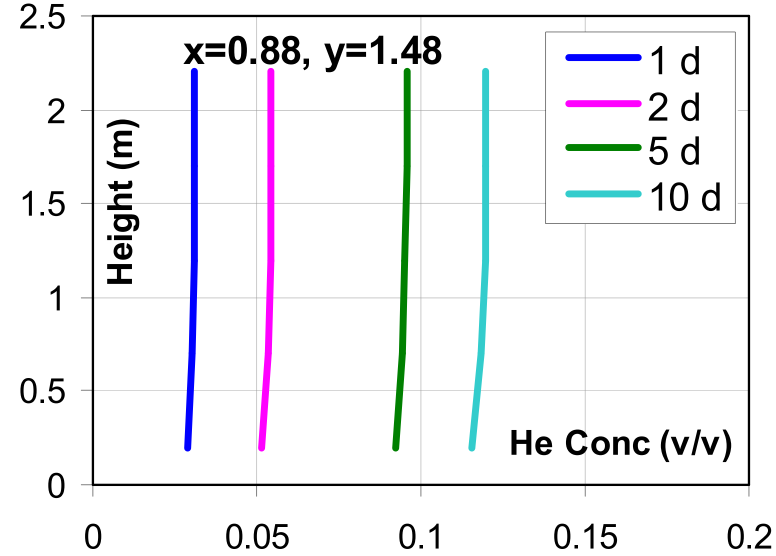


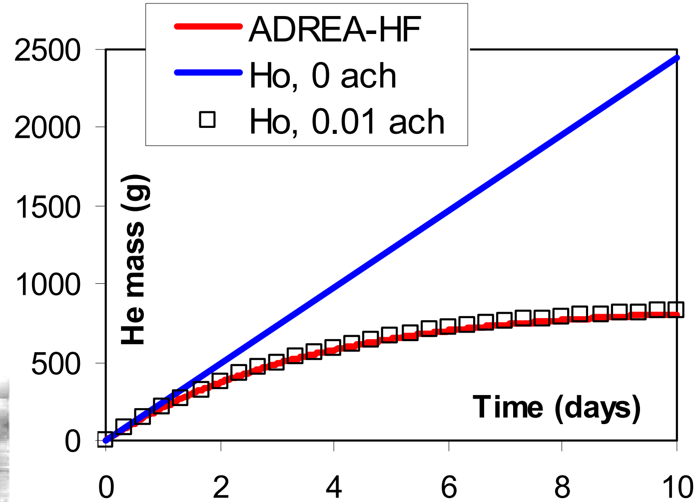


0.4% vertical concentration difference

ADREA-HF CEA-1 (1.0NL/min, 0.01 ACH)

