FireFOAM Modeling of Water Mist Suppression of Compartment Fires

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Water mist

- Effective for
  - Confined spaces
  - Compartment fires
  - Ignitable liquid
- Application
  - Hotel, office, data center, etc.
  - Shipboard, airplane, etc.
  - Flammable liquid, etc.
- Challenge
  - Complex suppression mechanisms
  - Limited codes and standards
  - Design, installation, inspection
  - Reliability

Water mist research

- Spray characterization
  - P.E. Santangelo, et al.
  - B. Ditch, et al.
- Tests
  - T. R. Nichols, et al. (Library fire)
  - A. Jenft, et al. (Enclosure liquid pool fire)
  - G. Heskestad, H.Z. Yu, et al. (Water mist physical scaling)
- Suppression modeling
  - H. Jiang, et al. (Office space fire suppression)
  - E. Kolstad, et al. (Engine room fire)

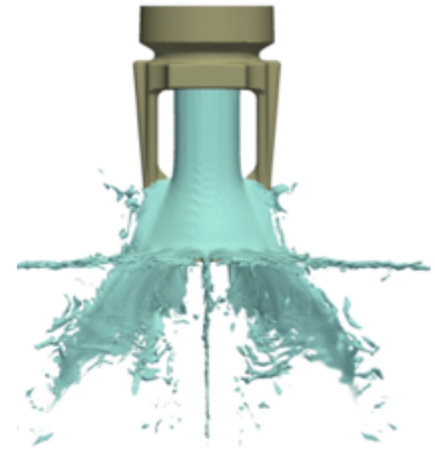
Modeling: Motivation

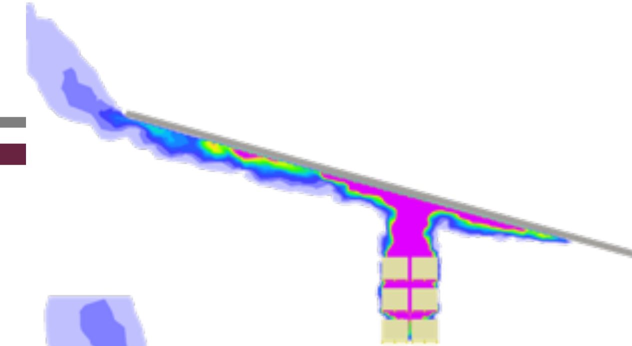
- Gain insight into water mist suppression mechanisms
  - Better understanding of the tests
- Provide engineering guidance
  - More efficient full-scale test design
  - Interpolation/extrapolation of the tests

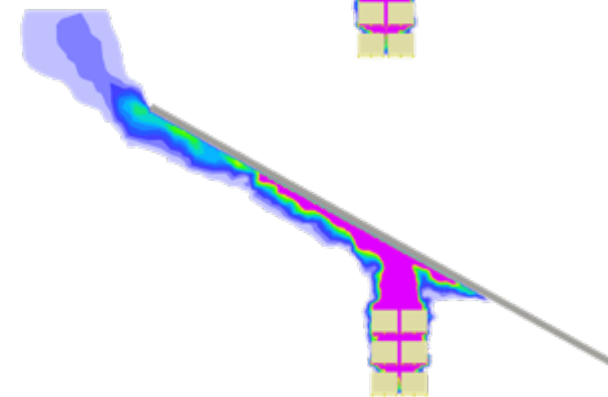
FireFOAM

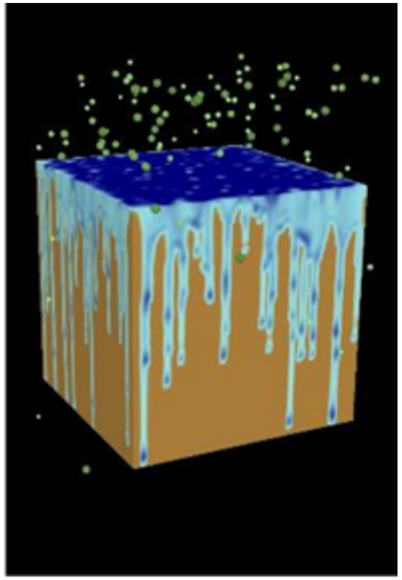
- FOAM (Field Operation And Manipulation)
- Open source fire modeling tool for research & engineering applications
  - https://github.com/fireFoam-dev
  - LES Solver (C++), based on OpenFOAM tool box
  - Unstructured mesh, massive parallel capability
- Physics based sub-models
  - Gas phase (combustion, soot/radiation)
  - Solid phase (pyrolysis)
  - Liquid phase (spray, surface water flow)

