The challenge of scaling-up wood crib fire experiments to travelling fires in large compartments

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THE UNIVERSITY *of* EDINBURGH

UKCTRF Annual Meeting
Imperial College, London
11 September 2019

UK CTRF UK CONSORTIUM ON TURBULENT REACTING FLOWS 2014 - 2023

Topics

- "Scaling-Up" fire*
- Crib/travelling fire experiments
  - Classical literature (Thomas, Harmathy…)
  - BST/FRS Large Compartment test 1993
  - Edinburgh Travelling Fire Test (ETFT) 2013
  - Uni Liège "Marchienne" tests 2018
  - Uni Ulster TRAFIR tests 2019
- Applications

* Torero, J.L. (2013) "Scaling-Up fire", Proc. Comb. Symp. 34:99-124


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Burning rates – timber cribs

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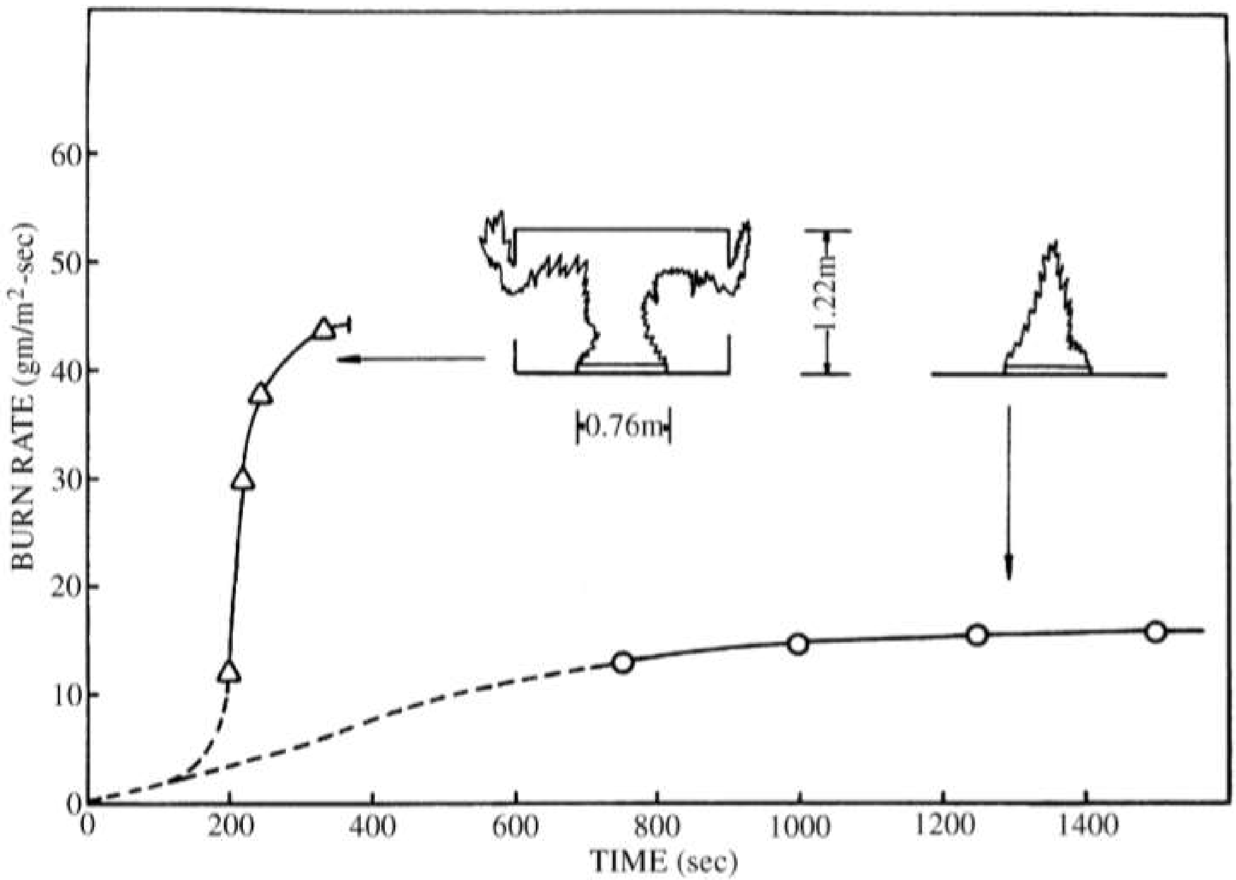

Figure 9.2 The effect of enclosure on the rate of burning of a slab of polymethylmethacrylate (0.76 m × 0.76 m) (Friedman, 1975)

c/o Drysdale, D.D. (2011) "An Introduction to Fire Dynamics", Wiley

Burning rates – timber cribs

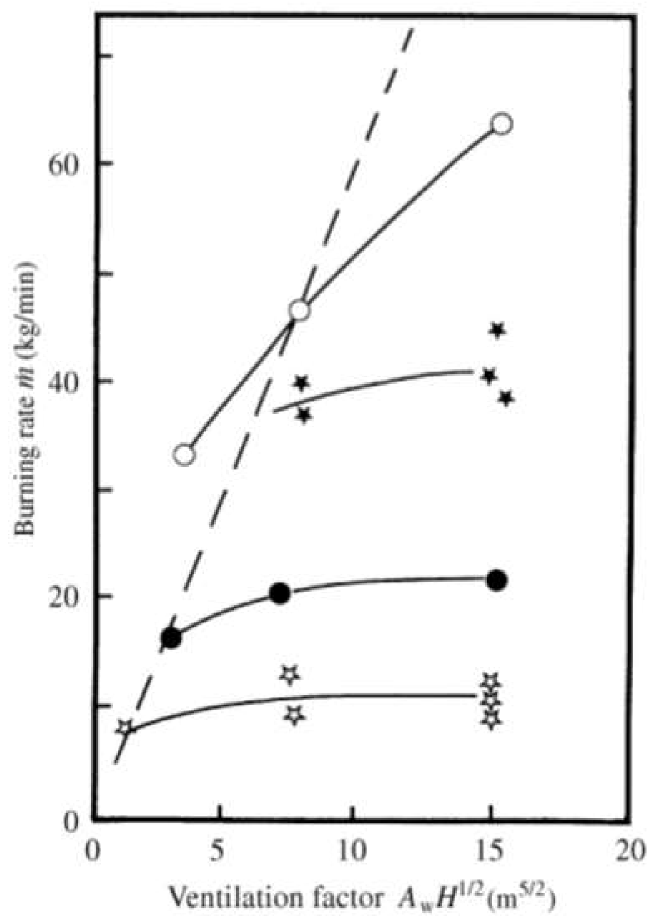

Figure 10.2 Variation of mass burning rate with $A_wH^{1/2}$ for large ventilation openings and different fire loads (wood cribs): ☆, 7.5 kg/m^2; ●, 16 kg/m^2; ★, 30 kg/m^2; ○, 60 kg/m^2. Dashed line (– – –) represents Equation (10.1) for the ventilation-controlled fire (Thomas *et al*., 1967a). Reproduced by permission of The Controller. HMSO. © Crown copyright

c/o Drysdale, D.D. (2011) “An Introduction to Fire Dynamics”, Wiley

Burning rates – timber cribs

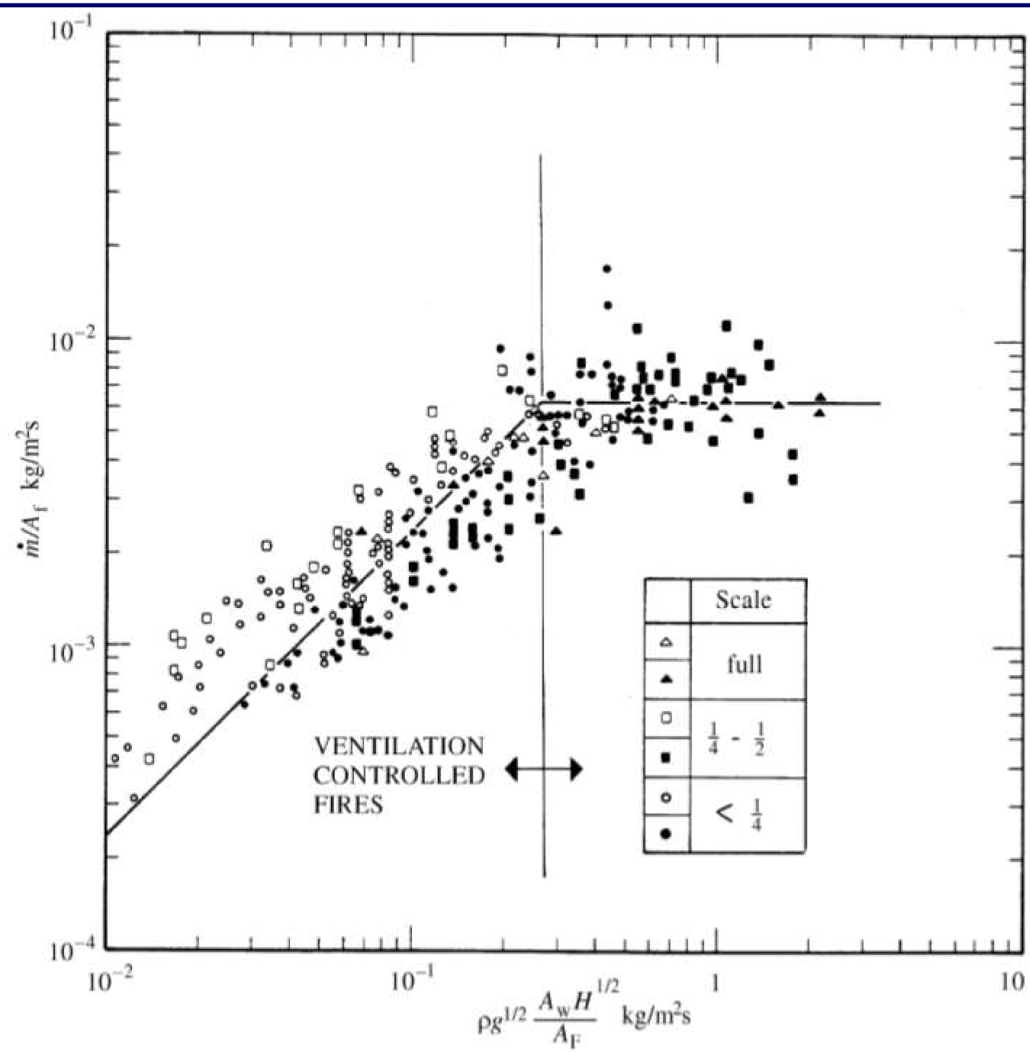

Figure 10.5 Identification of the transition between ventilation-controlled and fuel-controlled burning for wood cribs, according to Harmathy (1972)

c/o Drysdale, D.D. (2011) “An Introduction to Fire Dynamics”, Wiley

Burning rates – timber cribs

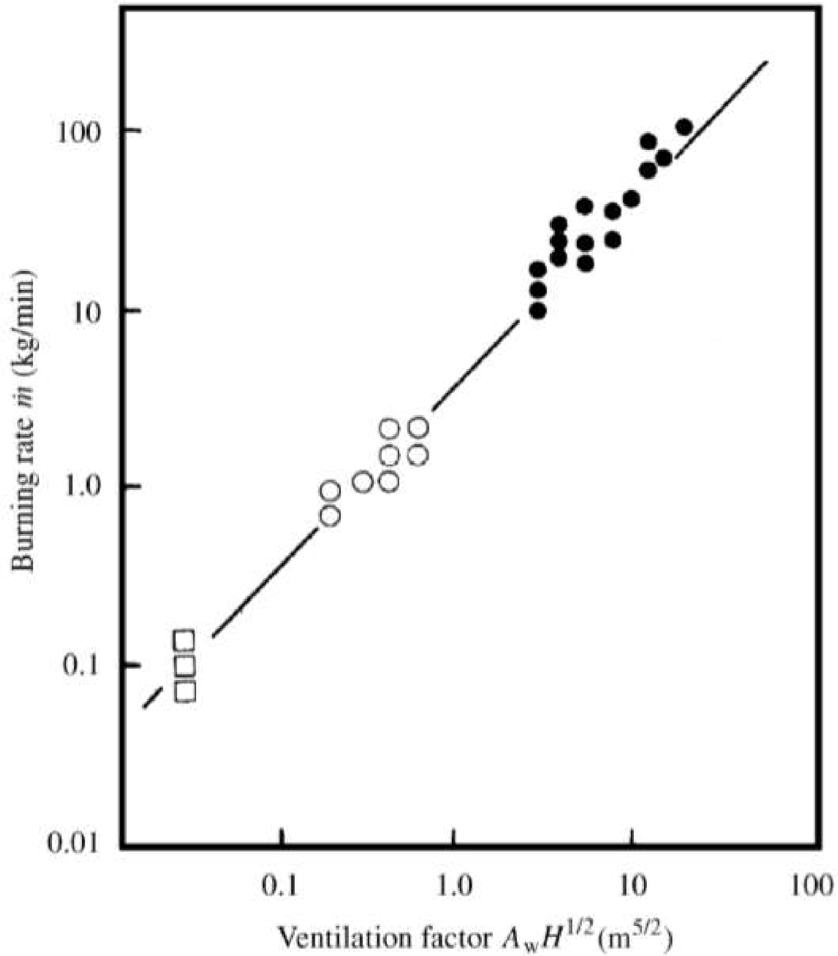

Figure 10.1 Mass burning rate of wood cribs in enclosures as a function of the ventilation factor, $A_w H^{1/2}$ for ventilation-controlled fires (Equation (10.1)): ●, full-scale enclosures; ○, intermediate-scale models; □, small-scale models (Kawagoe and Sekine, 1963). Reproduced by permission of Elsevier Applied Science Publishers Ltd

This behaviour is not intuitive, as the fuel burning rate should depend on compartment interaction, see Fig 9.2, not purely on oxidant supply; the reason may be partly the unique nature of fuel bed with the shielded internal fuel surfaces…

c/o Drysdale, D.D. (2011) “An Introduction to Fire Dynamics”, Wiley

Temperature correlation (1)

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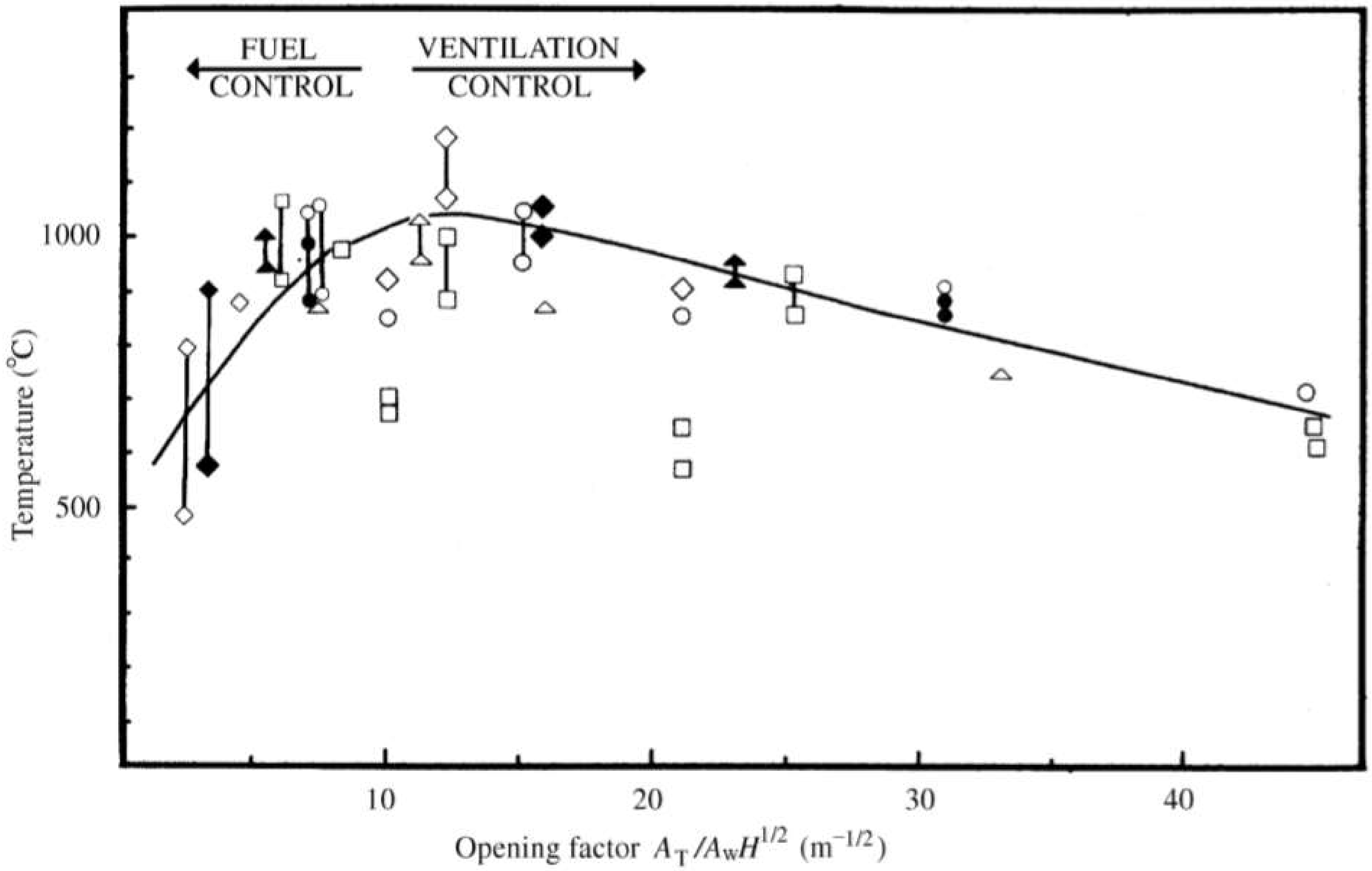

Figure 10.6 Average compartment temperatures during the steady burning period for wood crib fires in model enclosures as a function of the 'opening factor' $A_T/A_w H^{1/2}$. Symbols refer to different compartment shapes (see Table 9.3): ○, 1 × 2 × 1; Δ, 2 × 2 × 1; ◇, 2 × 1 × 1; □, 4 × 4 × 1. Solid points are means of 8–12 experiments (Thomas and Heselden, 1972). Reproduced by permission of The Controller, HMSO. © Crown copyright

c/o Drysdale, D.D. (2011) "An Introduction to Fire Dynamics", Wiley

Temperature correlation (2)

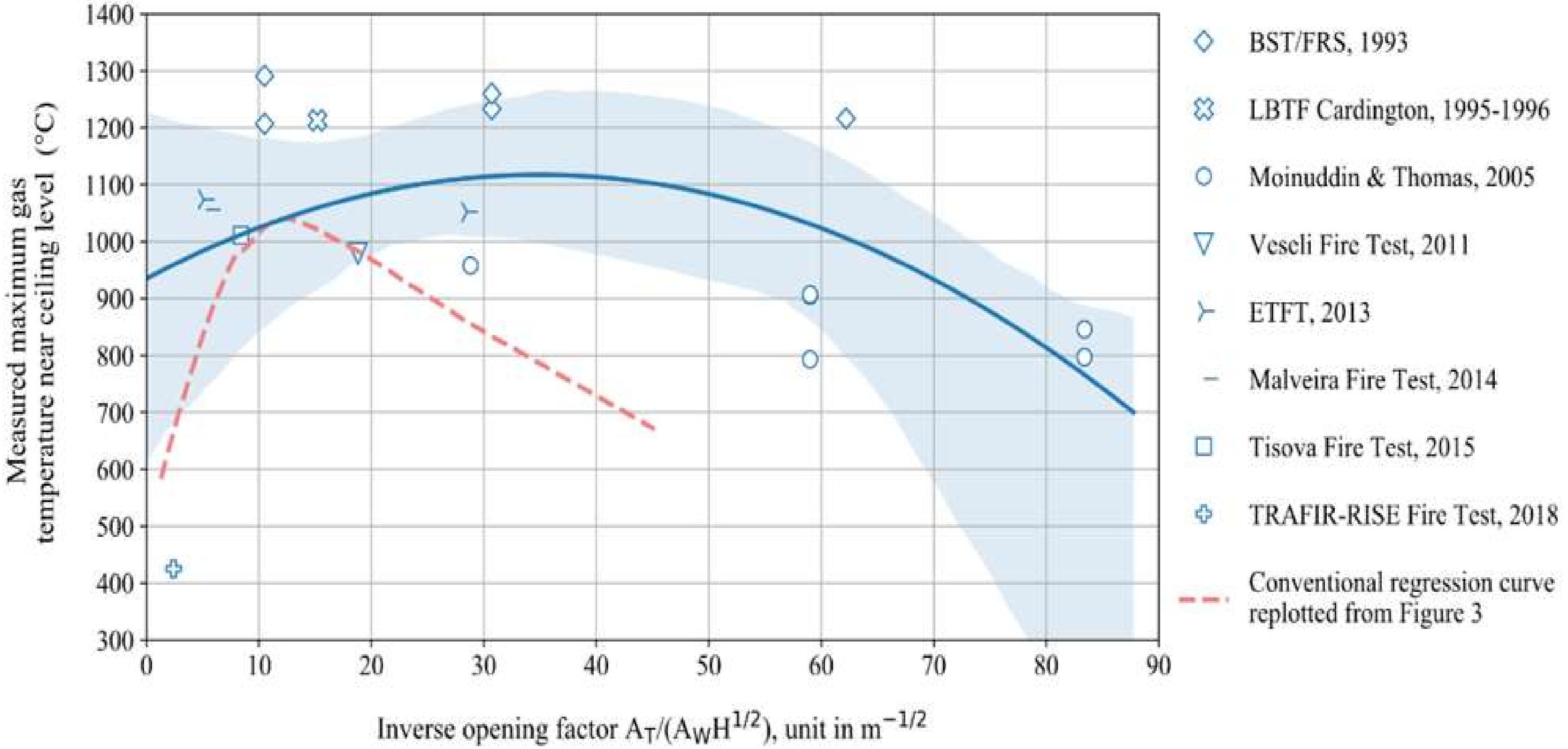

Figure 4. The relationship between the inverse opening factor $A_T/(A_w H^{1/2})$ and the measured maximum average gas phase temperature $T_{g,max}$ near ceiling level of test large compartments, through reviewing previous large-scale natural fire tests with a clear travelling fire development, performed in the past three decades. (solid curve in blue is the 2nd order polynomial regression line for all the reviewed travelling fire tests, and dashed red curve is the same curve presented in Figure 3 for small size compartments as a reference; the translucent blue band describes a bootstrap confidence interval of the estimated regression line according to the available data sampling points).

From: Dai, X. et al., (2018) "An Extended Travelling Fire Method Framework for Performance-Based Structural Design", ASTM E05 Workshop on Advancements in Evaluating the Fire Resistance of Structures, Washington DC, 6-7 December 2018

Burning rates – timber cribs

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(a) (b)

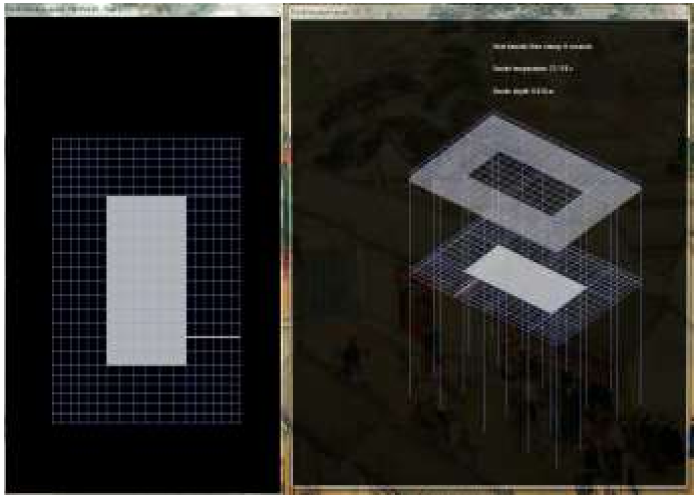
Figure 10.7 The effect of a large exposed fuel surface area on fire behaviour. (a) Fuel control regime, 15 kg/m^2. Fuel in the form of wood cribs, $A_f = 55$ m^2: no external flaming. (b) Ventilation control regime, 7.5 kg/m^2. Fuel was fibre insulating board, lining the walls and ceiling, $A_f = 65$ m^2; external flaming lasted for 5.5 minutes (Butcher *et al*., 1968). Reproduced by permission of The Controller, HMSO. © Crown copyright

the other. In the former, the wood was present in the form of cribs (with a surface area of 55 m^2, *including* the internal surfaces – see Figure 5.20), while in the other it was present as the wall lining material (exposed surface area 65 m^2) (Butcher *et al*., 1968). The large area of fuel directly exposed to the fire in the latter case produced flashover followed by Regime I burning with flames emerging from the window, while the wood cribs burned as a fuel-controlled fire (Regime II). Harmathy's method (Equation (10.18)) does not distinguish between these two scenarios.

c/o Drysdale, D.D. (2011) "An Introduction to Fire Dynamics", Wiley

Travelling fires

- Ultimate application is structural fire design
- Breaking out from highly oversimplified techniques
- Spatially and temporally varying boundary conditions
- OpenSees framework



TRAFIR Project

Characterization of TRAvelling FIRes in large compartments

Funded by Research Fund for Coal and Steel (RFCS)/European Commission

Full-scale tests, simulations, etc. (1/07/17→31/12/

European Commission

ArcelorMittal

Université de Liège ULg

RISE

Ulster University

BST/FRS large compartment, 1993

- **Date:** 1993 at Building Research Establishment (**BRE**), UK
- **Team:** BRE (Fire Research Station)/British Steel Technical (Swinden Laboratories)
- **Aim:** generating experimental data to validate the ‘**Time Equivalent**’ formula in Eurocode 1 for buildings with large/deep compartments, or large open plan offices

(a) (b) (c)

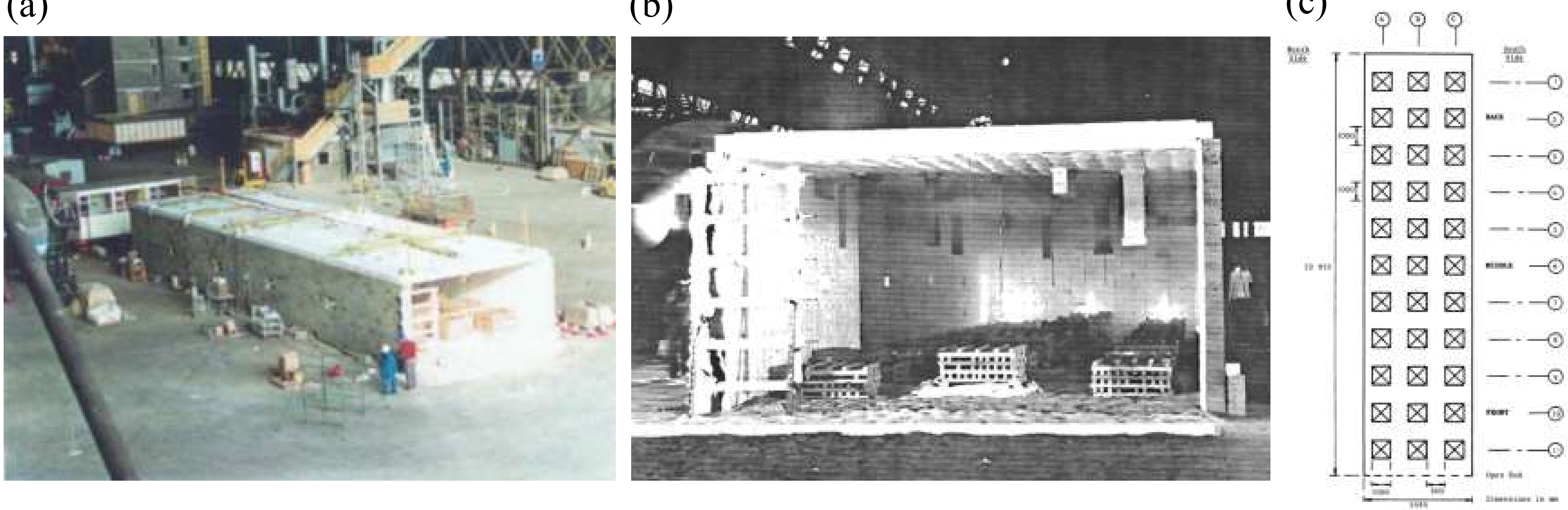
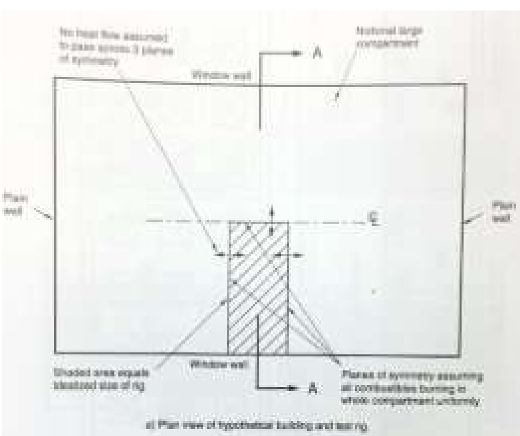


Fig. 1. (a): Test compartment of the BST/FRS 1993 Fire Test Series (22.8m × 5.6m × 2.75m); (b): Ignition of the first row of wood cribs in test number 2, front view; (c): Layout of the wood cribs distribution within the test compartment in plan view.

