cookeonfire.com

A presentation to the April 2017 meeting of the Structures in Fire (STIF) forum, held at the Institution of Structural Engineers, London,

The travelling fire scenario and its effect on fire severity - concept and experiment in a large fire compartment with restricted ventilation in one wall.

Gordon Cooke (Dr), **Chartered Civil Engineer and Fire Safety Consultant**, London, (Formerly Visiting Professor, School of Engineering and Mathematical Sciences, City University, London).

Here I am reflecting on experimental work I did in the early 1990's while working at the government's Fire Research Station, Building Research Establishment, Garston, UK.

One of the fully developed fires in the tests, 50% ventilation

Background and Aim

- In the early 1990's I designed and organised a program of nine tests with the aid of funds from government and British Steel.
- The tests were made in a purpose-built fire compartment 23 m deep by 6 m wide by 3 m high constructed in the BRE test facility in Cardington (the R101 airship hangar) and my aim was to check the validity of the then current" fire actions" Eurocode.
- Models of fully developed fire had hitherto been validated in cubicle compartments, but were they valid for deeper compartments of the kind found for example in large open plan offices?
- The tests would include specimens of both bare and fire-protected steel section near the ceiling so that, at the front, centre and back of the compartment, fire severity could be measured and also calculated using the 'Time equivalent' concept.

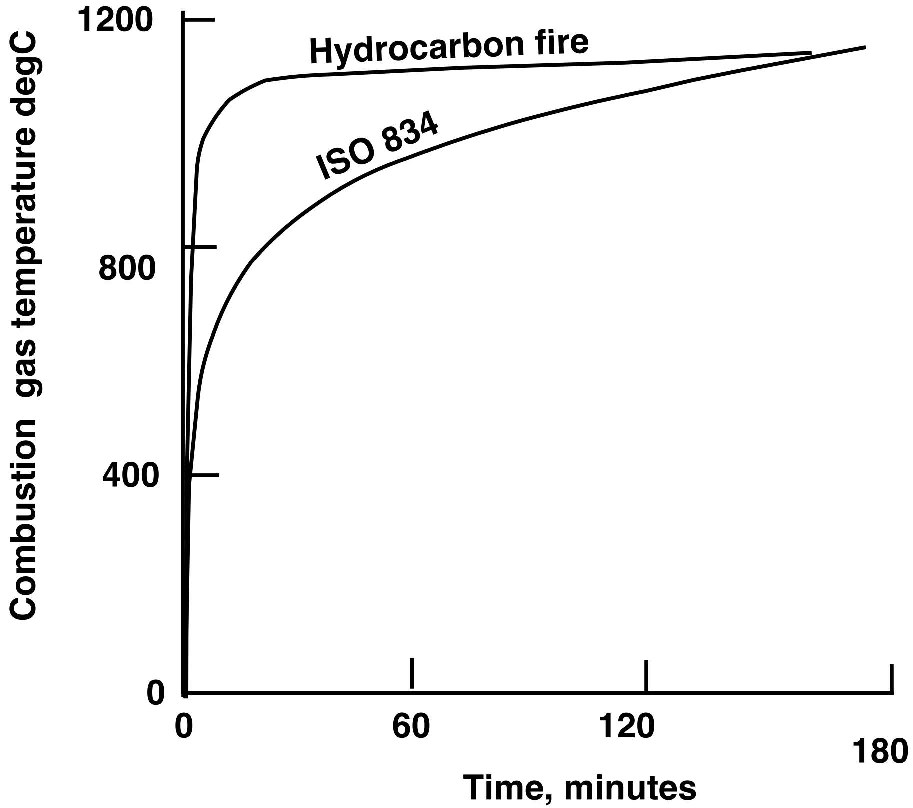
Background and Aim continued

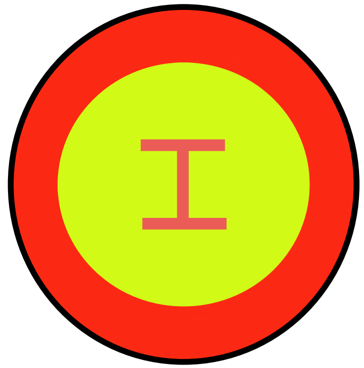
- These tests have been thoroughly documented elsewhere and the purpose here is to focus on and simplify the results of four of the tests which varied only in the amount of ventilation in the front wall and in which the active zone of combustion appeared to travel from front to back