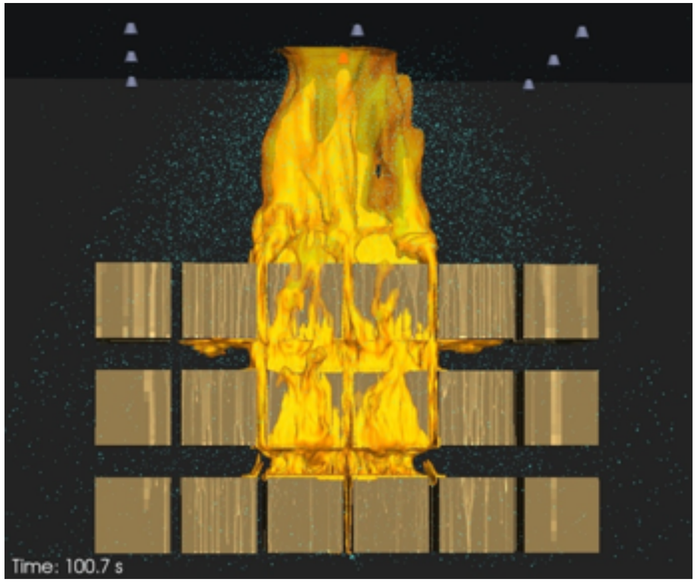
Overview

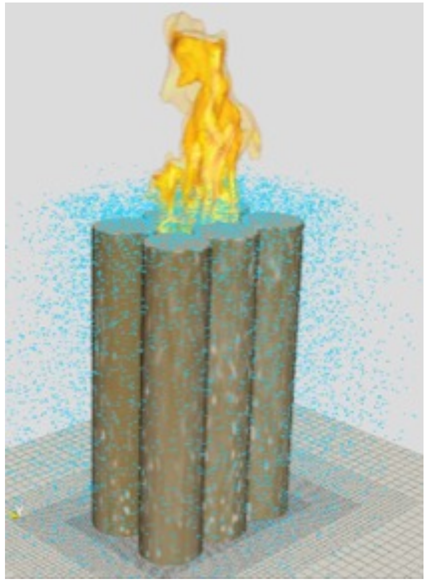










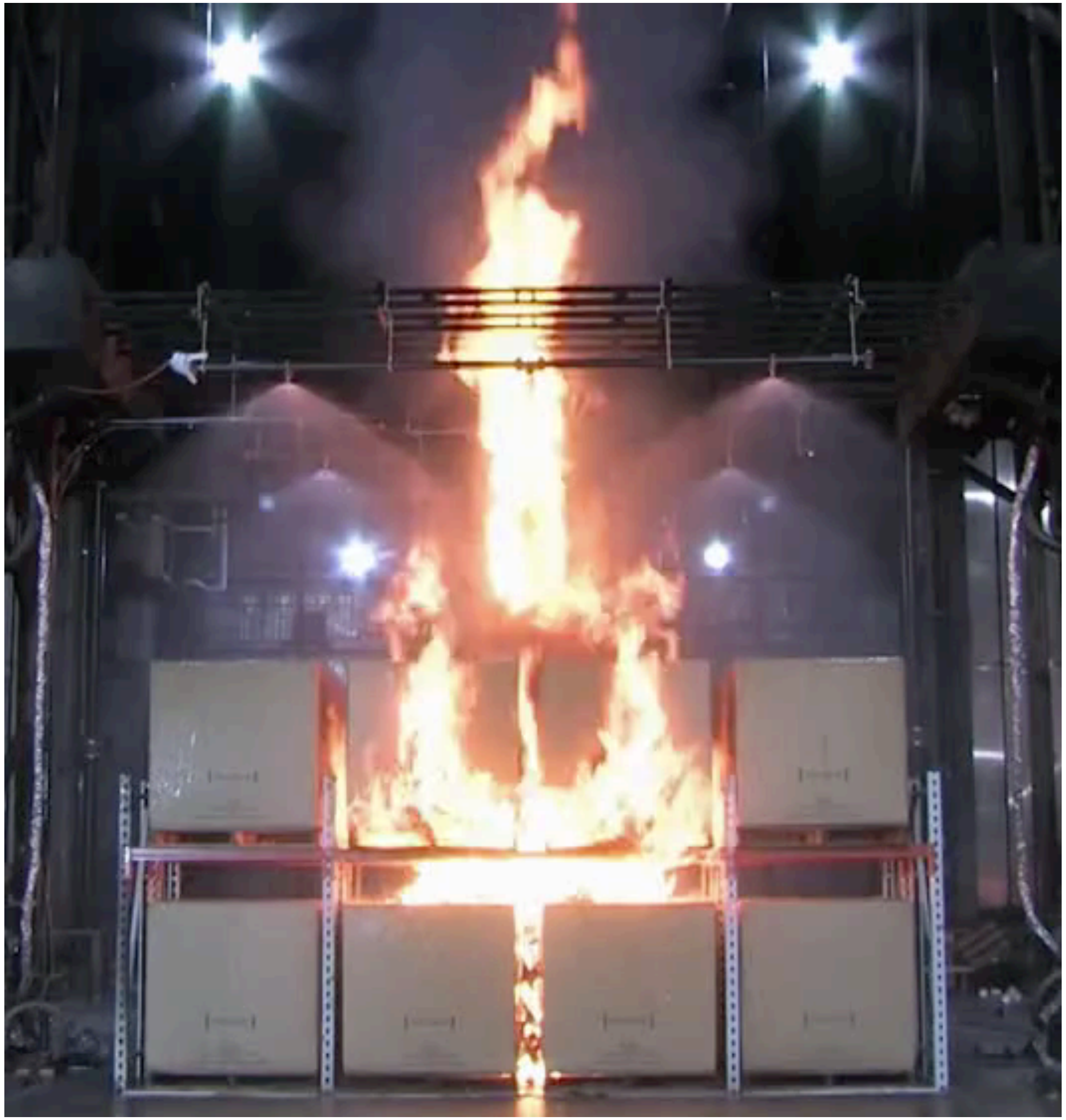


Objectives

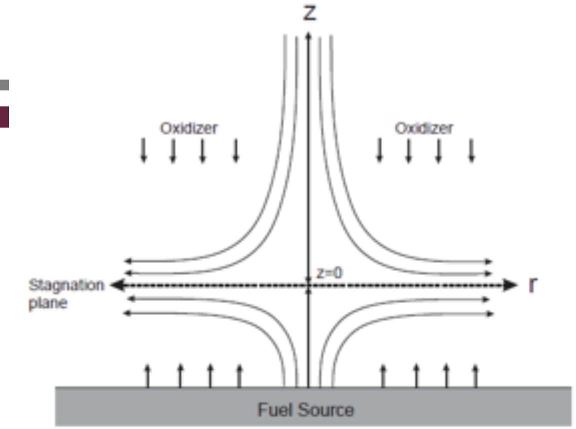
- Flame extinction
  - Develop a flame extinction model with the presence of water mist spray
- Validation
  - Bench-scale
    - Wolfhard-Parker line burner without spray (U. MD)
  - Full-scale
    - Enclosure fire suppression (H.Z. Yu et al.)

Flame extinction

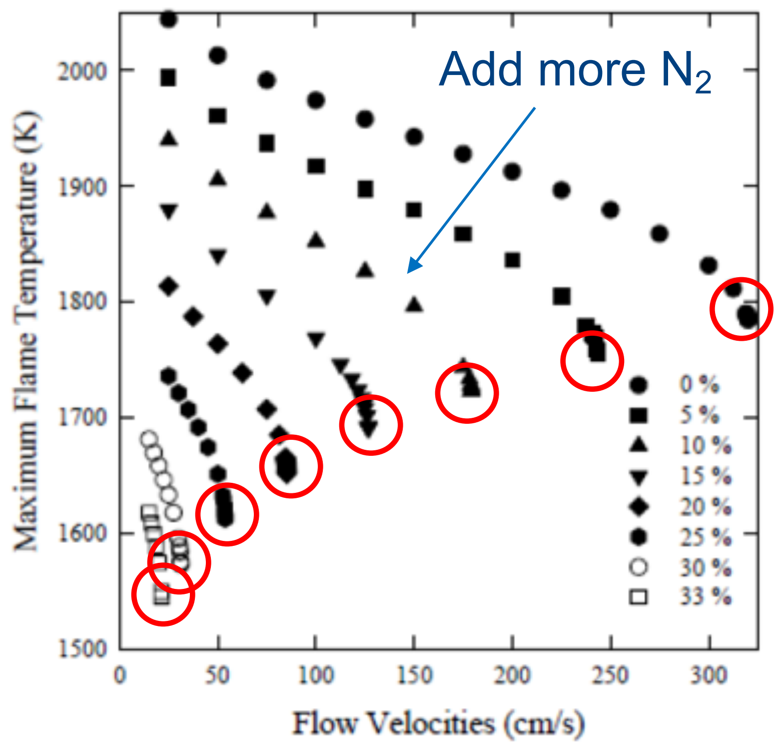
- Heat release rate
  - Fuel, oxidizer concentration
  - Flame temperature
- Heat loss rate
  - Strain rate
  - Radiation
  - Conduction
- Model
  - Critical flame temperature (FDS)
  - Temperature – strain rate

