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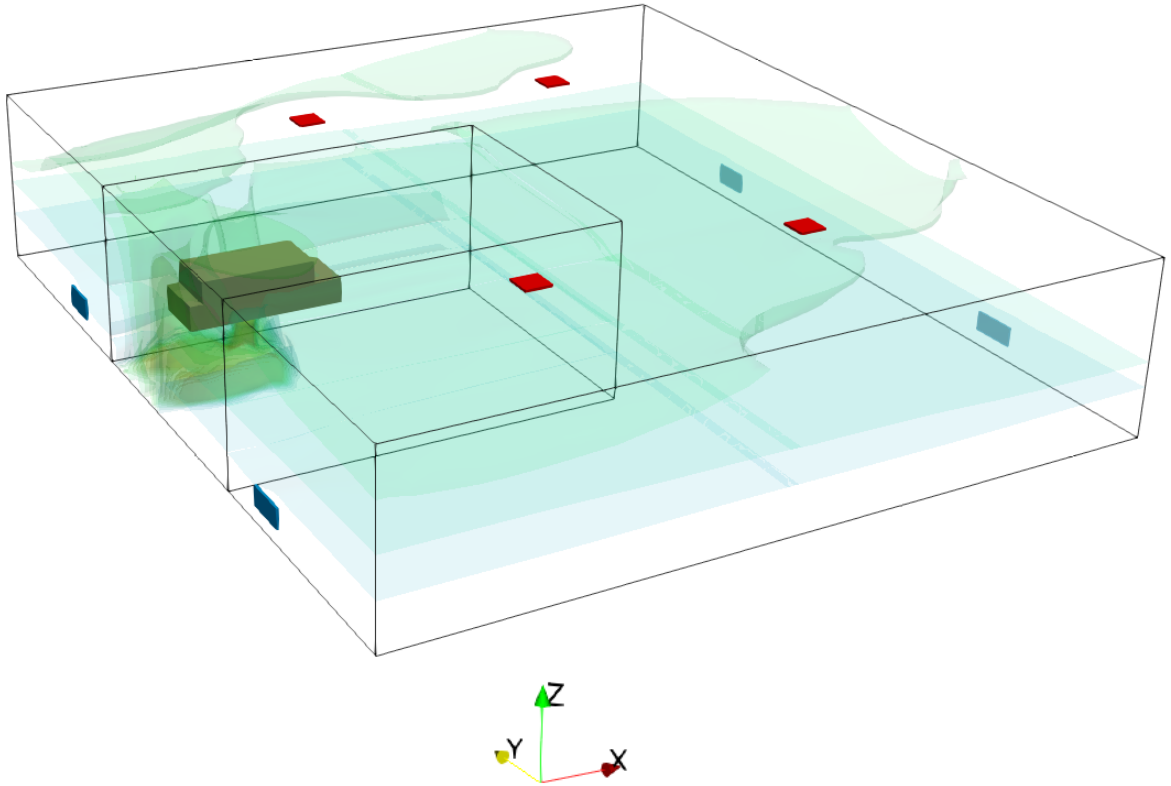
Accidental Releases of Hydrogen in Maintenance Garages: Modelling and Assessment



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10th International Conference on Hydrogen Safety

2023 September 19-21

Introduction

Motivations:

- Accumulation of H_2 in confined spaces (e.g., fuelling station or garage) is a safety concern.
- Gas dynamics during accidental leaks in indoor setting must be understood for risk assessment.
- Geometry for the risk assessment and CFD modelling studied by Ehrhart [1] was chosen.

Objectives:

- Study light gas dispersion in garage
- Assess predictive capability of GOTHIC

Example of Typical Maintenance Garage

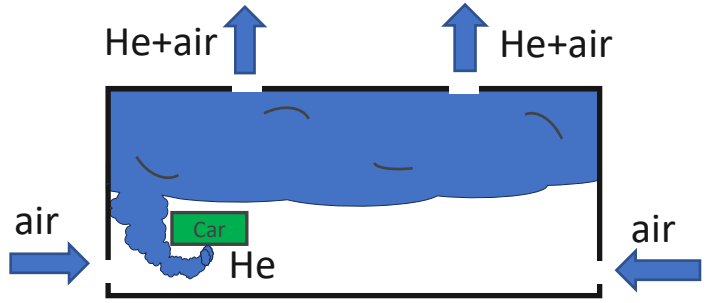
Source: https://envirocivil.com/energy/5-tips-for-starting-an-electric-car-repair-shop/