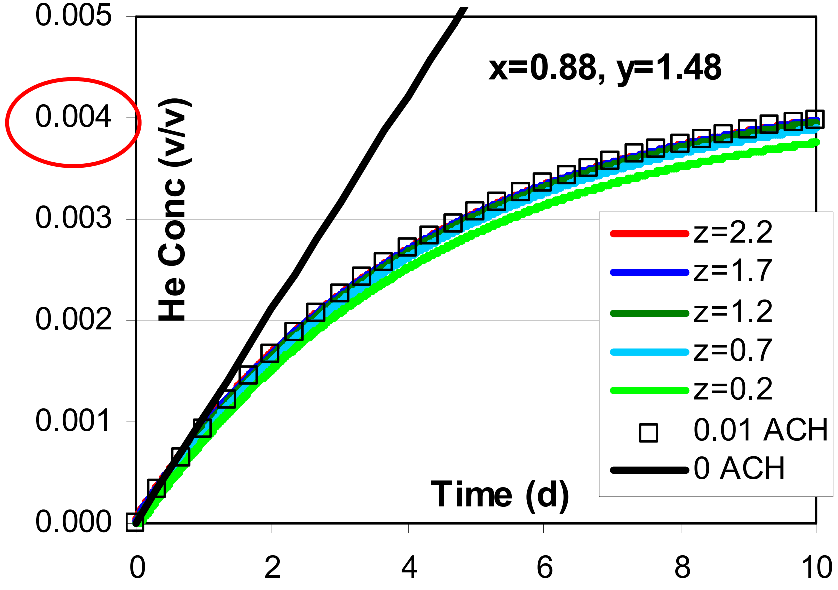


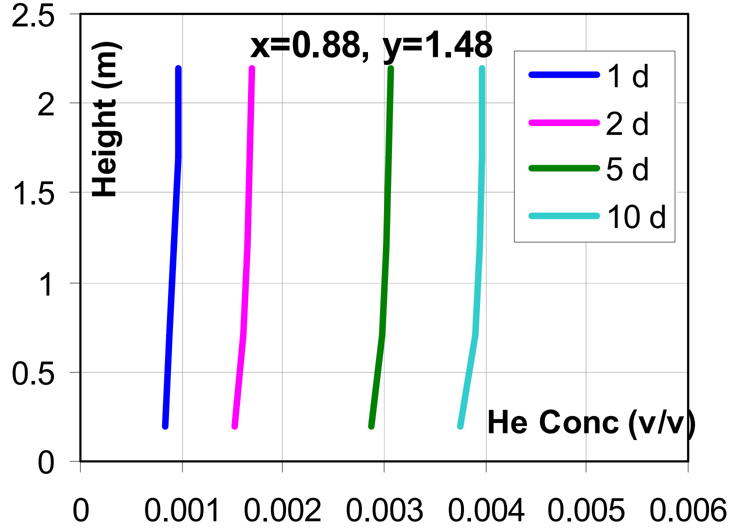


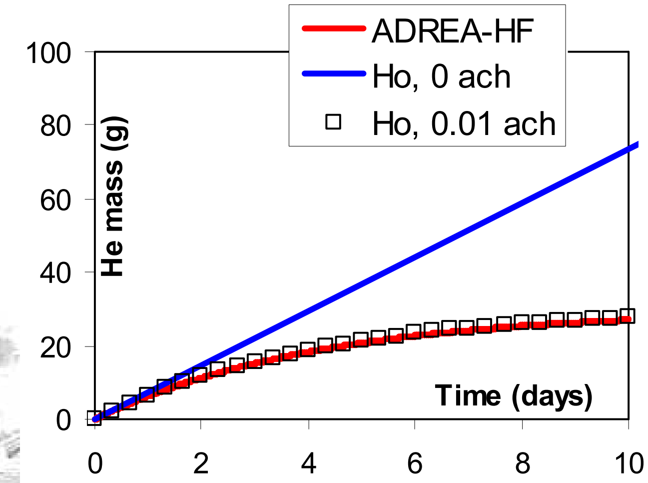


0.2% vertical concentration difference

ADREA-HF CEA-2 (0.03NL/min, 0.01 ACH)