Kirby, B., Wainman, D.E., Tomlinson, L.N., Kay, T.R. & Peacock, B.N. (1999) “Natural Fires in Large Scale Compartments”, Int. J. Performance-based Codes, 1(2): 43-58

BST/FRS large compartment, 1993

Parameter	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9
Compartment Size	Full size	Full size	Full size	Full size	Full size	Full size	[illegible] size	Full size	Full size
Walls and Ceiling Lining	Ceramic fibre	Ceramic fibre	Ceramic fibre	Ceramic fibre	Ceramic fibre	Ceramic fibre	Ceramic fibre	Plaster-board	Ceramic fibre
Fire Load Density, kg/m² of Floor	40	20	20	40	20	20	20	20.6	20
Ventilation×	1/1	1/1	1/2	1/2	1/4	1/8	1/4	1/1	1/1
Ventilation Factor, w_f	1.4795	1.4795	2.3087	2.3087	2.9396	3.2760	1.4790	1.5737	1.4795
Fire Load Density, q_f (MJ/m² of Floor)	759.9	380.1	380.1	759.9	380.1	380.1	380.1	402.3/ 507.2•	380.1
Ignition/Fire Progress*	Growing	Growing	Growing	Growing	Growing	Growing	Simult-aneous	Growing	Simult-aneous



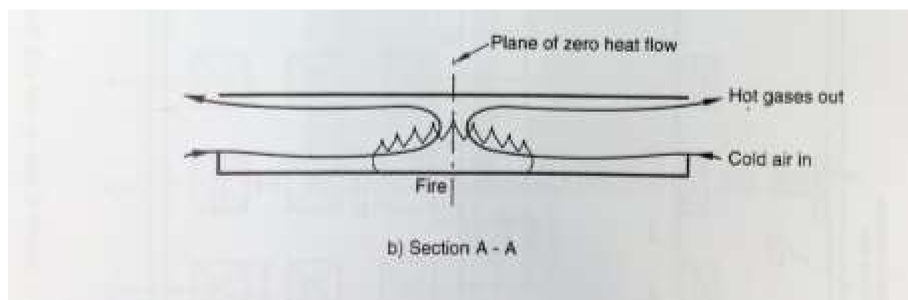
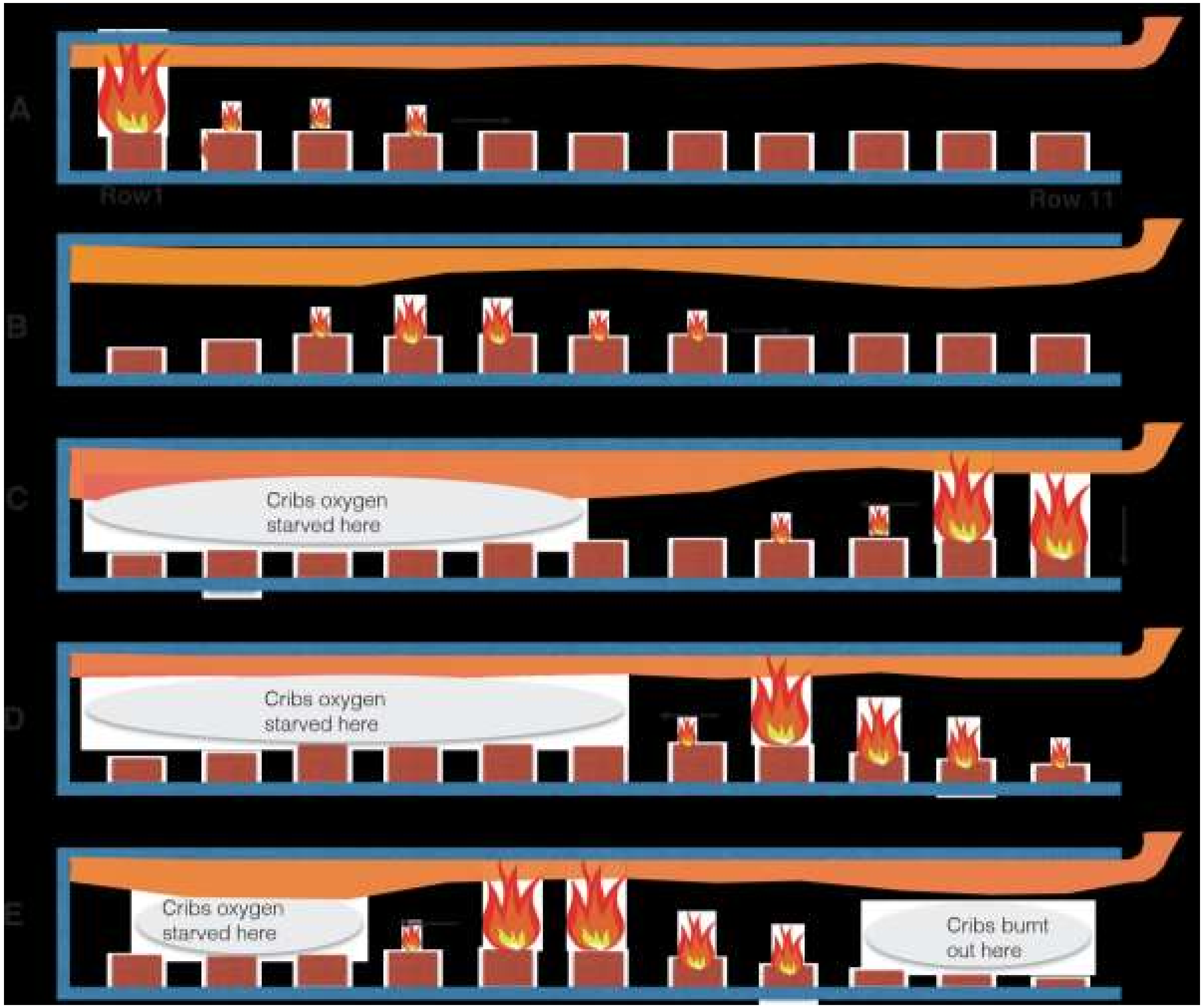


Figure 1 Concept of test rig showing planes of symmetry

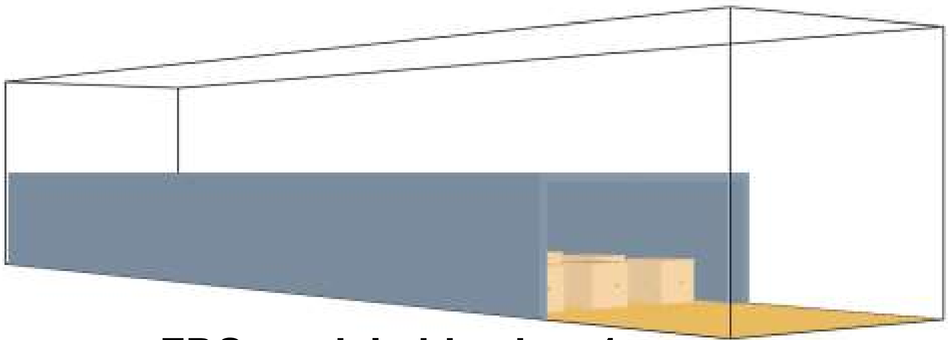
Kirby, B., Wainman, D.E., Tomlinson, L.N., Kay, T.R. & Peacock, B.N. (1999) "Natural Fires in Large Scale Compartments", Int. J. Performance-based Codes, 1(2): 43-58

BST/FRS large compartment, 1993

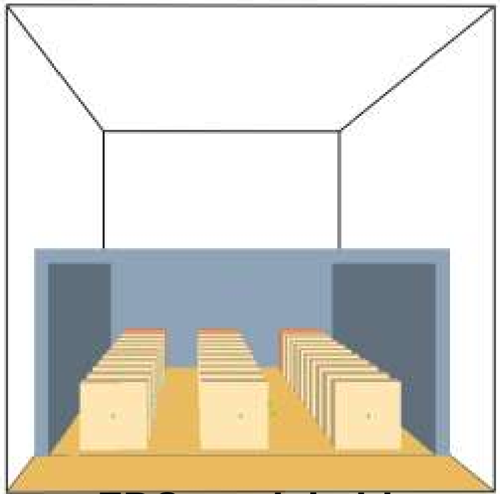


* Schematics c/o Gordon Cooke, from presentation at Structures in Fire Forum (STiFF), IStructE, London, 2017

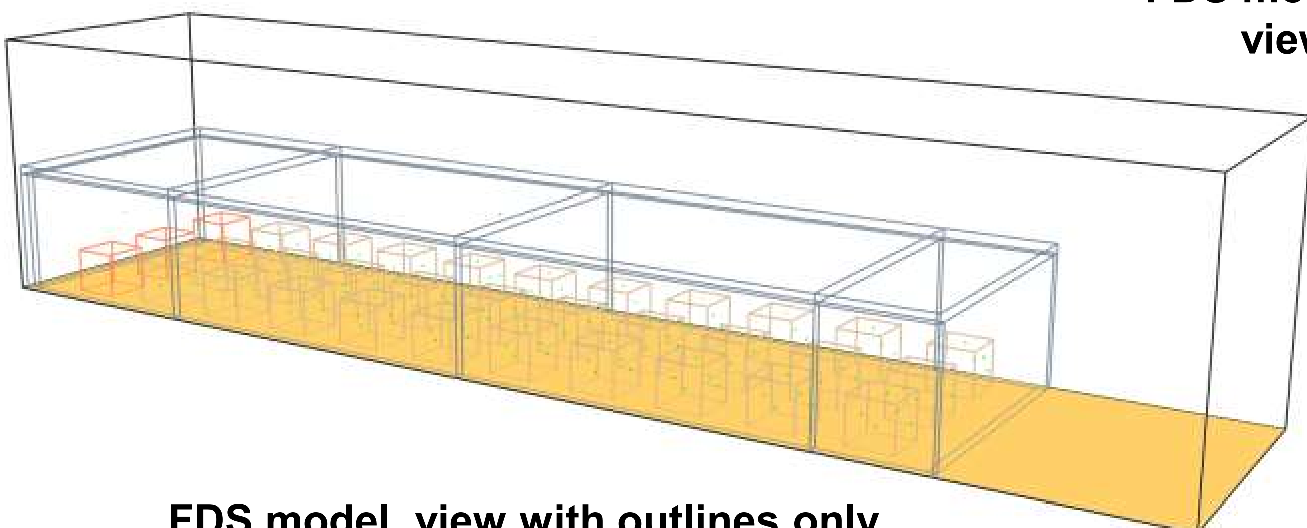
FDS simulation test no.2



FDS model side view 1

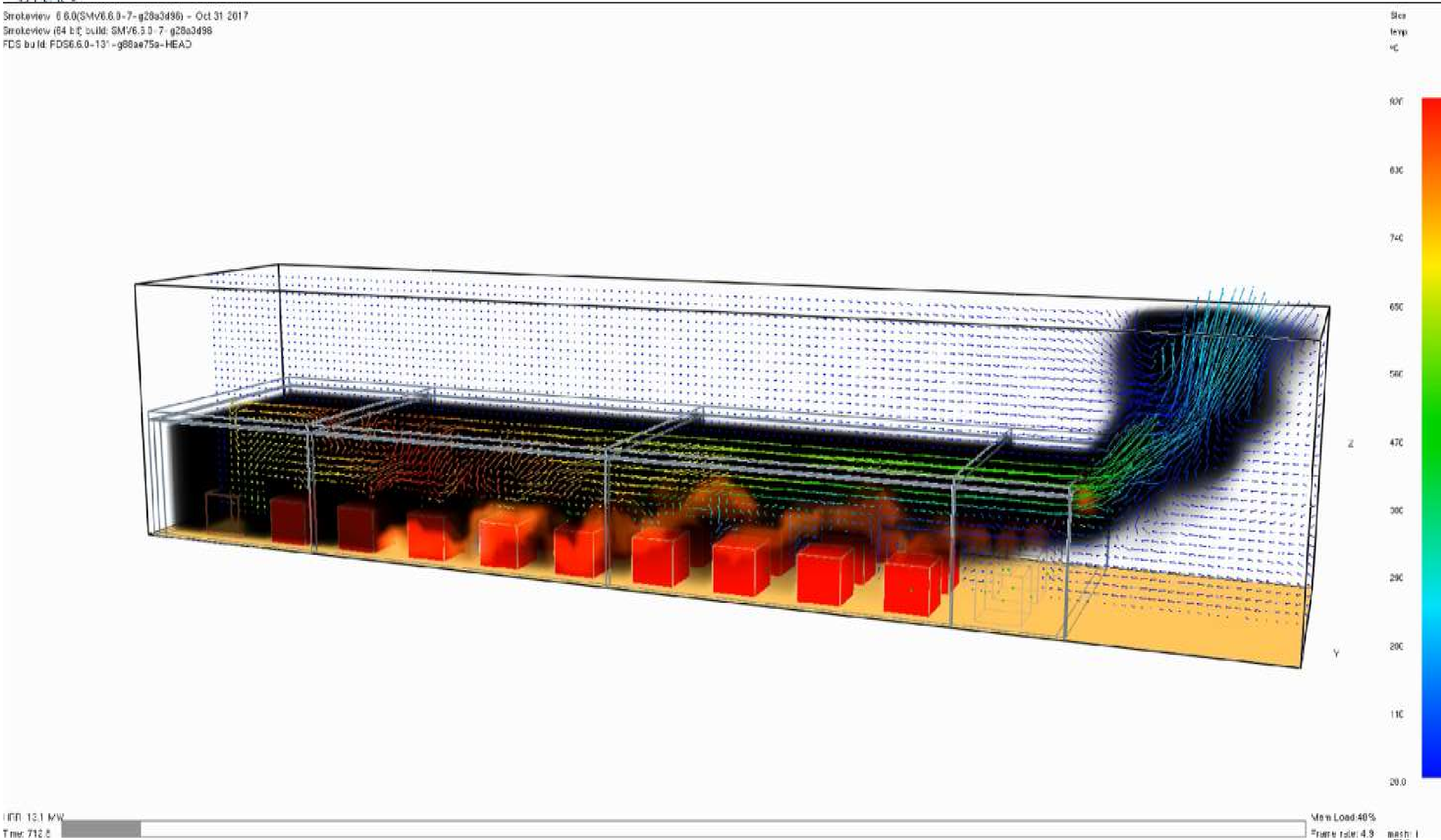


FDS model side view 2



FDS model, view with outlines only

FDS simulation test no.2

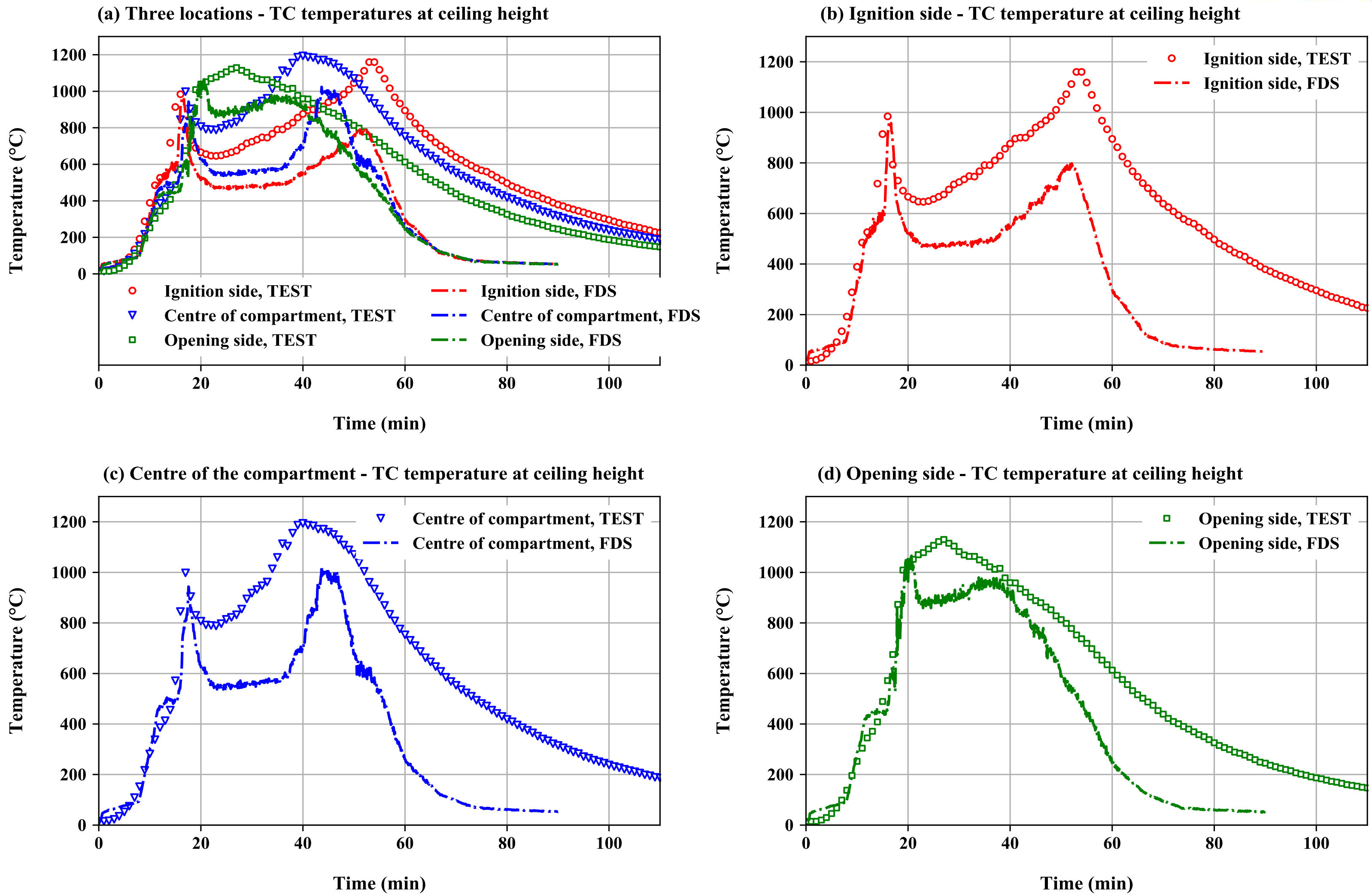


Dai, X., Welch, S. Rush, D., Charlier, M. & Anderson, J. (2019) "Characterising Natural Fires in Large Compartments – Revisiting an Early Travelling Fire Test (BST/FRS 1993) with CFD", Proc. 16th Interflam conference, London, June 2019

BST/FRS test 2, model comparison

BRE Centre *for* Fire Safety Engineering

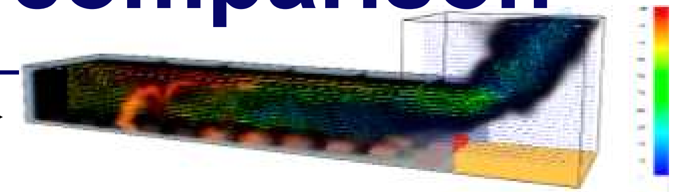
Ignition side of the compartment



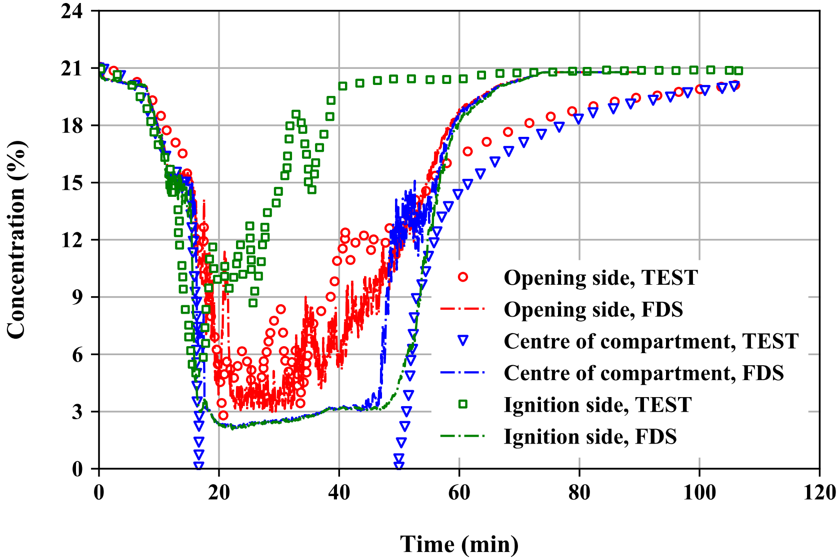
Comparison of thermocouple (TC) temperatures between test and model

BST/FRS test 2, model comparison

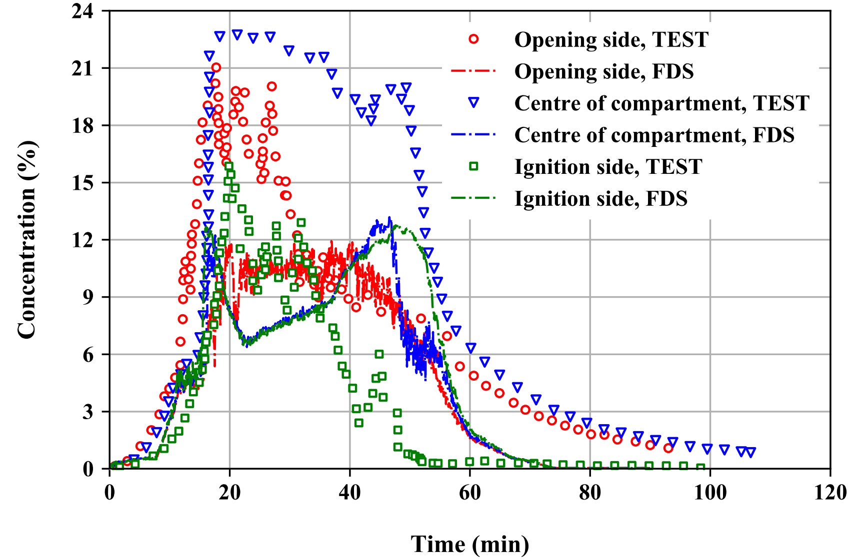
Ignition side of the compartment



(a) Oxygen concentrations



(b) Carbon dioxide concentrations



Comparison of gas concentrations between test and model (oxygen concentration test data at rear compartment invalid after 7 mins, due to pipe leakage)

Dai, X., Welch, S. Rush, D., Charlier, M. & Anderson, J. (2019) “Characterising Natural Fires in Large Compartments – Revisiting an Early Travelling Fire Test (BST/FRS 1993) with CFD”, Proc. 16th Interflam conference, London, June 2019

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Annual Fire Science & Fire Investigation Course, Edinburgh, 20-23 April 2015
Return of the Fire Dynamics & Fire Safety Engineering Design Course, Edinburgh, 27-29 April 2015
New course on Introduction to Tunnel Fires to be launched, Edinburgh, [Dates TBC] 2015

Wednesday, March 06, 2013

Edinburgh Travelling Fire Tests: Days 31-32 Video Blog

Hidalgo, J.P., Cowlard, A., Abecassis-Empis, C., Maluk, C., Majdalani, A.H., Kahrmann, S., Hilditch, R., Krajcovic, M. & Torero, J.L. (2017) “An Experimental Study of Full-scale Open Floor Plan Enclosure Fires”, Fire Safety Journal 89: 22-40

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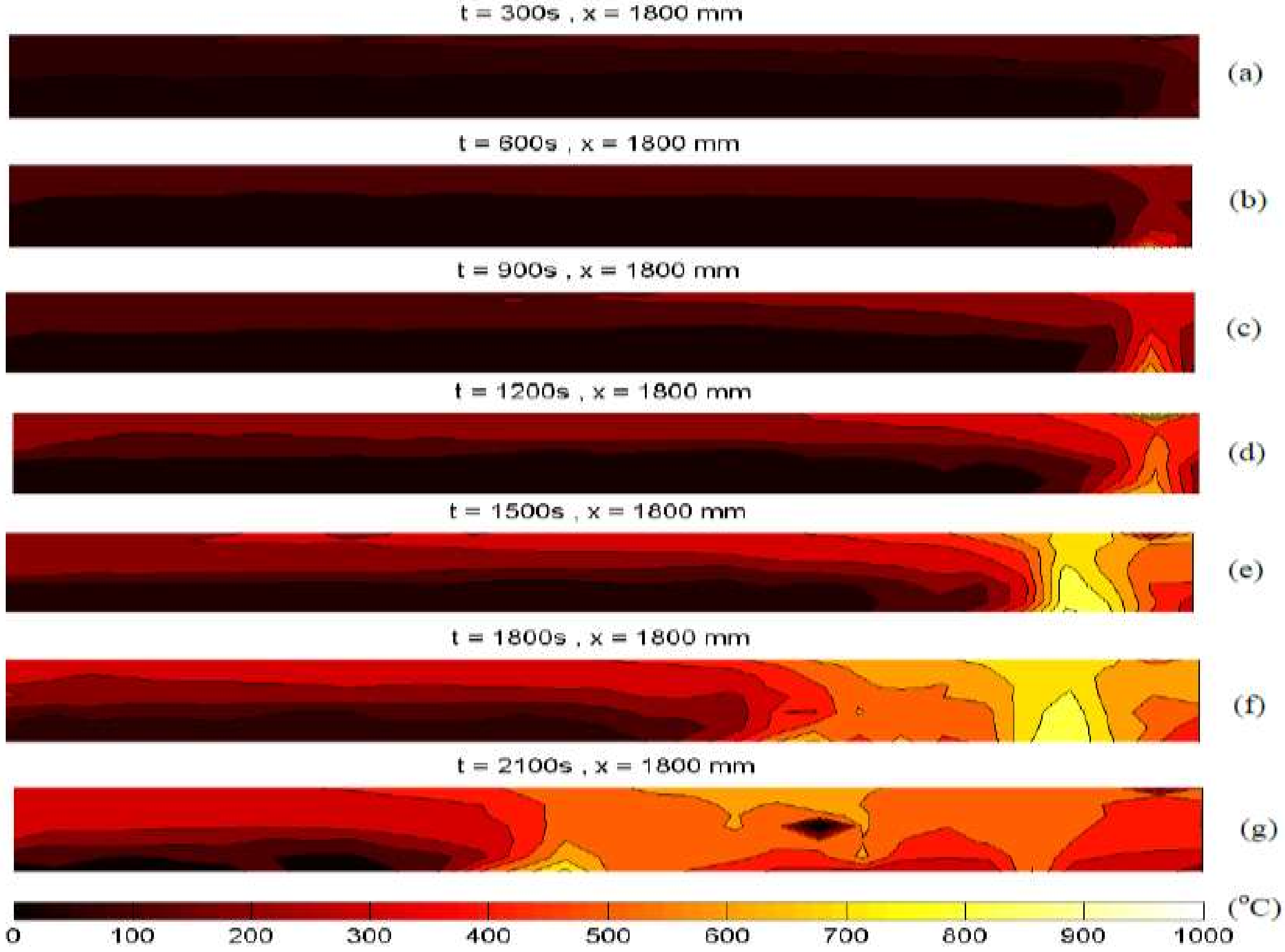
Fire spread in crib fire tests (ETFT)