- I had been promoted to Division Head level to work on my own, unencumbered by administrative duties, solely on European fire matters, and this programme and my associated experimental work on calibration of European fire resistance test furnaces were important parts of BRE work. What an opportunity and a challenge!

First a reminder of:

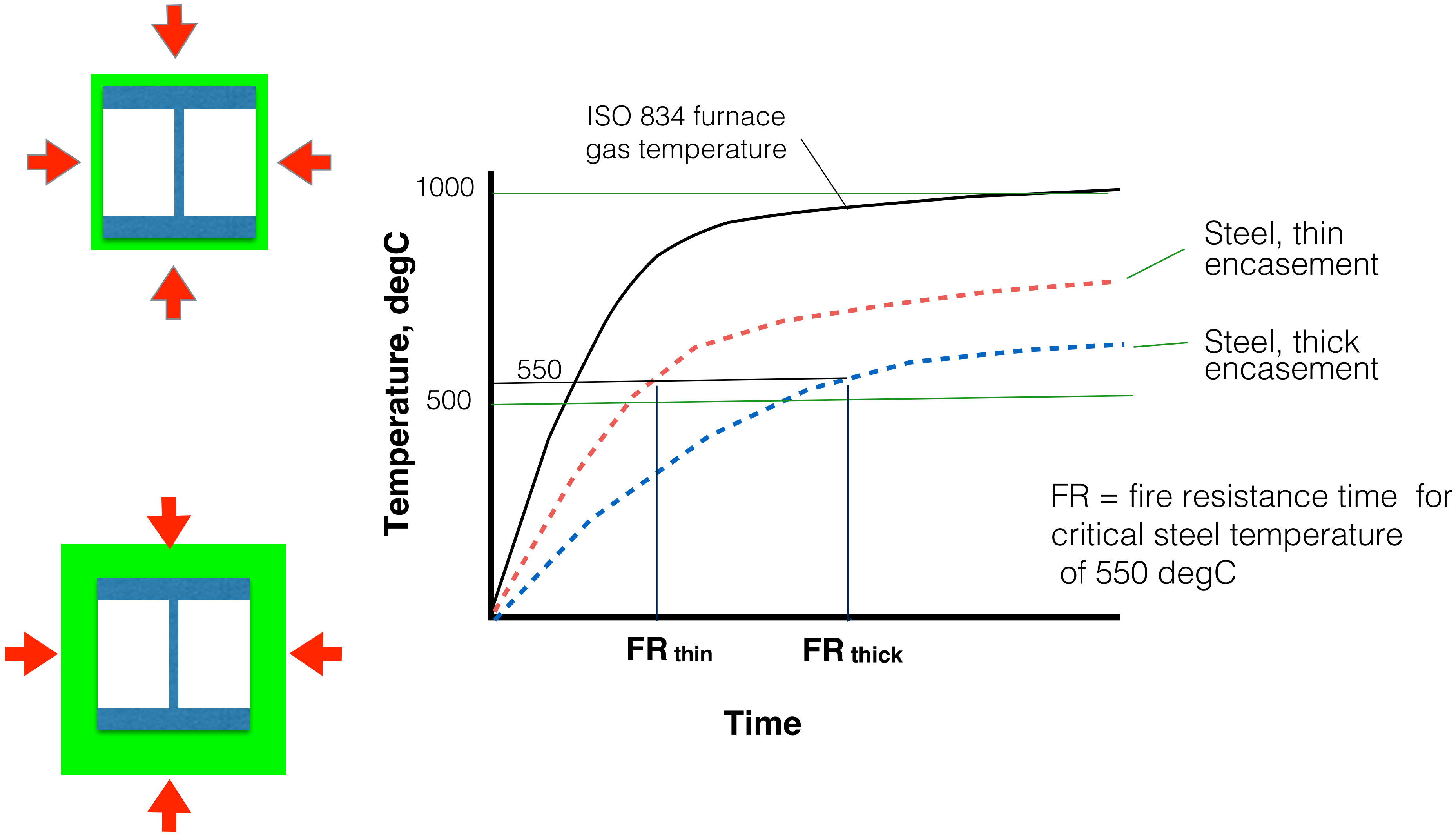
- fire resistance furnace exposure,
- how steel behaves in the furnace test and
- how fire resistance is measured using the critical temperature criterion.



