# SMOKE PROPAGATION IN TUNNELS – COMPARSION OF IN-SITU MEASUREMENTS, SIMULATIONS AND LITERATURE

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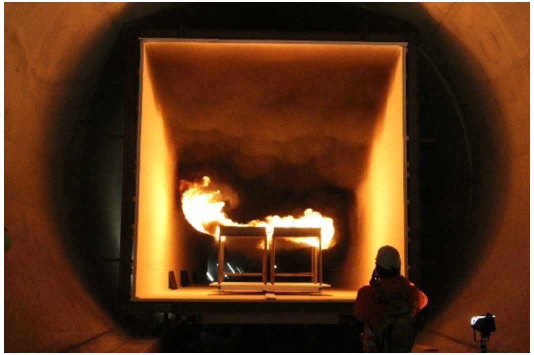
# Motivation

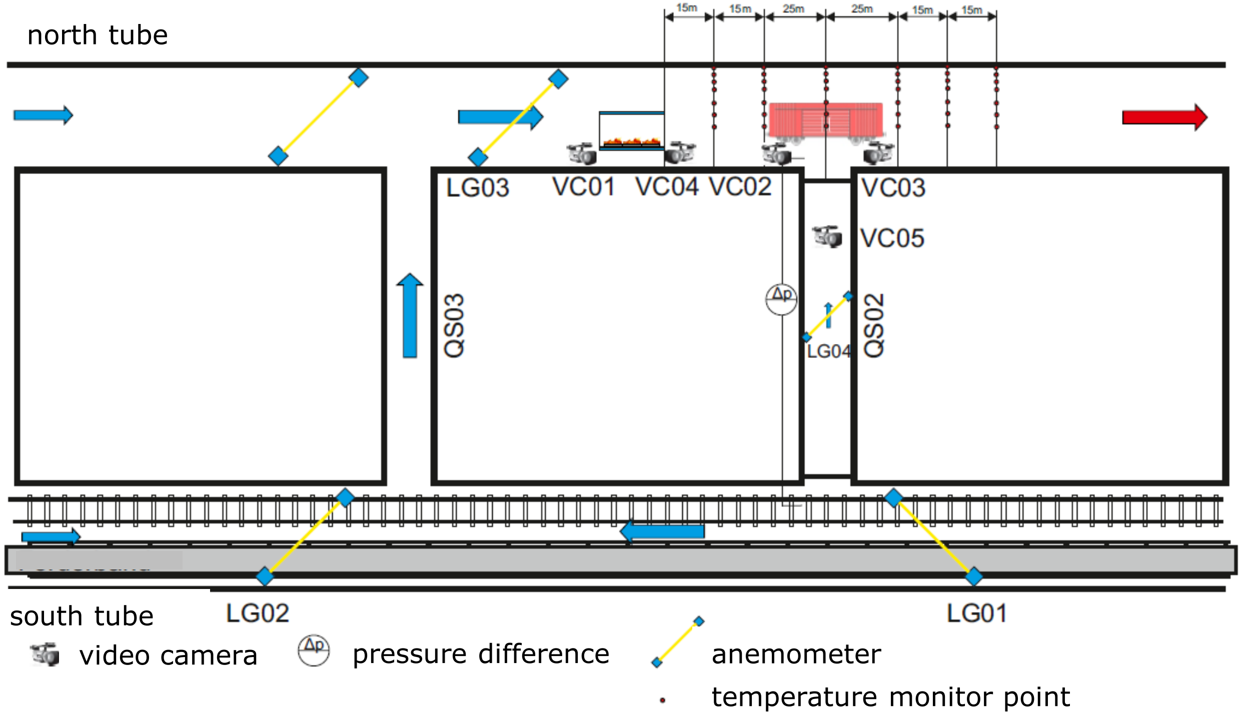
- More information about the smoke propagation in the near fire region (backlayering)
- Validation of CFD models
- Comparison to international standards and literature