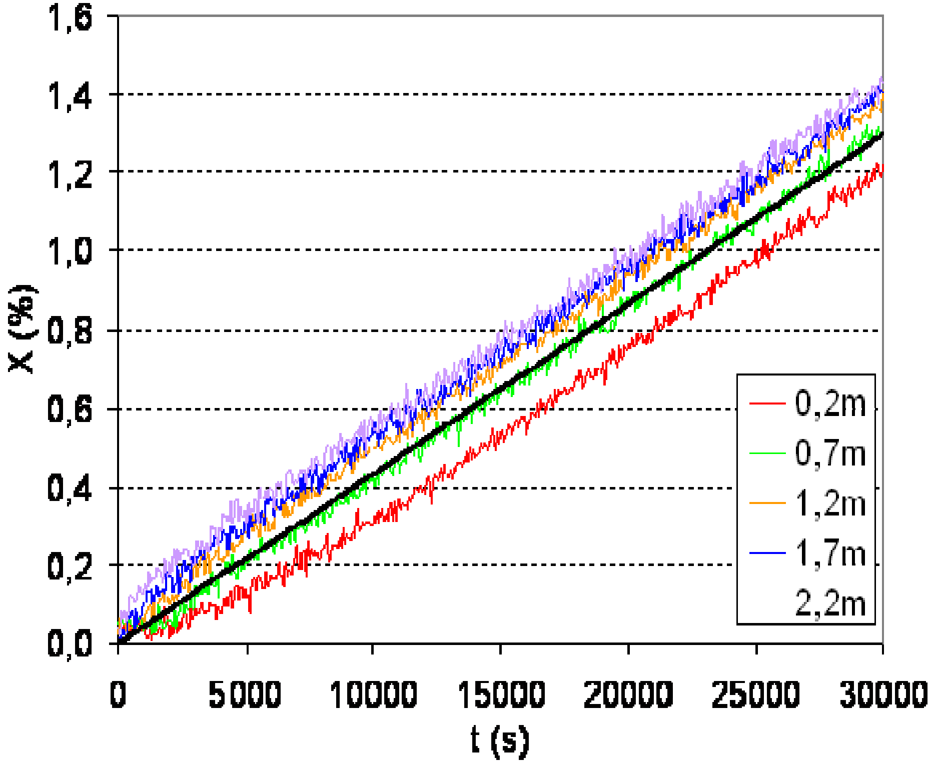
0.02% vertical concentration difference

CEA experiments

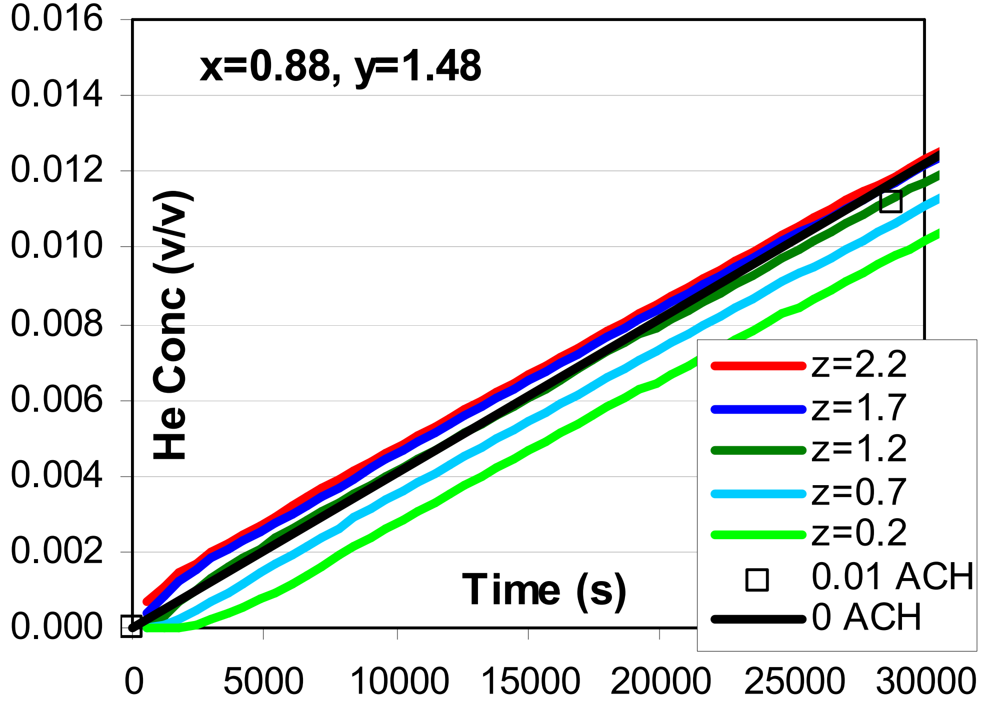
- Scenarios CEA-1 and CEA-2
- Local volume concentration is measured with mini-catharometers TCG-3880 from Xensor.
- 30 sensors are distributed in the enclosure along 6 vertical lines at 5 levels (0.2m, 0.7m, 1.2m, 1.7m and 2.2m from the floor).
- Temperature is measured with thermocouples at 10 locations near the floor and near the ceiling.
- The lowest leak rate of the enclosure was found to be 0.01 ACH
  - obtained by obstructing the tilting door and sealing the back door with aluminum tape. Both vents are closed

CFD validation CEA-1 (1NL/min, 0.01ACH)