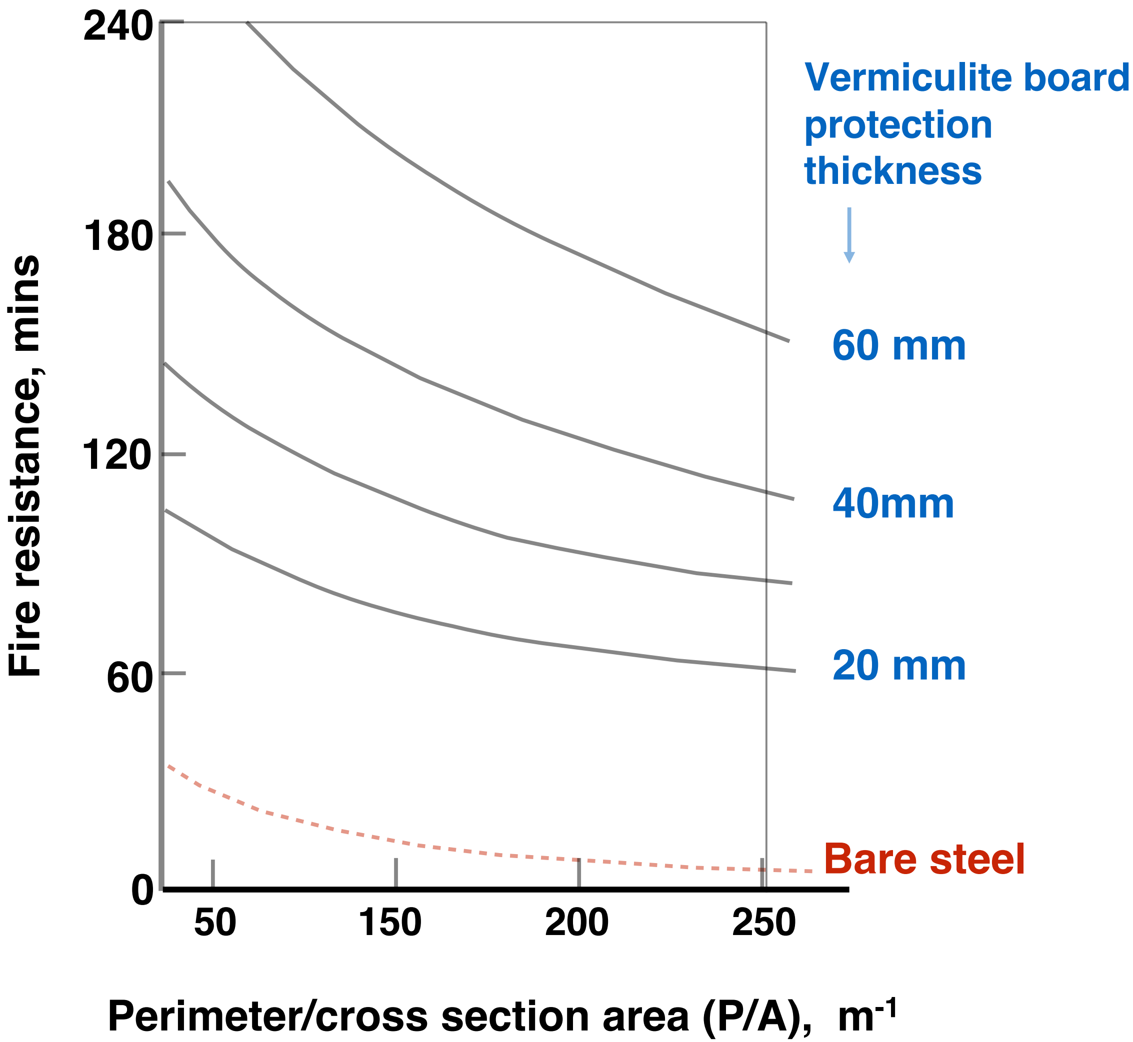


Column furnace

Standard fire resistance furnace temperature-time curves



Variation of fire resistance with encasement thickness

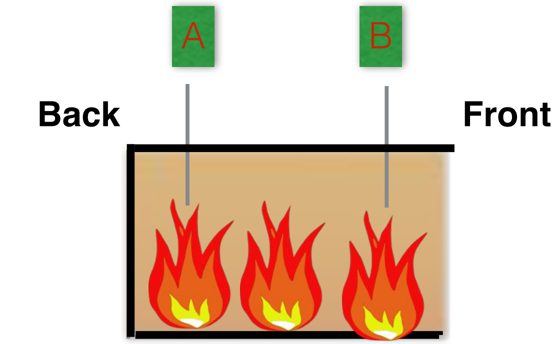