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Yang, P. (2016). “Prediction of Ignition and Fire Growth of Wood Materials by CFD Modelling”, IMFSE thesis, University of Edinburgh

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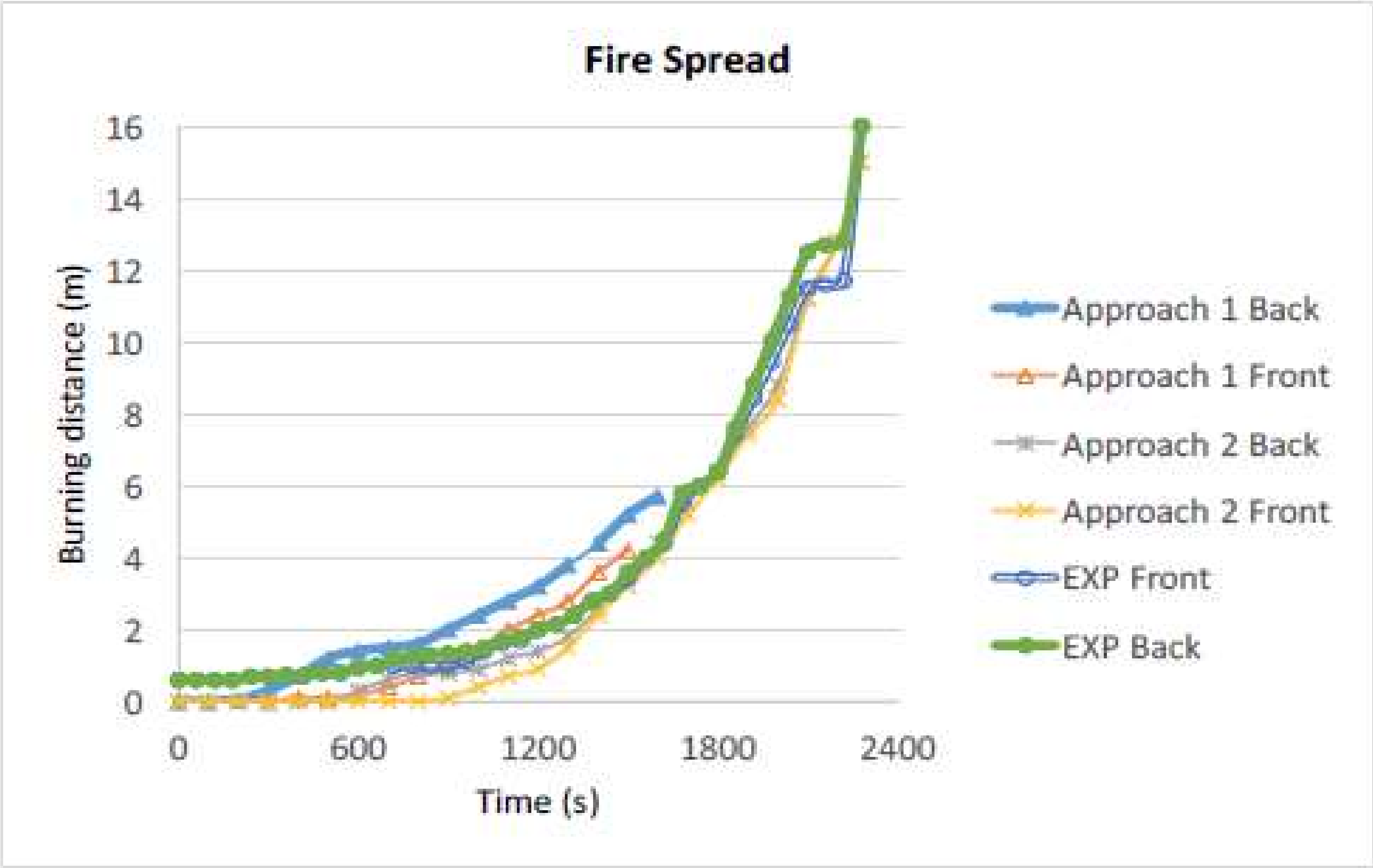

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Travelling fire simulations

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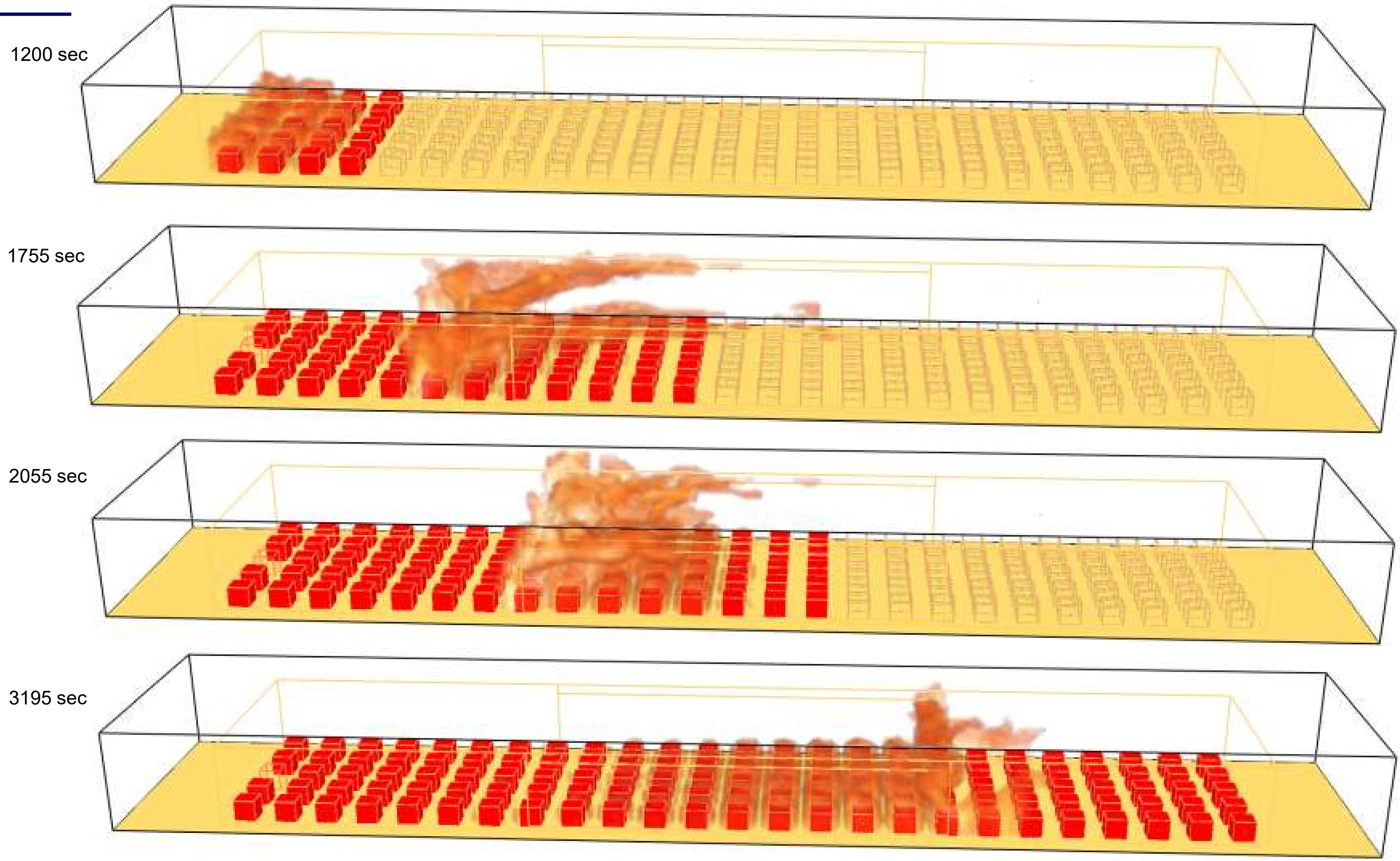
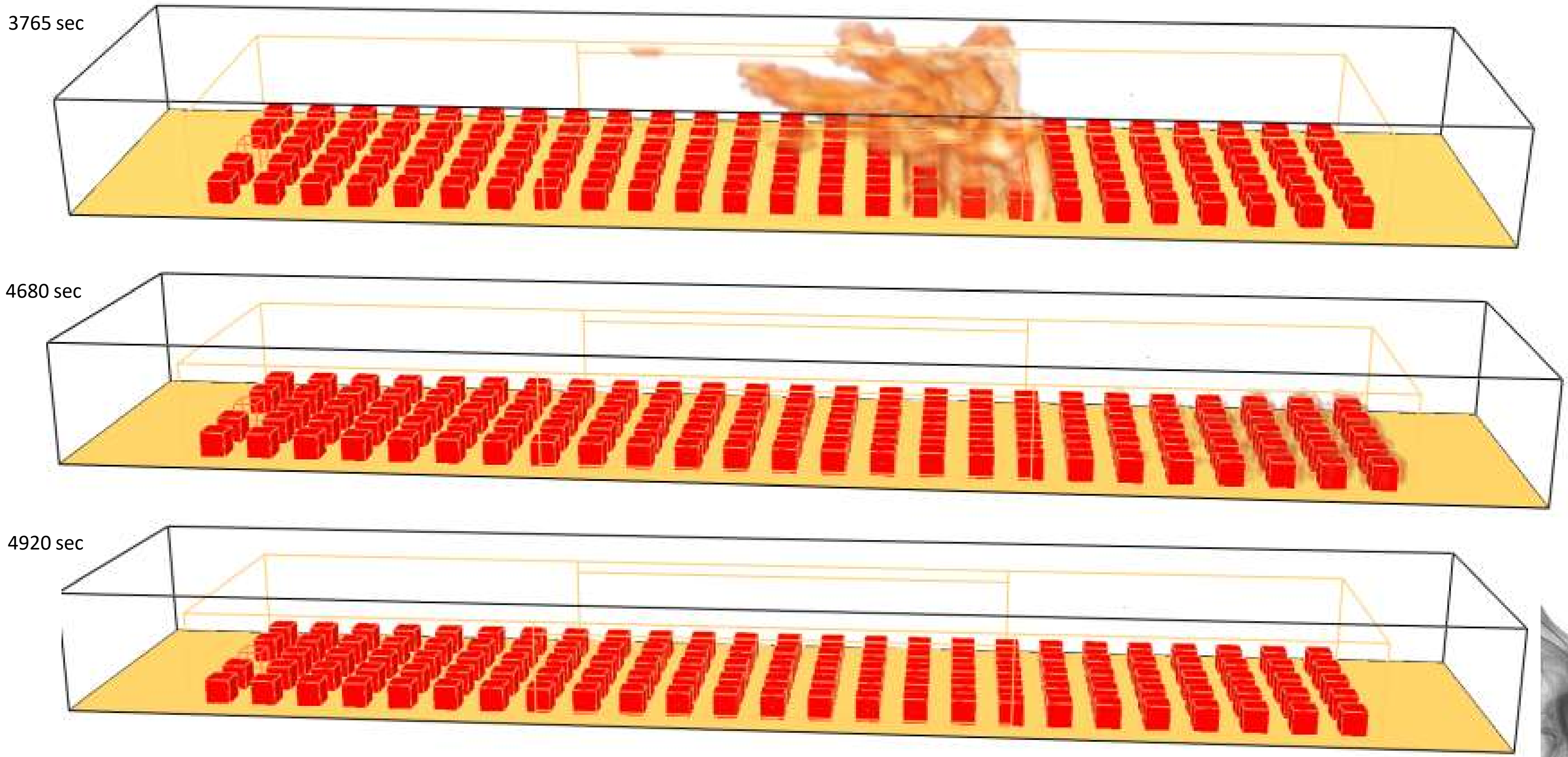


Charlier, M., Vassart, O., Gamba, A., Dai, X., Welch, S. & Franssen, J.-M. (2018) "CFD analyses used to evaluate the influence of compartment geometry on the possibility of development of a travelling fire", SiF 2018, Uni Ulster, 6-8 June 2018

Travelling fire simulations



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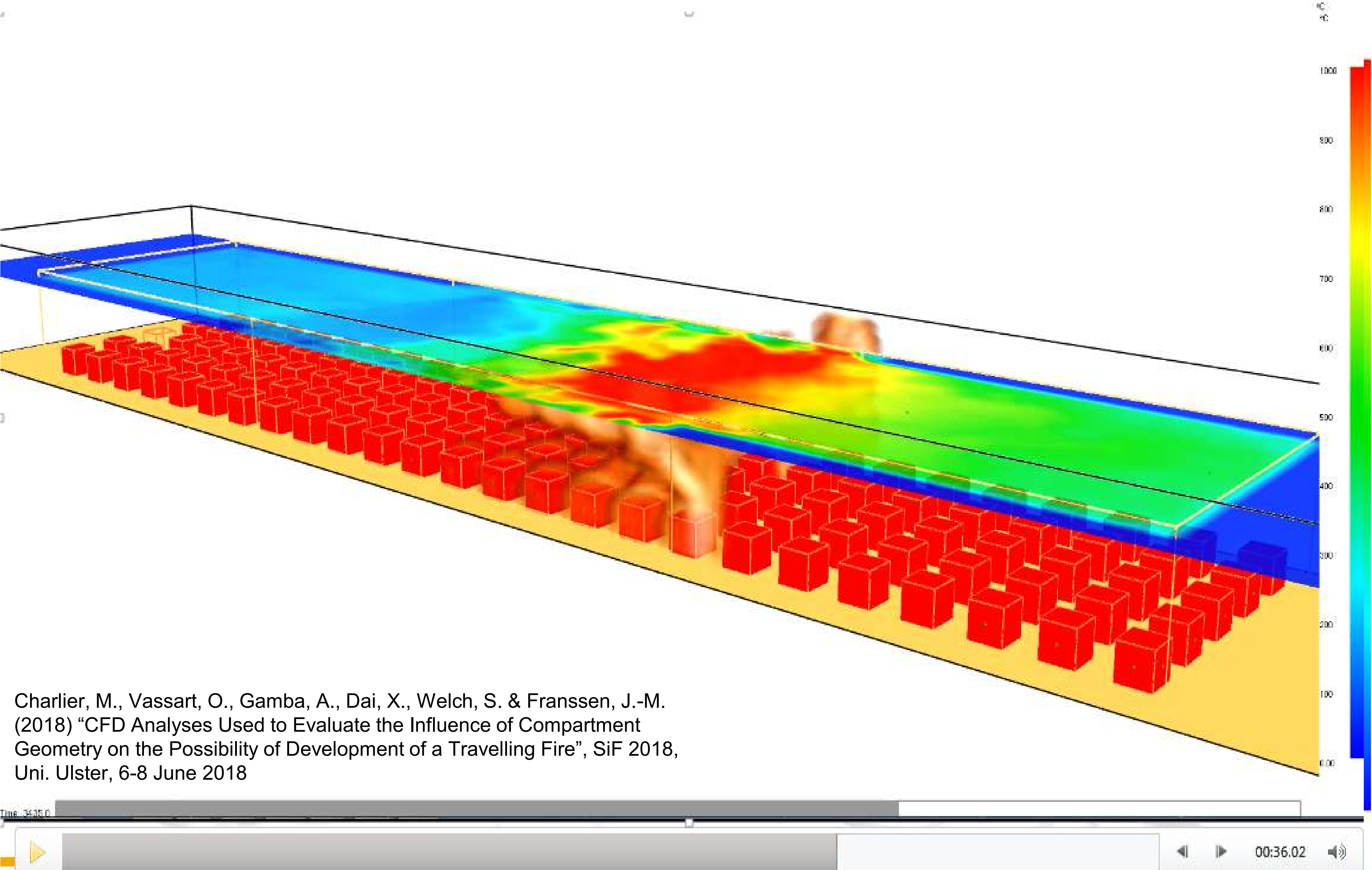
Travelling fire simulations



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"Liege test series", Marchienne, 2018

- **Isolated crib fire test series:**

Section	L1 x L2	Material
* 1:	30 x 35 mm	Epicea
* 2:	35 x 45 mm	Epicea
* 3:	15 x 15 mm	Sapin rouge du Nord
* PMMA:	3 x 100 mm	

Date	Test ID.	Section*	Orientation	Number of layers	Centre to Centre	Total height	Roof	Ethanol 96%
[-]	[-]	[-]	[-]	[-]	[mm]	[mm]	[-]	[ml]
28/08/18	M1	1	|	6	80	209	Yes	40
29/08/18	M2	2	|	6	135	285	Yes	40
29/08/18	M3	1	|	12	160	418	Yes	40
30/08/18	M4	2 PMMA	| -	5 3	135 270	247	Yes	40
29/08/18	M5	1 3	| □	5 4	80 80	234	Yes	40

1) Orientation = | means that the stick was placed with L1 of 30 mm on the ground so you have a height of 35mm
2) Orientation = - means that the stick was placed with L2 of 35 mm on the ground so you have an height of 30mm
3) Orientation = □ means that the stick was used with latches because L1 = L2

- **Why M7?**

Reason: larger stick spacing (i.e. better porosity) allow larger grid cells in FDS. Also a medium fire spread, close to target…

“Liege test series”, Marchienne, 2018

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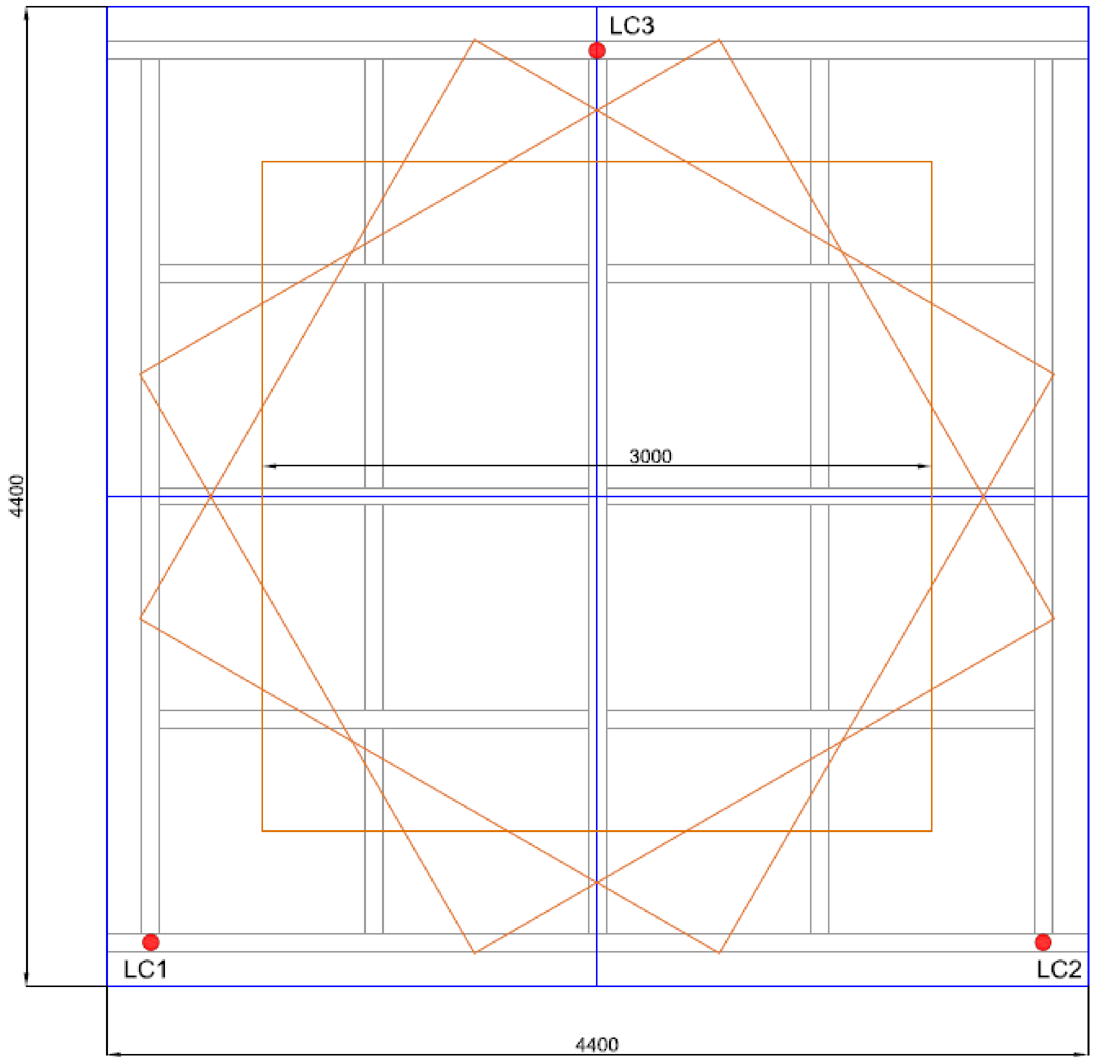
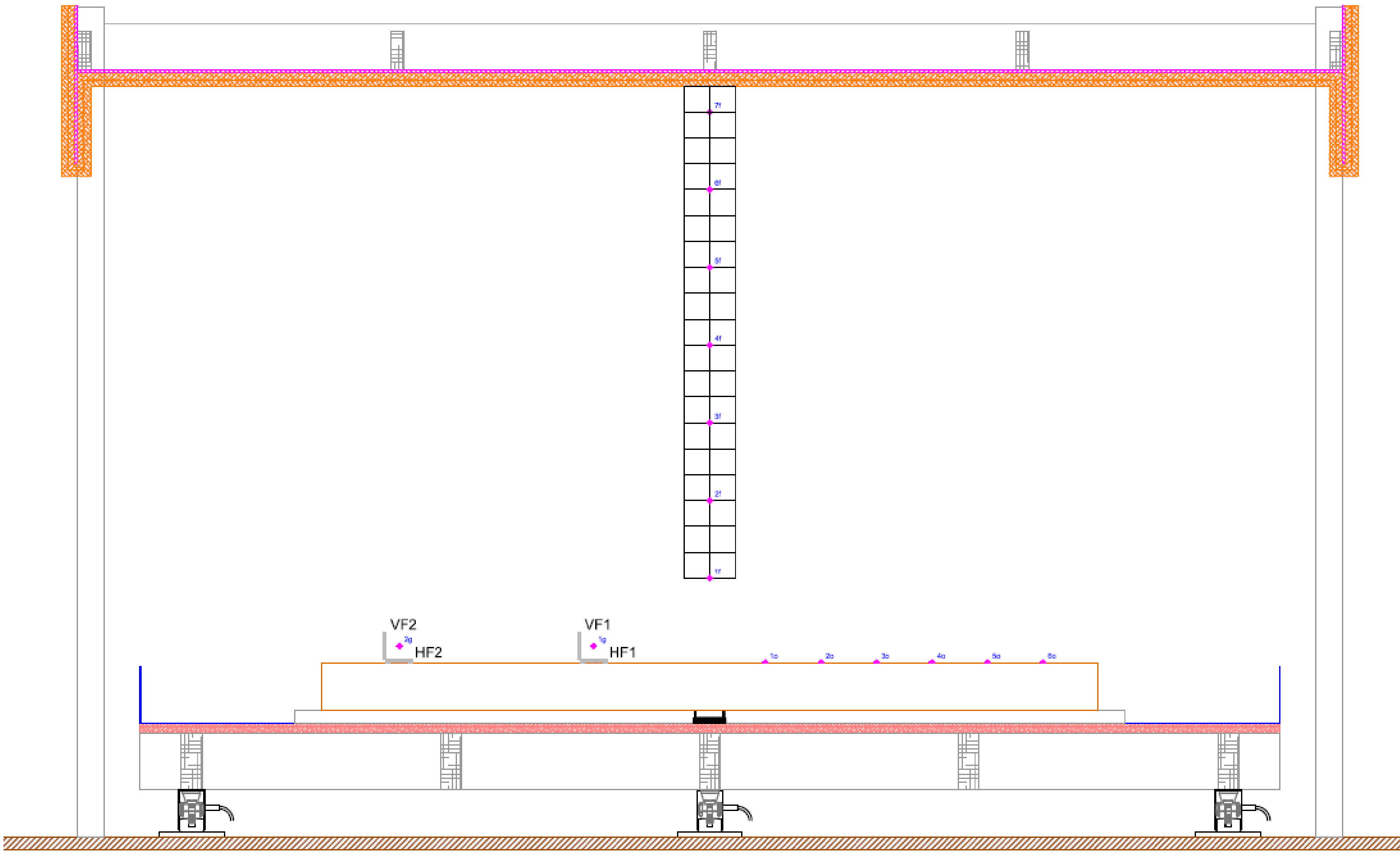
- Wood sticks layout in plan view (dimension units mm):



"Liege test series", Marchienne, 2018

- Wood sticks layout in elevation view 1 (dimension units mm):