# Review – Koralmtunnel (KAT) fire tests

- Full scale fire tests in Koralmtunnel (Austria) carried out by IVT and ÖBB in 2016-2017 (see: “Hot smoke tests for smoke propagation investigations in long rail tunnels”, Fire Safety Journal, Volume 105, April 2019)
- 14 pool fire tests including HRRs up to 21MW



# Review – KAT fire tests



# Numerical investigations

- CFD code: FDS 6.7
- 2 reference cases:

| | vel_avg [m/s] | no. pools [#] | HRR_avg [MW] | HRR_peak [MW] | Duration [min] |
|---|---|---|---|---|---|
| Test 3 | 1.22 | 2 | 2.3 | 4.0 | 15 |
| Test 7 | 1.5 | 8 | 14.5 | 19.5 | 8 |

- Calc. domain: 350m x 10m x 10m
- Base grid: 0.25m x 0.25m x 0.25m

# Numerical investigations

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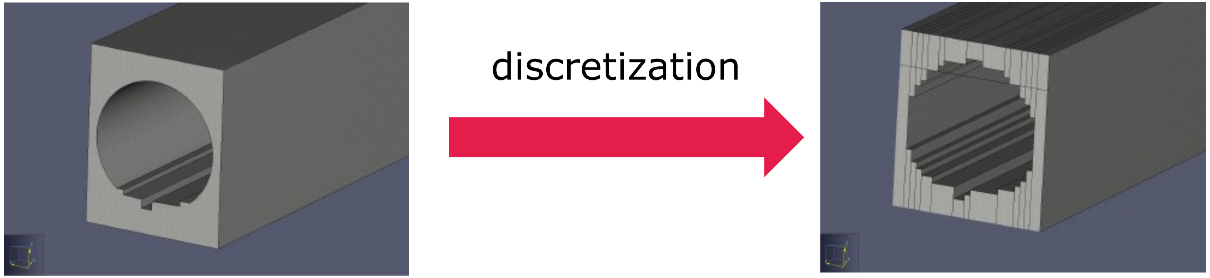
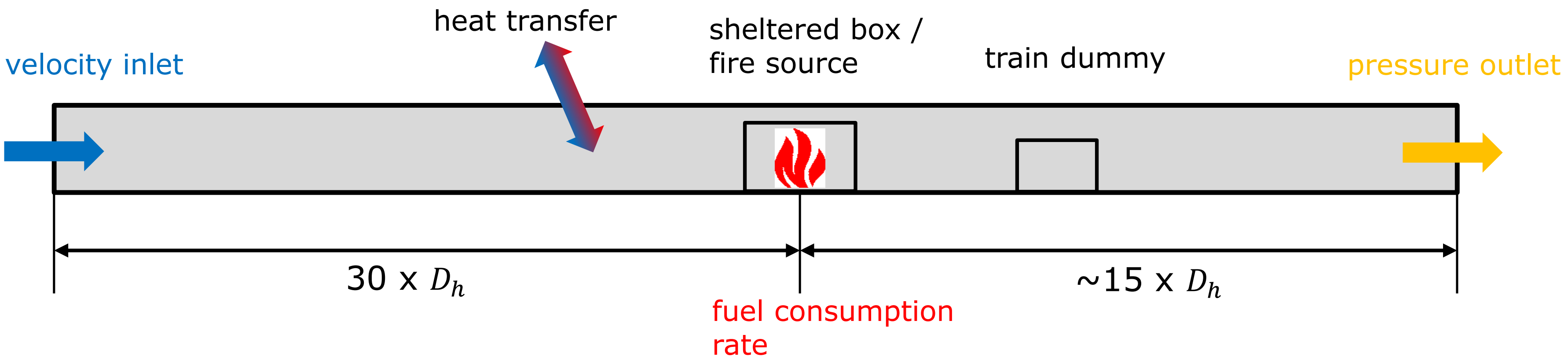
- Base grid:

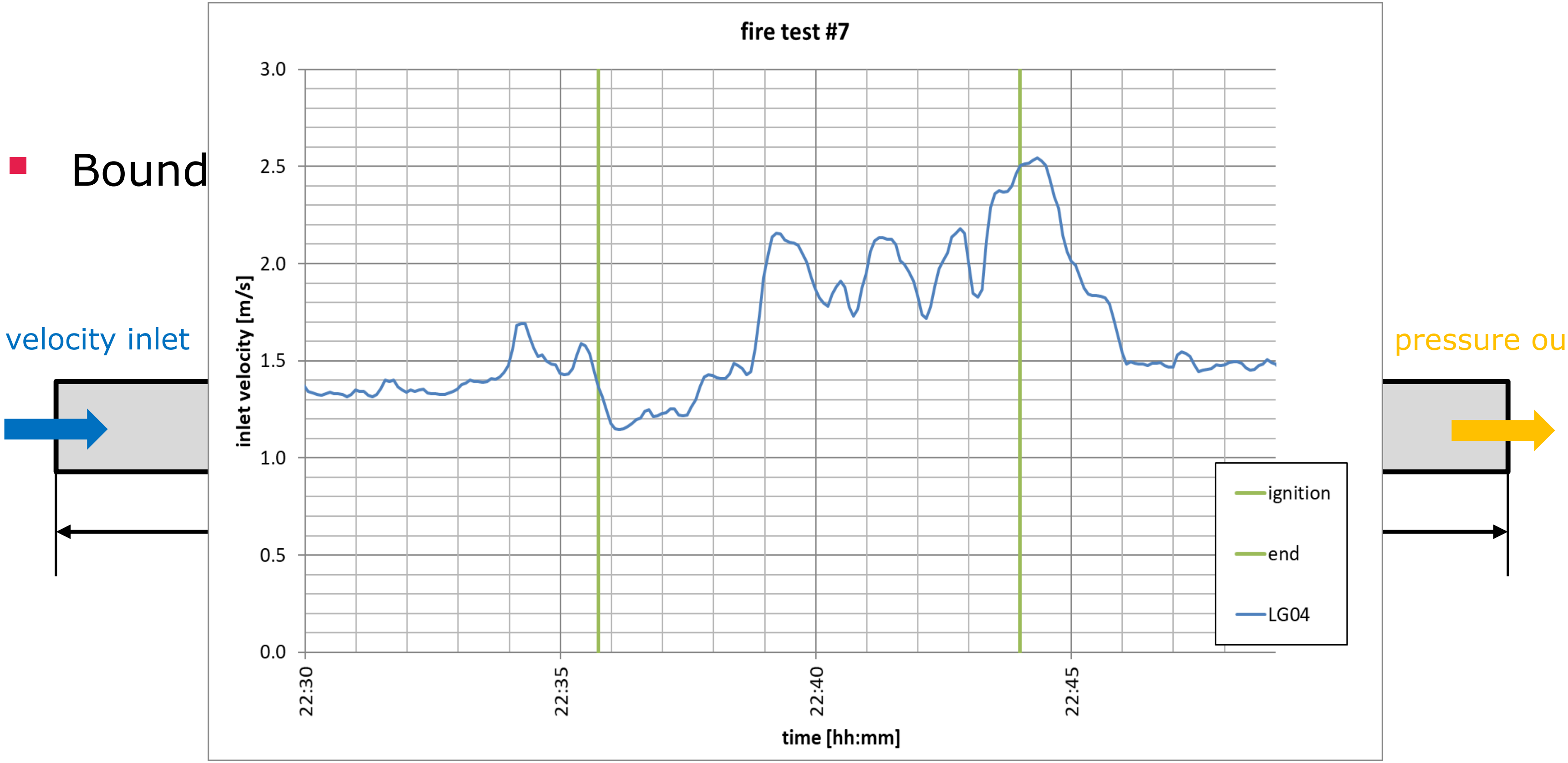


# Numerical investigations

- Boundary conditions

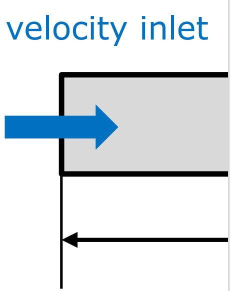


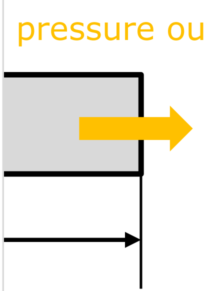
- Bound