Fire resistance of steel

The fire spread mechanism in compartments with low ceilings

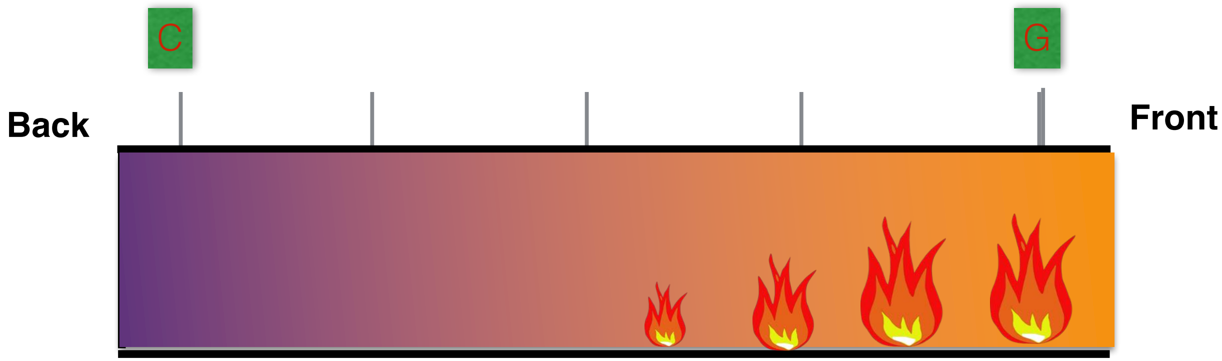
Traveling fire - Concept

(Compartment ventilation opening only at front)