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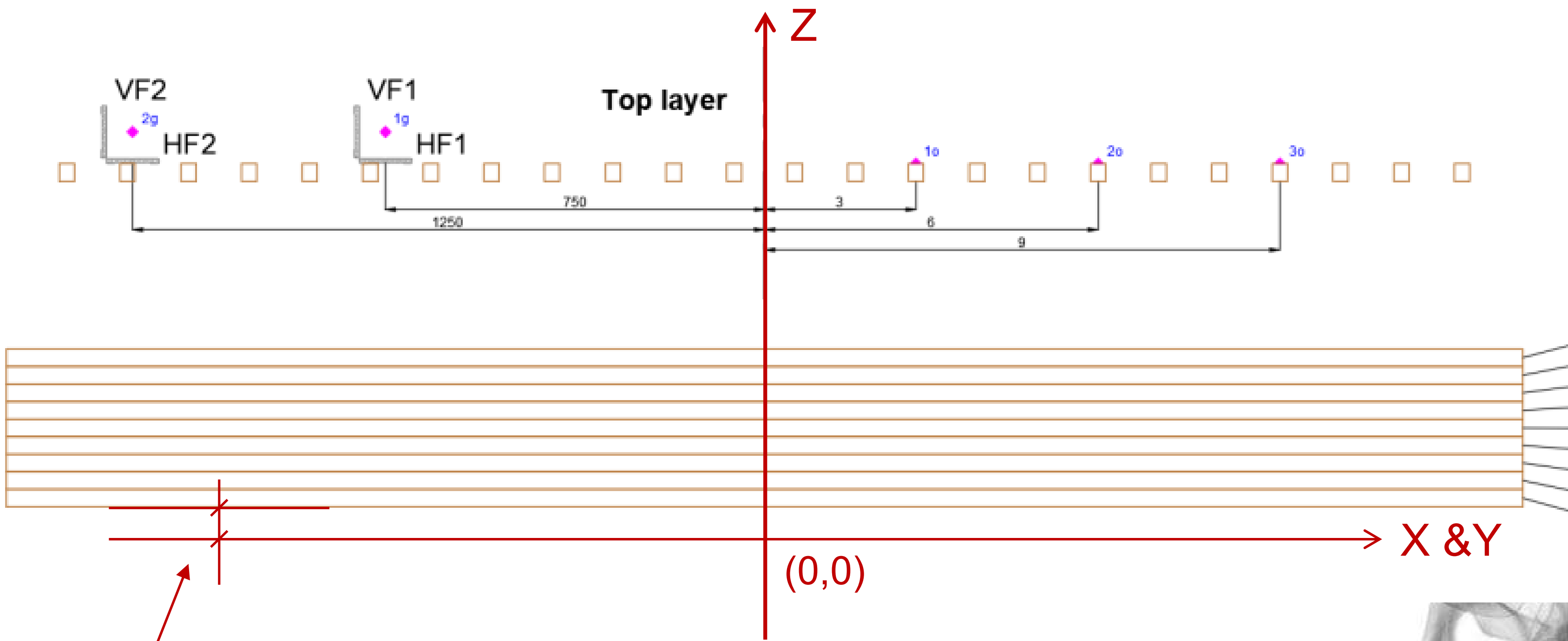
“Liege test series”, Marchienne, 2018

- Wood sticks representation, and coordinate system, in elevation:



50mm offset for the ignition
burner & steel tubes

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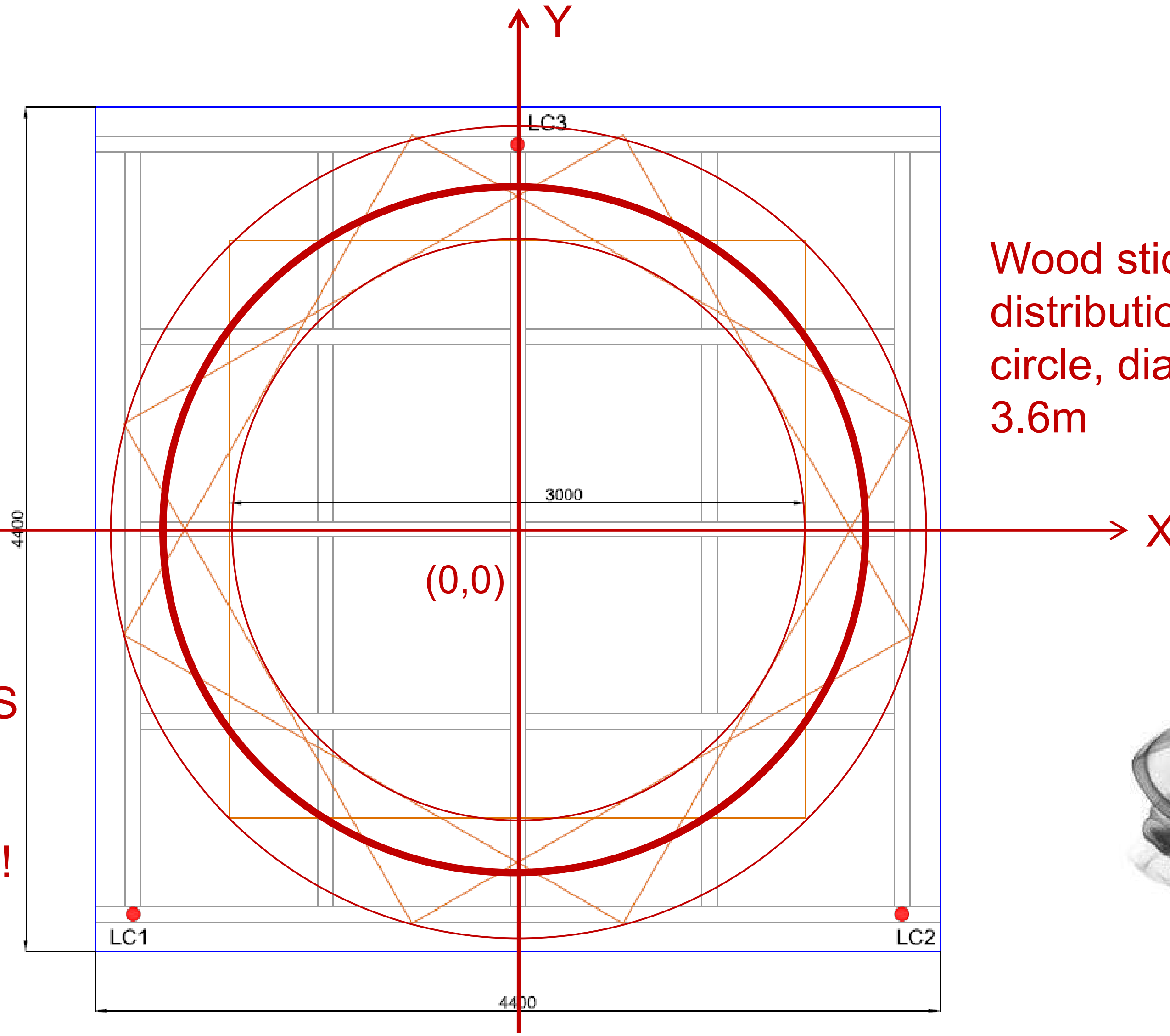
“Liege test series”, Marchienne, 2018

- **Wood sticks representation, and coordinate system, in plan view:**

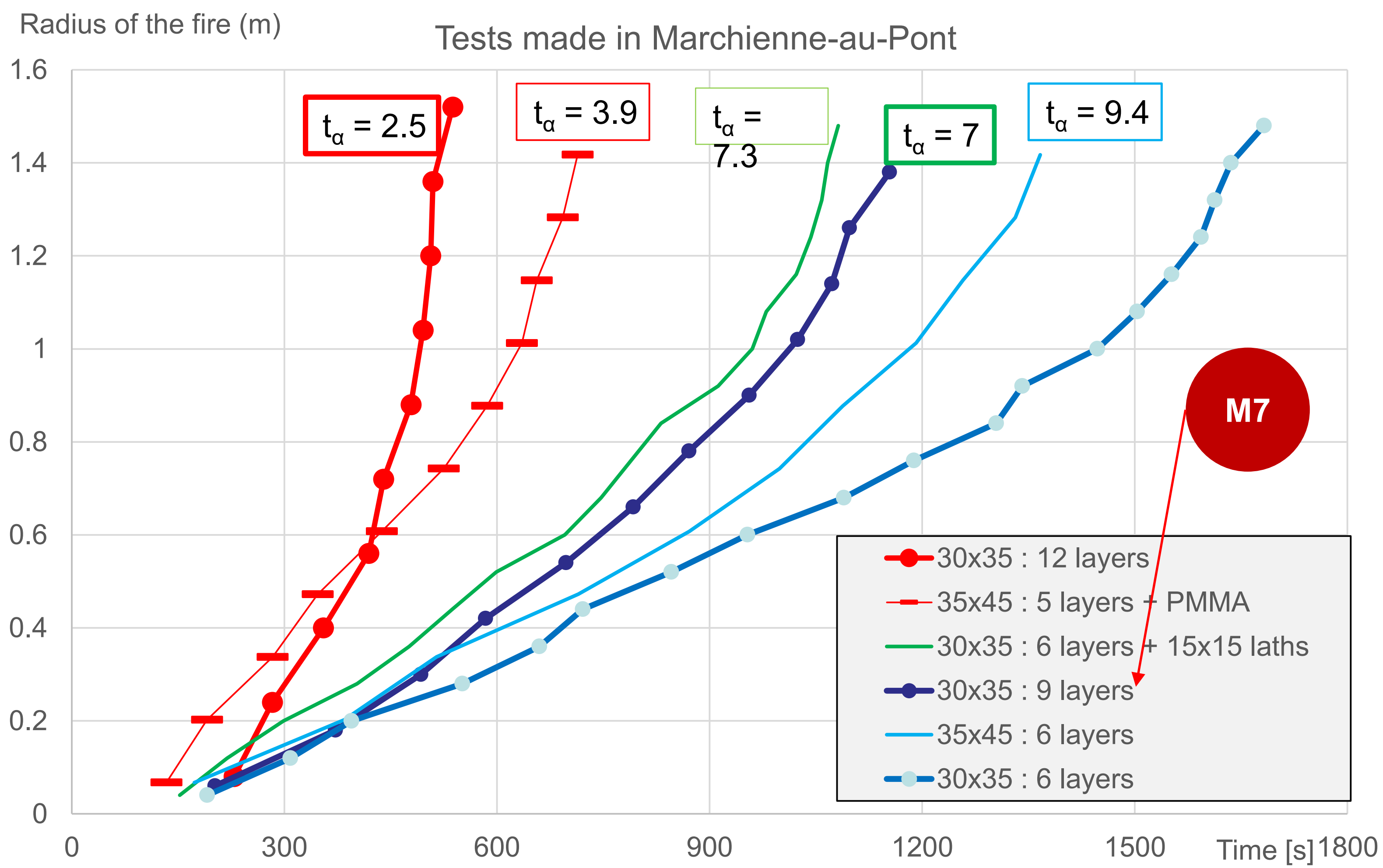


Wood stick distribution as a circle, diameter 3.6m

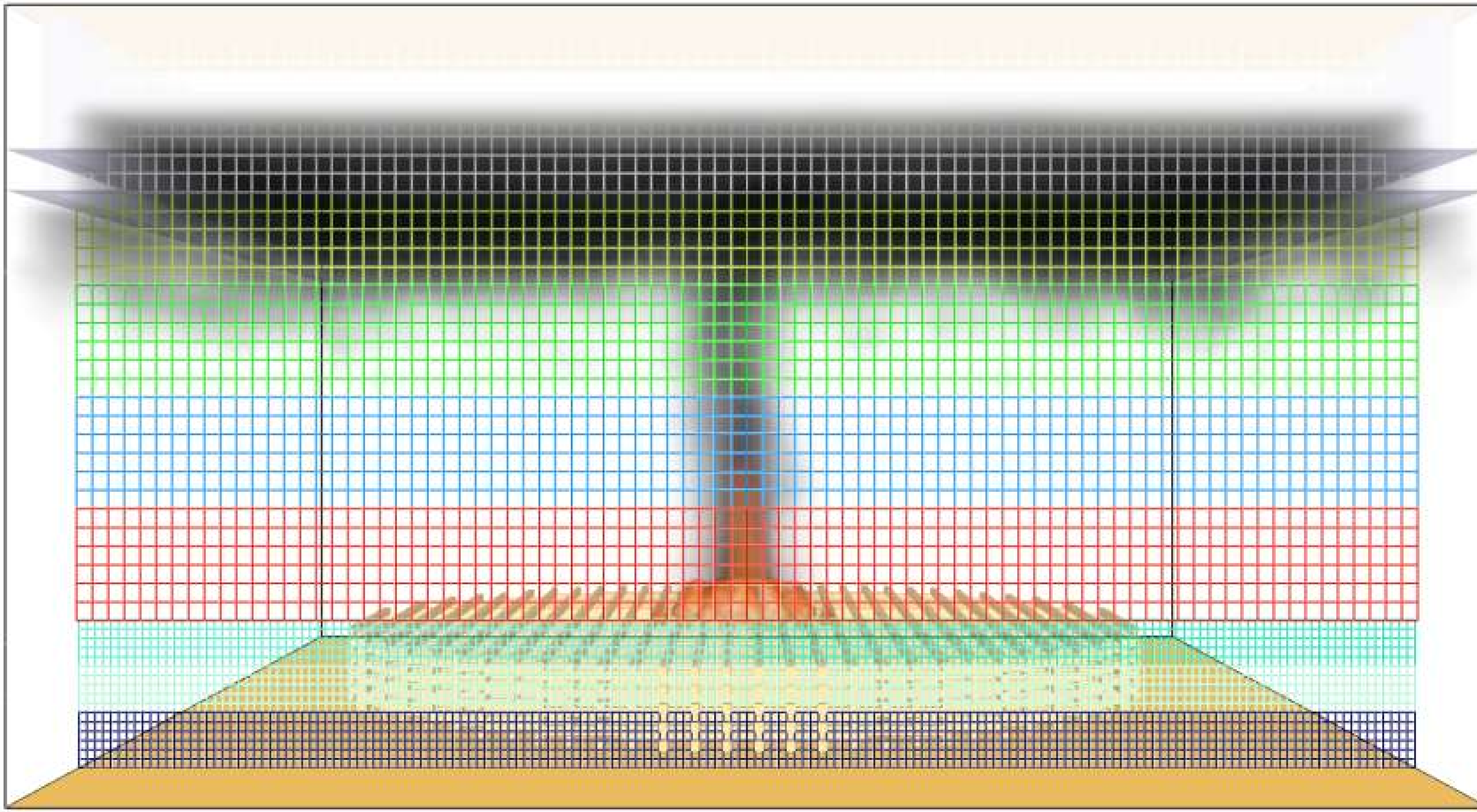
NB – wood sticks in FDS must be arranged orthogonally!

"Liege test series", Marchienne, 2018

- **Fire spread in terms of t squared format:**



FDS simulation "Liège test series" M7

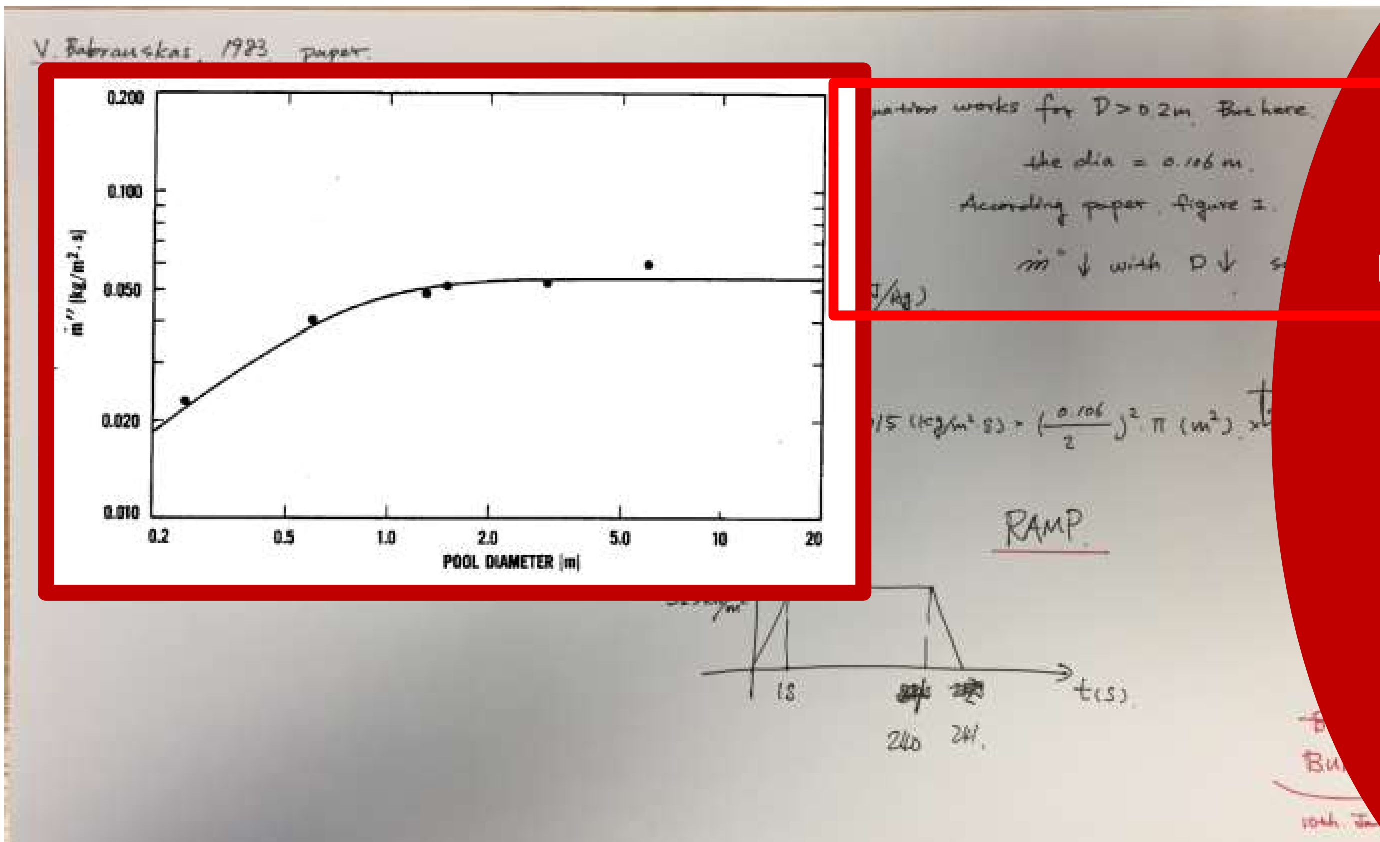


MPI used, 11 meshes in total, cell size 0.03m×0.03m×0.035m (to fit per cell - per cross section) for wood sticks; cell size 0.06m×0.06m×0.07m for upper flame and ceiling part; total number of cells 670 320

FDS simulation “Liège test series” M7

Ethanol burner, part of the FDS model script

```
&SURF   ID                        = 'VIRTUAL_ETHANOL'
        COLOR                     = 'RED'
        HRRPUA                    = 323.
        RAMP_Q                    = 'VIRTUAL_ETHANOL_RAMP' / virtual ethanol, HRRPUA curve based on Quintiere formula and duration measured
&RAMP   ID = 'VIRTUAL_ETHANOL_RAMP', T=0.0,   F=0. /
&RAMP   ID = 'VIRTUAL_ETHANOL_RAMP', T=1.0,   F=1. /
&RAMP   ID = 'VIRTUAL_ETHANOL_RAMP', T=240.0, F=1. /
&RAMP   ID = 'VIRTUAL_ETHANOL_RAMP', T=241.0, F=0. /
```



Babrauskas model works when fire diameter is larger than 0.2m. However, our ethanol ignitor has diameter 0.106m only. Based on Fig.1 from Babrauskas 1983 paper, we are over-estimating the HRRPUA of our burner, resulting to a shorter burning time. Any free ethanol burning test so we can get the time duration? @Antonio

FDS simulation “Liège test series” M7

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Spruce wood material model, FDS input script

```
&MATL   ID                  = 'PICEA'
        FYI                 = 'Density measured by ULG, HOC from SFPE (times 0.8) p3449, Cond & SH from Pei Ying Yang'
        SPECIFIC_HEAT_RAMP  = 'PICEA_SH_RAMP'
        CONDUCTIVITY_RAMP   = 'PICEA_COND_RAMP'
        DENSITY             = 468.0

&RAMP ID = 'PICEA_COND_RAMP',  T = 20.0,   F = 0.1
&RAMP ID = 'PICEA_COND_RAMP',  T = 360.0,  F = 0.1
&RAMP ID = 'PICEA_COND_RAMP',  T = 1200.0, F = 0.1
&RAMP ID = 'PICEA_SH_RAMP', T = 20.0,   F = 1.24
&RAMP ID = 'PICEA_SH_RAMP', T = 99.0,   F = 1.43
&RAMP ID = 'PICEA_SH_RAMP', T = 120.0,  F = 2.12
&RAMP ID = 'PICEA_SH_RAMP', T = 200.0,  F = 2.0
&RAMP ID = 'PICEA_SH_RAMP', T = 250.0,  F = 1.62
&RAMP ID = 'PICEA_SH_RAMP', T = 300.0,  F = 0.71
&RAMP ID = 'PICEA_SH_RAMP', T = 350.0,  F = 0.85
&RAMP ID = 'PICEA_SH_RAMP', T = 400.0,  F = 1.0
&RAMP ID = 'PICEA_SH_RAMP', T = 600.0,  F = 1.4
&RAMP ID = 'PICEA_SH_RAMP', T = 800.0,  F = 1.65
&RAMP ID = 'PICEA_SH_RAMP', T = 1200.0, F = 1.65
```

NB – only **wood density** is known. **Heat of combustion** (20.4×0.8=16.32MJ/kg) is from SFPE Handbook with assumed combustion efficiency 0.8; **specific heat** and **conductivity** RAMP from fit by Yang (2016) IMFSE thesis

Table A.32 (continued)

Material	Gross, $\Delta h_c''$ (MJ/kg)	Net, $\Delta h_c'$ (MJ/kg)
Paraffin wax	46.2	43.1
Peat	16.7–21.6	
Petroleum jelly ($C_{7.118}H_{12.957}O_{0.091}$)	45.9	
Rayon fiber	13.6–19.5	
Rubber—buna N	34.7–35.6	
—butyl	45.8	
—isoprene (natural) C_5H_8	44.9	42.3
—latex foam	33.9–40.6	
—GRS	44.2	
—tire, auto	32.6	
Silicone rubber (SiC_2H_6O)	15.5–16.8	
—foam	14.0–19.5	
Sisal	15.9	
Spandex fiber	31.4	
Starch	17.6	16.2
Straw	15.6	
Sulfur—rhombic		9.28
—monoclinic		9.29
Tobacco	15.8	
Wheat	15.0	
Wood—beech	20.0	18.7
—birch	20.0	18.7
—douglas fir	21.0	19.6
—maple	19.1	17.8
—red oak	20.2	18.7
—white pine	19.2	17.8
—hardboard	19.9	
Woodflour	19.8	
Wool	20.7–26.6	

SFPE Handbook, 5th edition, p. 3449

FDS simulation “Liège test series” M7

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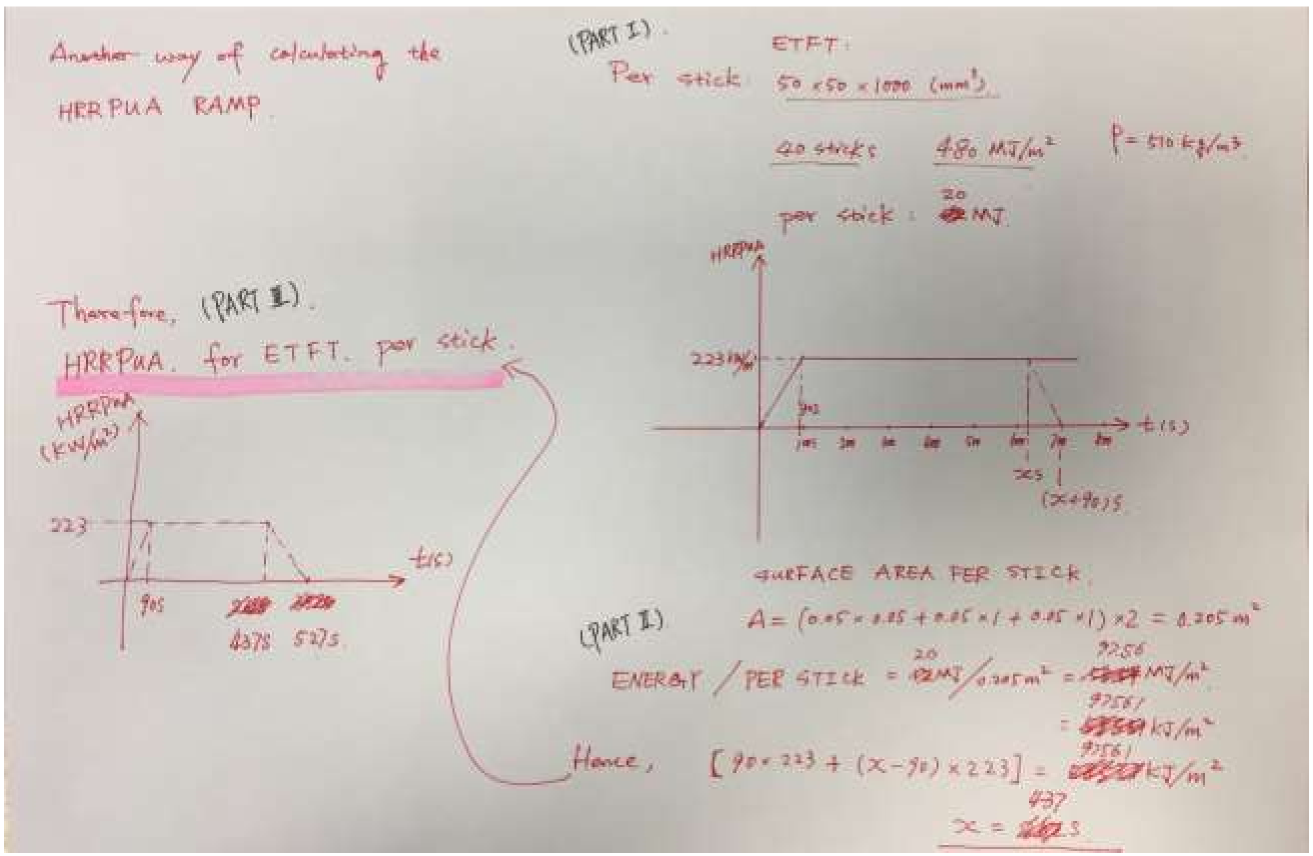
Wood SURF & HRRPUA, FDS input script

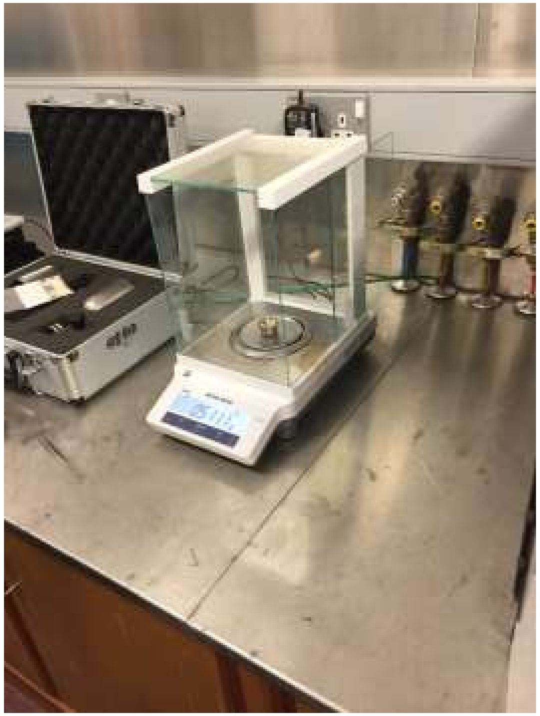
```
&SURF   ID                         = 'wood_stick'
        COLOR                      = 'TAN'
        HRRPUA                     = 223.
        RAMP_Q                     = 'WOOD_RAMP'
        IGNITION_TEMPERATURE       = 200.0
        MATL_ID                    = 'PICEA'
&RAMP   ID = 'WOOD_RAMP', T=0.0,   F=0.0 /
&RAMP   ID = 'WOOD_RAMP', T=90.0,  F=1.0 /
&RAMP   ID = 'WOOD_RAMP', T=437.0, F=1.0 /
&RAMP   ID = 'WOOD_RAMP', T=527.0, F=0.0 / HRRPUA curve based on HRRPUAmax from Pei Ying Yang, and duration obtained considering 20MJ per stick.
```

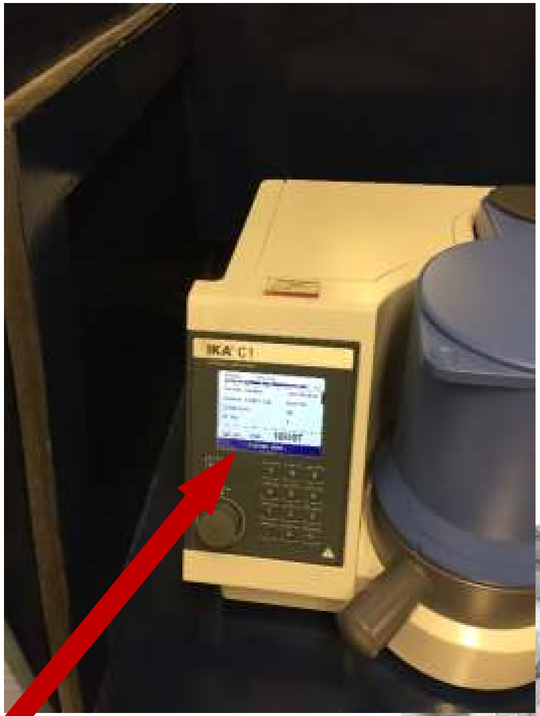


HRRPUA 223kW/m² is from fit in Yang’s work, accompanying with per stick (50mm×50mm ×1000mm) is 20MJ, the **RAMP_Q** can be estimated

Spruce (*Picea abies*) characterisation in bomb

Bomb calorimetry for heat of combustion (gross)





The gross chemical heat of combustion of Spruce (*Picea abies*), is 18MJ/kg, very small amount of sample (i.e. around 0.5g) tested in bomb calorimeter

Spruce (*Picea abies*) characterisation in cone

After the piloted ignition in the cone

After the piloted ignition in the cone

Weight measurement after the test

Cone calorimetry for critical flux, ignition temperature, burning rate, etc.