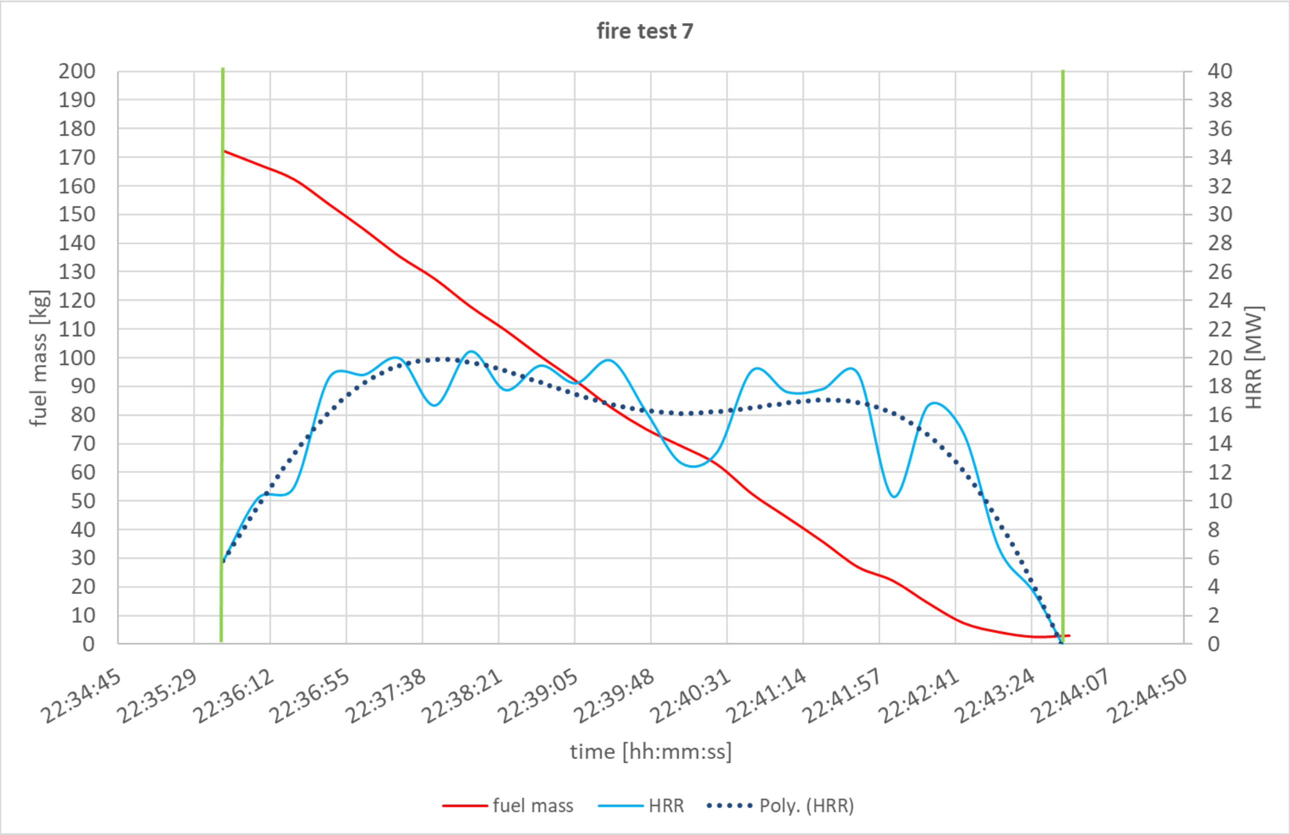


velocity inlet
pressure outlet
fire test #7
3.0
2.5
2.0
1.5
1.0
0.5
0.0
inlet velocity [m/s]
22:30
22:35
22:40
22:45
time [hh:mm]
ignition
end
LG04