[1] B.D. Ehrhart et al., Int J Hydrog Energy, 46 (23), 2021

Experimental Setup

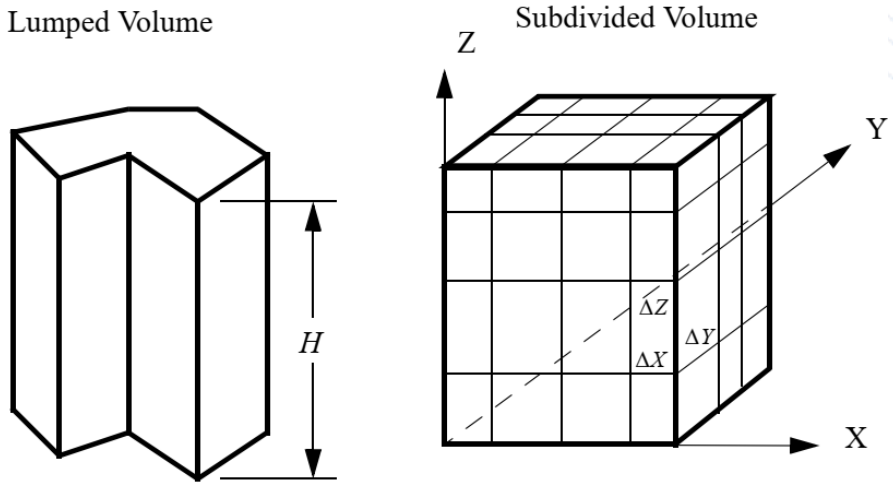
- 1/8th scale experimental garage enclosure with 4 top and 4 bottom vents
- Downward helium injection through 1-mm nozzle below a model car
- Natural and forced ventilation conditions
- Instrumentation
  - Helium concentration sensors at 25 locations
  - Flow velocity meters at 8 vents
  - Helium injection at a flow rate of 1, 5 and 10 L/min

Scale-down Maintenance Garage

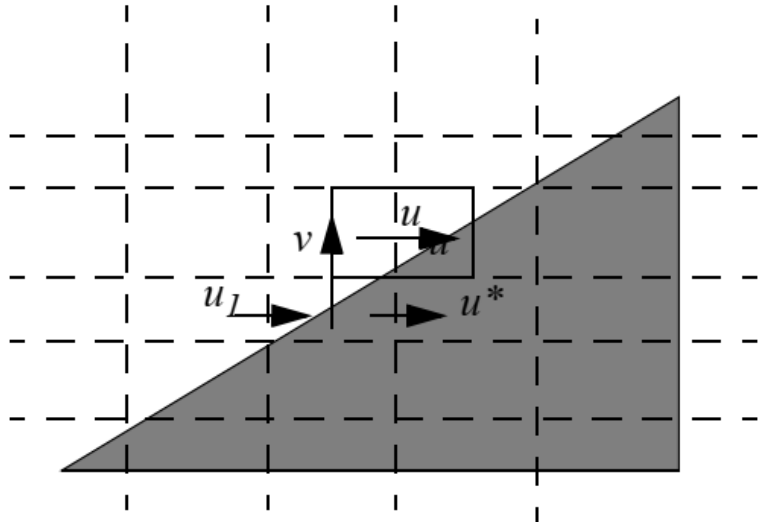


GOTHIC Numerical Method

- Rectangular coordinate system with finite volume method
- Governing equation with porosity functions
  - Mass
  - Momentum
  - Energy
- FAVOR - Fractional Area/Volume Obstacle Representation
- First order time, First Order Upwind Scheme (FOUP)



Typical sub-volumes



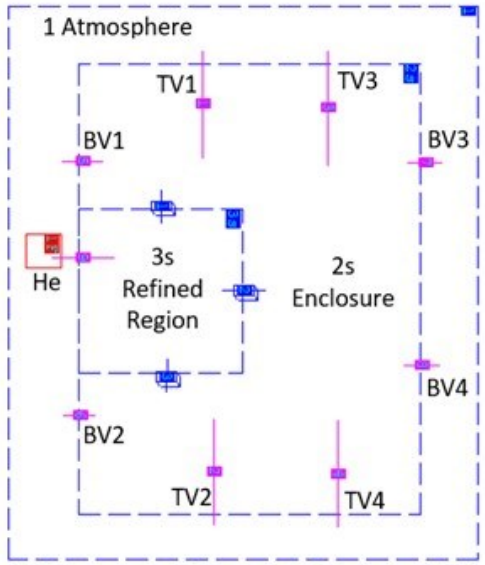
FAVOR Scheme

Computational Grid

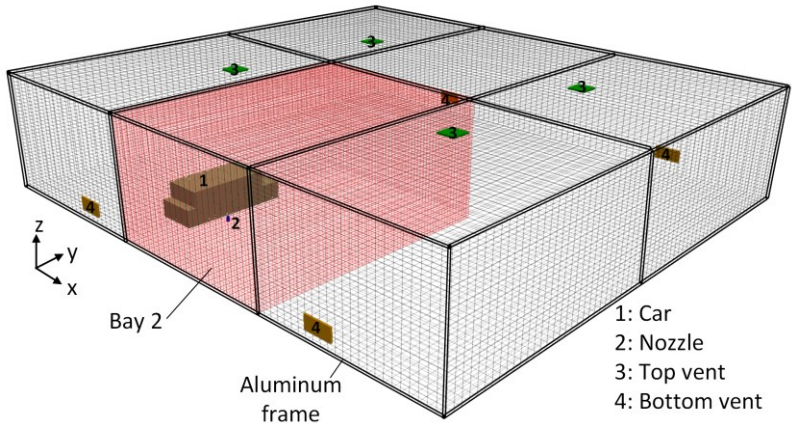
- Enclosure and refinement region
- Boundaries: injector, top vent, bottom vent
- Grid sensitivity study performed
- Fine grid selected for testing