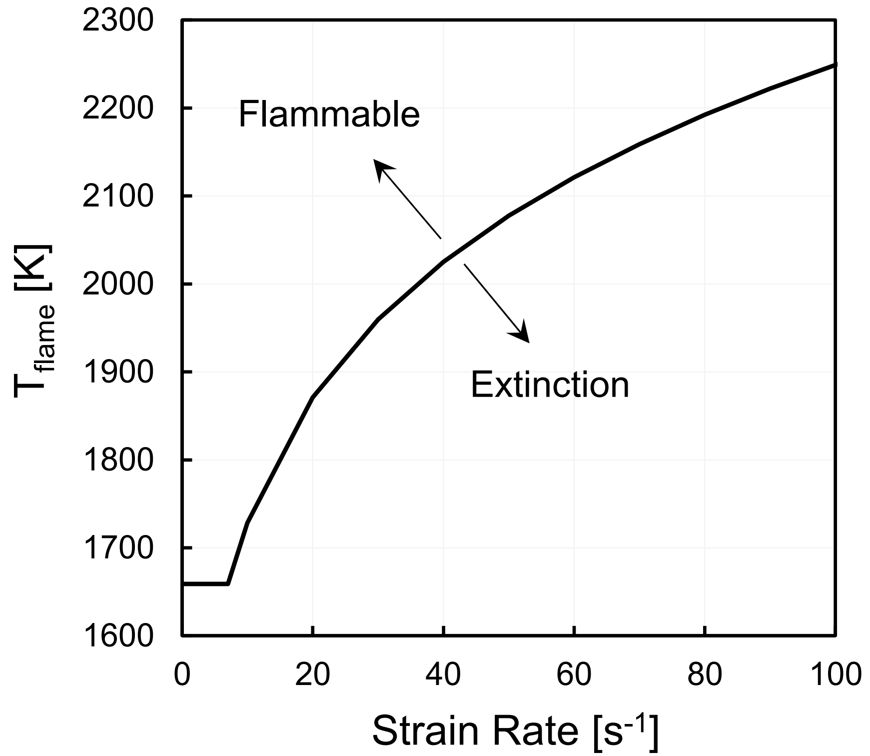


Temperature – strain rate



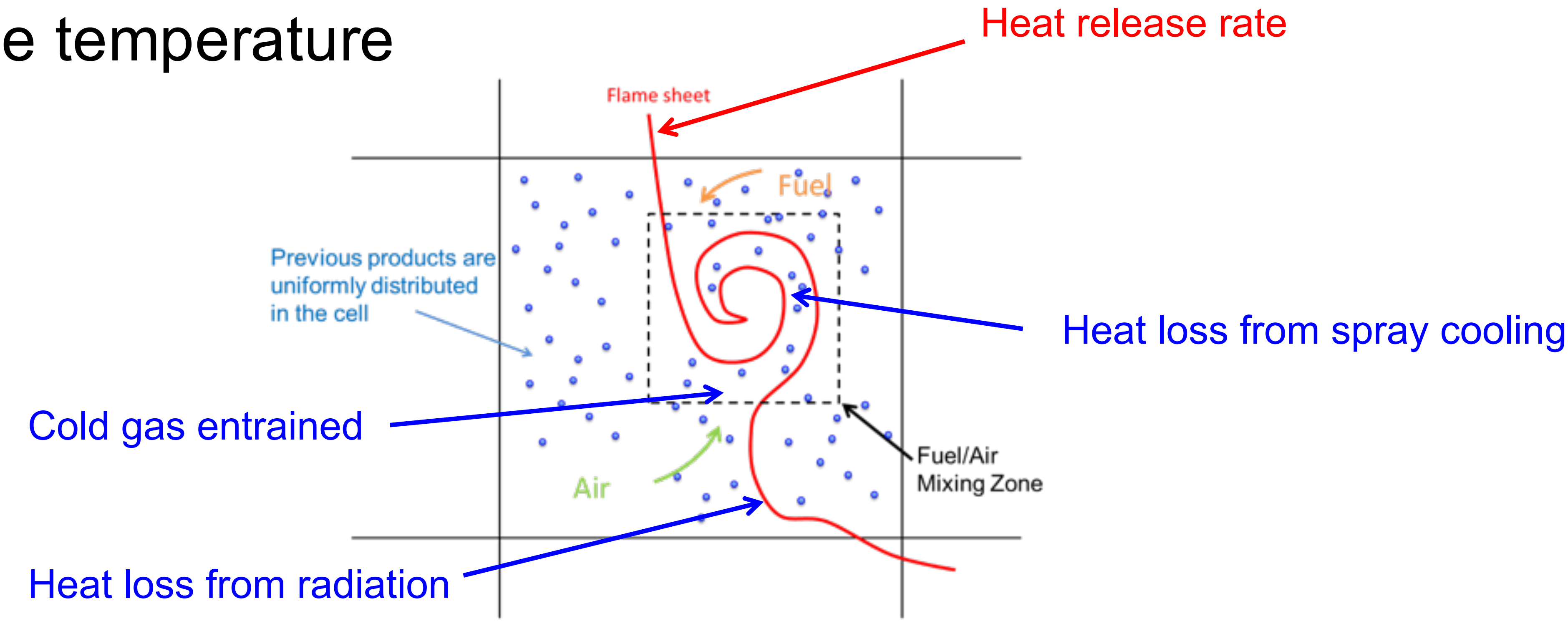
- Bert Yu
  - Opposite flow with detailed chemistry model (OPPDIF)





Sub-gird model

- Strain rate
  - Flame stretch $$S_{f,sgs} = C_{strain} \frac{\varepsilon_{sgs}}{k_{sgs}}$$
- Flame temperature

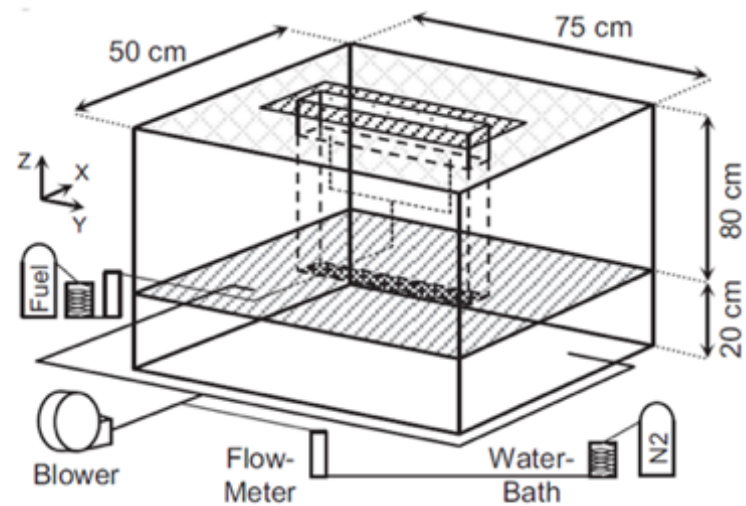


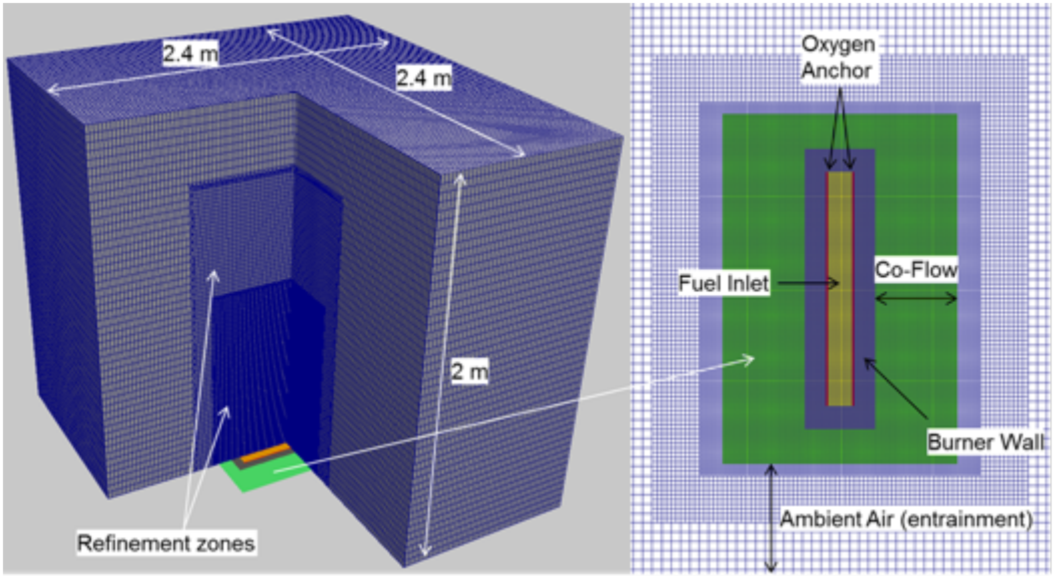
Bench-scale validation

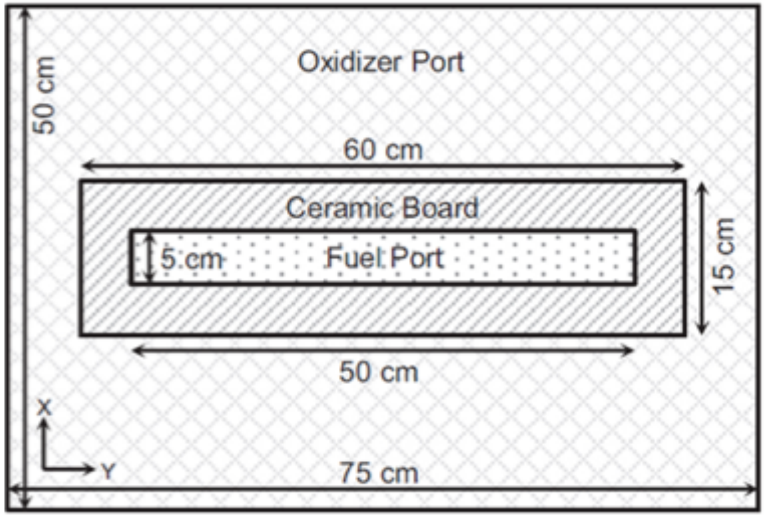
(Wolfhard-Parker Burner)

Validation (J. White et al.)

- Propane fires of 50 kW
- Inert quenching
  - Oxygen mole fraction ranges from 12% to 21% in co-flow