- Bound


velocity inlet


pressure outlet


fire test 7
fuel mass [kg]
HRR [MW]
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
22:34:45
22:35:29
22:36:12
22:36:55
22:37:38
22:38:21
22:39:05
22:39:48
22:40:31
22:41:14
22:41:57
22:42:41
22:43:24
22:44:07
22:44:50
time [hh:mm:ss]
fuel mass
HRR
Poly. (HRR)

# Numerical investigations

- Combustion model: simple chemistry model

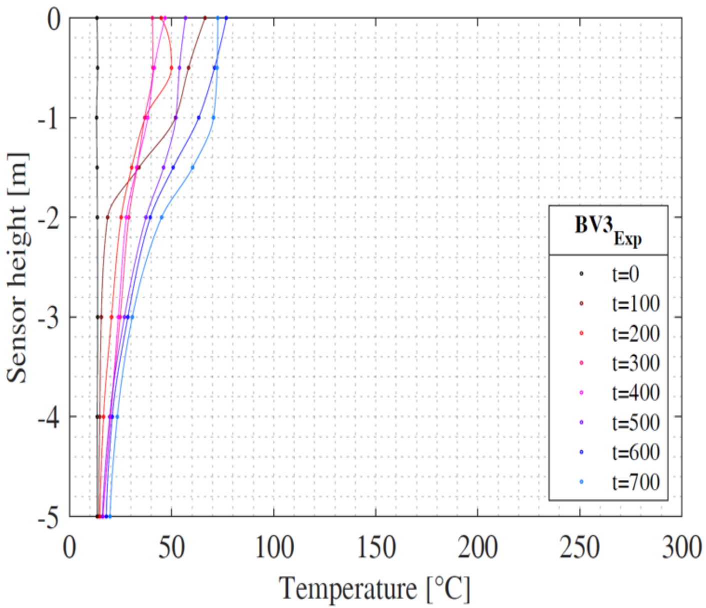
| Variable | Value | Unit |
|---|---|---|
| Carbon – mol fraction | 0.344 | mol/mol_fuel |
| Oxygen –mol fraction | 0.002 | mol/mol_fuel |
| Hydrogen – mol fraction | 0.654 | mol/mol_fuel |
| Rate of Combustion | 42.6 | MJ/kg_fuel |
| Radiative fraction | 33 | % |
| CO – yield | 0.01 | kg/kg_fuel |
| Soot - yield | 0.04 | kg/kg_fuel |

# Results

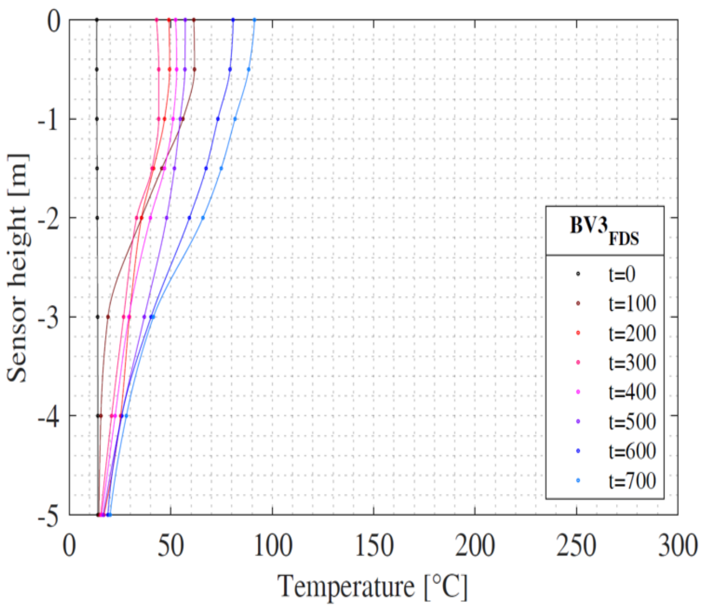
## test 3:

- 2 pools
- HRR_avg = 2.3MW
- HRR_peak = 4.0MW
- v_air_avg = 1.22m/s

experiment




FDS

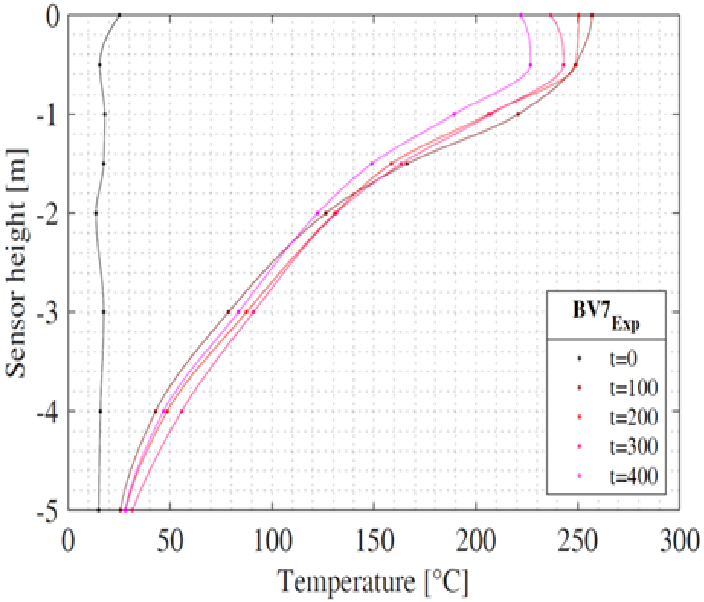


# Results

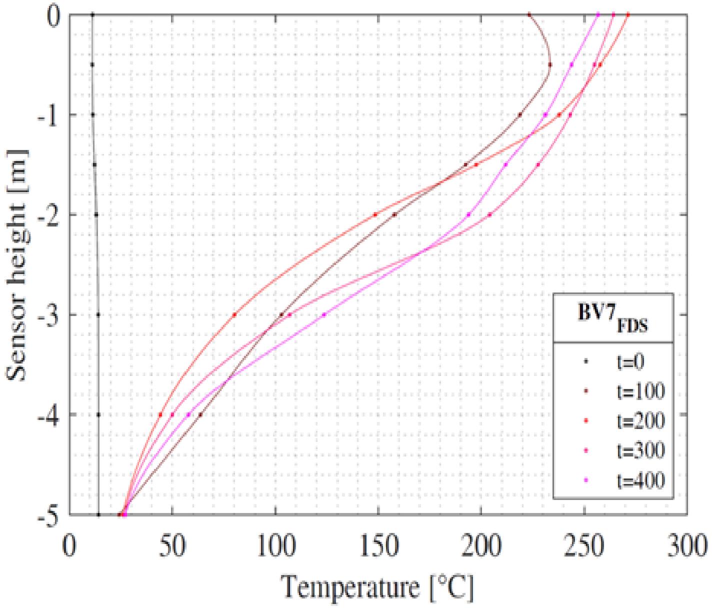
## test 7:

- 8 pools
- HRR_avg = 14.5MW
- HRR_peak = 19.5MW
- v_air_avg = 1.5m/s

experiment




FDS



# Backlayering

- Approaches from literature:

  - Thomas: $$L_B = H * 0.6 * \left(\frac{2*g*H*\dot{Q}}{\rho_0*c_p*T_0*U_0^3*A} - 5\right)$$