CEA Experiment



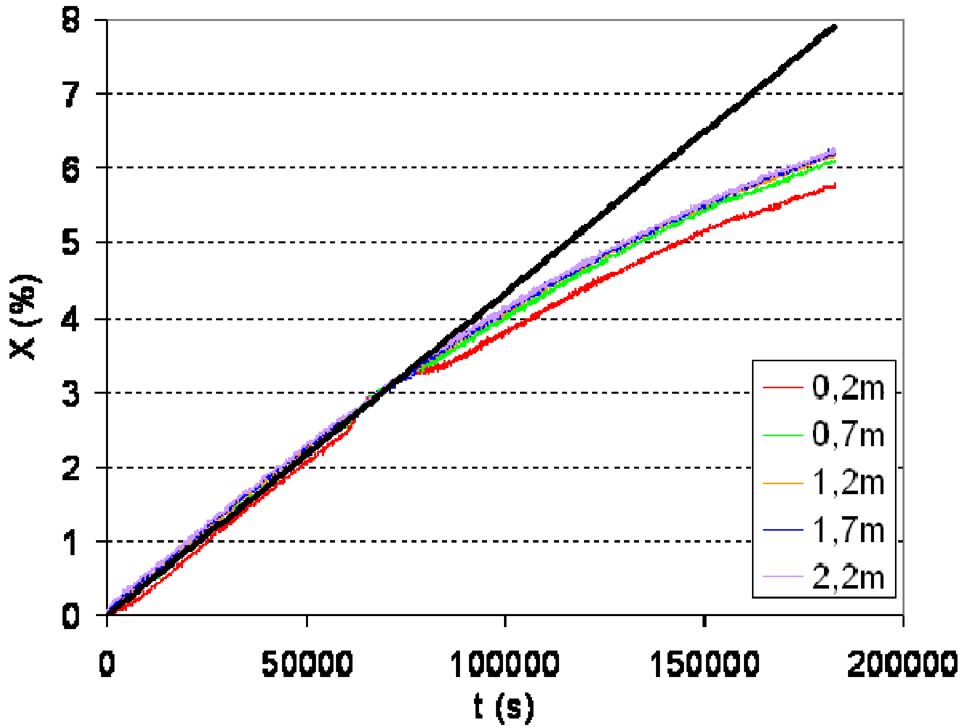
ADREA-HF prediction



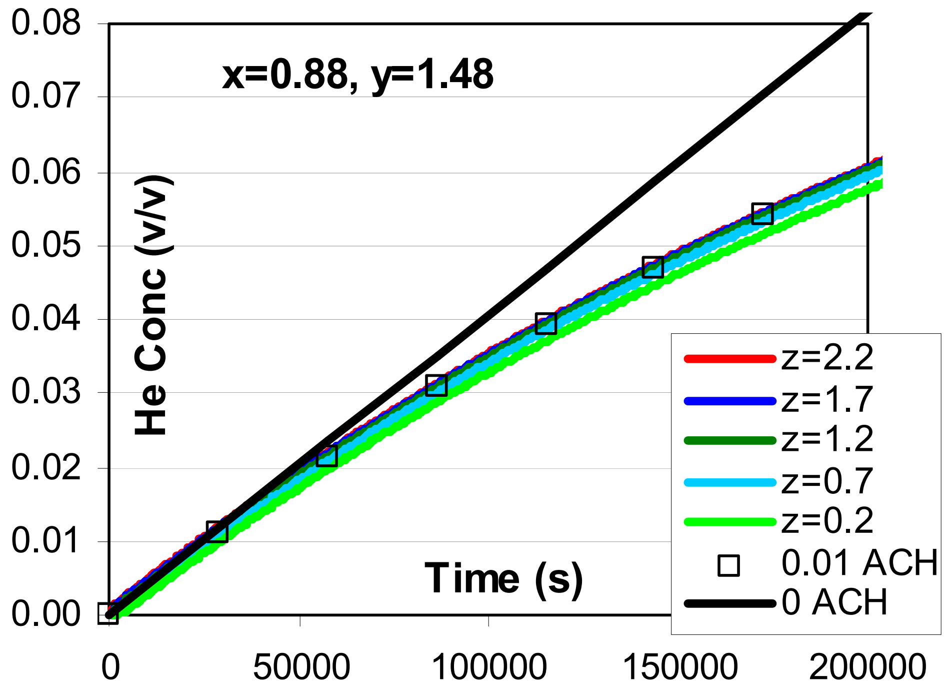
0 - 8.3 hours

CFD validation CEA-1 (1NL/min, 0.01ACH)