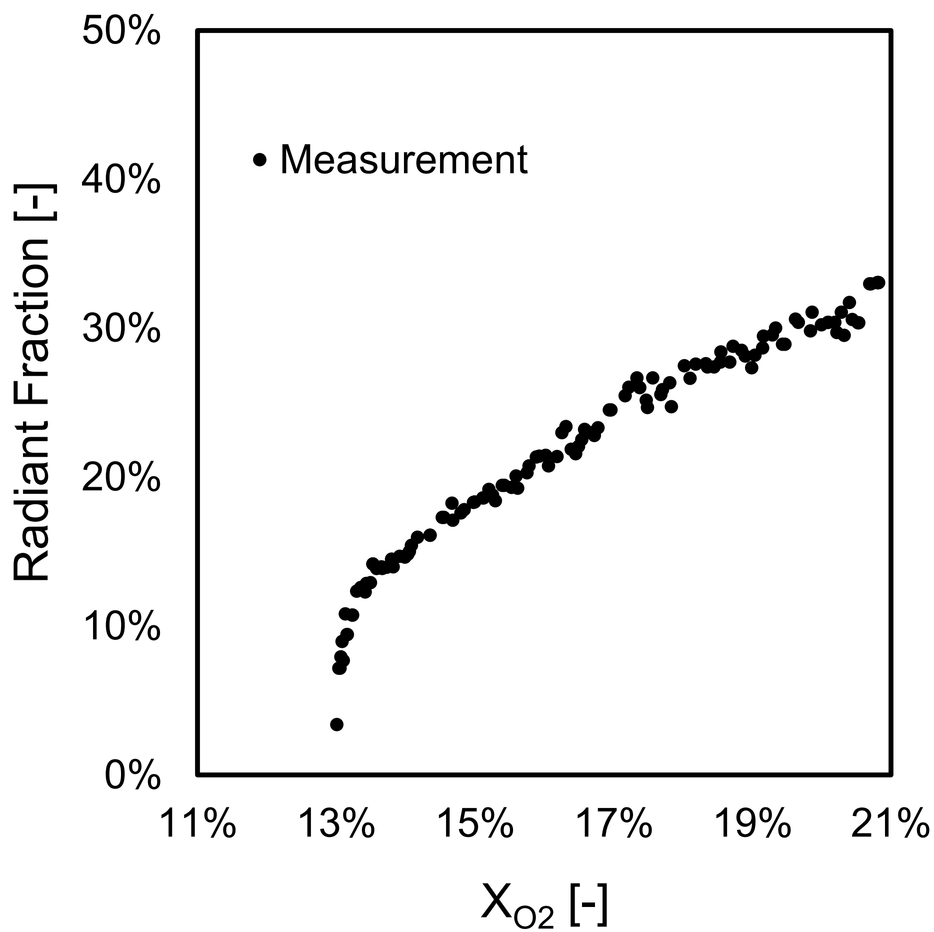


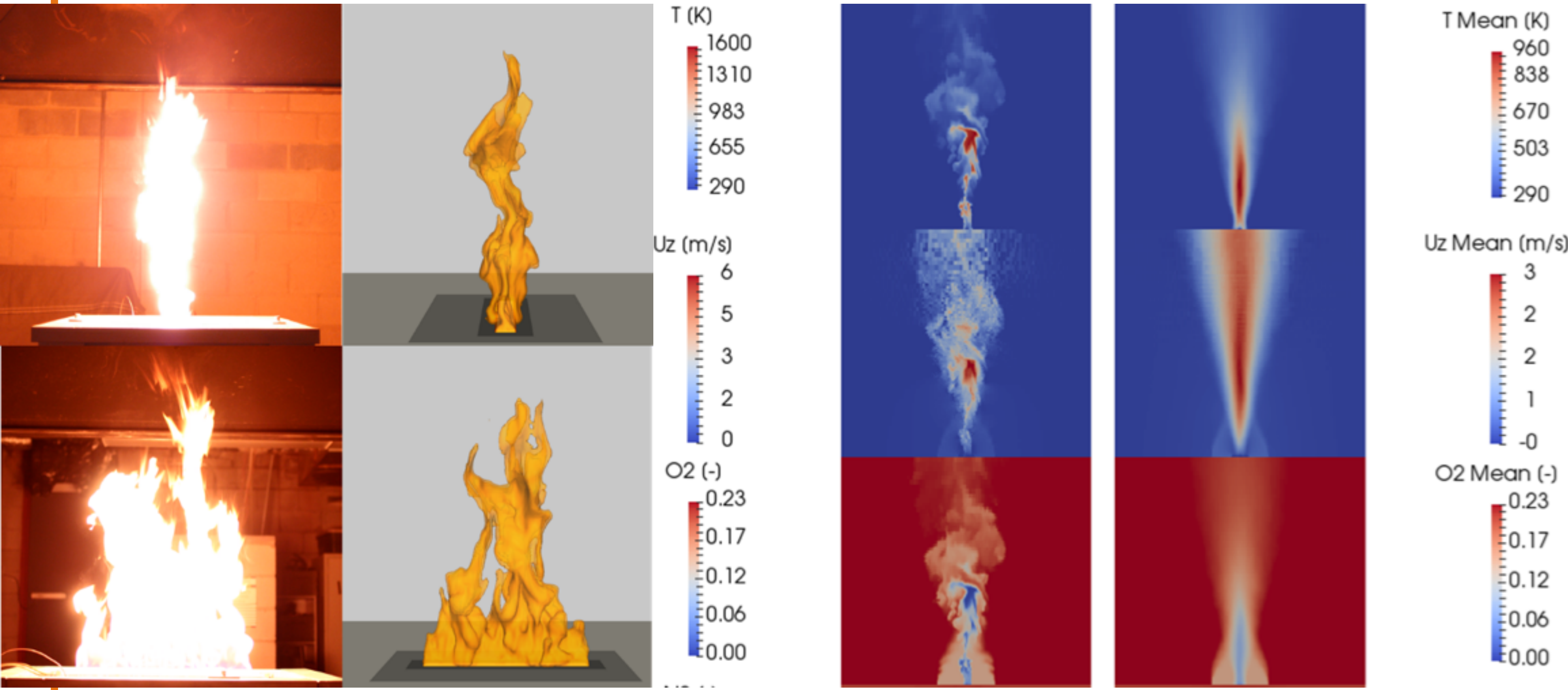




J.P. White, E.D. Link, A.C. Trouve, P.B. Sunderland A.W. Marshall, J.A. Sheffel, M.L. Corn, M.B. Colket, M. Chaos, H.Z. Yu, "Radiative emissions measurements from a buoyant, turbulent line flame under oxidizer-dilution quenching conditions," Fire Safety Journal, Vol. 76 (2015) pp. 74-84

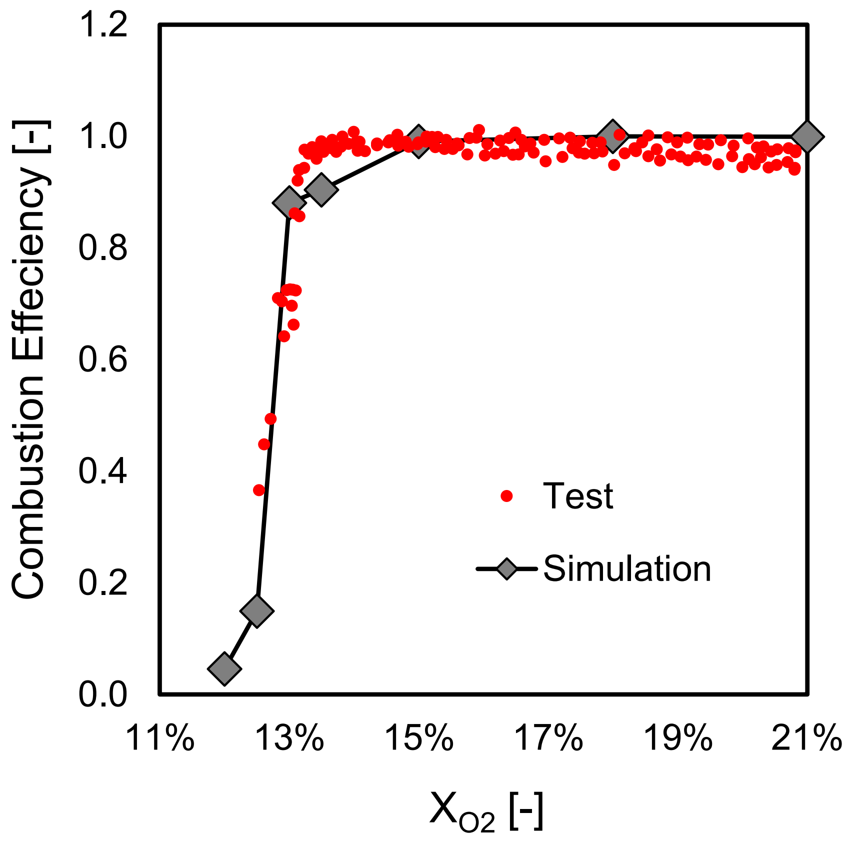
Radiation (J. White et al.)