FDS simulation “Liège test series” M7

Simple combustion, part of the FDS model script

```
&MATL ID                   = 'PICEA'
      FYI                  = 'Density measured by ULG,
      SPECIFIC_HEAT_RAMP   = 'PICEA_SH_RAMP'
      CONDUCTIVITY_RAMP    = 'PICEA_COND_RAMP'
      DENSITY              = 468.0

```

```
&REAC ID                   = 'Wood'
      FYI                  = 'Picea abies, the Norwa
      FUEL                 = 'REAC_FUEL_WOOD_PICEA'
      C                    = 1.0
      H                    = 3.584
      O                    = 1.55
      CO_YIELD             = 0.005
      SOOT_YIELD           = 0.015
      HEAT_OF_COMBUSTION   = 1.684E4 /
```

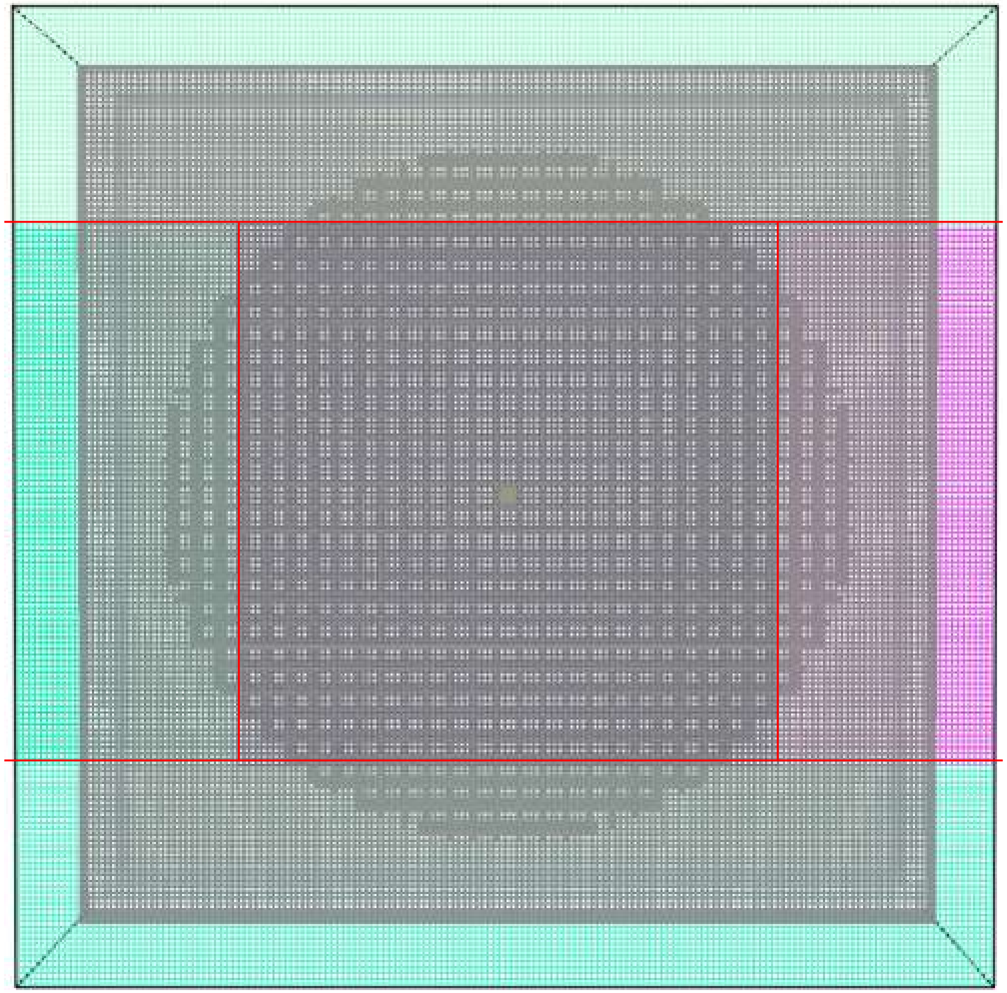
Table A.32 (continued)

Material	Gross, $\Delta h_c''$ (MJ/kg)	Net, $\Delta h_c'$ (MJ/kg)
Paraffin wax	46.2	43.1
Peat	16.7–21.6	
Petroleum jelly $(C_{7.118}H_{12.957}O_{0.091})$	45.9	
Rayon fiber	13.6–19.5	
Rubber—buna N	34.7–35.6	
—butyl	45.8	
—isoprene (natural) C_5H_8	44.9	42.3
—latex foam	33.9–40.6	
—GRS	44.2	
—tire, auto	32.6	
Silicone rubber (SiC_2H_6O)	15.5–16.8	
—foam	14.0–19.5	
Sisal	15.9	
Spandex fiber	31.4	
Starch	17.6	16.2
Straw	15.6	
Sulfur—rhombic		9.28
—monoclinic		9.29
Tobacco	15.8	
Wheat	15.0	
Wood—beech	20.0	18.7
—birch	20.0	18.7
—douglas fir	21.0	19.6
—maple	19.1	17.8
—red oak	20.2	18.7
—white pine	19.2	17.8
—hardboard	19.9	
Woodflour	19.8	
Wool	20.7–26.6	

From SFPE Handbook, 5th edition, p. 3449

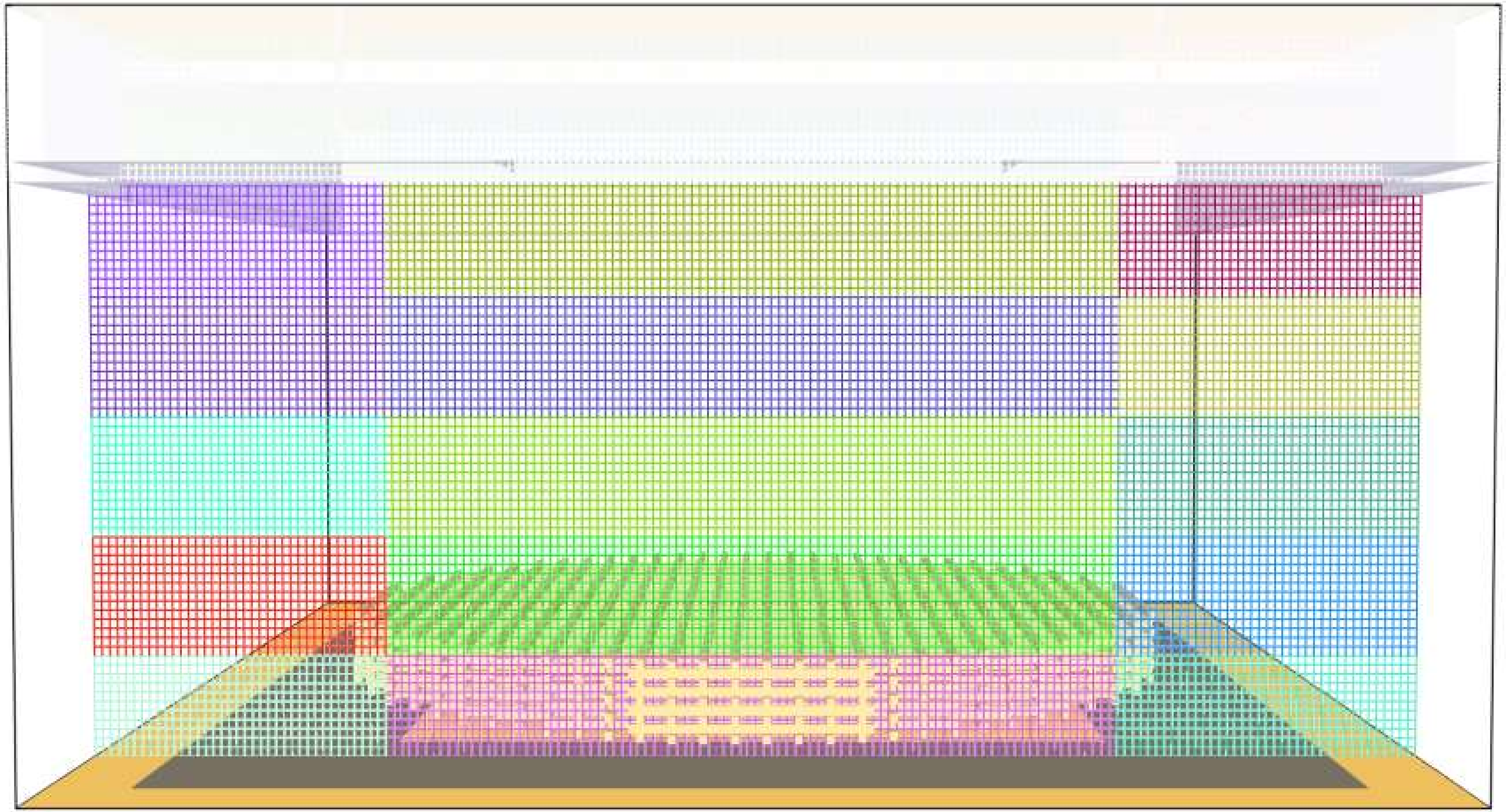
Heat of combustion value is updated according to the ‘Picea abies’ wood sample test at UEDIN using bomb calorimeter. Gross chemical heat of combustion (HoC) is 18MJ/kg. According to relationship between gross HoC and net HoC of spruce from Table A.32 in SFPE Handbook, net HoC of Spruce (*Picea abies)* is estimated as (20.4×18)/21.8 = 16.84MJ/kg, assuming combustion efficiency 0.8 the effective HoC is estimated as 16.84×0.8 = 13.48MJ/kg.

FDS simulation “Liège test series” M7



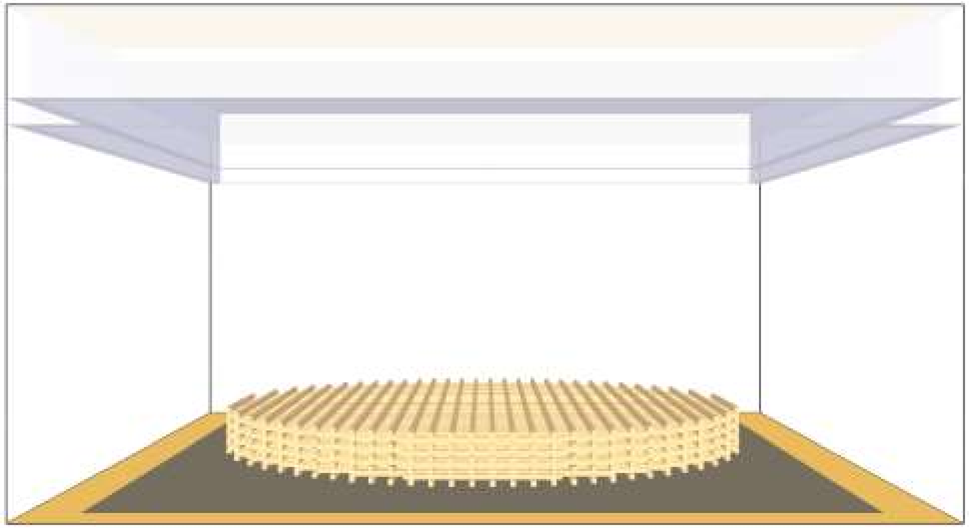
Multi-mesh in elevation view, mesh number 30 in total, cell size 0.03m×0.03m×0.035m (to fit per cell - per cross section) for wood sticks, total number of cells 2,201,472 (HPC on ARCHER via UKCTRF)

FDS simulation "Liège test series" M7

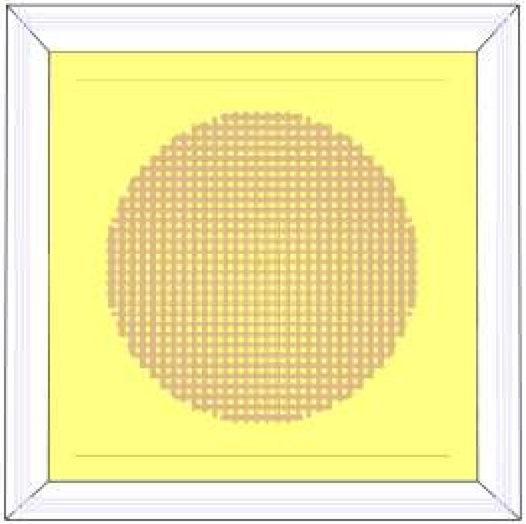


Multi-mesh in elevation view, mesh number 30 in total, cell size 0.03m×0.03m×0.035m (to fit per cell - per cross section) for wood sticks, total number of cells 2,201,472 (HPC on ARCHER via UKCTRF)

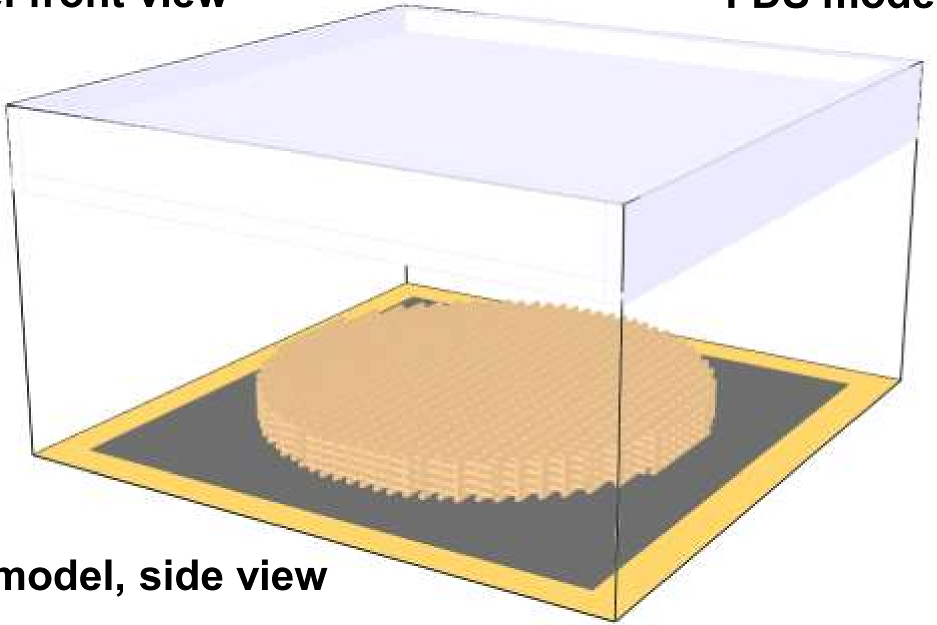
FDS simulation “Liège test series” M7



FDS model front view



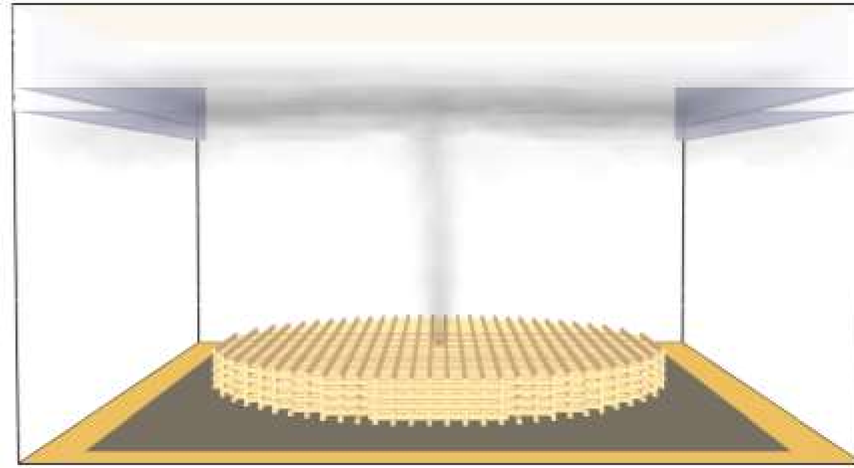
FDS model top view



FDS model, side view

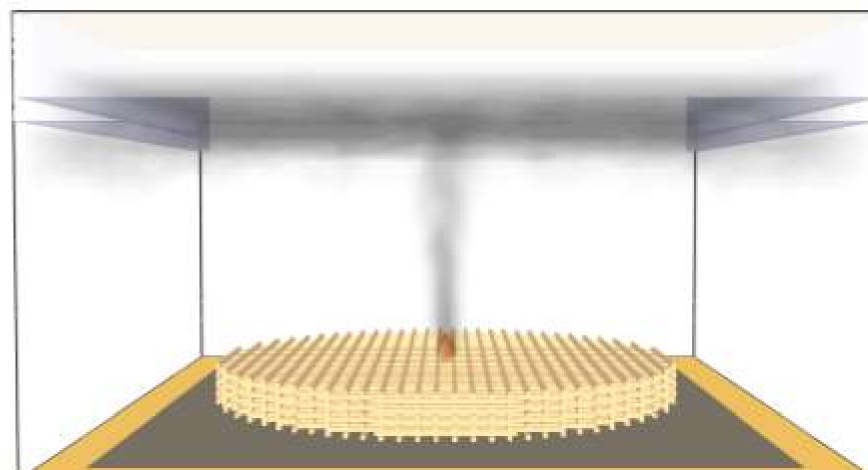
FDS simulation “Liège test series” M7

60s from test (at 20min of the full test video is regarded as t=0s)



60s from FDS

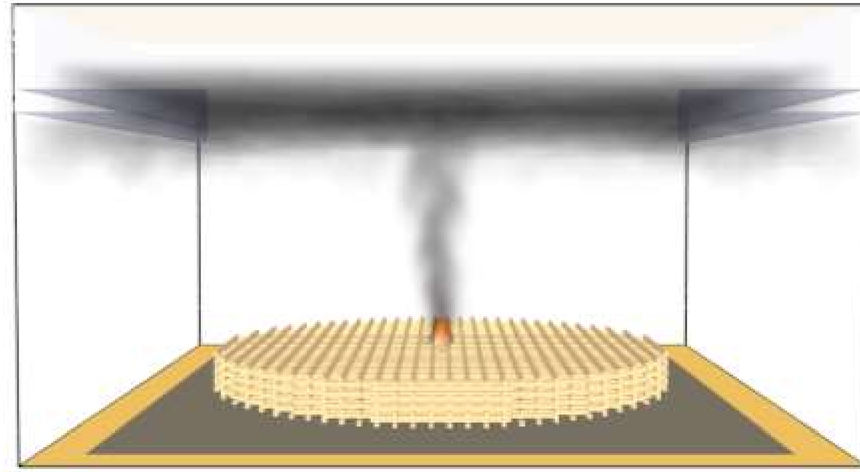
120s from test



120s from FDS

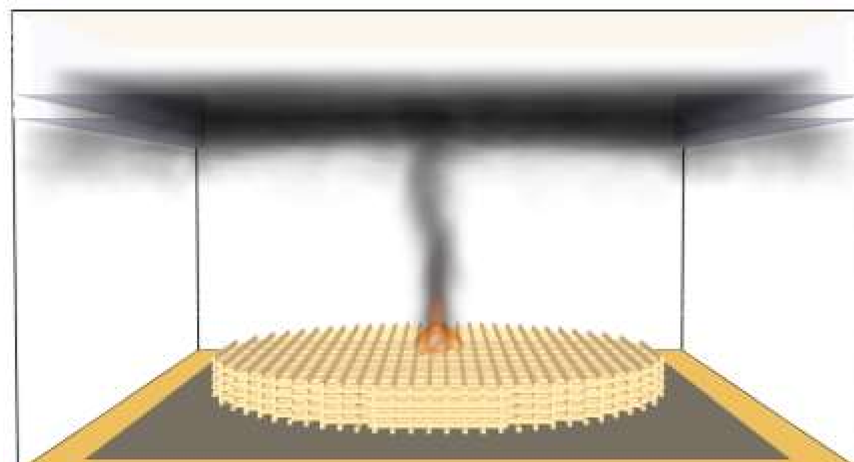
FDS simulation “Liège test series” M7

180s from test



180s from FDS

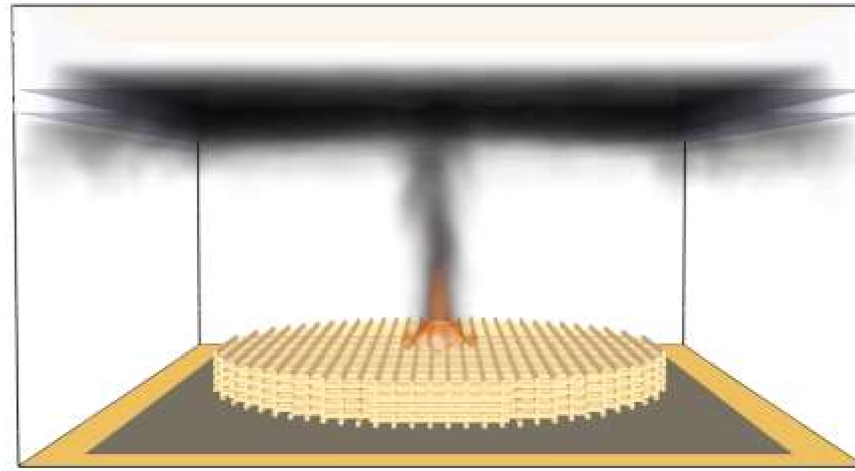
240s from test



240s from FDS

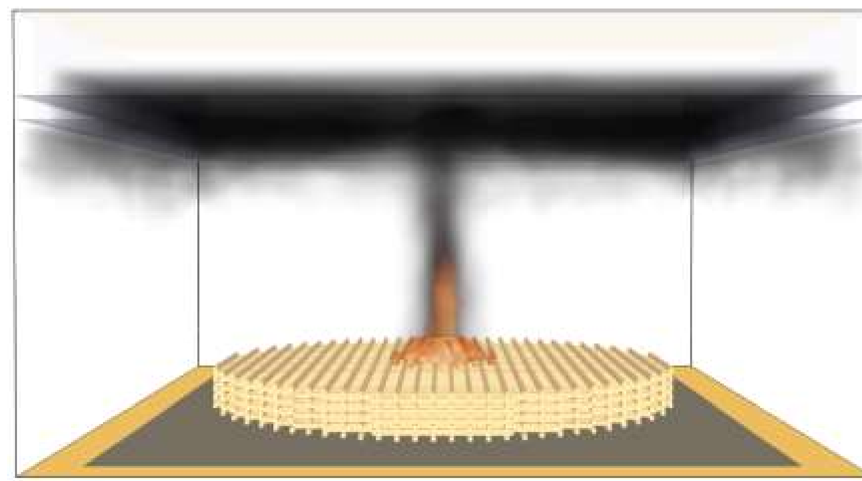
FDS simulation “Liège test series” M7

300s from test



300s from FDS

360s from test



360s from FDS

FDS simulation “Liège test series” M7

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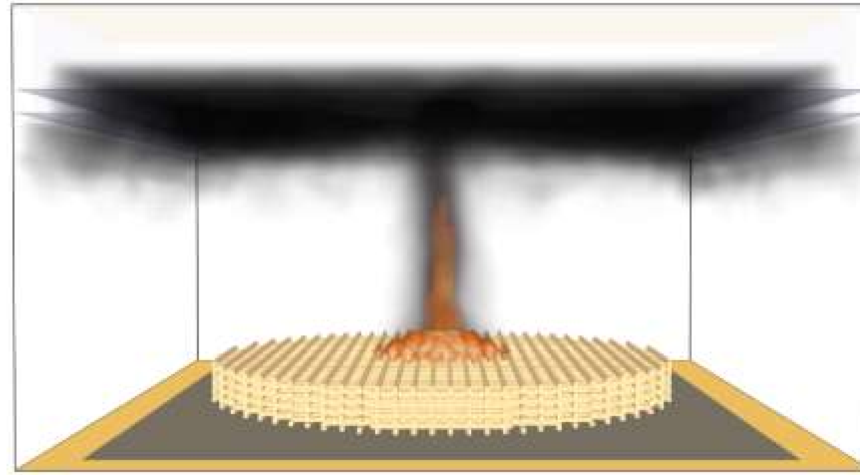
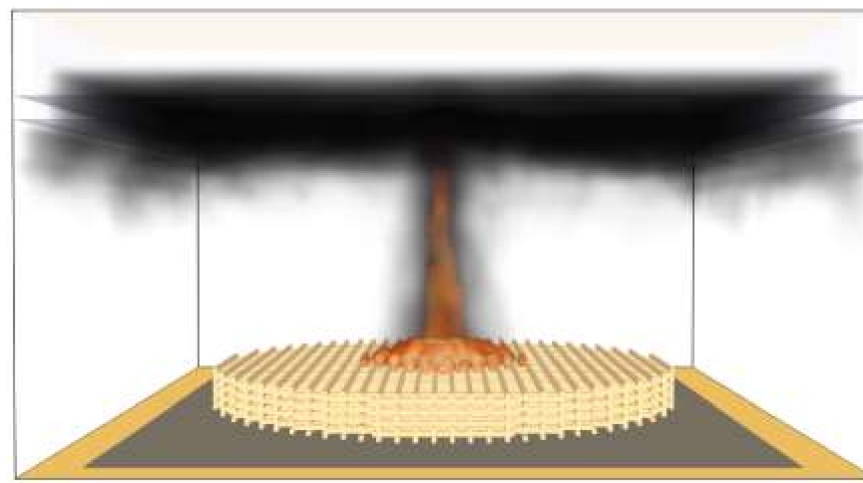
420s from test