Grid Size for Fine Mesh

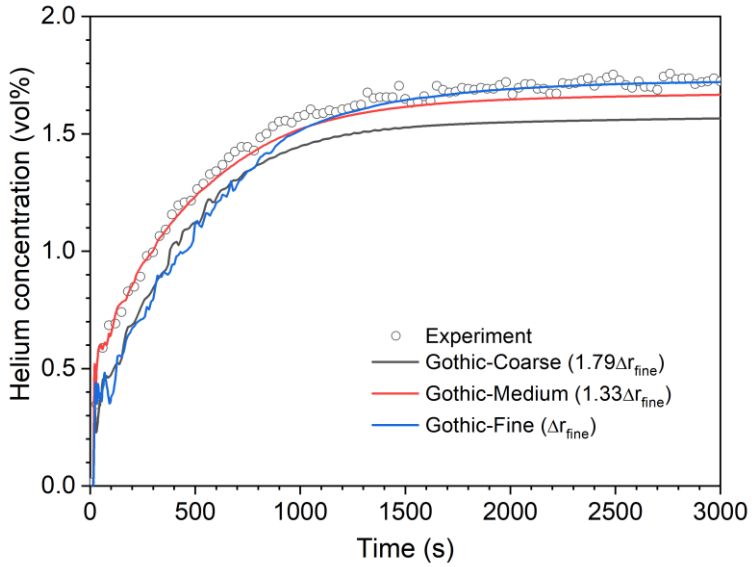
Region (Fine)	Δx, m	Δy, m	Δz, m
Default	0.10	0.08	0.041
Refined	0.035	0.025	0.021



Domain Regions

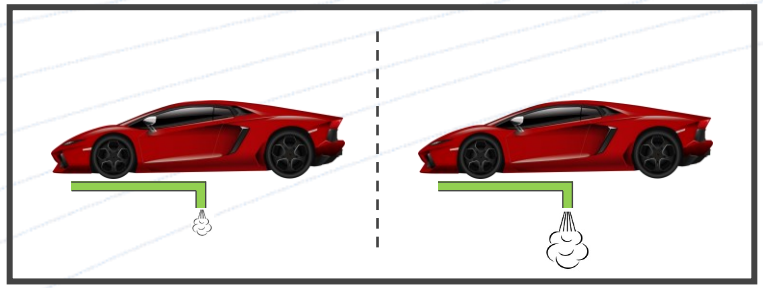


3D Mesh of Garage

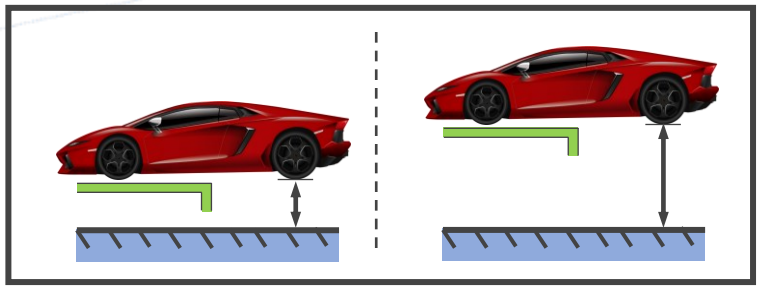


Grid Sensitivity Study

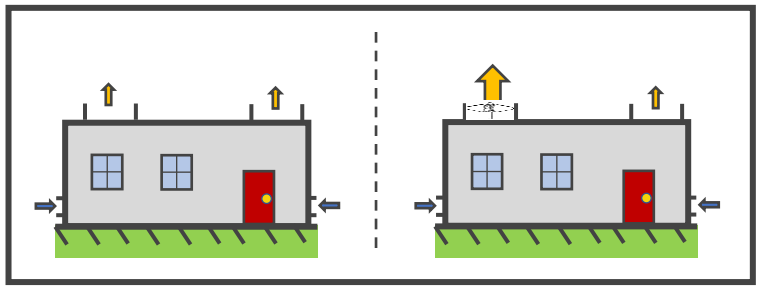
Test Cases



Helium Flow Rate
(1, 5, 10 SLPM)



Car and Nozzle Elevation
(11, 24 cm)