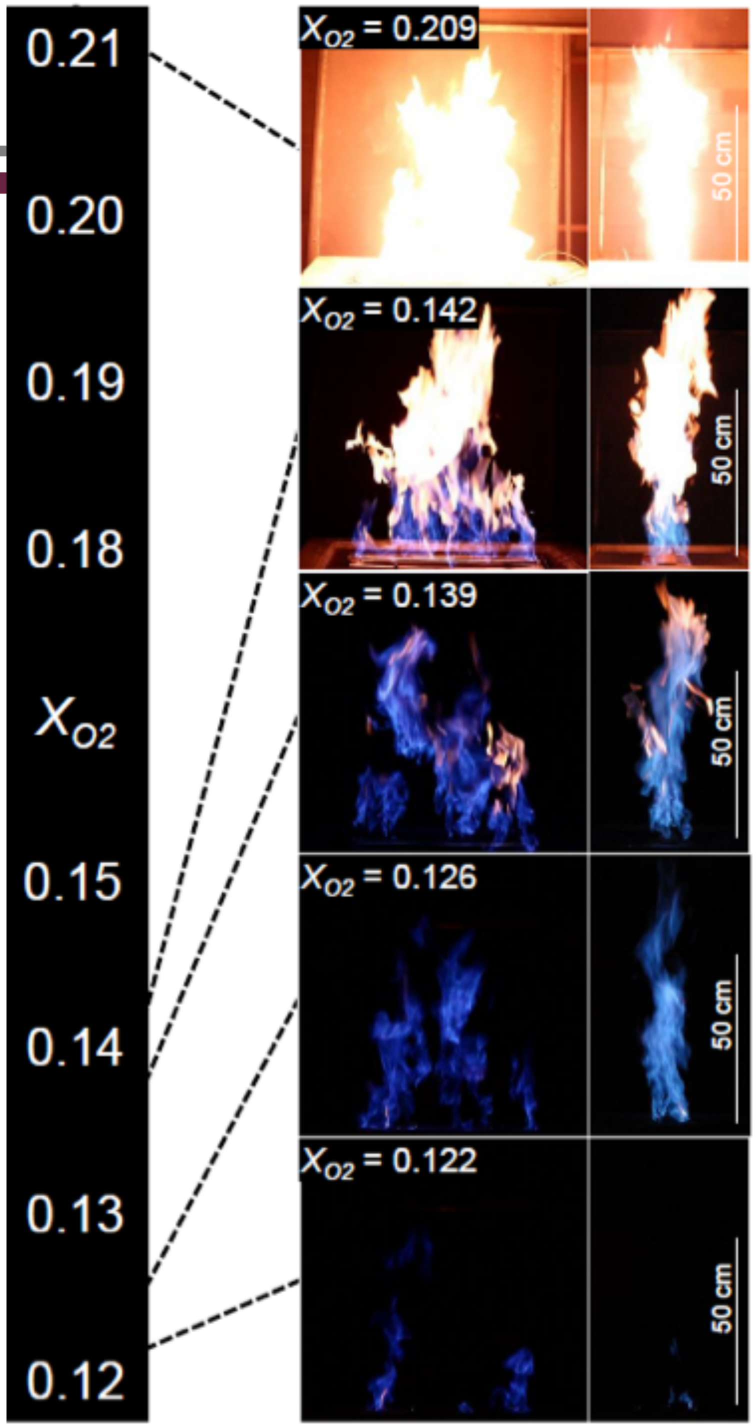



T (K)
1600
1310
983
655
290
Uz (m/s)
6
5
3
2
0
O2 (-)
0.23
0.17
0.12
0.06
0.00
T Mean (K)
960
838
670
503
290
Uz Mean (m/s)
3
2
2
1
-0
O2 Mean (-)
0.23
0.17
0.12
0.06
0.00