Fire severity at A = Fire severity at B

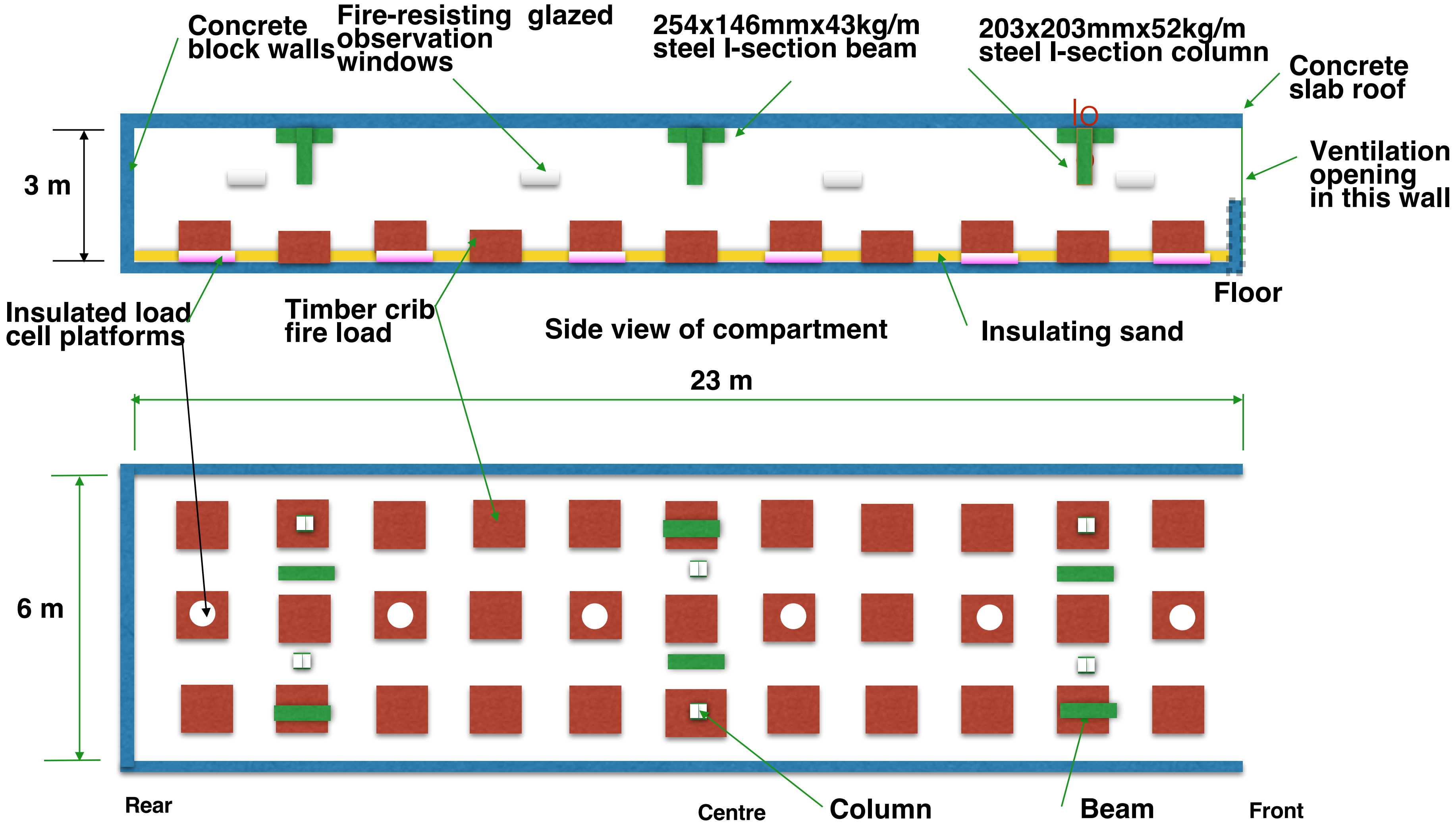
Fire severity at C ≠ Fire severity at G



← **Fire travels front to back**

The compartment fire experiments

The purpose-built experimental rig at Cardington



Plan view of compartment