420s from FDS

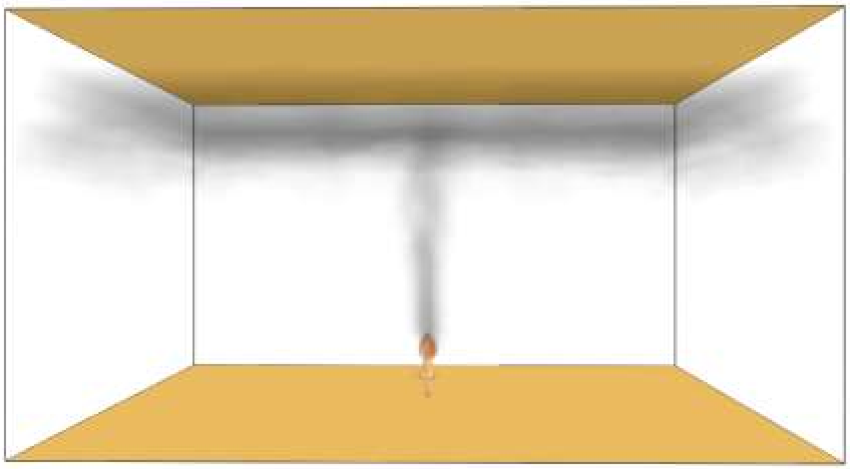
468s from test



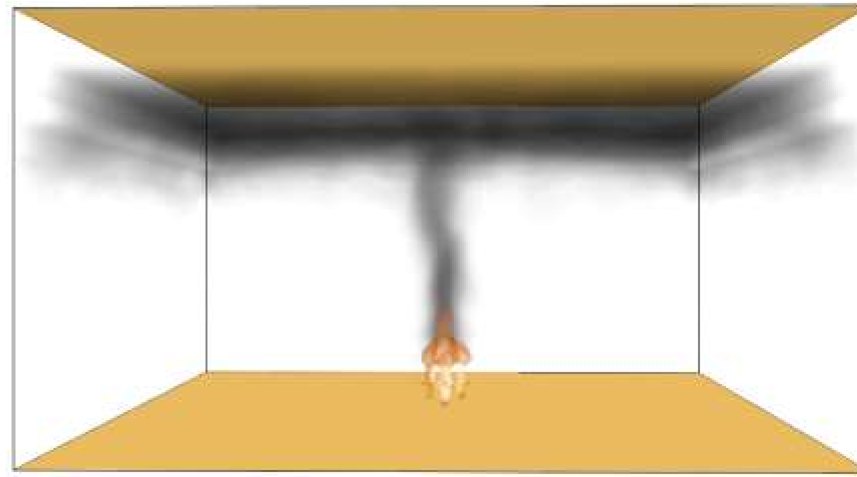
468s from FDS

FDS simulation “Liège test series” M7

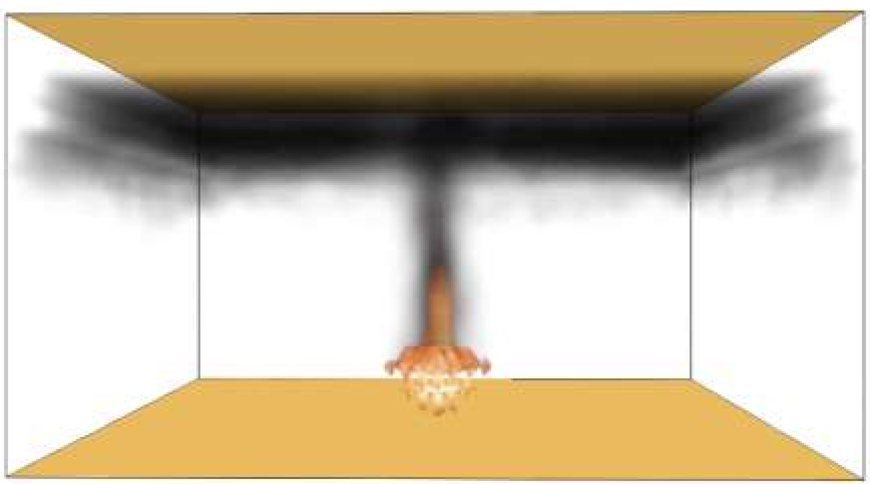
How fire spreads among the wood stick layers



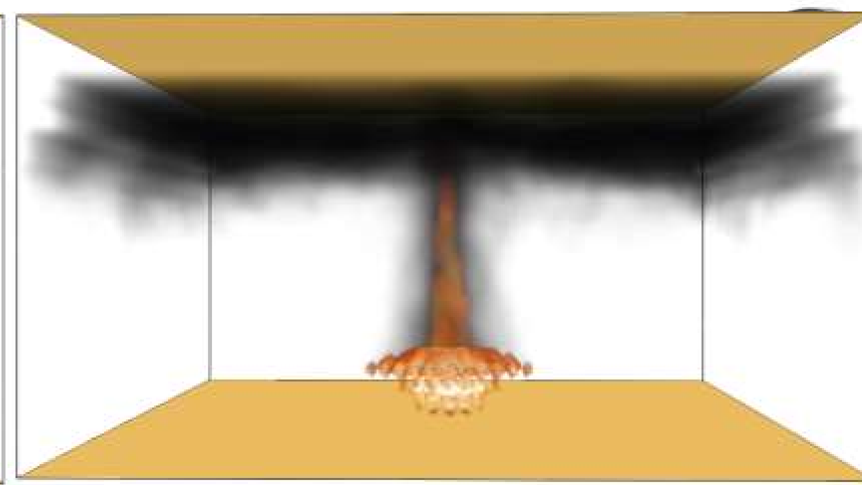
120s from FDS



240s from FDS



360s from FDS



468s from FDS

FDS simulation “Liège test series” M7

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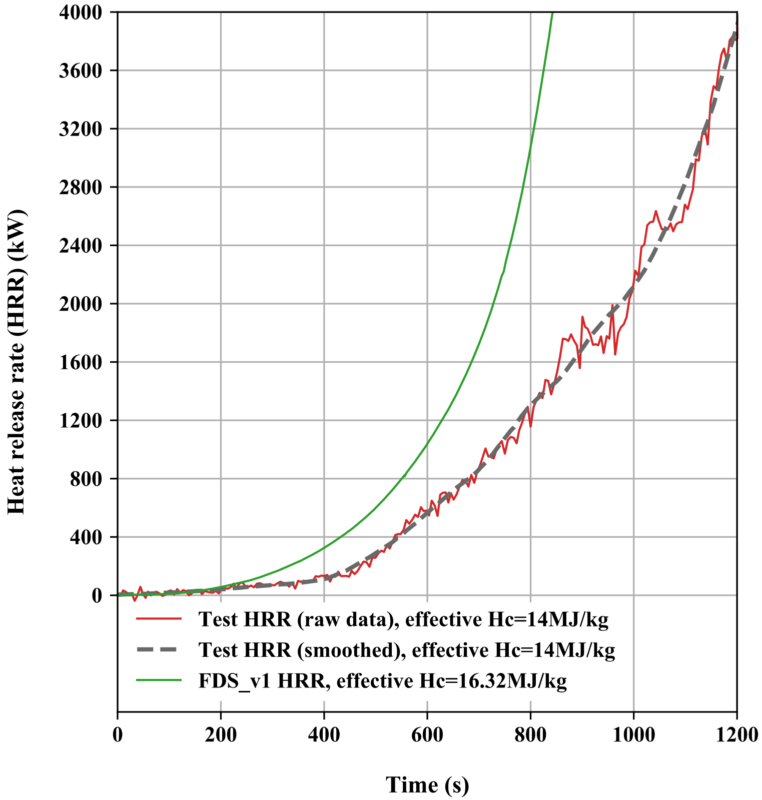
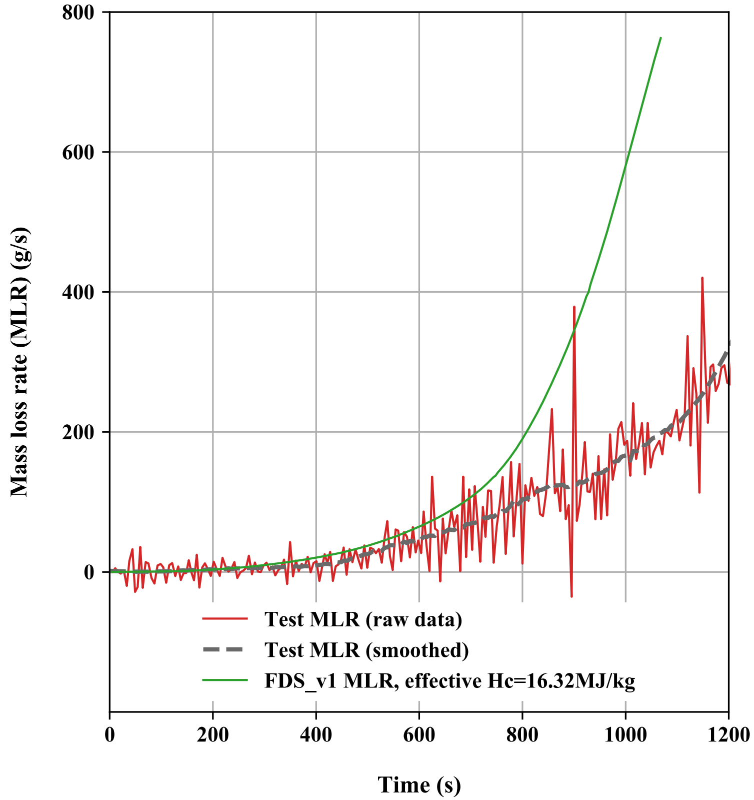
BUT, despite superficial agreement on spread, the HRR & MLR from FDS is twice that of the test!

Estimated HRR based on mass loss data vs. FDS HRR



Estimated MLR based on mass loss data vs. FDS MLR



HRR comparison between test and FDS, for M7

FDS simulation “Liège test series” M7

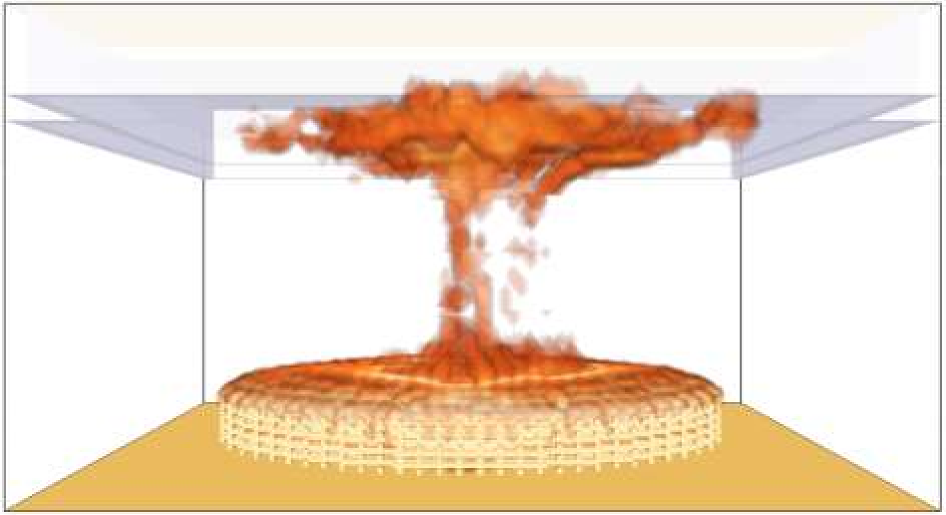
860s from FDS

860s from test

Issues spotted towards end of simulation

The fire plume is not well developed in this early version of FDS model, compared with the test at 860s; again, the fire spread rate in the model is much faster than the test

FDS simulation "Liège test series" M7



1060s from FDS

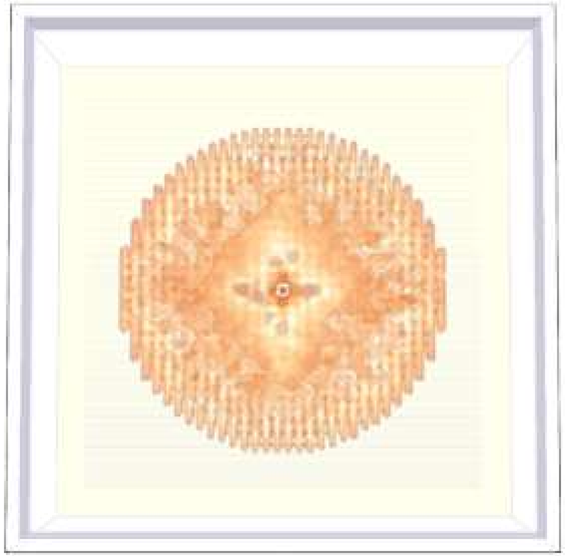
1060s from test

Issues spotted towards end of simulation

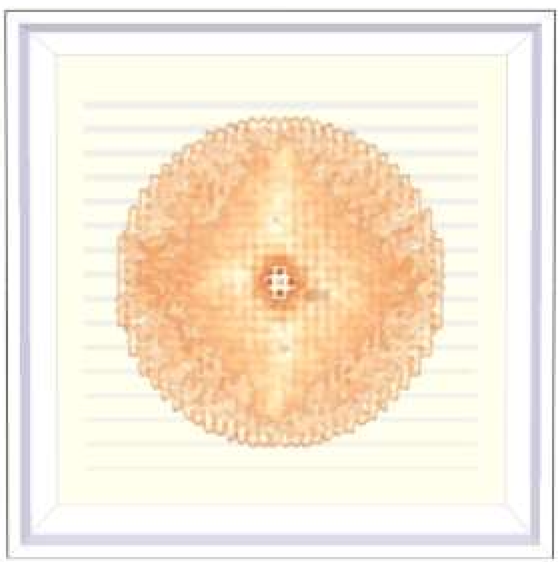
The fire plume is not well developed in this early version of FDS model, compared with the test at 860s; again, the fire spread rate in the model is much faster than the test

FDS simulation "Liège test series" M7

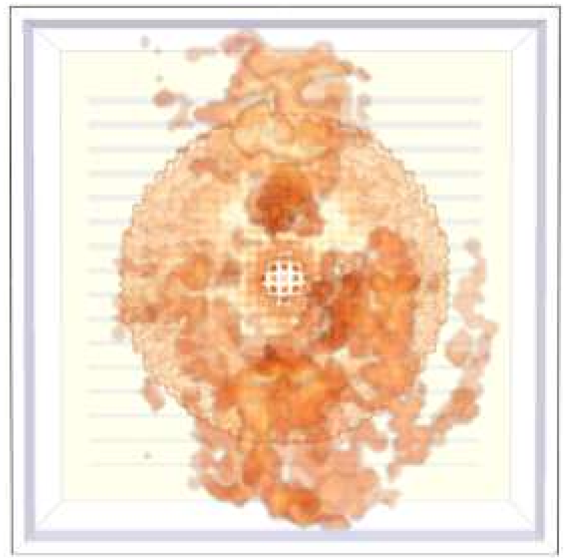
Examination of burn-out



820s from FDS



940s from FDS



1060s from FDS

Key constraint – match of burn-out i.e. a doughnut-like burning format is observed in the model.

FDS simulation "Liège test series" M7

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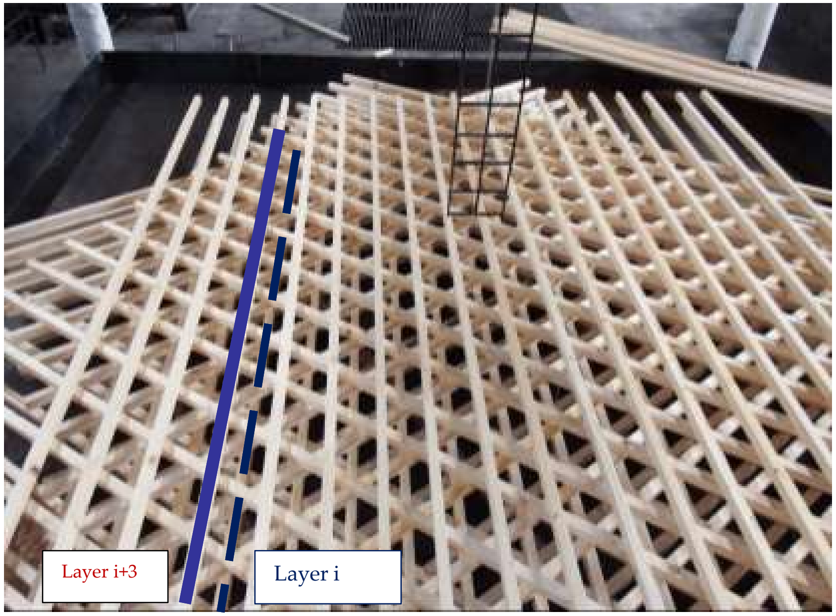
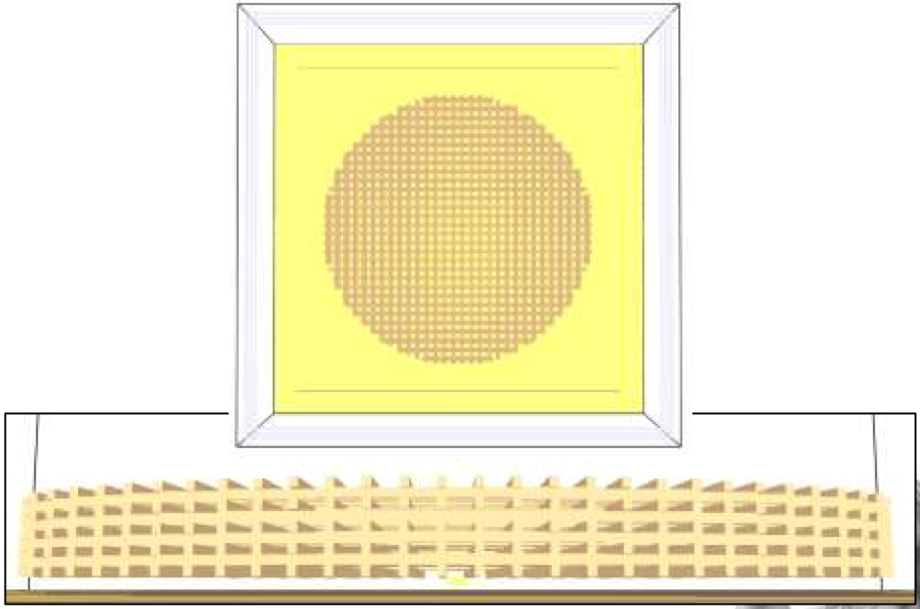
Significant challenge in calibrating mass loss rate – possibly due to over-simplified wood stick representation in the FDS model



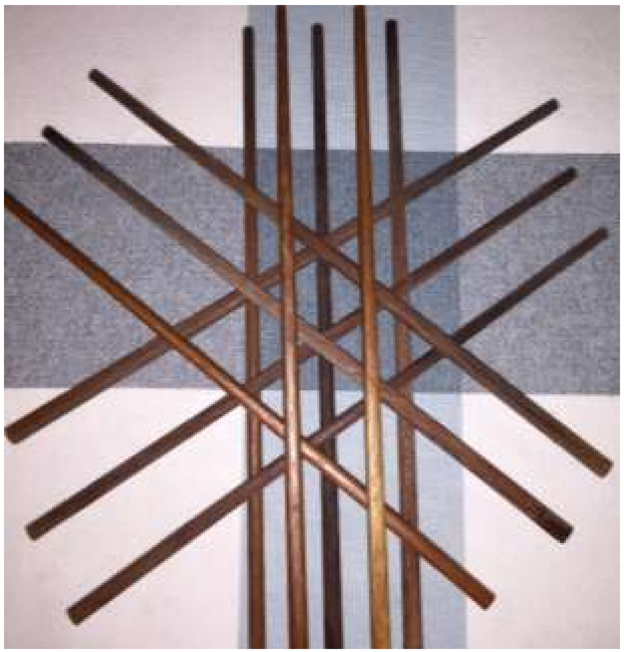


Shifted fuel load arrangement for test M7; Test M7 is made of 9 layers of sticks with an axis distance of 120 mm, layers i and i+3 were shifted laterally by 60 mm.

In the FDS model, we have no offset, hence less porosity (i.e. lower layers support reduced fire spread).

FDS simulation “Liège test series” M7

A demo with chop sticks…



ULG, M7 test

Wood sticks in current FDS model

Wood sticks in the proposed FDS model

The overall aim is to increase porosity of wood crib to boost fire spread at lower layers

FDS simulation "Liège test series" M7

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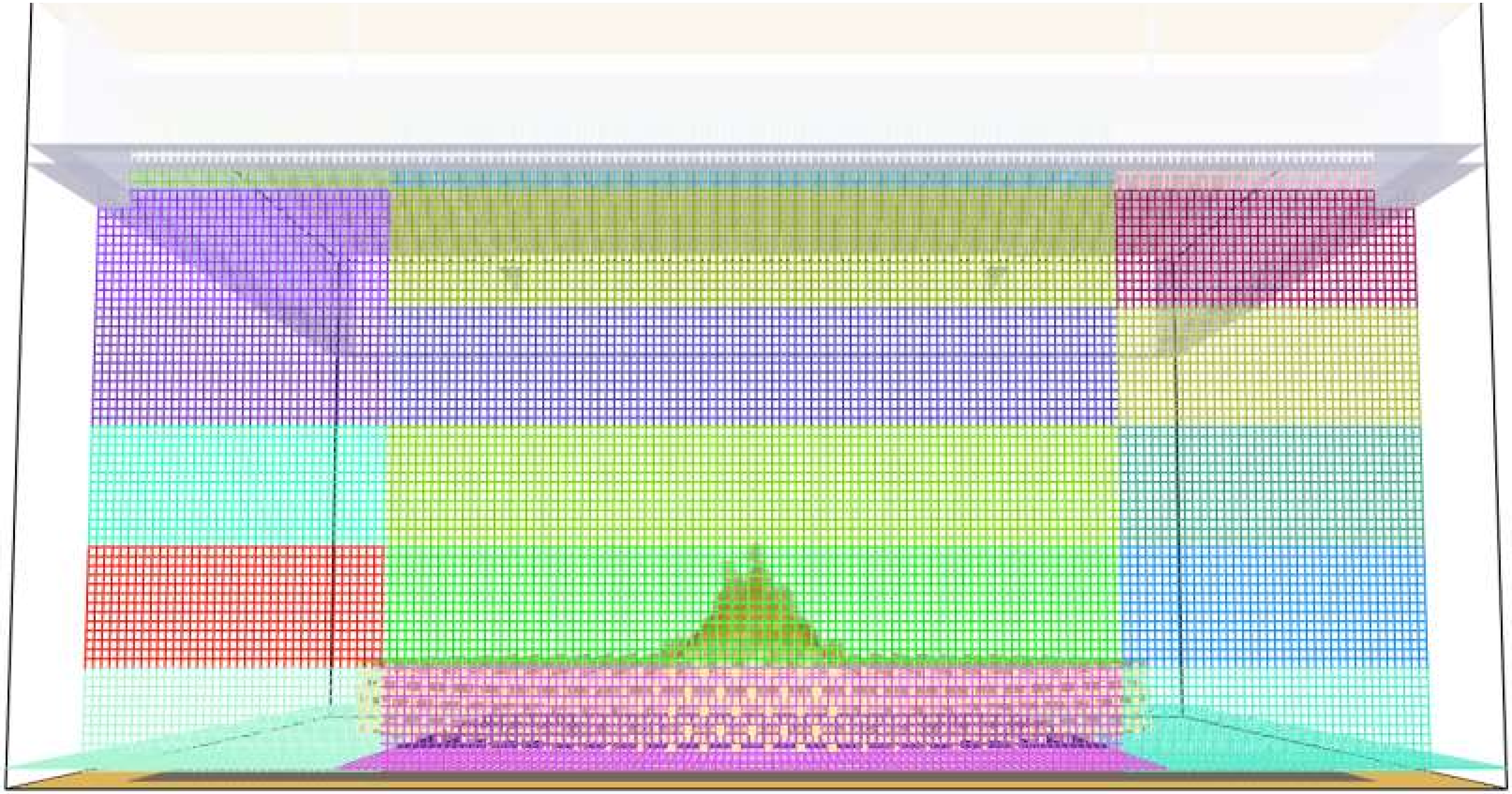
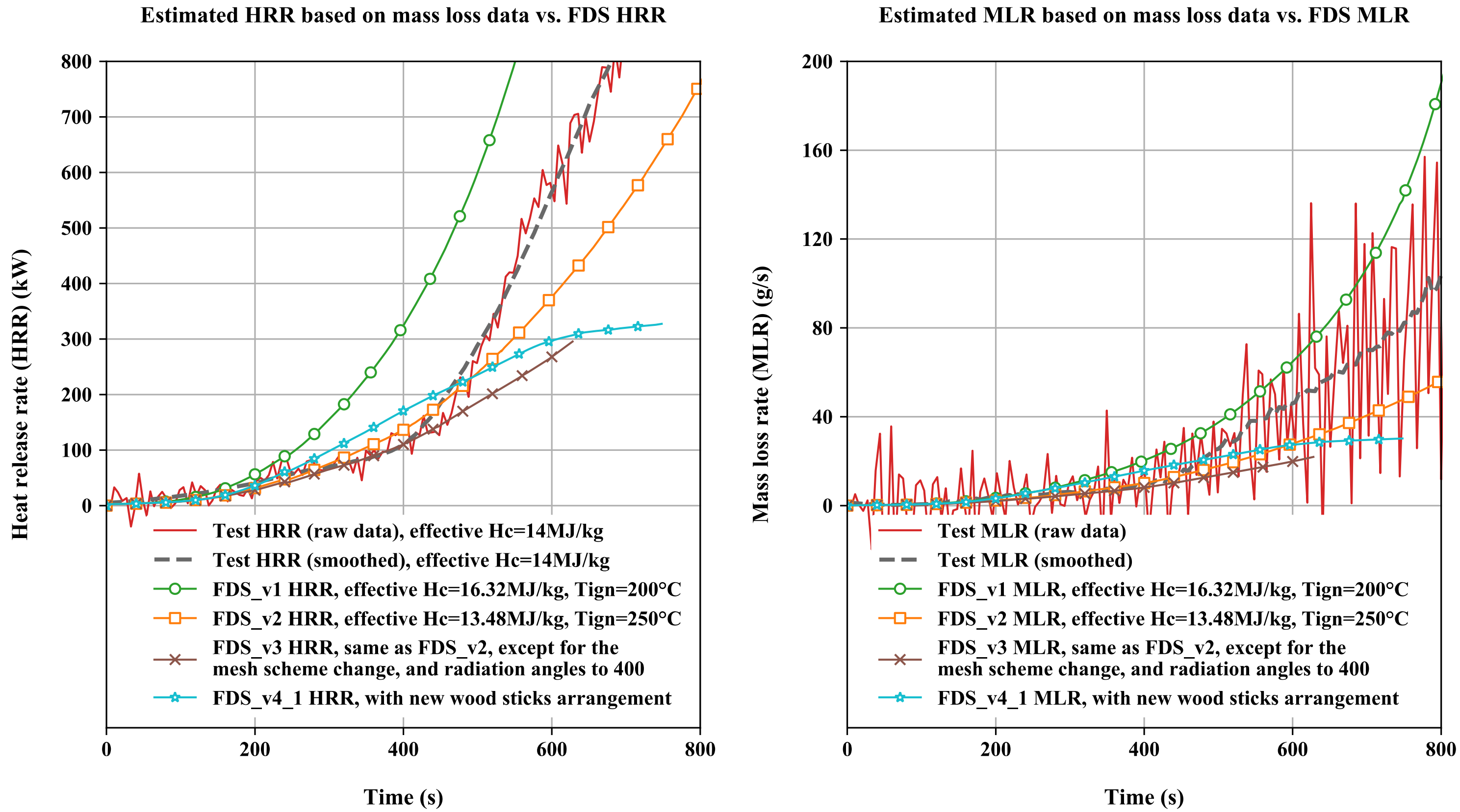
Now every 2 layers we have the wood sticks 'offset' in parallel distance of 60mm, to generate higher porosity for FDS model, v4 series. Multi-mesh shown below.