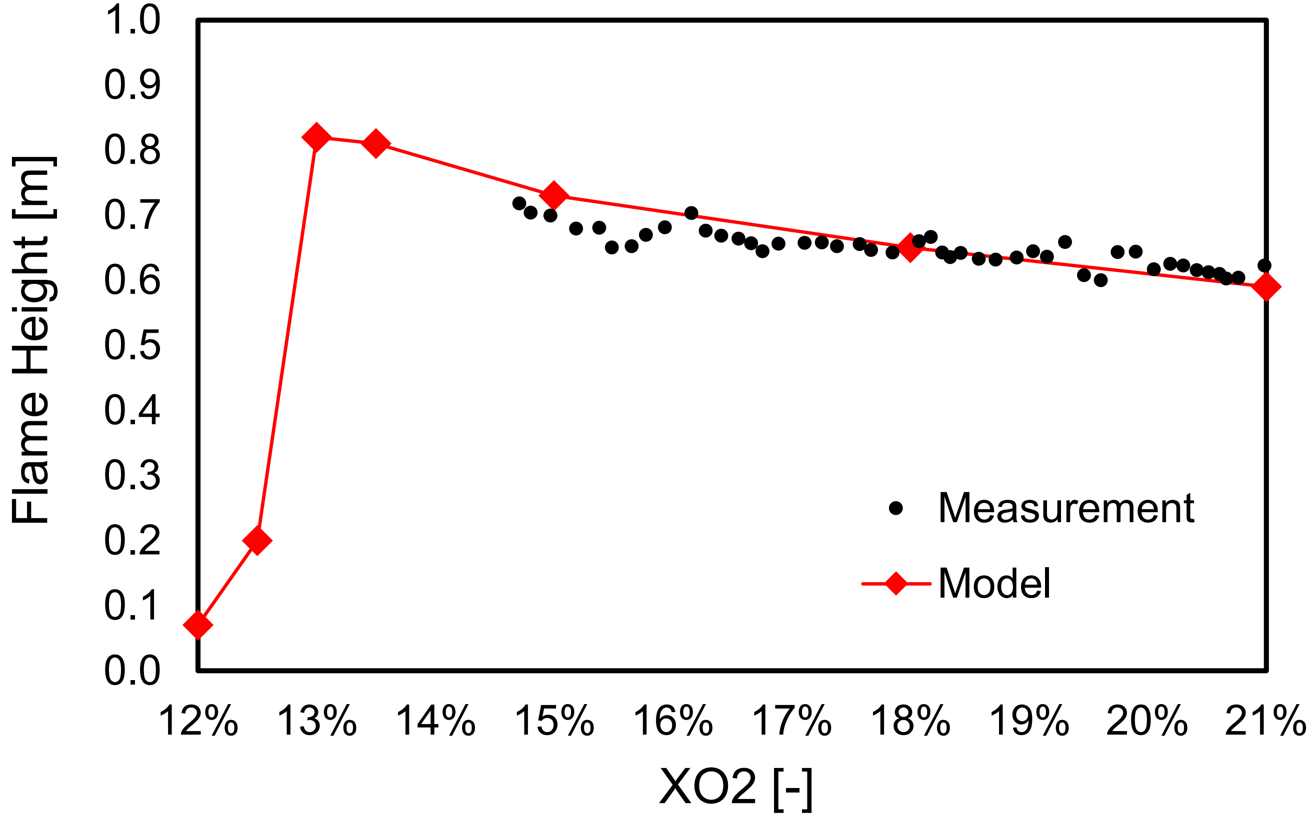
Combustion efficiency

Combustion efficiency $\frac{\overline{HRR}}{\dot{m}_F \Delta H_c}$





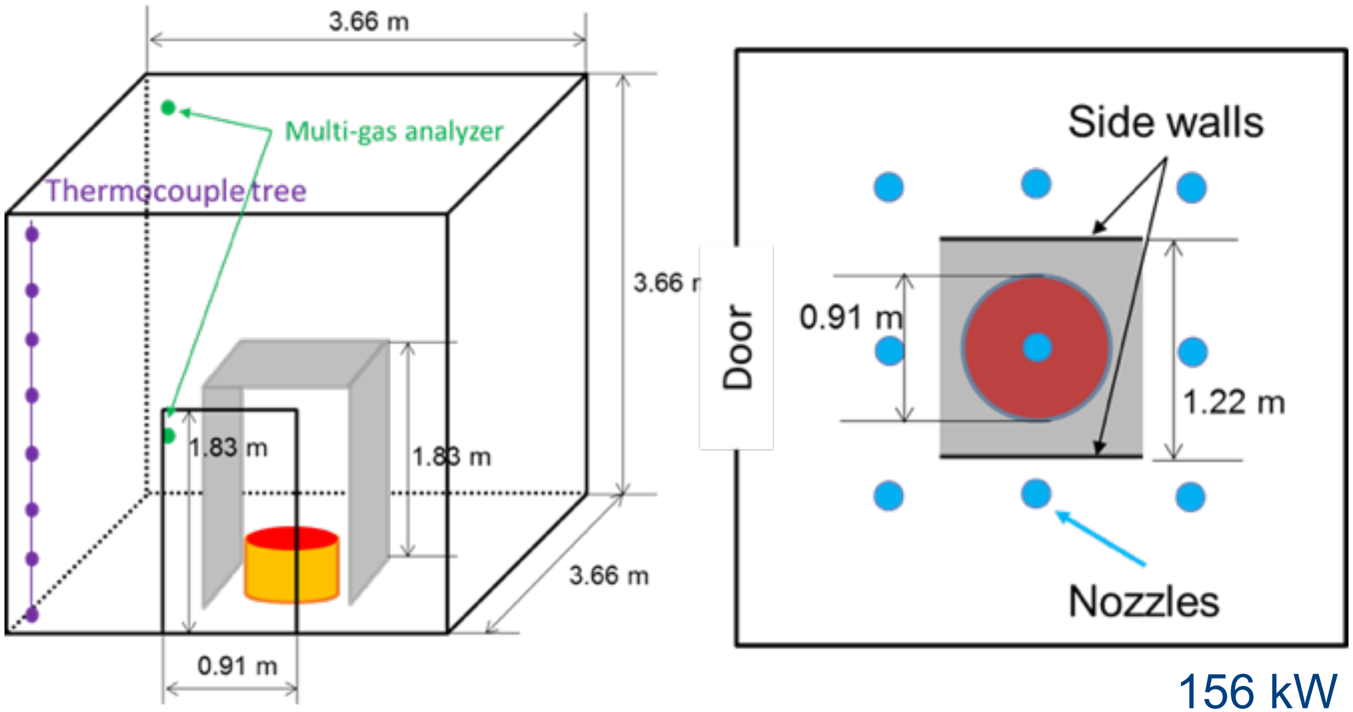
Flame height



Full-scale validation

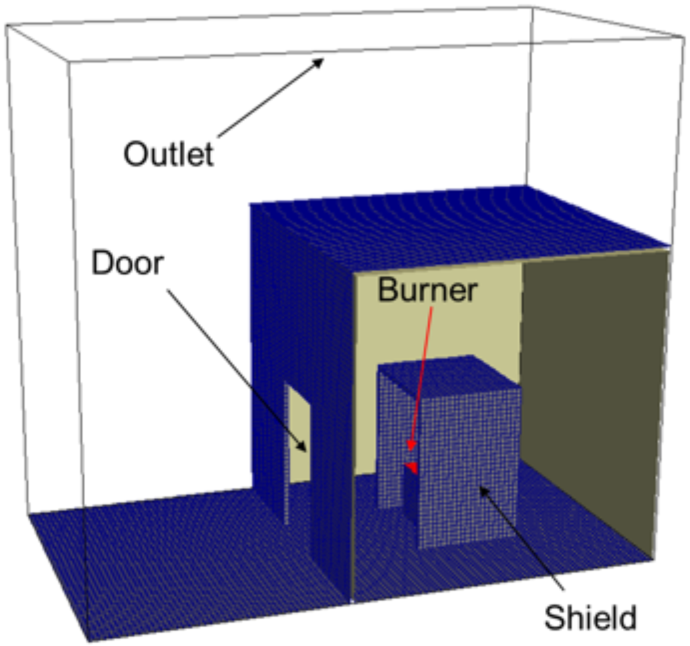
(Enclosure fire suppression)

Full scale enclosure fire



156 kW
686 kW

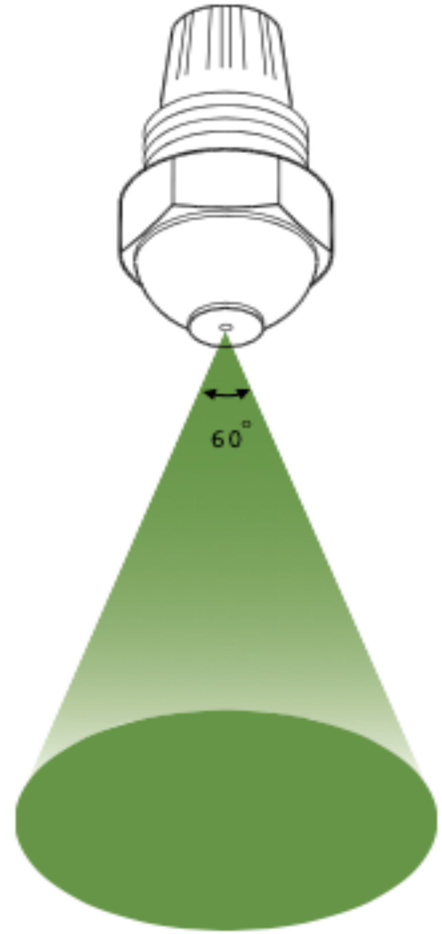
Experimental setup

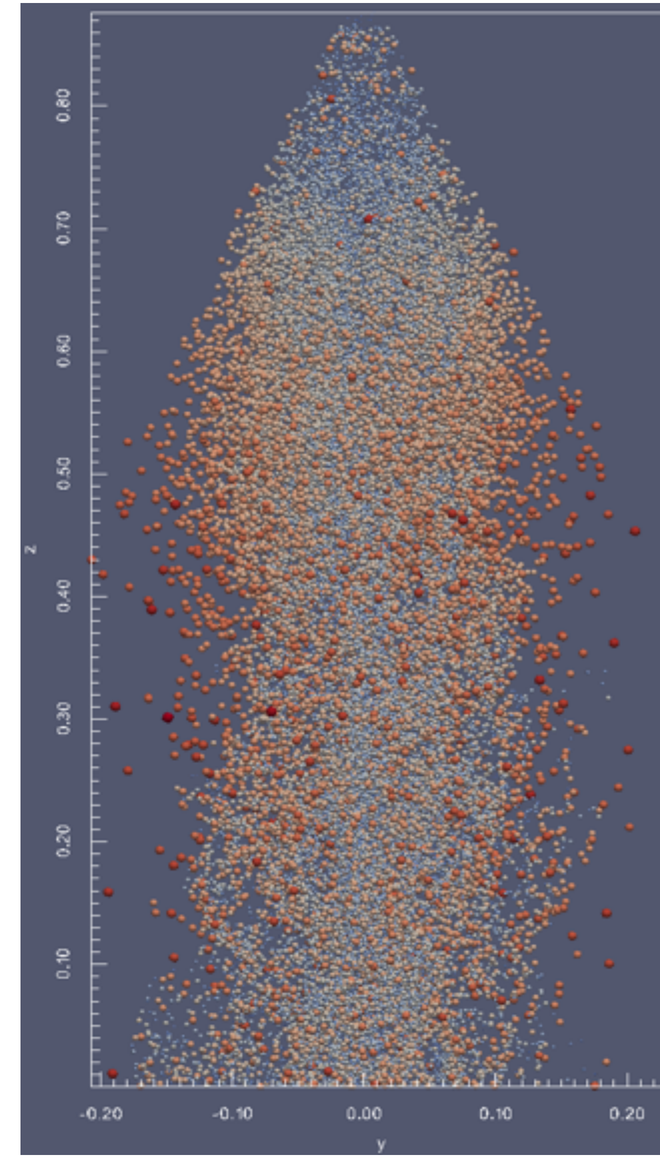


Numerical setup

Spray info

- Hago 20-60P nozzle
- Full cone with 60° cone angle
- Discharge pressure 41.4 bar (90 m/s)
- Flow rate 2.78 L/min per nozzle
- Median volumetric diameter of spray: 88 micron