The 23 m long fire compartment at Cardington around 1993

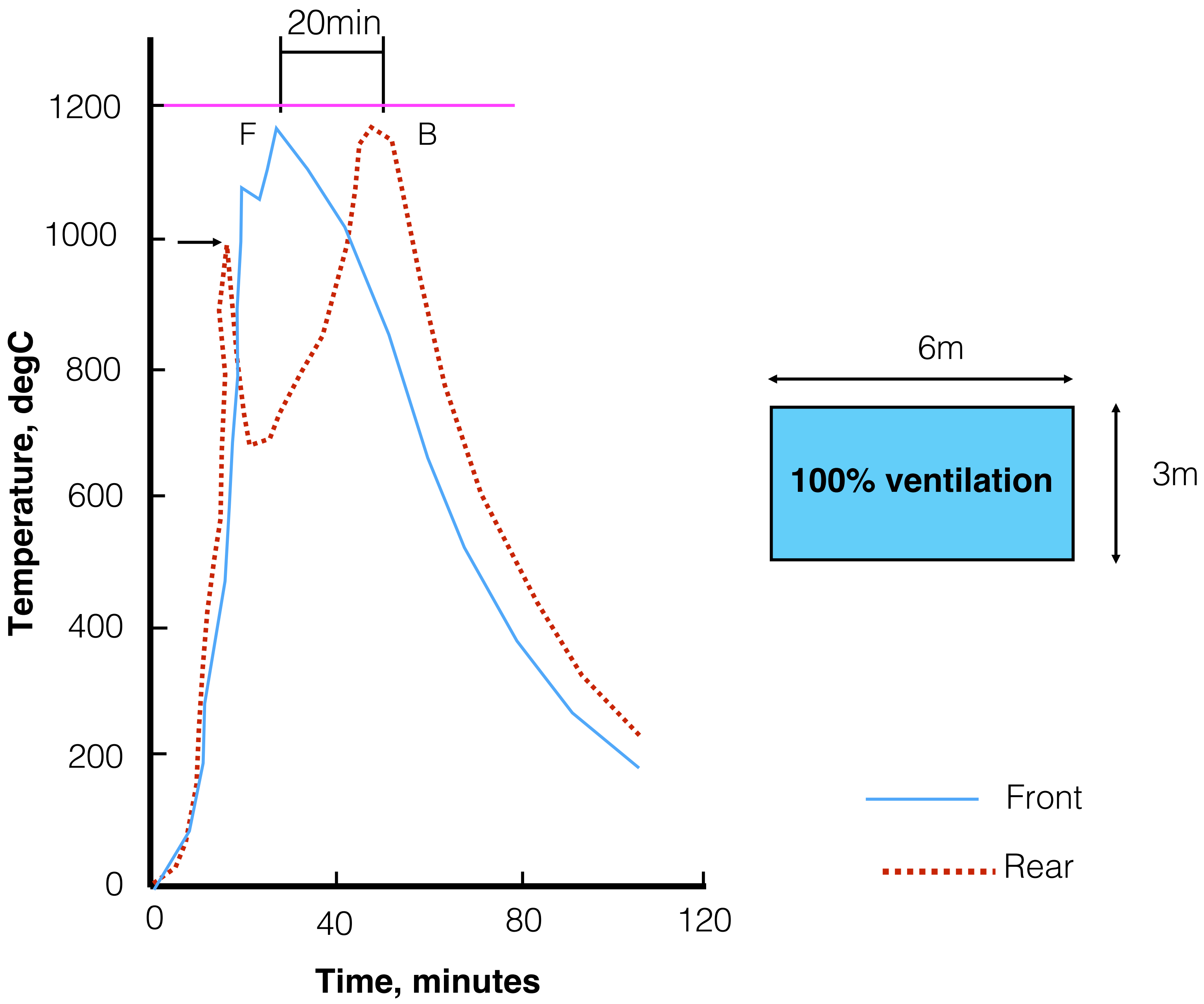
Crib construction in progress (40 kg/m^2 floor area shown here)

The Cardington R101 airship hanger where the tests were conducted in a controlled environment.