CEA Experiment



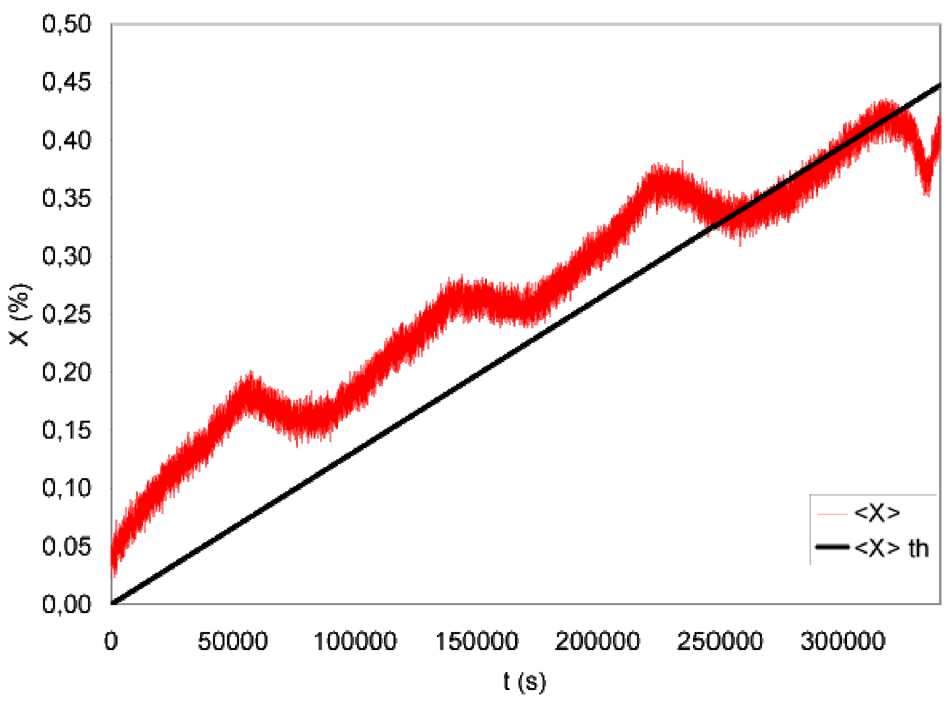
ADREA-HF prediction



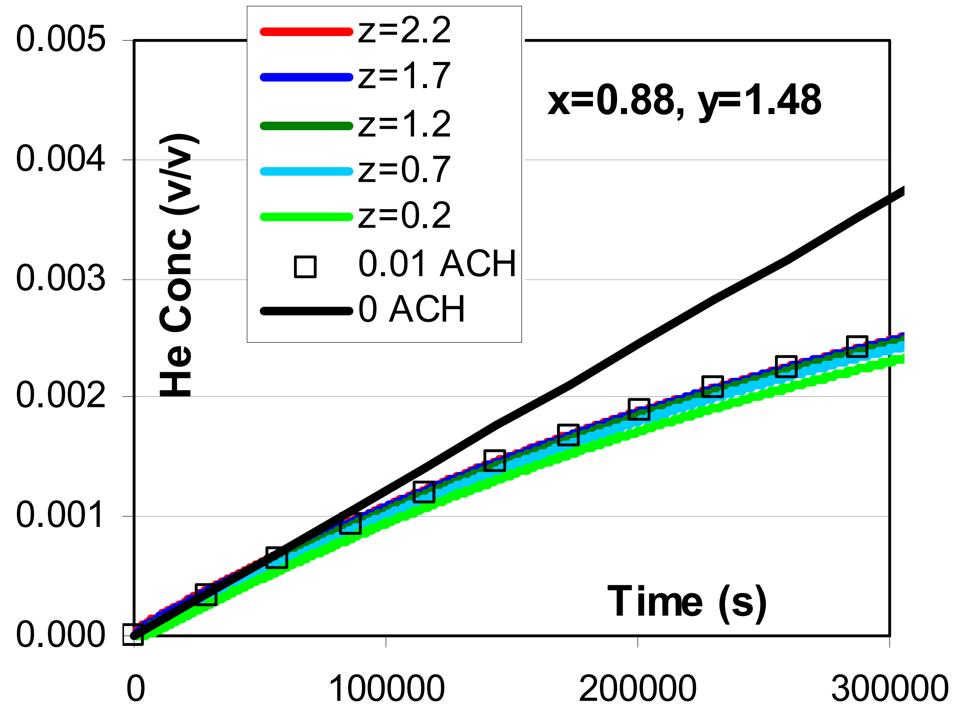
0 – 2.3 days