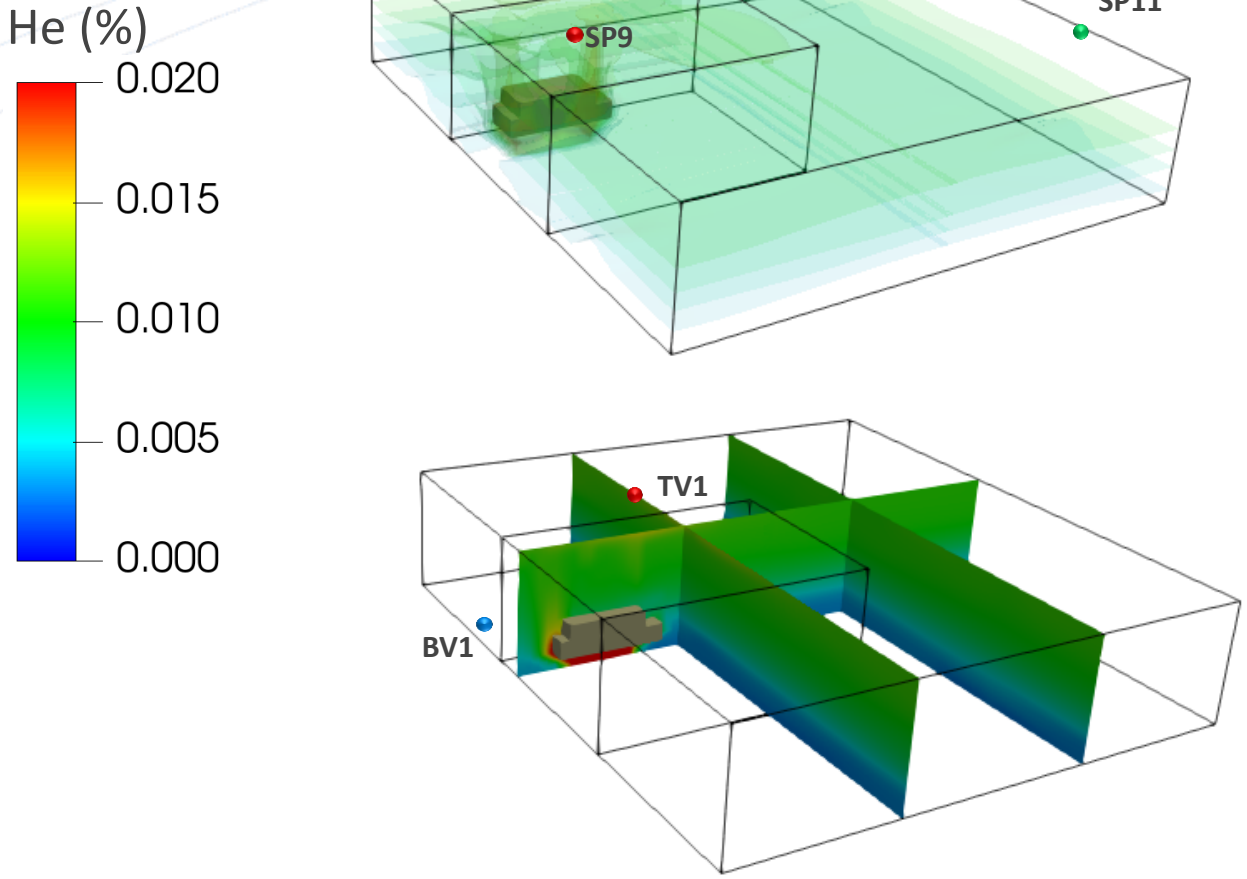


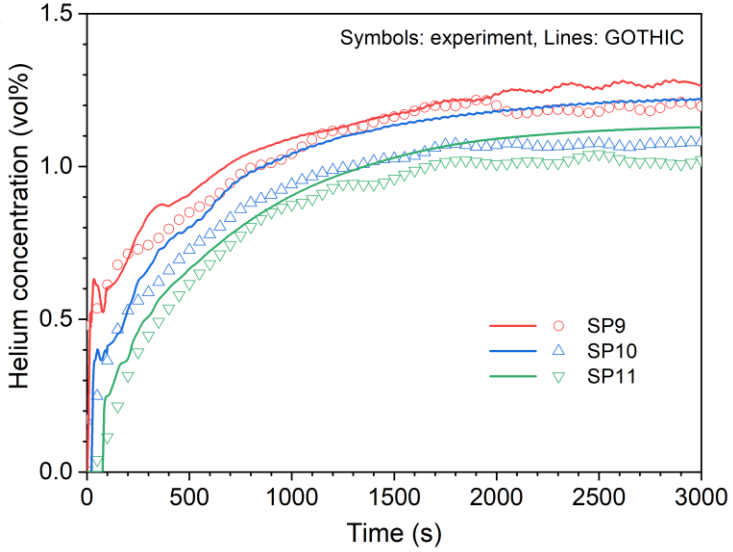
Ventilation
(Natural, Forced)

Test Matrix

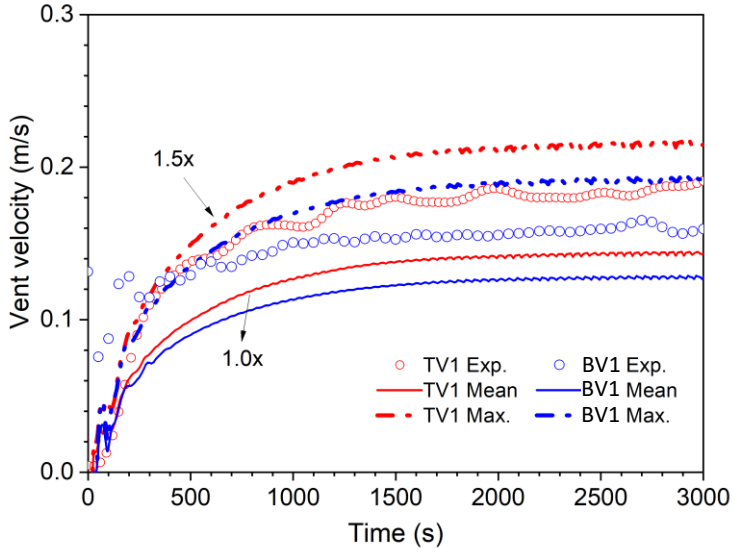
	He Release Rate (SLPM)	Forced Ventilation	Car Elevation (cm)
1	1	No	11
2	5	No	11
3	10	No	11
4	5	No	24
5	5	TV2 (1.0 m/s)	11
6	10	TV2 (1.0 m/s)	11

Baseline Case: 5 LPM, Natural Conv., 11cm Elv.