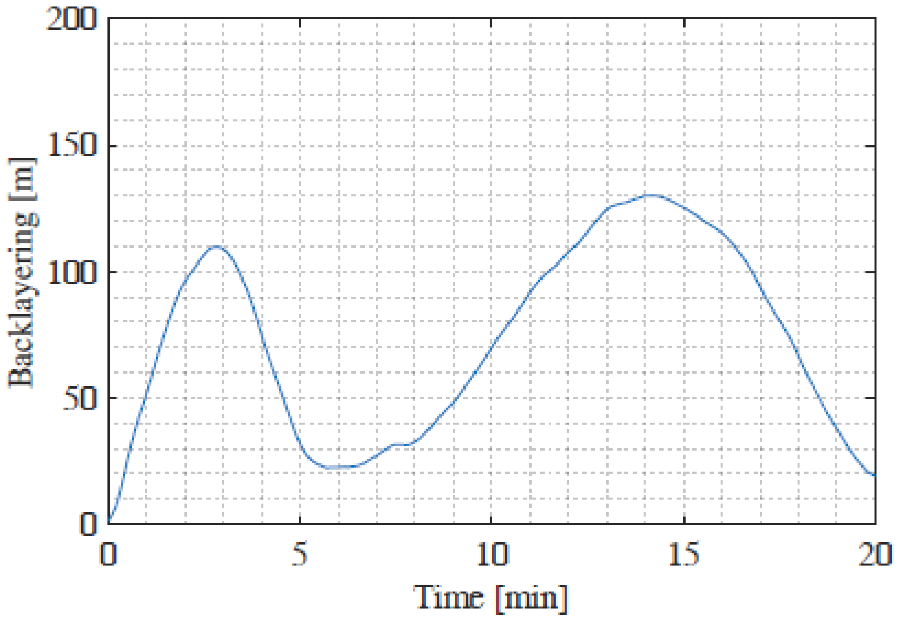
  - Li/Ingason°: $$L_B = H * 18.5 * ln\left(0.81 * {Q^*}^{1/3} / u^*\right); \quad Q^* \leq 0.15$$

    $$L_B = H * 18.5 * ln(0.43 / u^*); \quad Q^* > 0.15$$

°Equations are derived for short backlayering lengths (<50m)

# Backlayering - Results

FDS simulation: backlayering as a function of time during KAT test 3



# Backlayering - Results

| Test | Experiment | | | FDS simulation | | Thomas | | Li/Ingason | |
|---|---|---|---|---|---|---|---|---|---|
| no. | Peak. HRR | supply air velocity | **Backlayering length** | **Backlayering length** | % from experiment | **backlayering length** | % from experiment | **backlayering length** | % from experiment |
| [-] | [MW] | [m/s] | **[m]** | **[m]** | [%] | **[m]** | [%] | **[m]** | [%] |
| 3 | 4.0 | 1.10 | **90** | **130** | *145* | **85** | *71* | **77** | *86* |
| 4 | 7.7 | 1.30 | **90** | **140** | *156* | **103** | *114* | **83** | *92* |
| 5 | 11.5 | 1.61 | **120** | **100** | *84* | **79** | *66* | **74** | 61 |
| 6 | 14.3 | 2.00 | **110** | **100** | *90* | **43** | *39* | **57** | *52* |
| 7 | 19.5 | 1.25 | **160** | **150** | *94* | **256** | *160* | **103** | *64* |
| 8 | 6.7 | 1.32 | **100** | **140** | *140* | **82** | *82* | **76** | *76* |
| 13 | 21.0 | 1.72 | **140** | **135** | 97 | **124** | 89 | **75** | 54 |