CFD validation CEA-2 (0.03NL/min, 0.01ACH)

CEA Experiment



ADREA-HF prediction



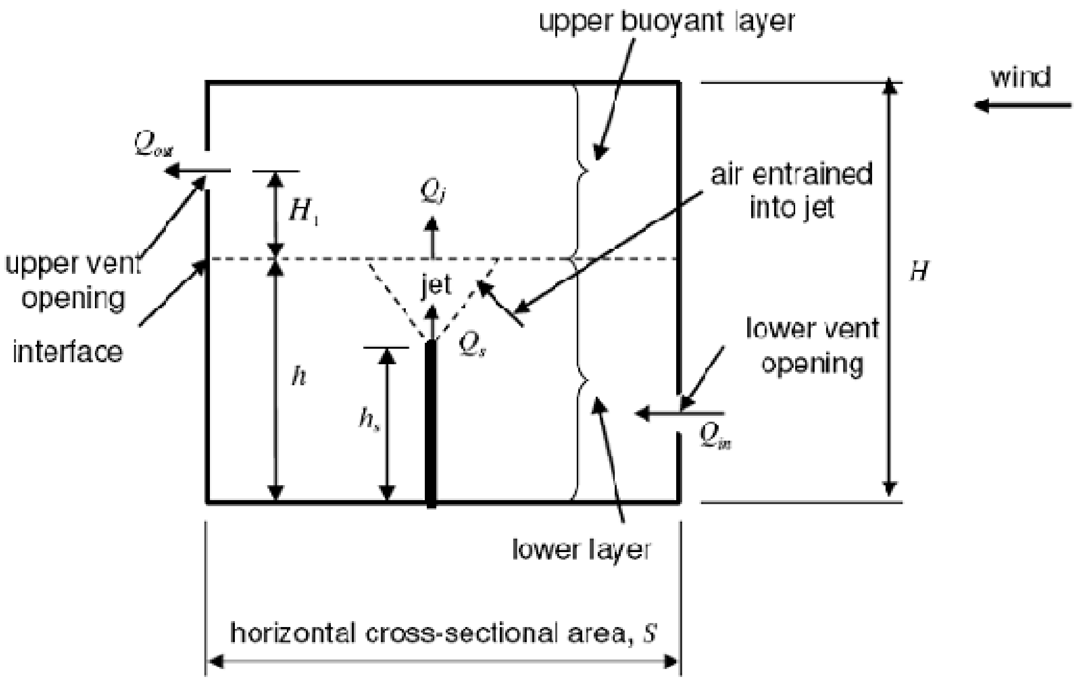
0 – 3.5 days

Two-layer model applicability (1/2)