Helium Concentration



Vent Velocity

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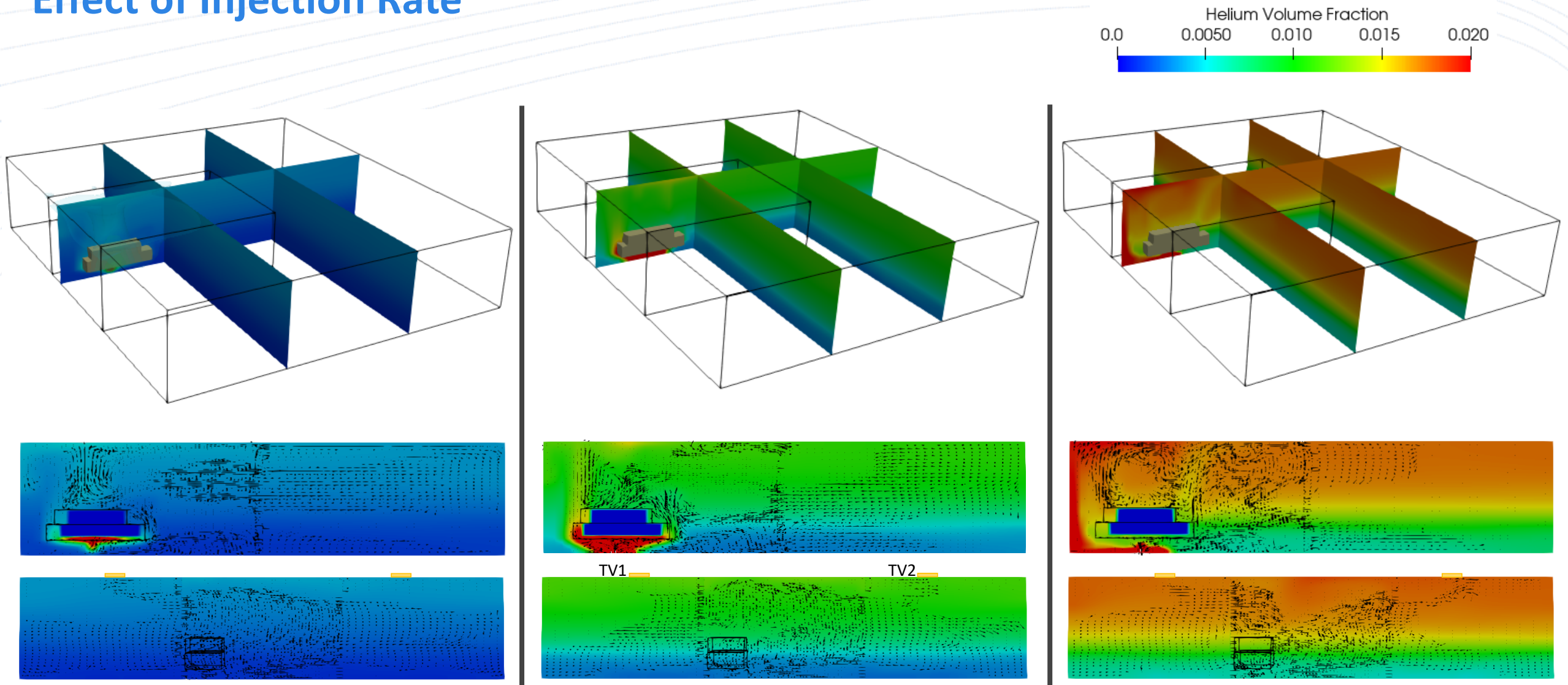
Effect of Injection Rate



Case 1: 1 SLPM
(t = 2000 s)

Case 2: 5 SLPM
(t = 2000 s)

Case 3: 10 SLPM
(t = 2000 s)

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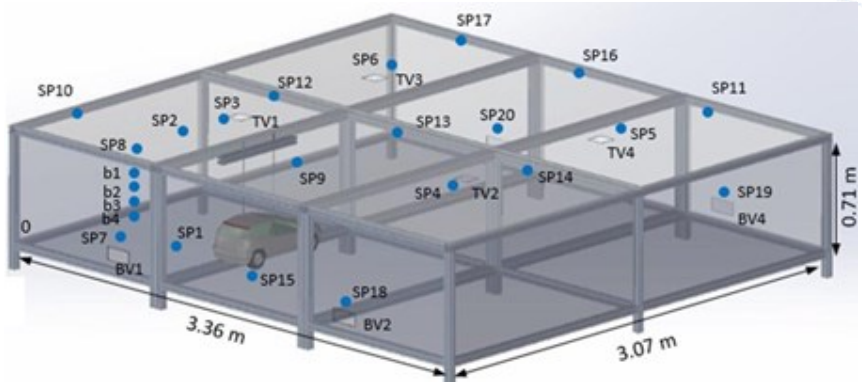
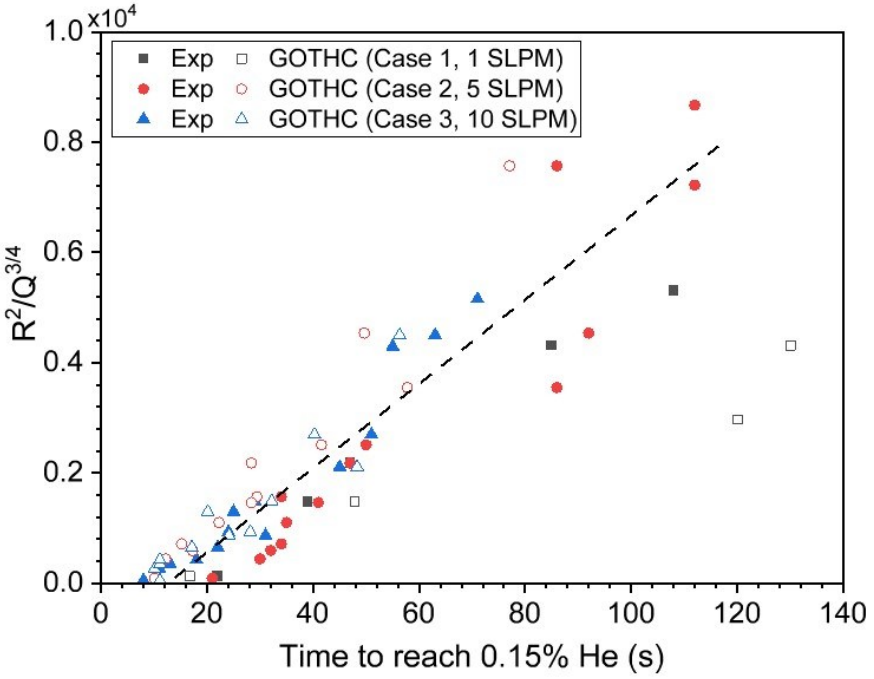
Effect of Injection Rate – Arrival Time