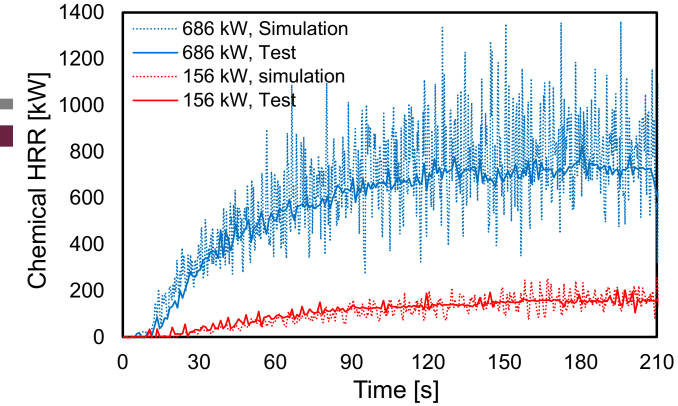


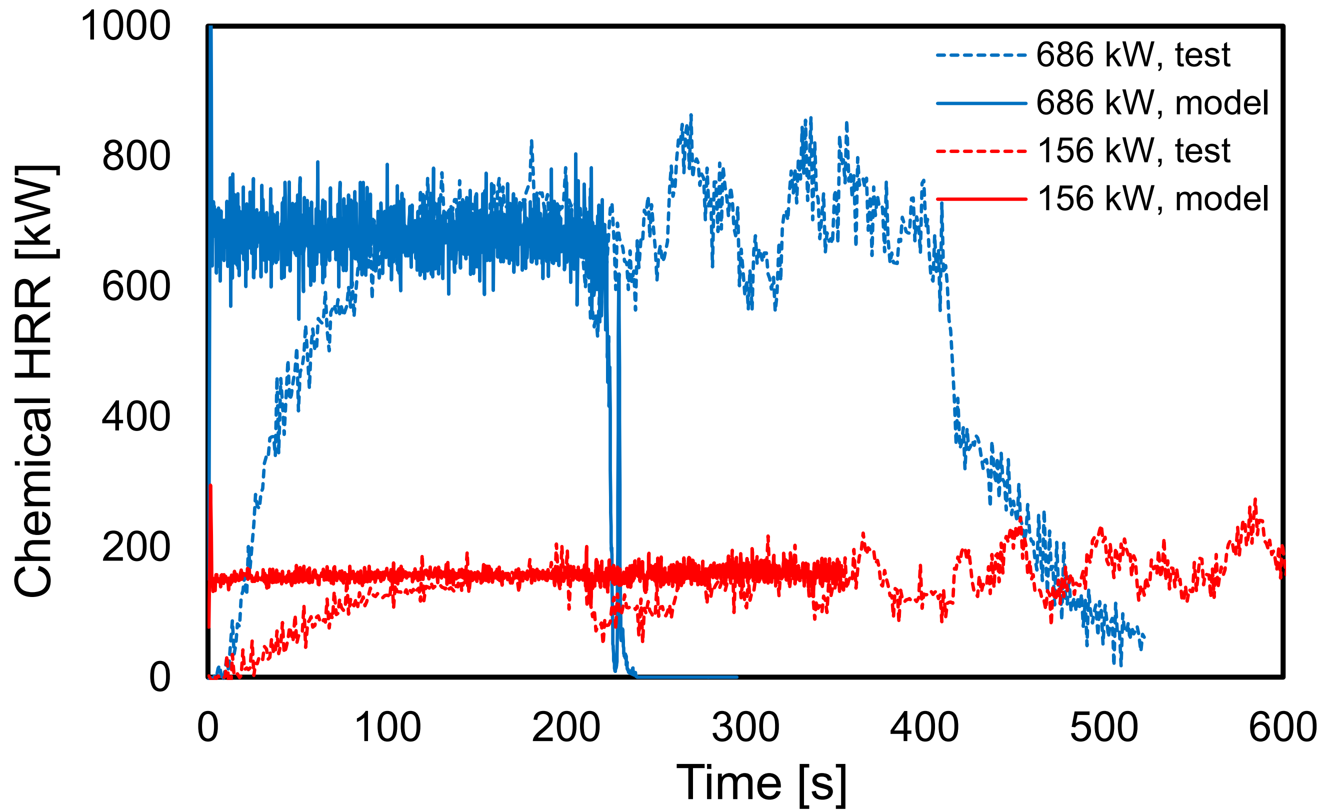


686 KW


t = 10 s
t = 210 s
Smoke layer
t = 246 s
36 s after injection
t = 249 s
t = 390 s
t = 402 s
t = 430 s
Global flame extinction
t = 433 s