Top layer

$$\frac{dV_{up}}{dt} = Q_j - (Q_s + Q_{in})$$

$$V_{up}\frac{dc}{dt} = Q_s - c(Q_s + Q_{in})$$



Jet

$$\frac{dWR^2}{dz} = 2R\alpha W$$

$$\frac{dW^2R^2}{dz} = g'(\lambda R)^2$$

$$\frac{dg'WR^2}{dz} = 0$$

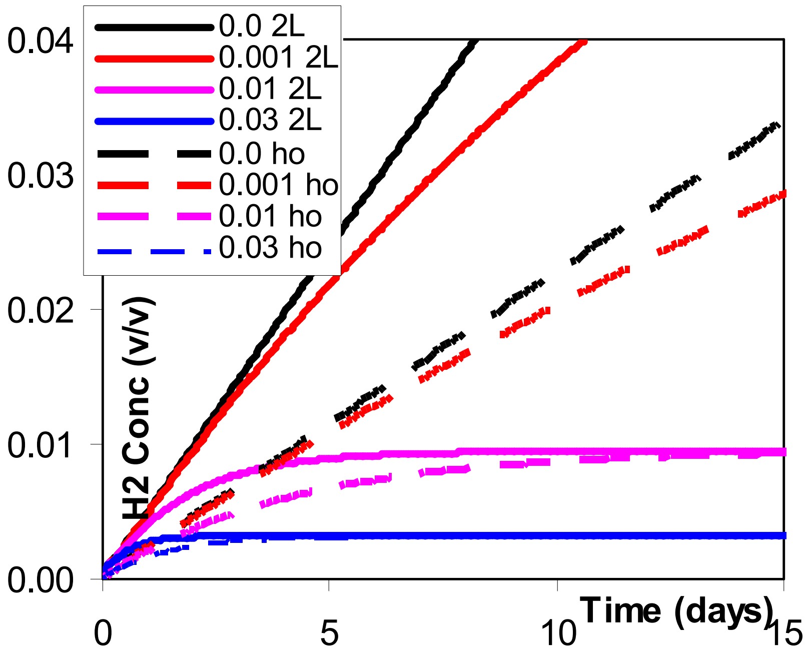
$$a = 0.05$$

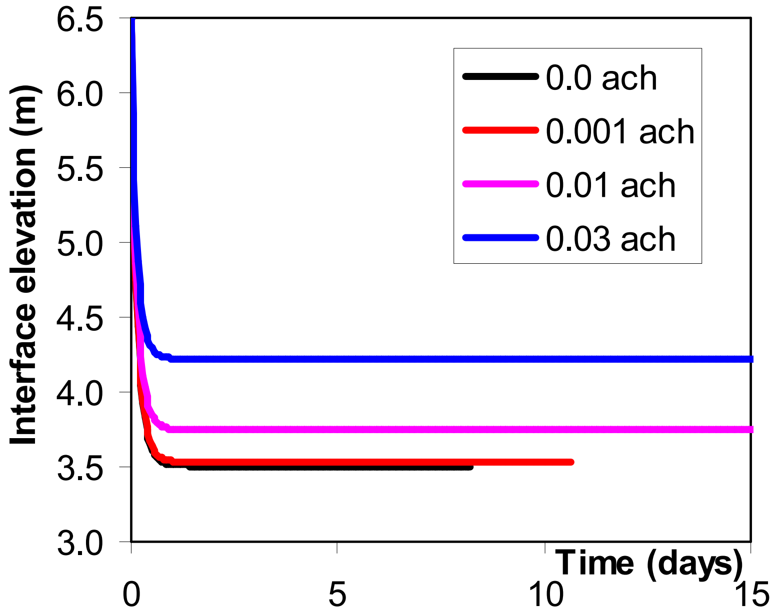
$$\lambda = 1.1$$

Lowesmith et al., ICHS-2, 2007

Two-layer model applicability (2/2)

1.087 NL/min, 680 m^3 garage volume





Conclusions (1/2)

- The CFD simulations performed with the ADREA-HF code showed good agreement with the helium dispersion experiments and the homogeneous model. Discrepancy between CFD and measurements for the very low flow rate of 0.03 L/min was attributed to experimental uncertainty due to the very limiting flow rate condition.
- Vertical concentration profiles were observed to be structured as the superposition of the concentration at the floor (driven by laminar diffusion) plus a concentration difference between floor and ceiling (driven by buoyancy forces).
- When the concentration difference is much smaller than the level of the floor concentration, the distribution pattern can be considered as “homogeneous”, while when the difference is much larger than the level of the floor concentration, the distribution pattern can be considered as “stratified”.
- “Stratified” conditions were predicted with the CFD for one scenario. This was attributed to the level of ventilation being large enough. When the ventilation level was very low “homogeneous” conditions were found.

Conclusions (2/2)

- For the examined scenarios maximum predicted vertical concentration difference between floor and ceiling was 0.5 vol. %.
- For the particular scenario where “stratified” conditions were observed the concentrations predicted by the homogeneous model were within less than 0.5% of those predicted by the CFD.
- The two-layer model is not applicable for permeation type releases

Thank you!!