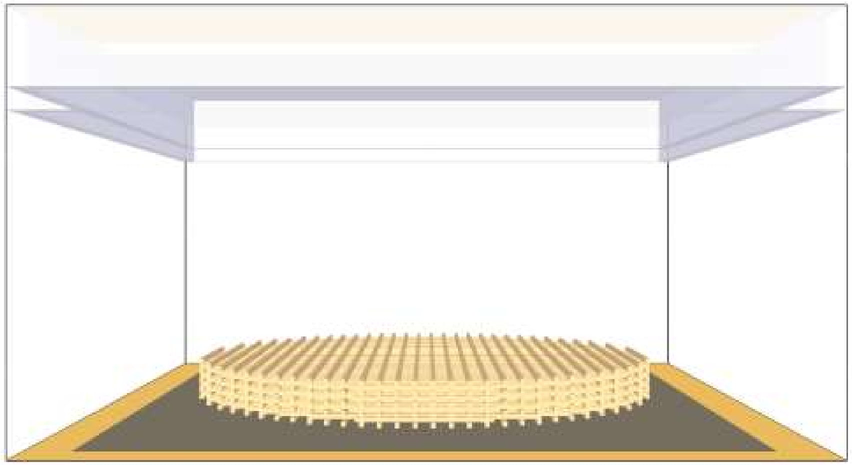
FDS simulation “Liège test series” M7



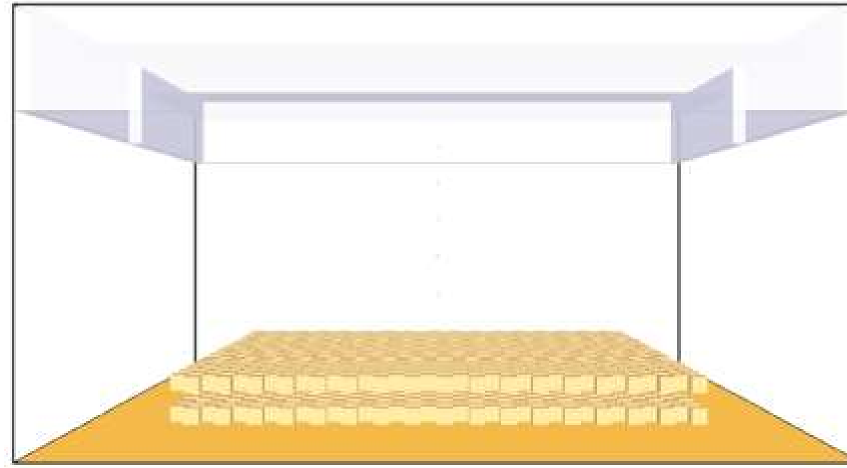
HRR comparison between test and FDS, for M7

Note: with new wood arrangement in FDS model v4_1, this t-squared fire development in terms of HRR, or MLR becomes unclear or even diminishes. This wood stick rearrangement is not successful!

FDS simulation “Liège test series” M7



Stick-stick-model



Chessboard model

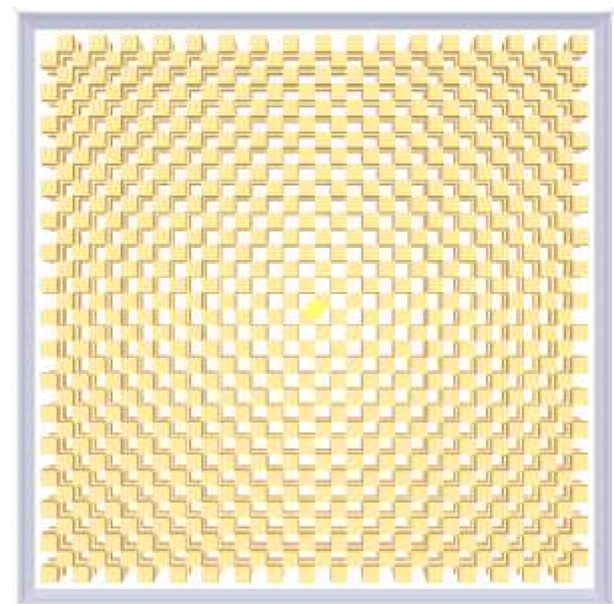
Why chessboard model?

Advantages:

- larger grid cells
- consistent mass/air ratio
- still uniform fuel bed

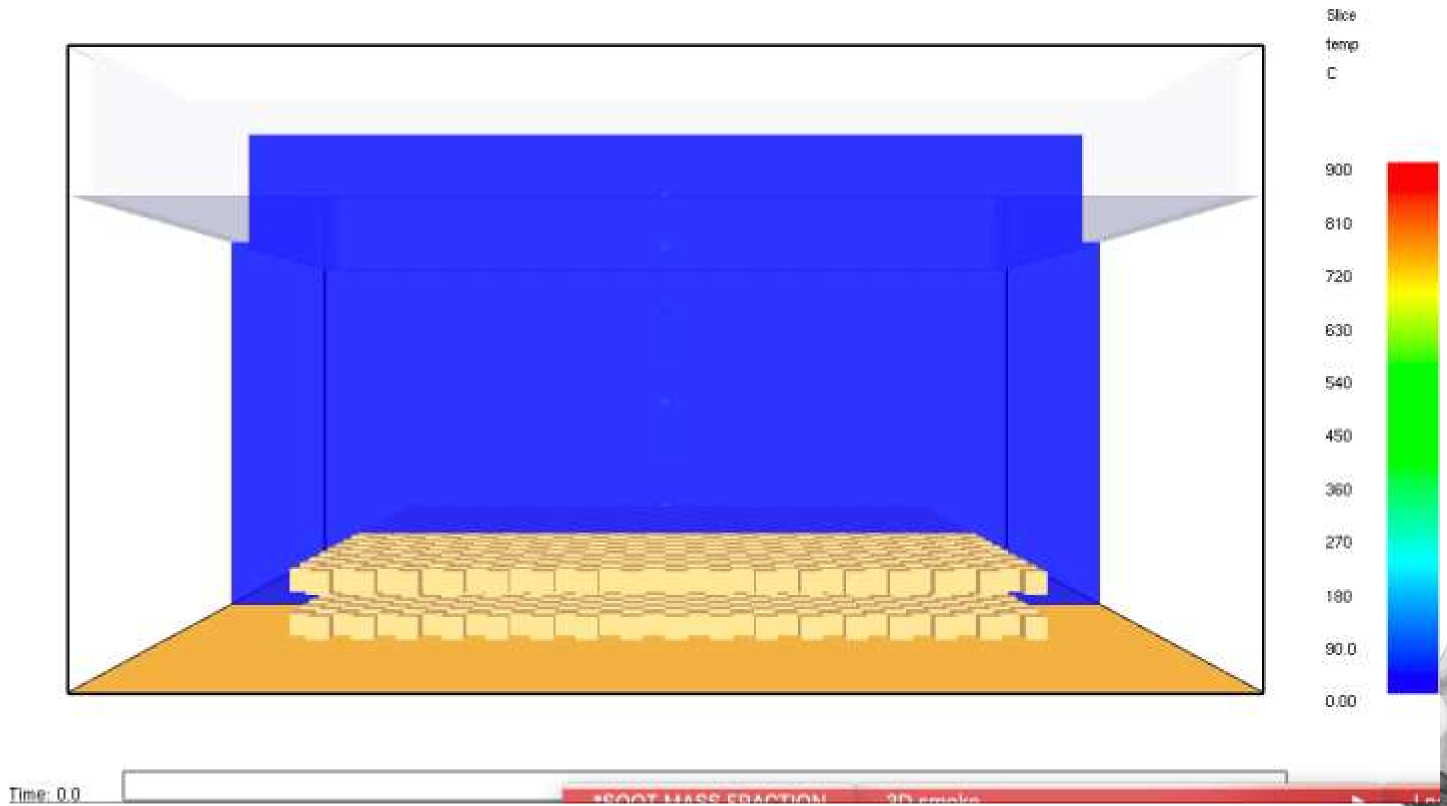
Disadvantages:

- worse fuel-bed resolution
- unknown reliability of this method



FDS simulation “Liège test series” M7

Method developed in VTT, Finland and pioneered by Horová, K. “Modelling of Fire Spread in Structural Fire Engineering”, PhD Thesis, Czech Technical University In Prague, 2015



Updated M7 calibration with chessboard method

FDS simulation "Liège test series" M7

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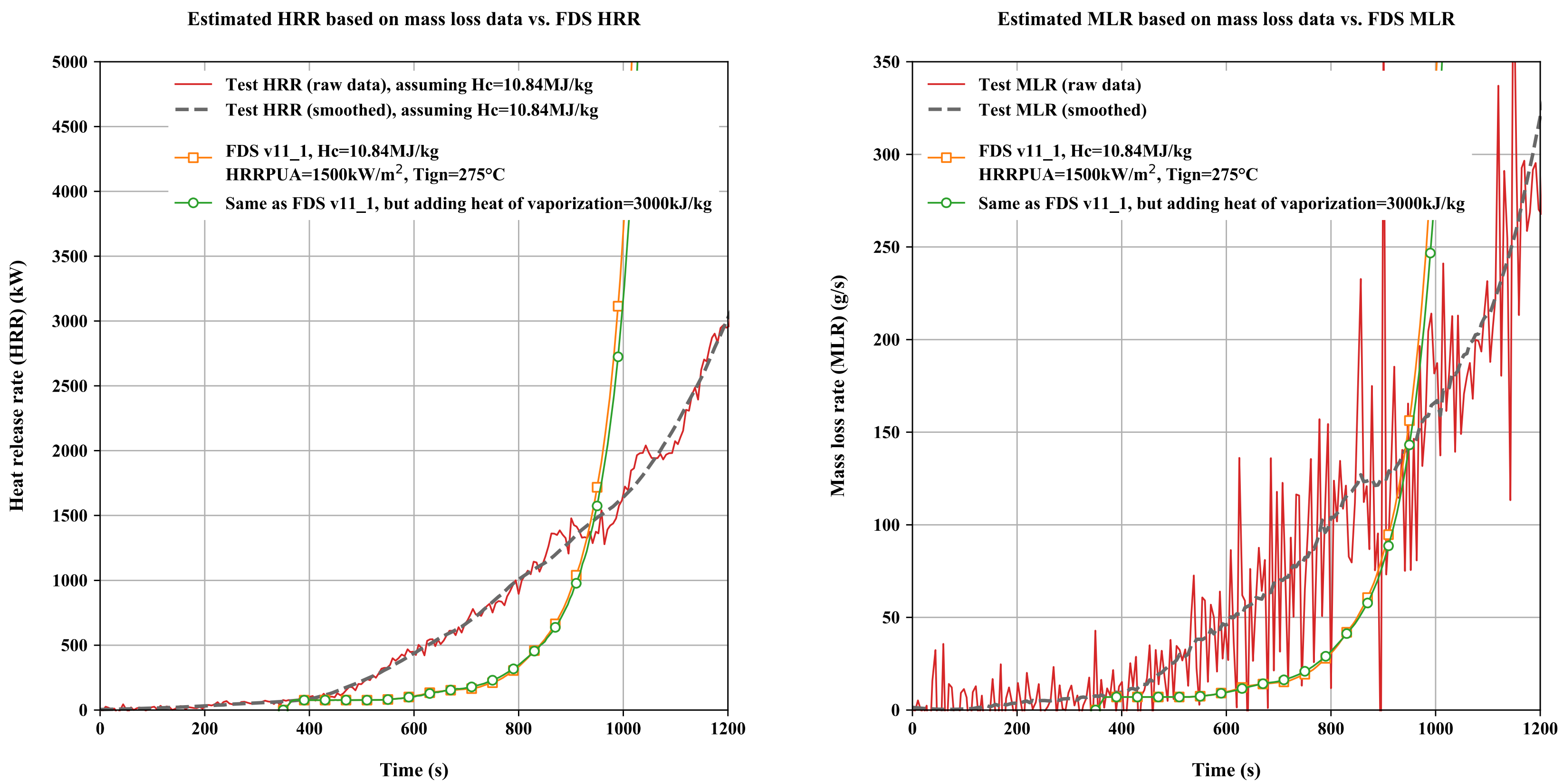
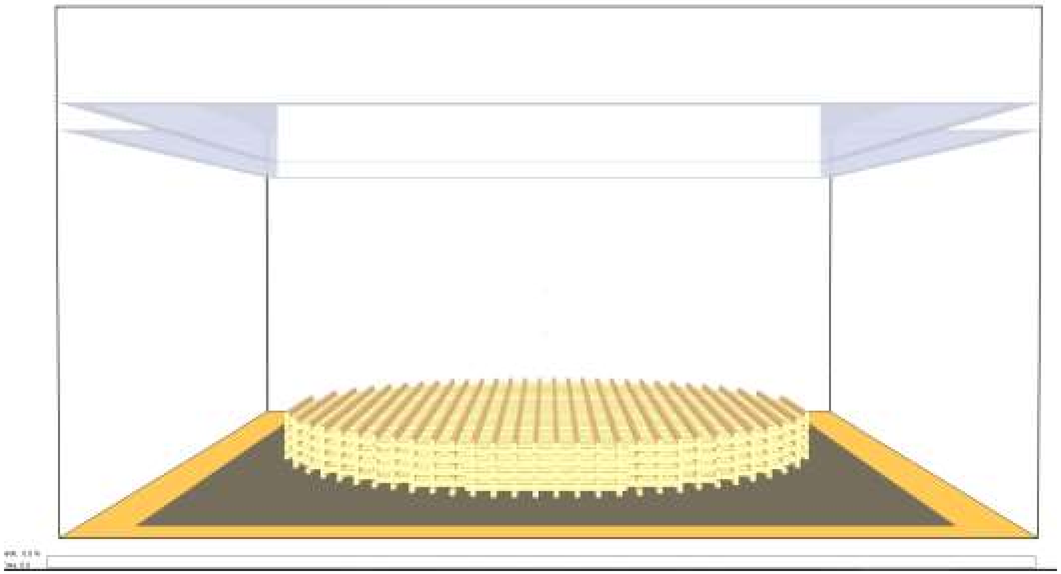
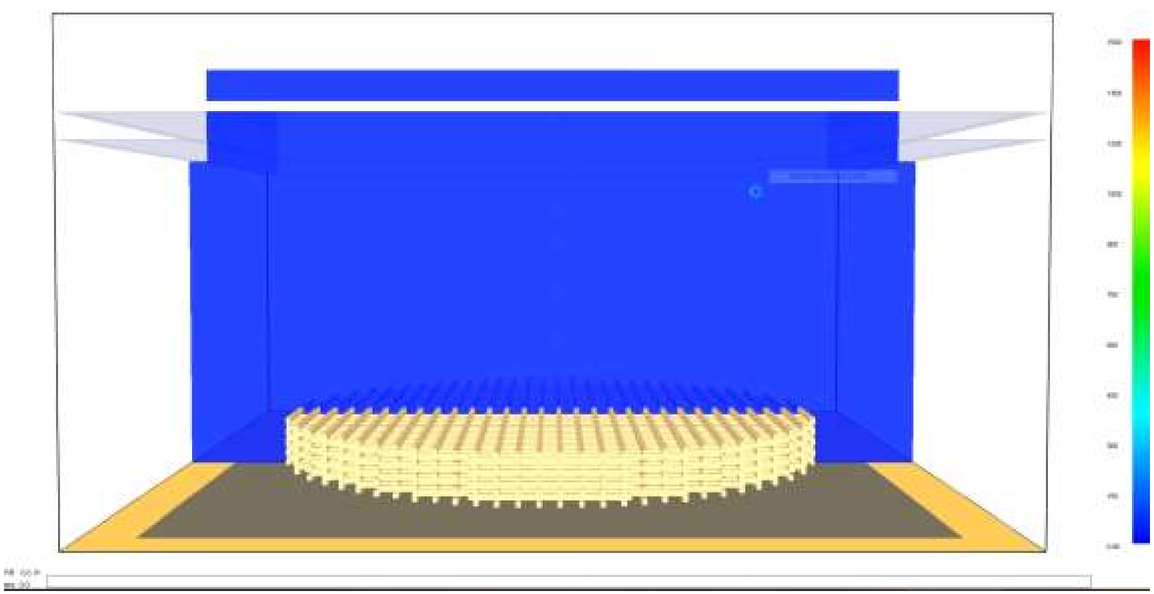
HRR comparison between test and FDS, for M7



Extremely difficult to match the full behaviour of the fire, i.e. spread, HRR, MLR, temperature, etc.

FDS simulation “Liège test series” M7





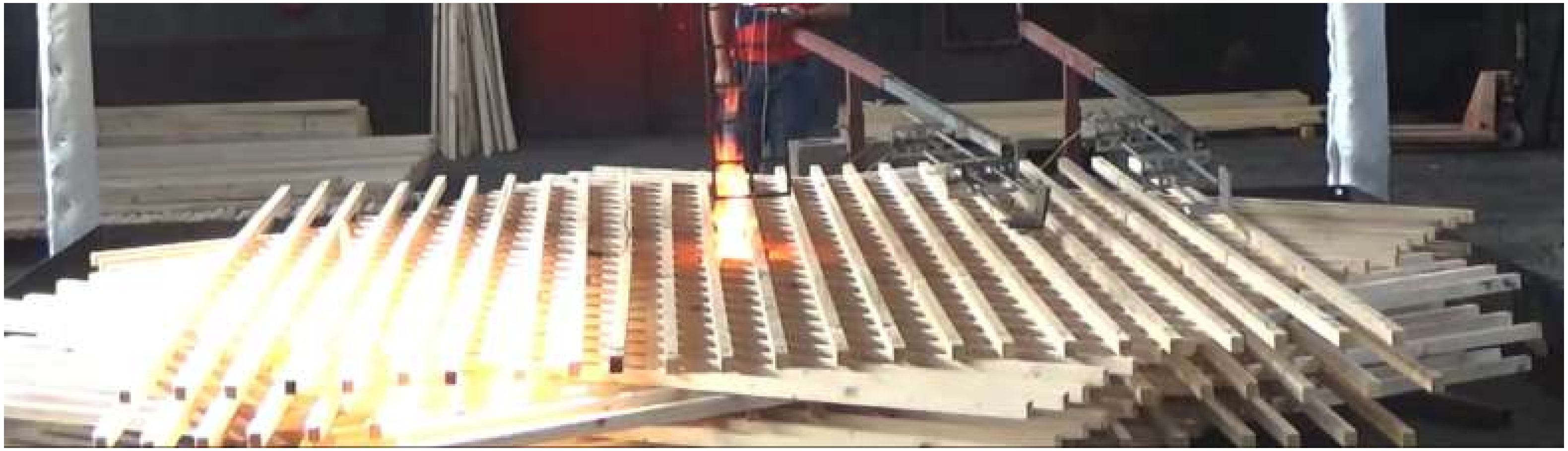
FDS modelling animation

HRR: 0.0 W

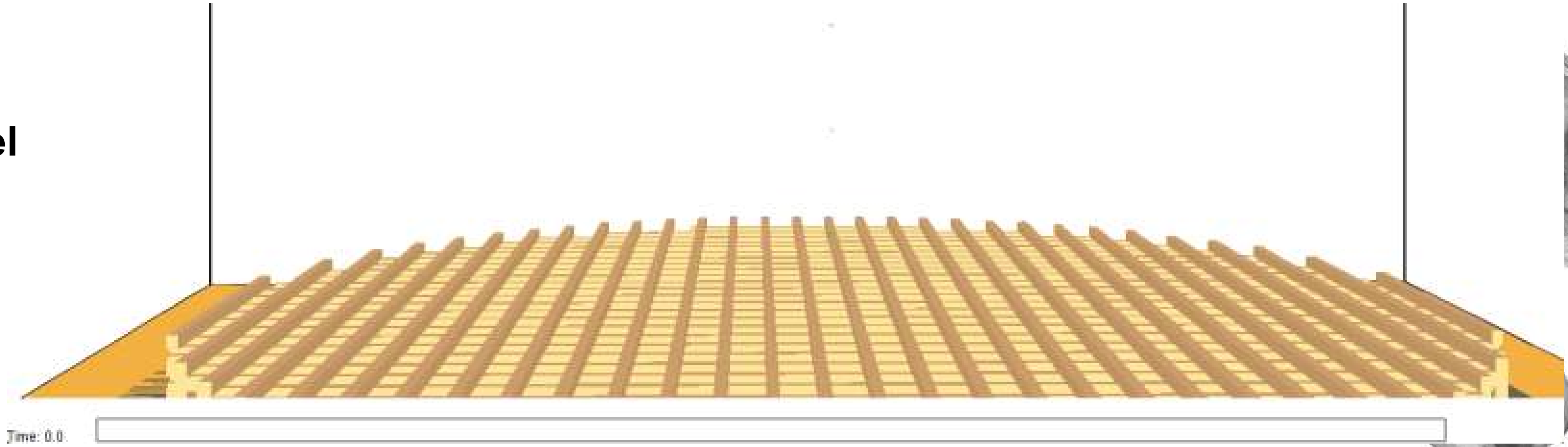
Time: 0.0

FDS simulation "Liège test series" M7

Test



Model



FDS simulation "Liège test series" M7

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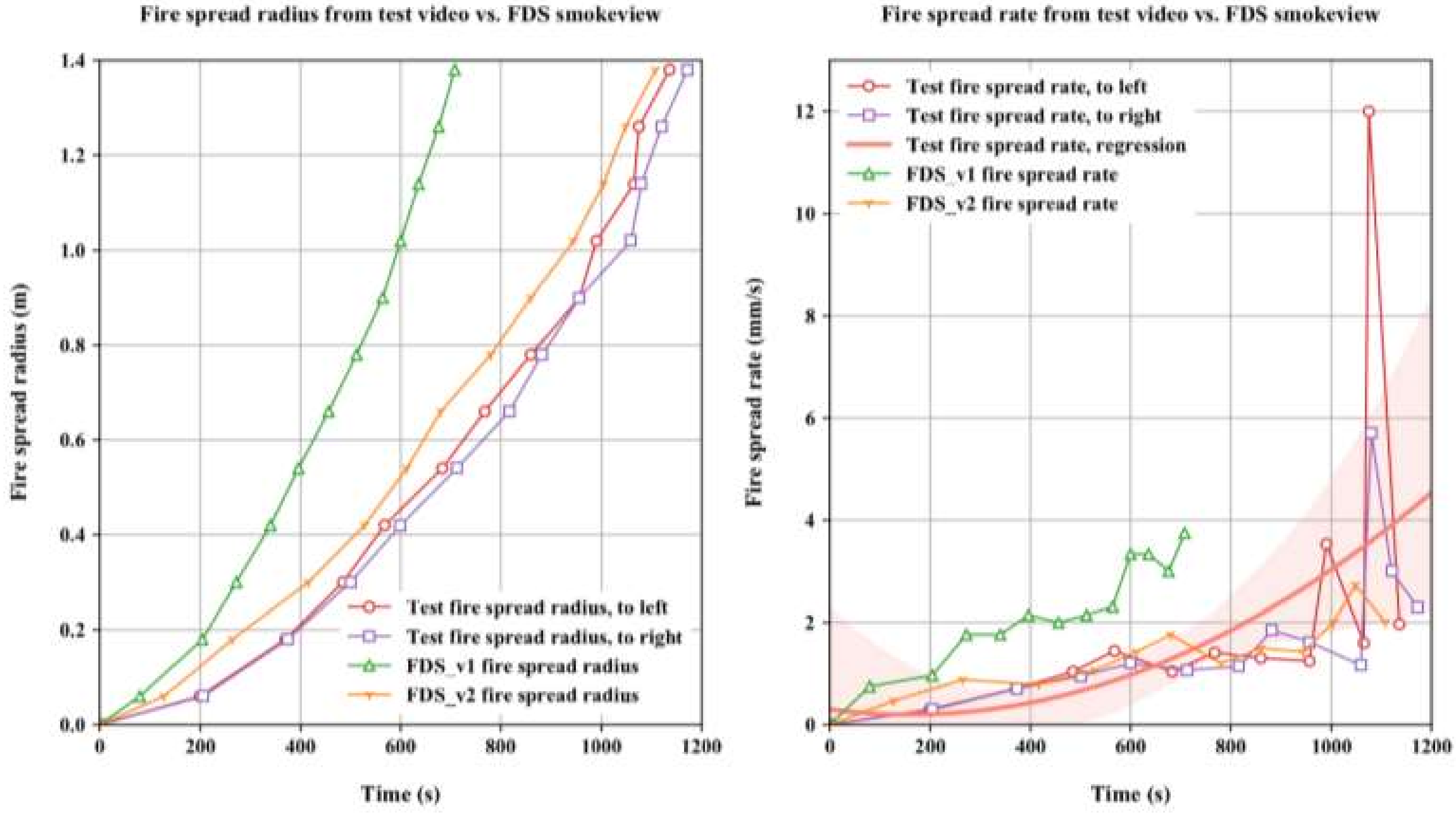
HRR comparison between test and FDS, for M7



After extensive series of trials finally achieving a better qualitative matching to the observed fire spread behaviour

FDS simulation "Liège test series" M7

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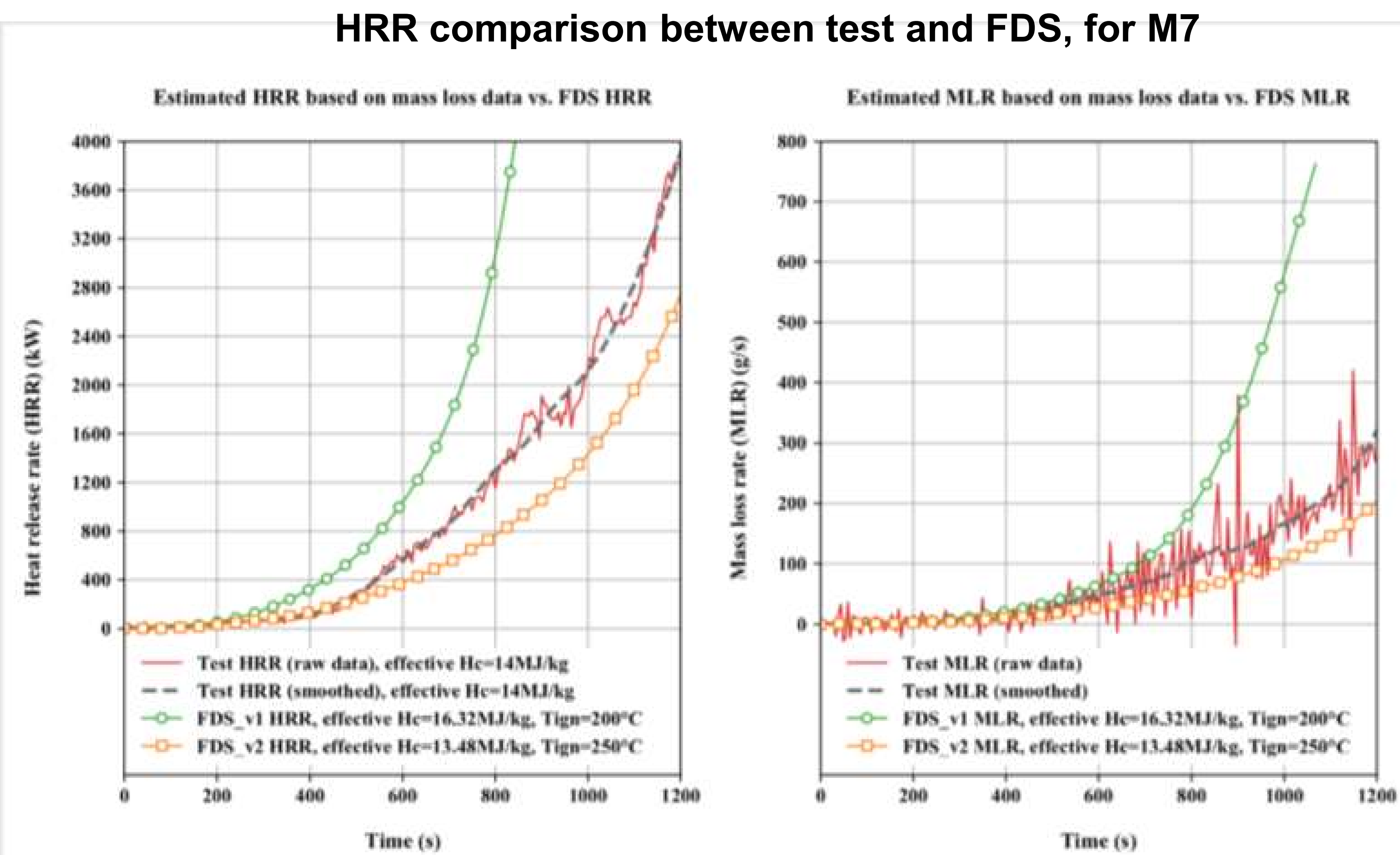


Remaining discrepancy is HRR, seems we need to explicitly consider the link to the fire exposure (but crib fire plots from Drysdale had suggested otherwise!)