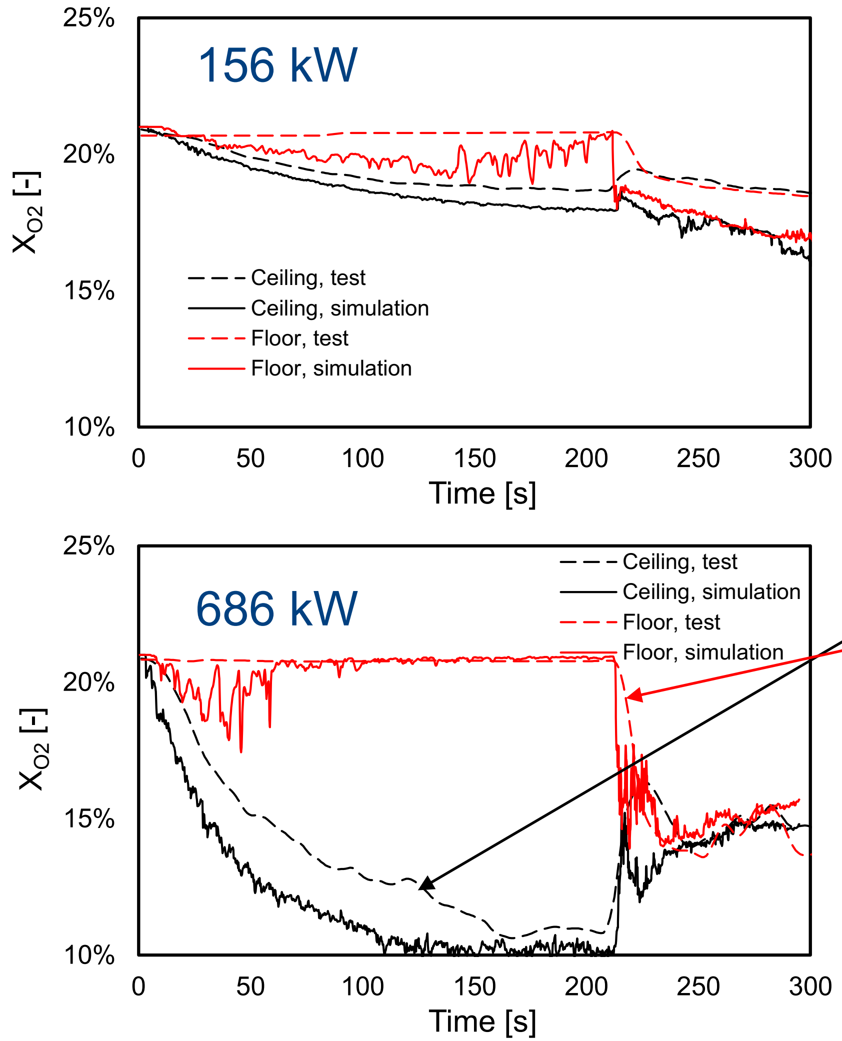
Chemical HRR

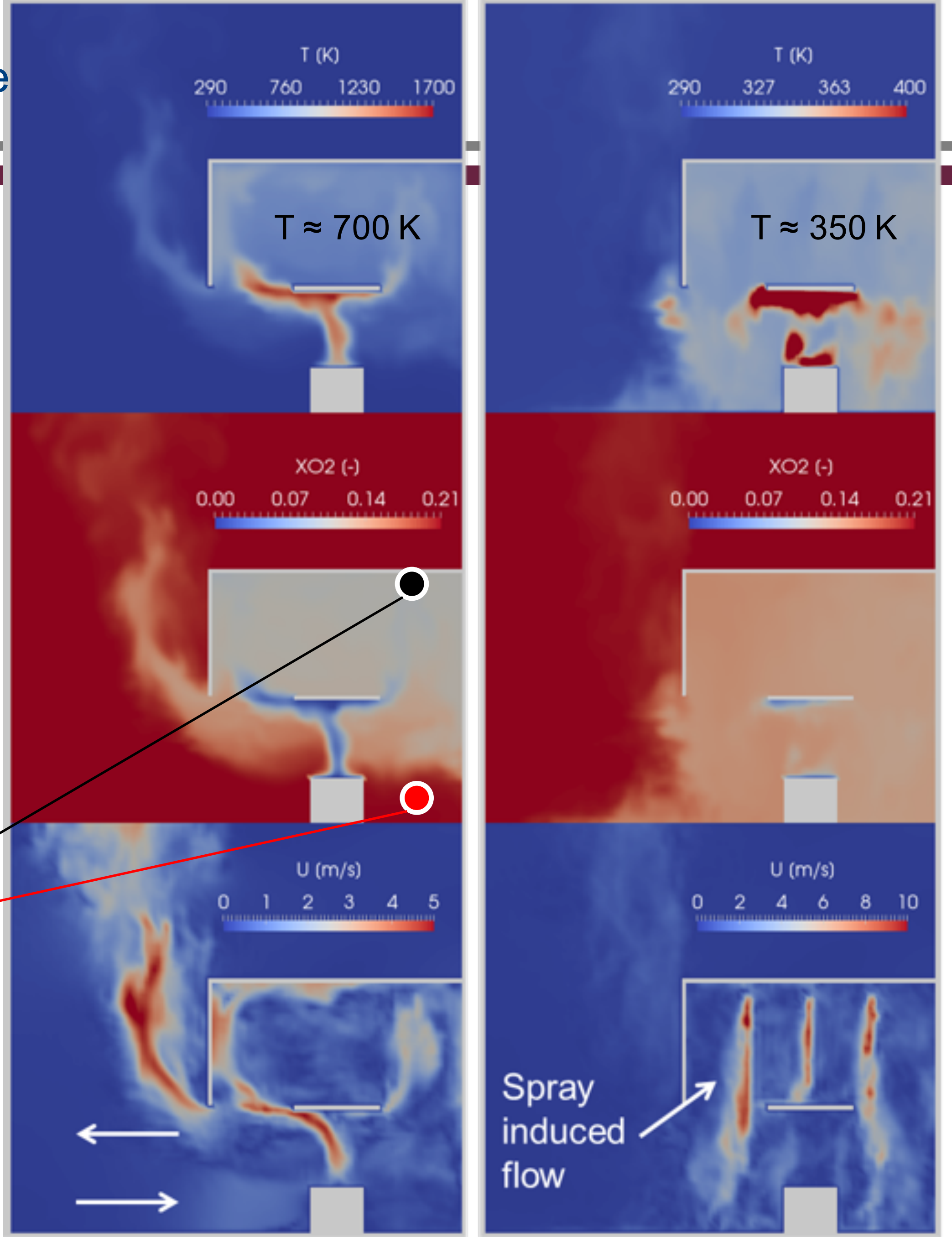




686 kW case

Oxygen depletion



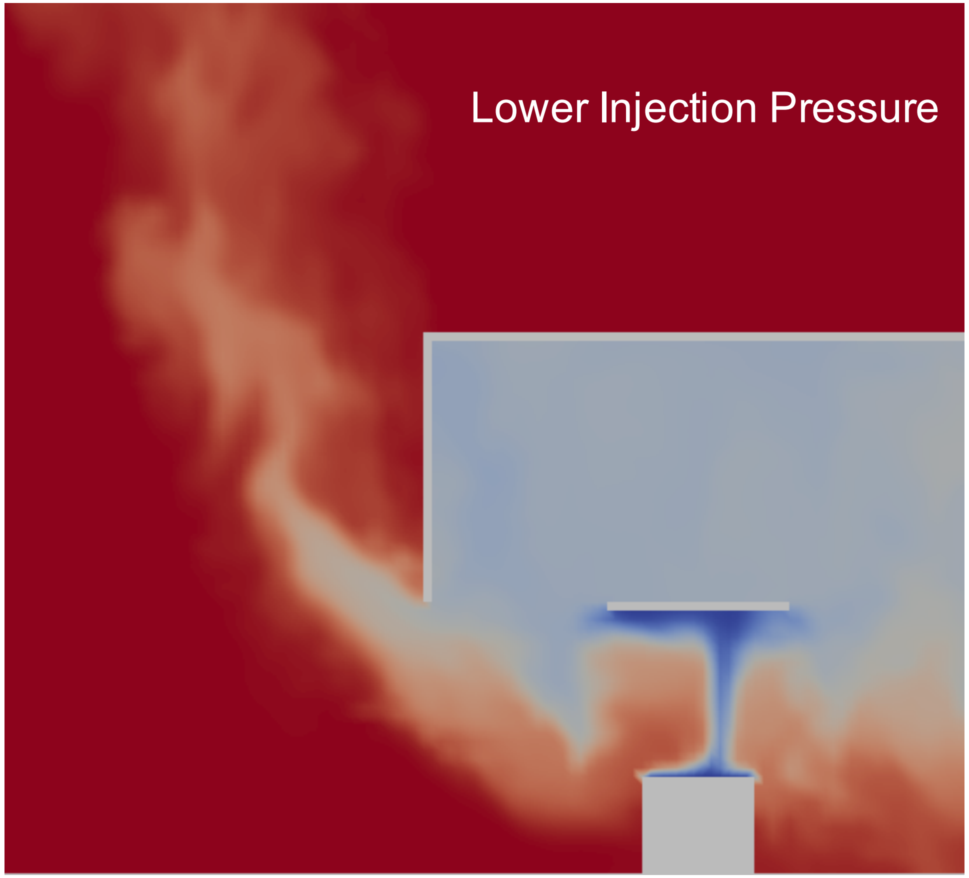


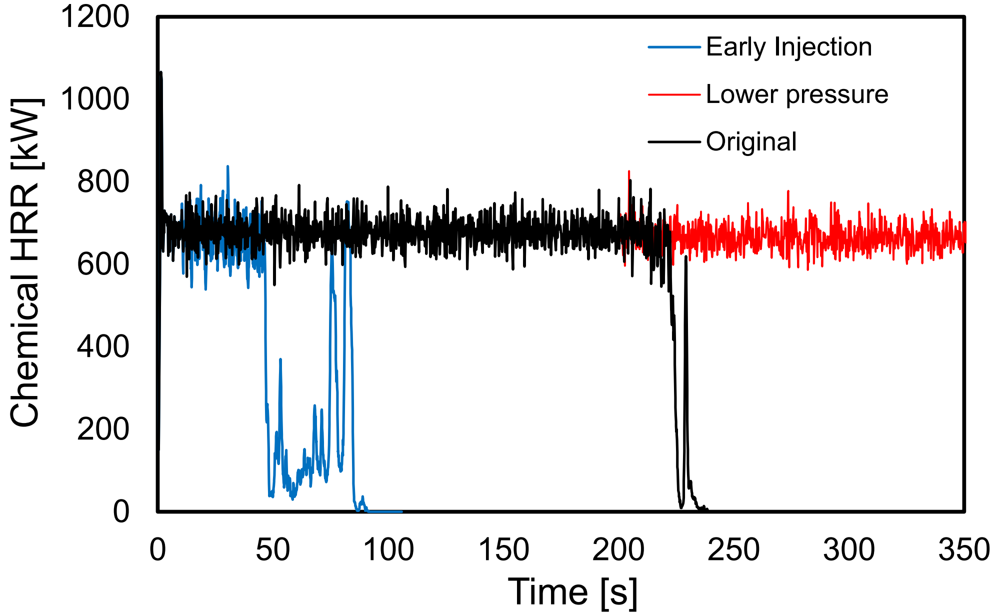
t = 210 s (before injection)

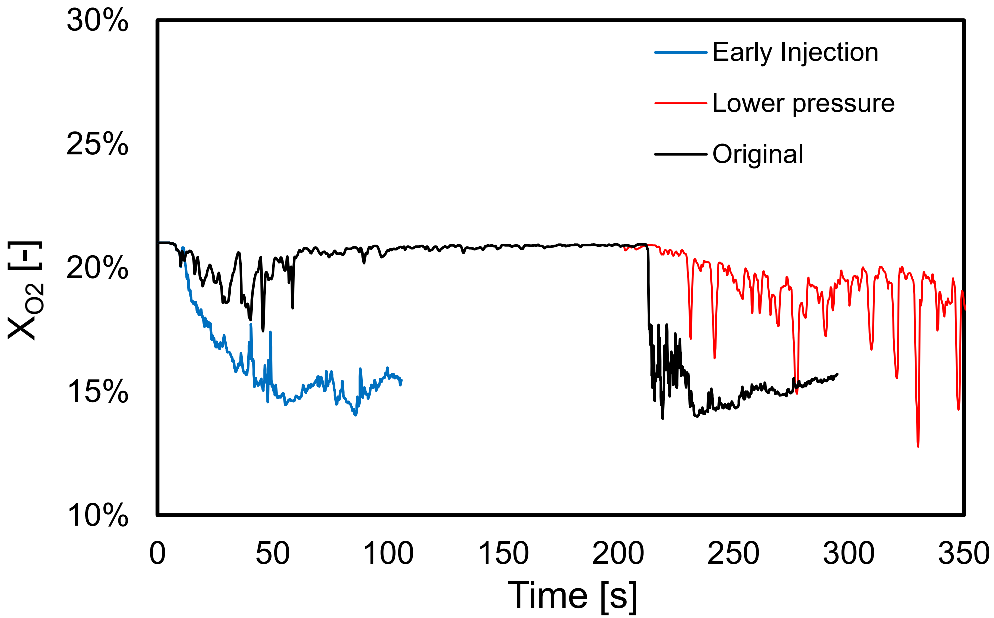
t = 230 s (after injection)

FM Global

Parametric study







Summary

- A temperature – strain rate based flame extinction model is developed in FireFOAM and validated
- Wolfhard-Parker line burner
  - Inert thermal-quenching
- Enclosure fire suppression
  - Spray mixing is important
  - Hot smoke layer enhance spray evaporation
    - Larger fire & hotter environment facilitates flame extinction

Acknowledgement

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  - Sergey B. Dorofeev
  - Louis Gritzo
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  - Prof. André Marshall
  - Prof. Arnaud Trouvé
  - Dr. James White

Questions?