- Arrival time – time for sensor to reach 0.15%
- Distance presented using $R^2/Q^{3/4}$, proposed by Britter
  - R – Distance from ceiling position above nozzle [m]
  - Q – Helium flow in m^3/s
- During the initial spread, the helium front is driven by buoyancy
- The spread rate is a function of the buoyancy flux emanating from the source



Sensor Locations

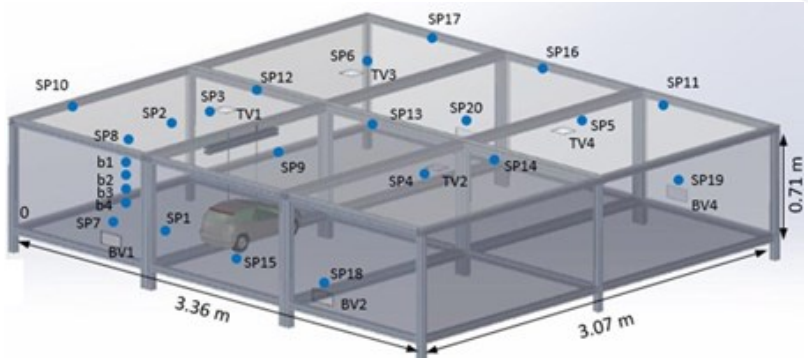


Time to Arrival at Sensors

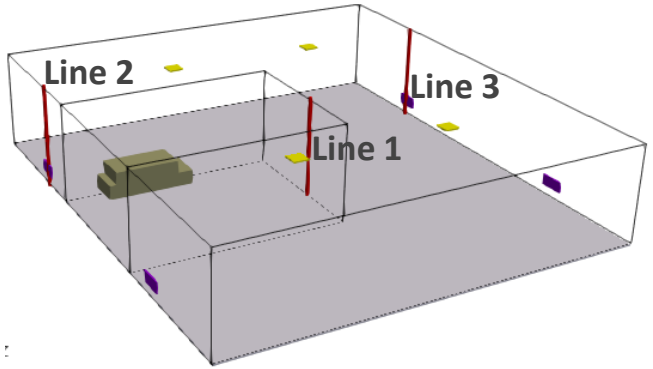
R. E. Britter, The Spread of a Negatively Buoyant Plume in a Calm Environment, Atmospheric Environment, Vol. 13, pp. 1241 – 1247, 1979

Effect of Injection Rate: Steady-State He Profile

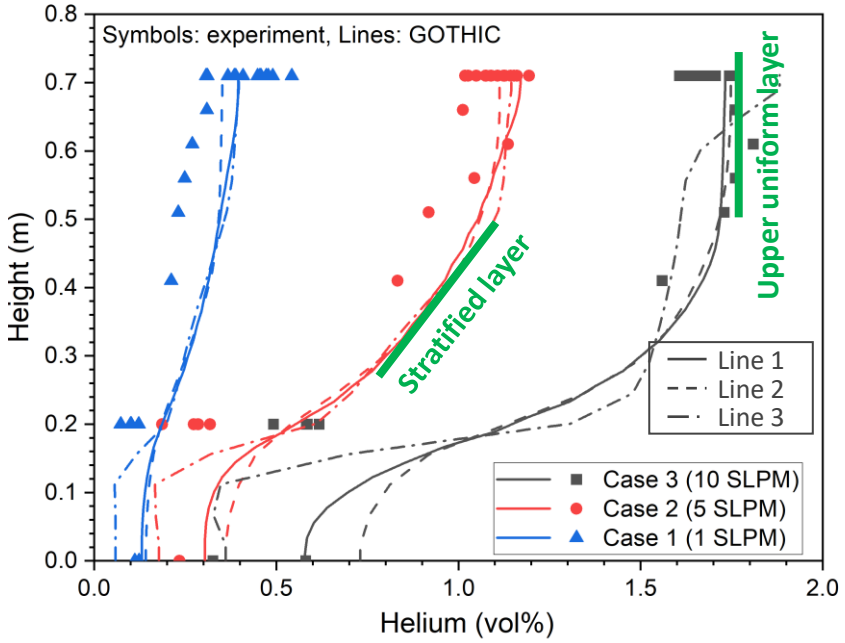
- Both simulations and experiments show that in the vertical helium profile:
  - ➢ an upper uniform layer + a stratified layer forms
  - ➢ interface it thinner at a lower injection rate
  - ➢ decreases sharply below the 0.2 m height
- Similar profiles as tests conducted in the enclosure with a larger height-to-length ratio