# Backlayering - Results

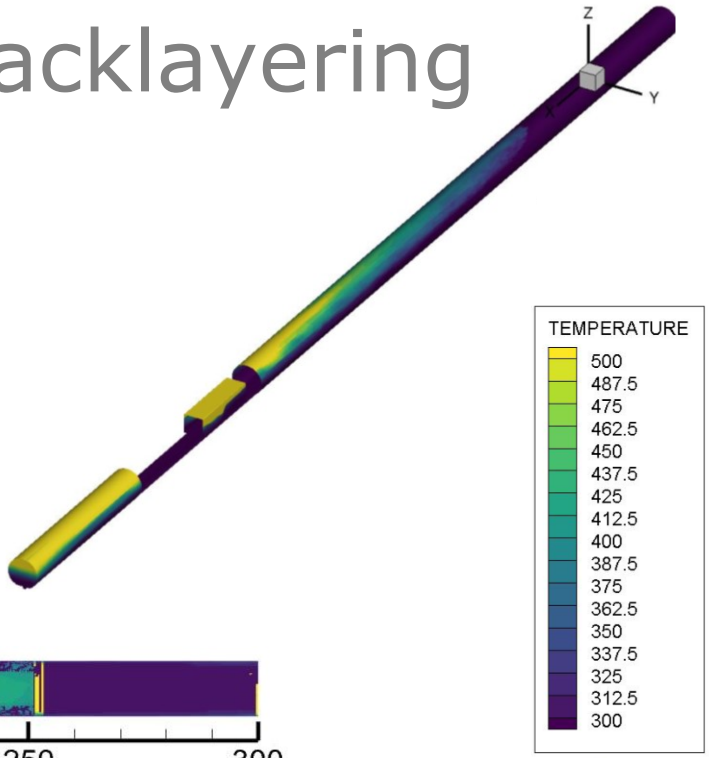
| Peak heat release rate | FDS | Li/Ingason | Thomas |
|---|---|---|---|
| < 10 MW | + | - | +/- |
| > 10 MW | - | - | +/- |

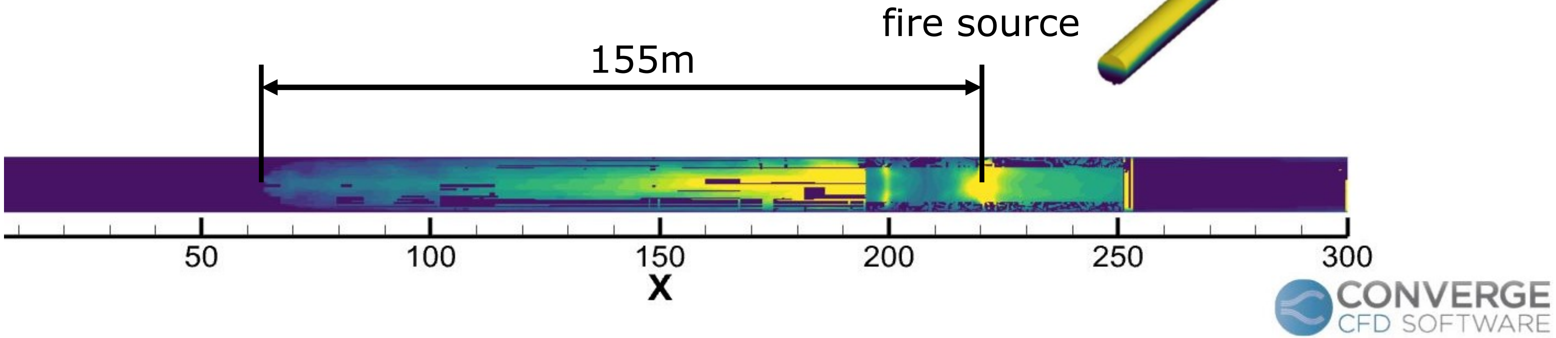
+ oversetimation; - underestimation

=> FDS simulations led to accurate results

# CFD Simulation -Backlayering

| Test 7 | experiment | FDS | Converge |
|---|---|---|---|
| Backlayering-length [m] | 160 | 150 | 155 |



# Conclusion

- Comparison of in-situ measurements and numerical investigations
- Accurate CFD results in temperature stratification
- Application of CFD models on the assessment of the backlayering
- Comparison of Backlayering
  - FDS -> results depending on HRR: $\uparrow$ if HRR<10MW & $\downarrow$ if HRR>10MW
  - Converge CFD -> results fit with data from experiments
  - Li/Ingason approach -> good results for shorter backlayering length
  - Thomas -> no clear tendency