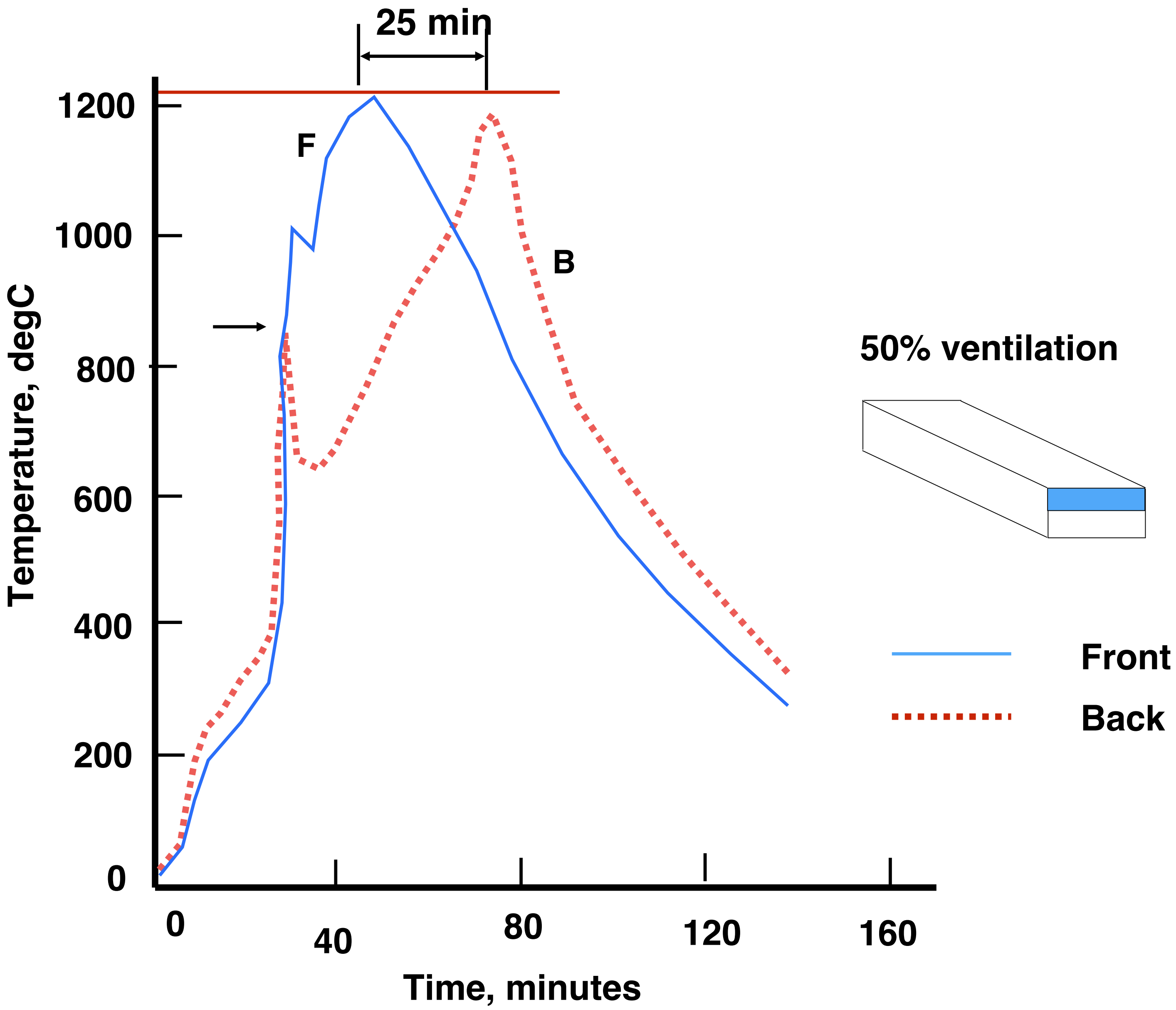
Fully developed fire with 50% ventilation

Compartment gas temperatures at front and back for different amounts of ventilation in front wall.