Ulster University TRAFIR fire tests

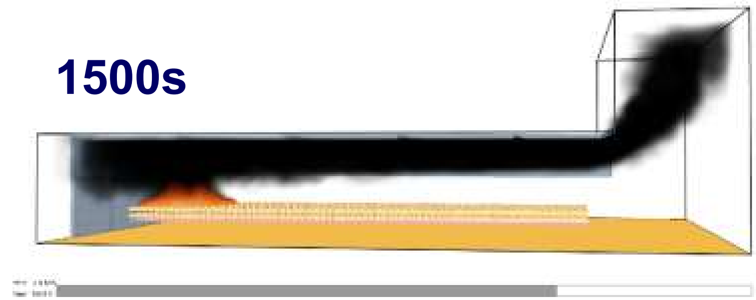
Photo © University of Ulster
https://www.bbc.co.uk/news/uk-northern-ireland-48707462

A priori simulation, Ulster TRAFIR #1

- **All input parameters for this *a priori* model (e.g. HRRPUA, ignition temperature, material properties, etc) are based on M7 model**

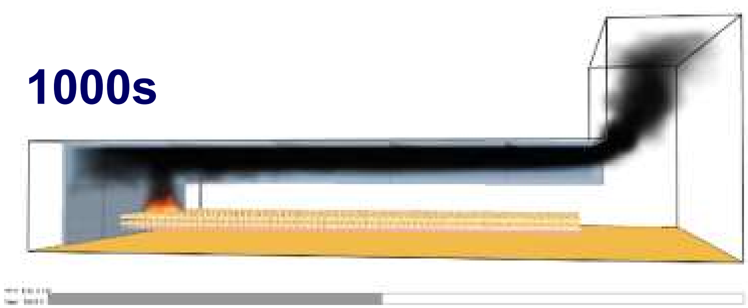
100s

1500s



500s

1000s

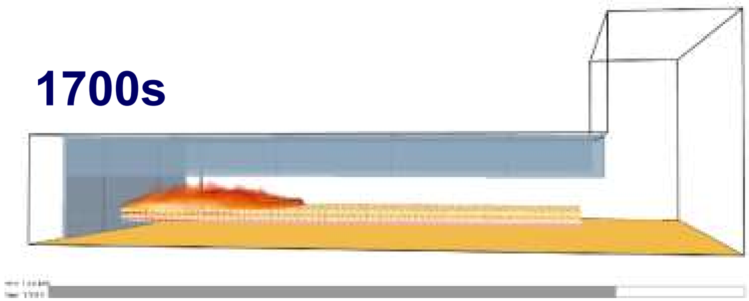


At this stage of the simulation, the model is still comparable to the test, based on the observations on test site.

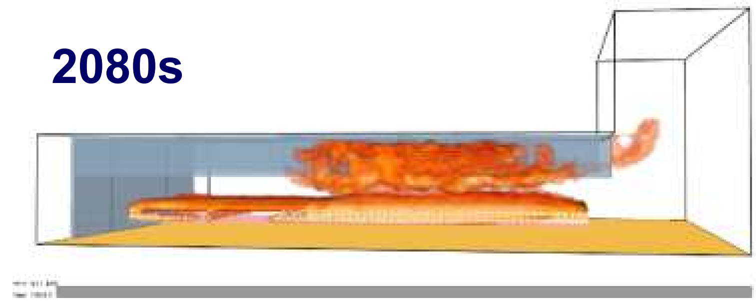
A priori simulation, Ulster TRAFIR #1

- **All input parameters for this *a priori* model (e.g. HRRPUA, ignition temperature, material properties, etc) are based on M7 model**

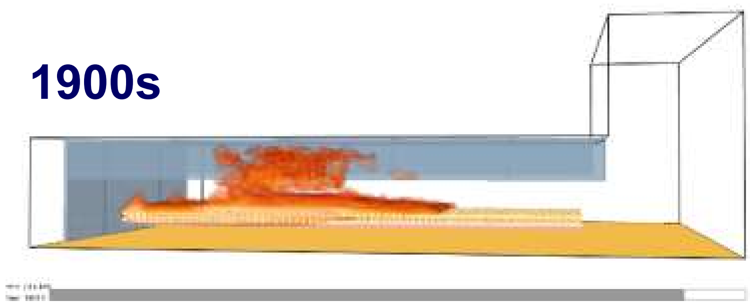
1700s



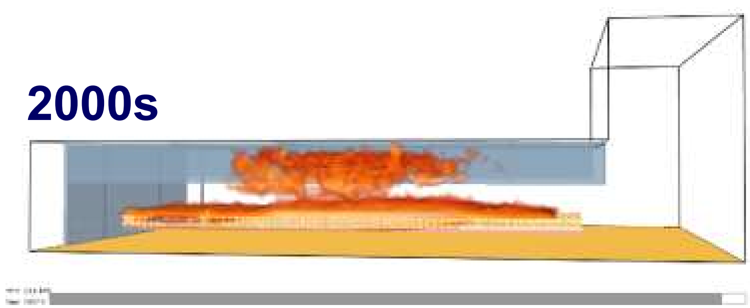
2080s



1900s



2000s

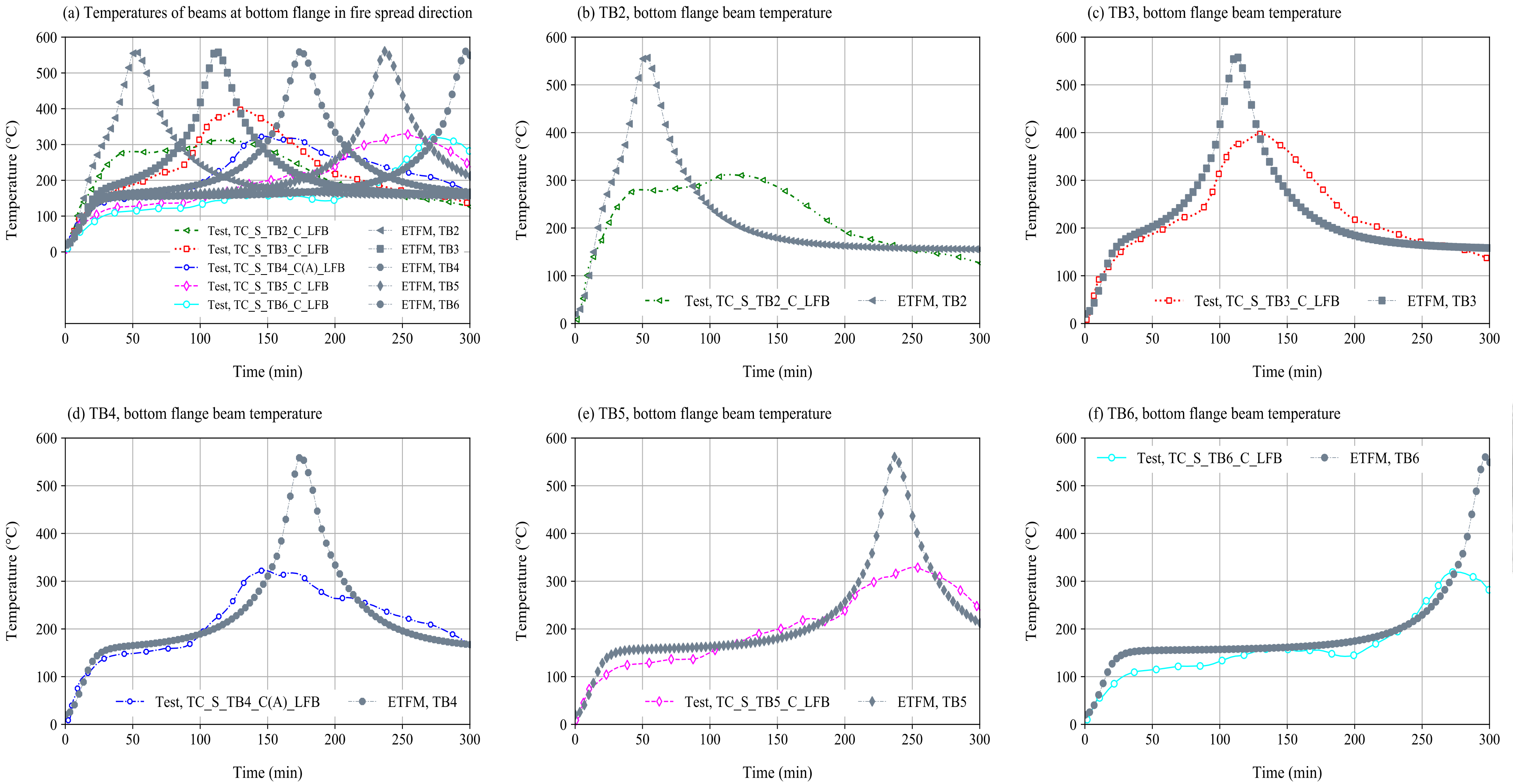


However, after 1500s the agreement diverges, presumably because the burn-away function in the model was not properly resolved in the previous M7 calibration!

ETFM framework application, TRAFIR #1

- Structural & fuel layout **similarity** between TRAFIR-RISE natural fire test (Dec-18), and TRAFIR-Ulster Travelling Fire Test No.1, ETFM framework "**calibrated**" with RISE test

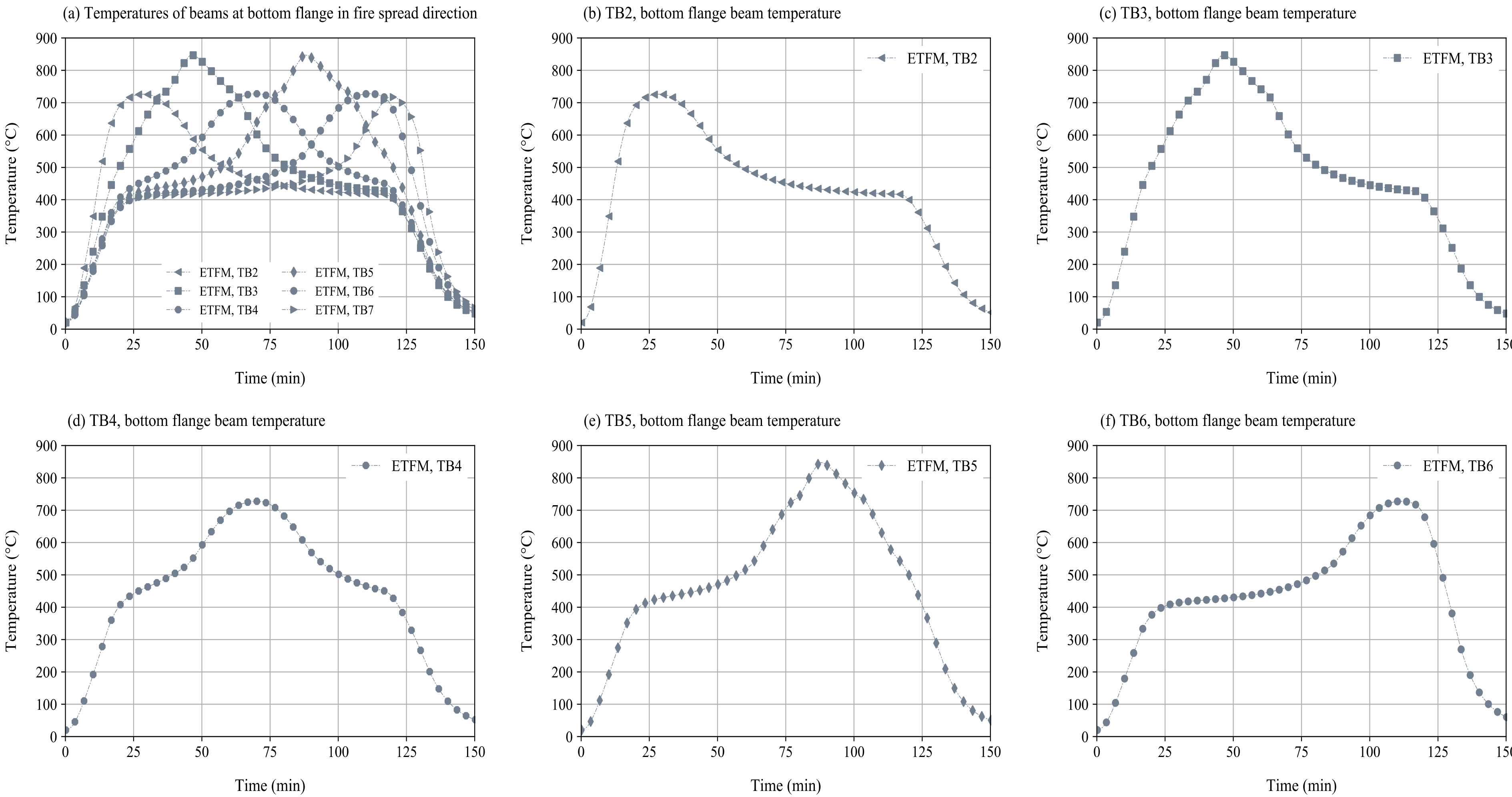
TRAFIR-RISE wood crib fire test vs. ETFM framework modelling



ETFM framework application, TRAFIR #1

- **Then assuming the fire spread rate in the Ulster Travelling Fire Test No.1 is 2mm/s, based on the M7 test observation between 10-20mins…**

TRAFIR-Ulster wood crib fire test using ETFM framework



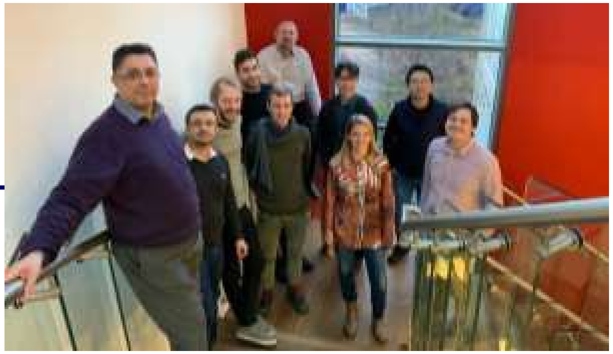
Conclusions (1)

- Methods of representing a crib fire using simplified fuel representations (coarser sticks, and different stick arrangements) are being explored;
- The models tend to have a highly over-simplified treatment of the flow within the crib, as there is insufficient grid resolution;
- Simplified 'engineering' models of burning behaviour are postulated to overcome this;
- Direct measurement of required reaction-to-fire properties obtained from relevant bench-scale tests;
- It proves to be very challenging to replicate full-scale fire development with the simplified models, where spread, HRR, MLR and burn-out all provide validation constraints;
- Nevertheless, latest results with a finer mesh within the depth of the crib, are closer to satisfying the set of constraints;
- A reasonable case can be made that grid resolutions should be different in the bulk flow and within the crib structure itself;
- Fire spread in the depth of the crib is much harder to assess as it is difficult to observe in the test, however it is generally slower than surface spread;

Conclusions (2)

- **Application to full-scale scenarios is ongoing, taking the "validated model" from crib fire experiments and performing *a priori* simulations of travelling fire tests in a 15x9x2.8m compartment (series of tests with 3 different opening factors);**
- **Some success in prediction of early spread but still tendency for run-away later in test;**
- **The challenge of fire spread prediction compounds existing difficulties in representing fire temperatures in post-flashover/under-ventilated conditions (e.g. BST/FRS 1993);**
- **Further difficulties in representing conditions in *cooling* phase of fire, where mass loss data is absent/unreliable;**
- **Despite the challenges in travelling fire prediction, including both spread and burn-out, the technology has great potential in representing the interaction of the fire and the structure;**
- **This will assist in providing engineers with simple and practical methodologies for structural fire design;**
- **Work is supported by and done in close cooperation with industrial partners (ArcelorMittal), with EU funding via RFCS;**
- **UKCTRF support has been vital in enabling more simulations.**

Thanks to TRAFIR team



TRAFIR Project

Characterization of TRAvelling FIRes in large compartments

Funding from Research Fund for Coal and Steel (RFCS) - European Commission

European Commission

Eight work packages (1/07/2017 → 31/12/2020):

- **testing** (isolated elements and simplified fire progression, as well as a full-scale large compartment)
- **modelling** (both simplified analytical/phenomenological models and CFD).

Project partners:

ArcelorMittal

The University of Edinburgh

Université de Liège

RISE

Ulster University

BRE Centre credits

- **Colleagues and students:**
  - **10 Academic Staff (+1 retired)**
  - **6 Research staff**
  - **c. 20 PhD Students**
  - **40+ MSc students**
  - **5-10 pa UG fire students**
  - **Visiting researchers**
- **External Relationships:**
  - **UKCTRF**
  - **EPSRC**
  - **ArcelorMittal (Charlier, Vassart…)**
  - **BRE Trust**
  - **Fire & rescue services**
  - **International academic/research partners**
    - **UQ (Hidalgo, Maluk, Lange, Gupta…)**
    - **CVUT Prague (Wald, Horová…)**
    - **RISE (Sjöström, Anderson…)**
    - **Liege (Franssen, Gamba…)**
    - **Ulster (Nadjai, Alam …)**

BRE Centre *for* Fire Safety Engineering

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www.ukctrf.com

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UK CTRF UK CONSORTIUM ON TURBULENT REACTING FLOWS

EPSRC Engineering and Physical Sciences Research Council

archer

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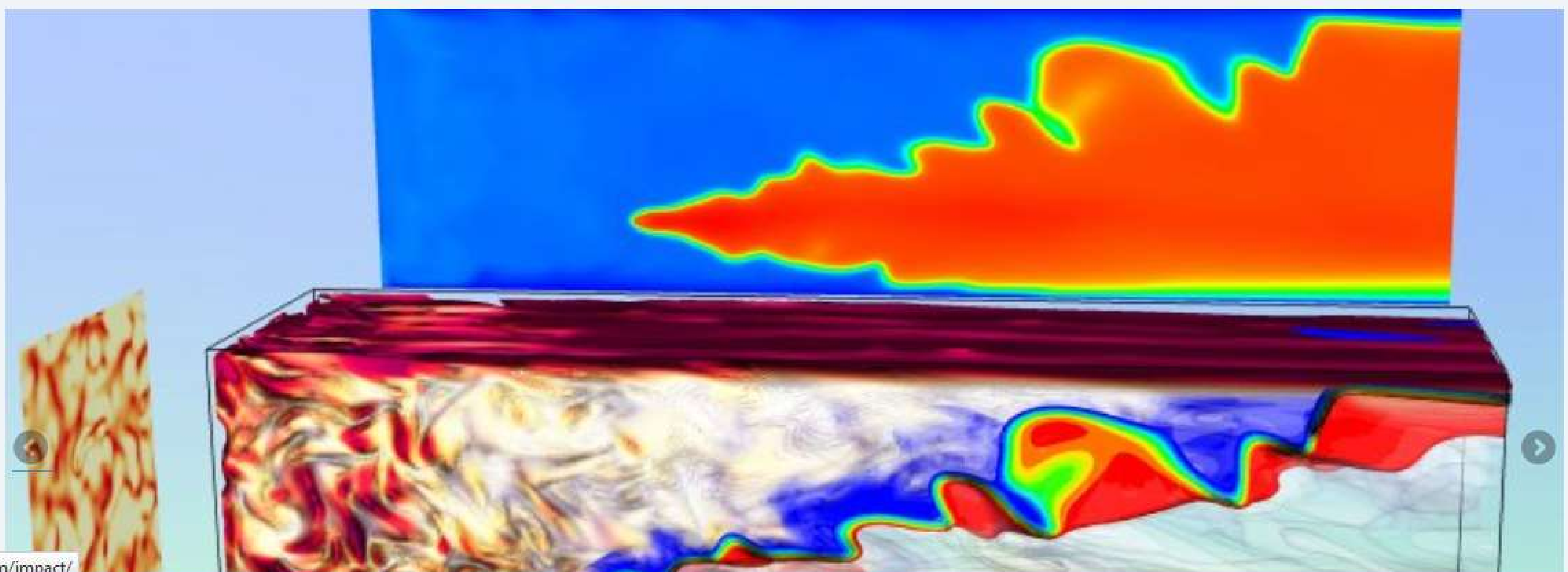
UK Consortium on Turbulent Reacting Flows

A group of leading academics from 19 United Kingdom institutions have been joined by internationally recognised experts to form UKCTRF. As a consortium, they will make a focussed effort to address the global and UK challenges of energy efficiency, environmental friendliness and high-fidelity fire safety.



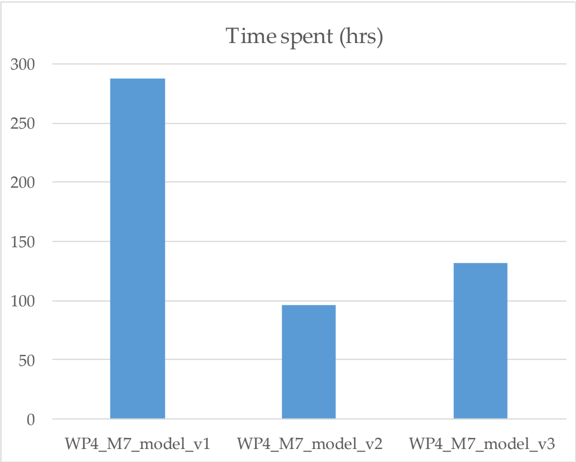
www.ukctrf.com/impact/

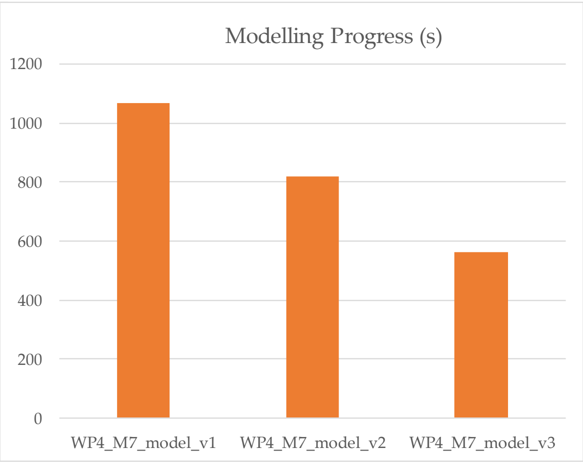
Questions?

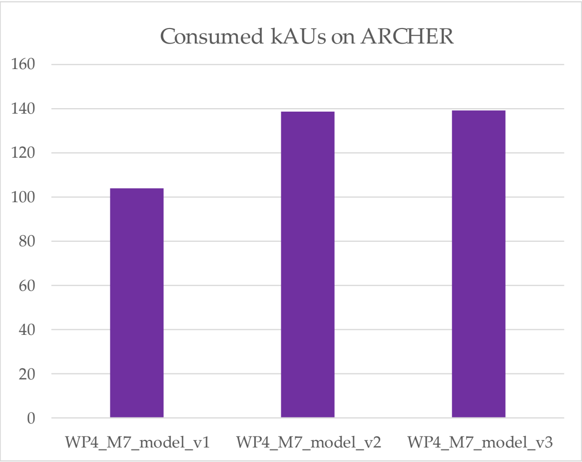
Appendix – computational expenses

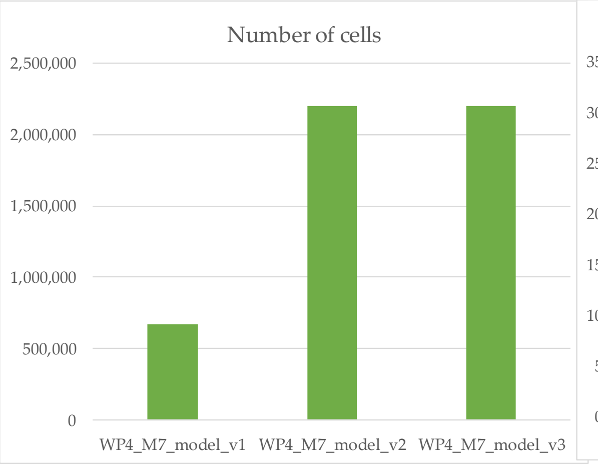
BRE Centre *for* Fire Safety Engineering

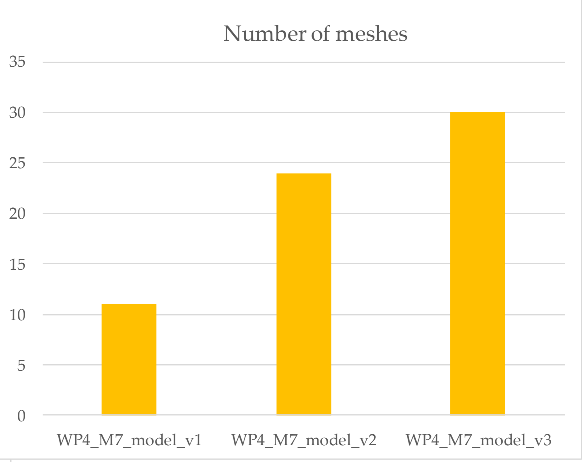
Summary of computational expenses of initial models on ARCHER, c/o UKCTRF











Note: this is just a summary rather than a benchmarking for ARCHER, we don't want to consume more than 150kAUs per job at this stage of TRAFIR WP4