Sensor Locations



GOTHIC Line Location



Steady Vertical Helium Profile

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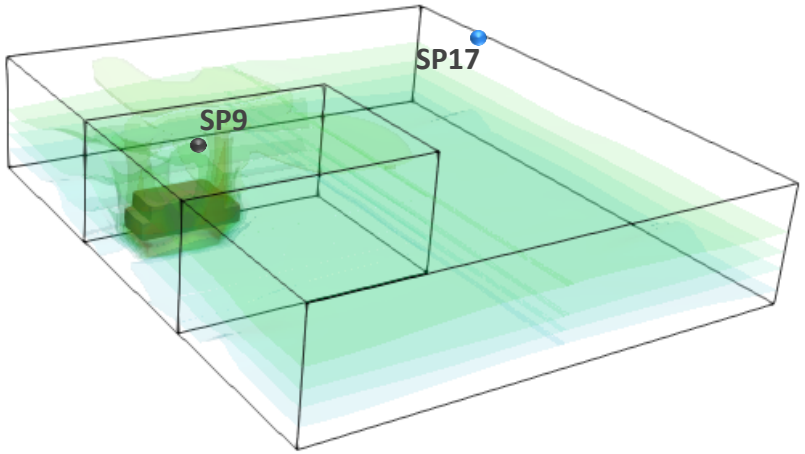
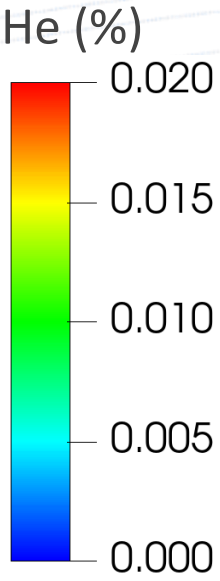
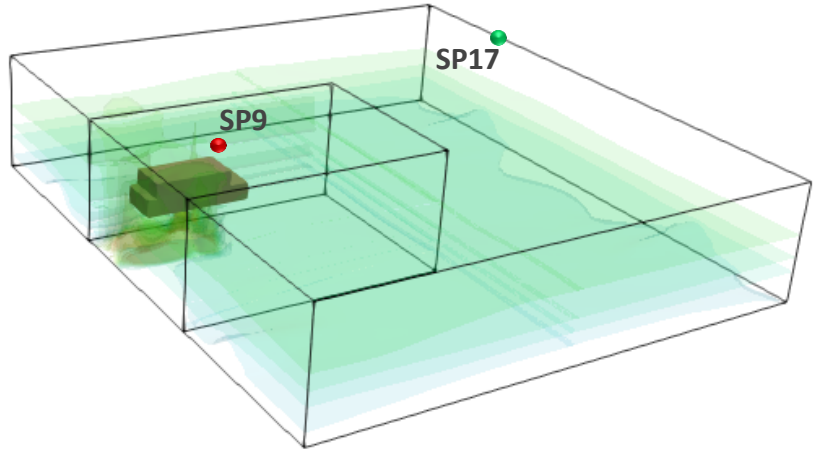
Effect of Car Elevation

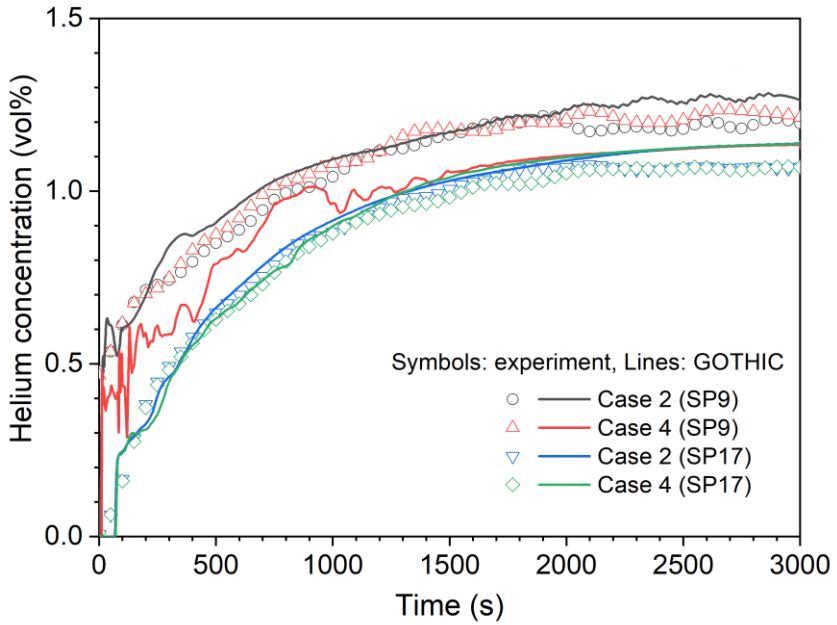






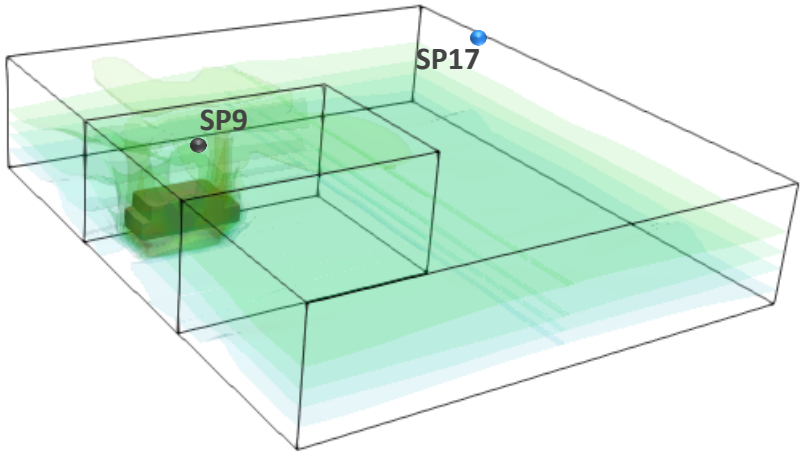
Case 2 (Baseline, H=11 cm)

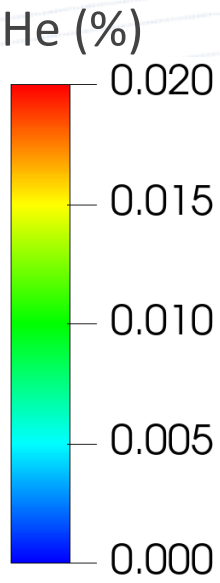
Case 4 (Elevated, H=24cm)

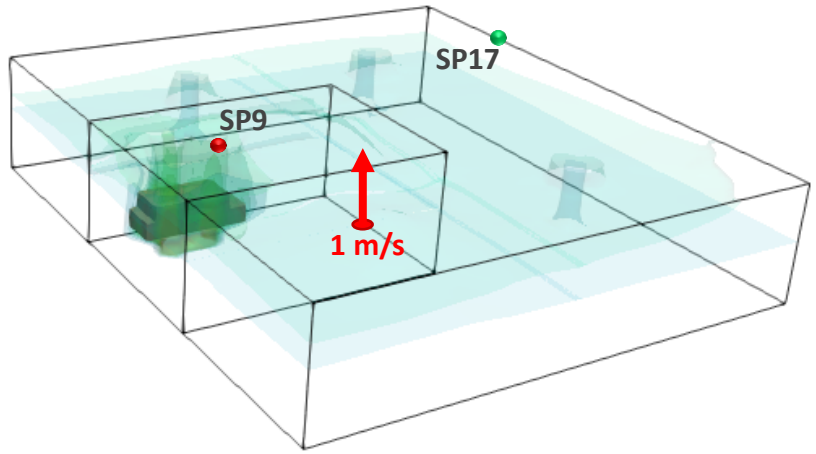


Helium Concentration Transients

Effect of Ventilation

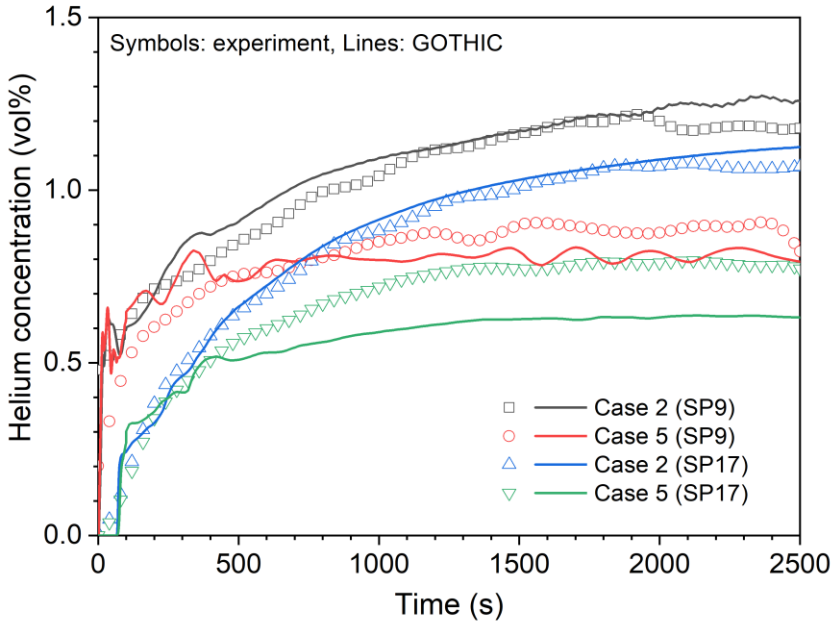






Case 2 (Natural Vent)

Case 5 (Forced Vent)



Helium Concentration Transients

Conclusions

- Higher inject rates resulted in higher steady concentration
  - Initial spread of the helium was a function of the buoyancy flux
  - Helium profile with uniform upper layer and a stratified lower layer
- Forced ventilation reduced helium concentration and modified helium distribution
- Highest concentration was below the car; a local fan could mitigate the accumulation
- Overall, GOTHIC demonstrated good predictive capability

Questions