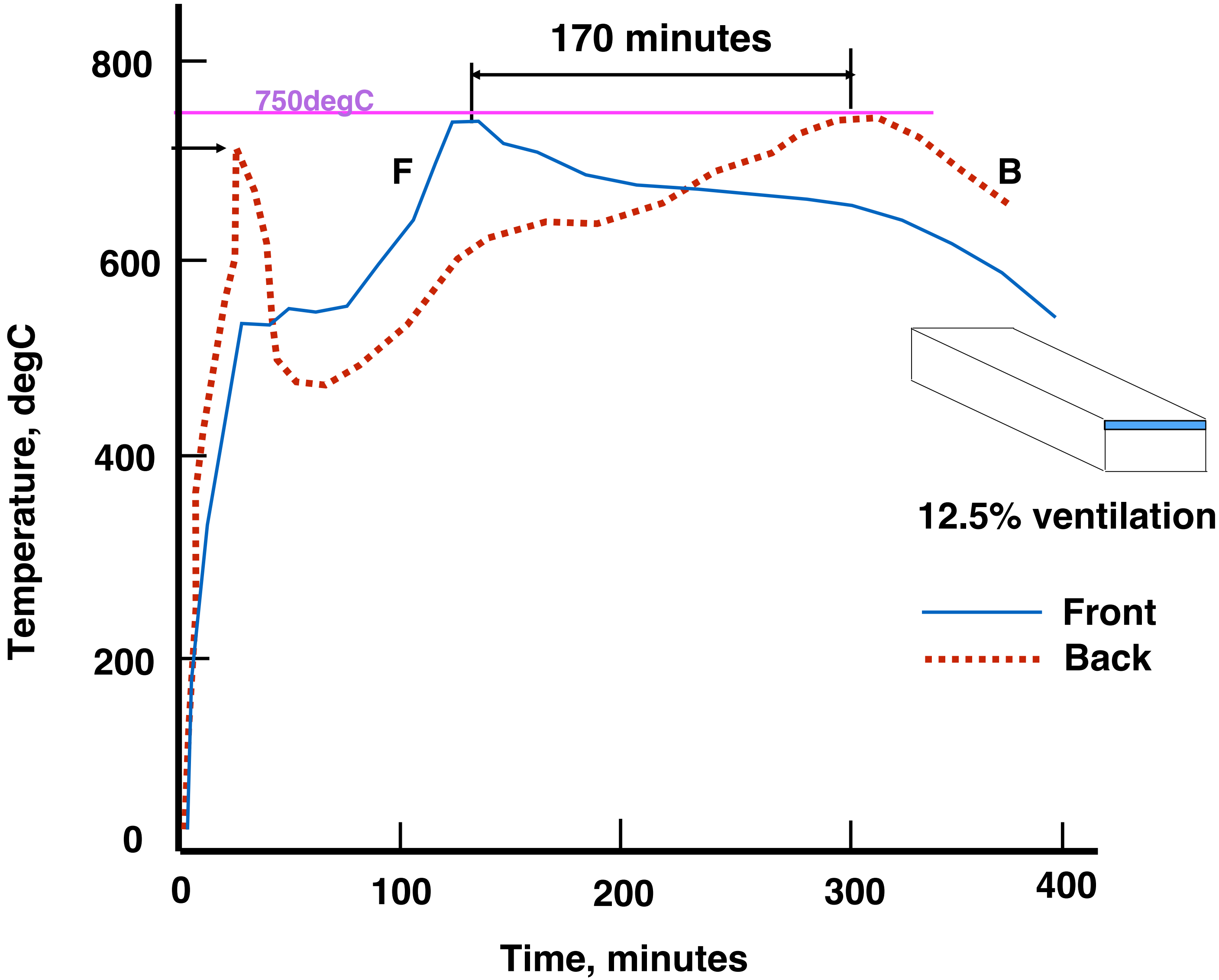
Combustion gas temperatures, front and back, 100% ventilation in front wall.



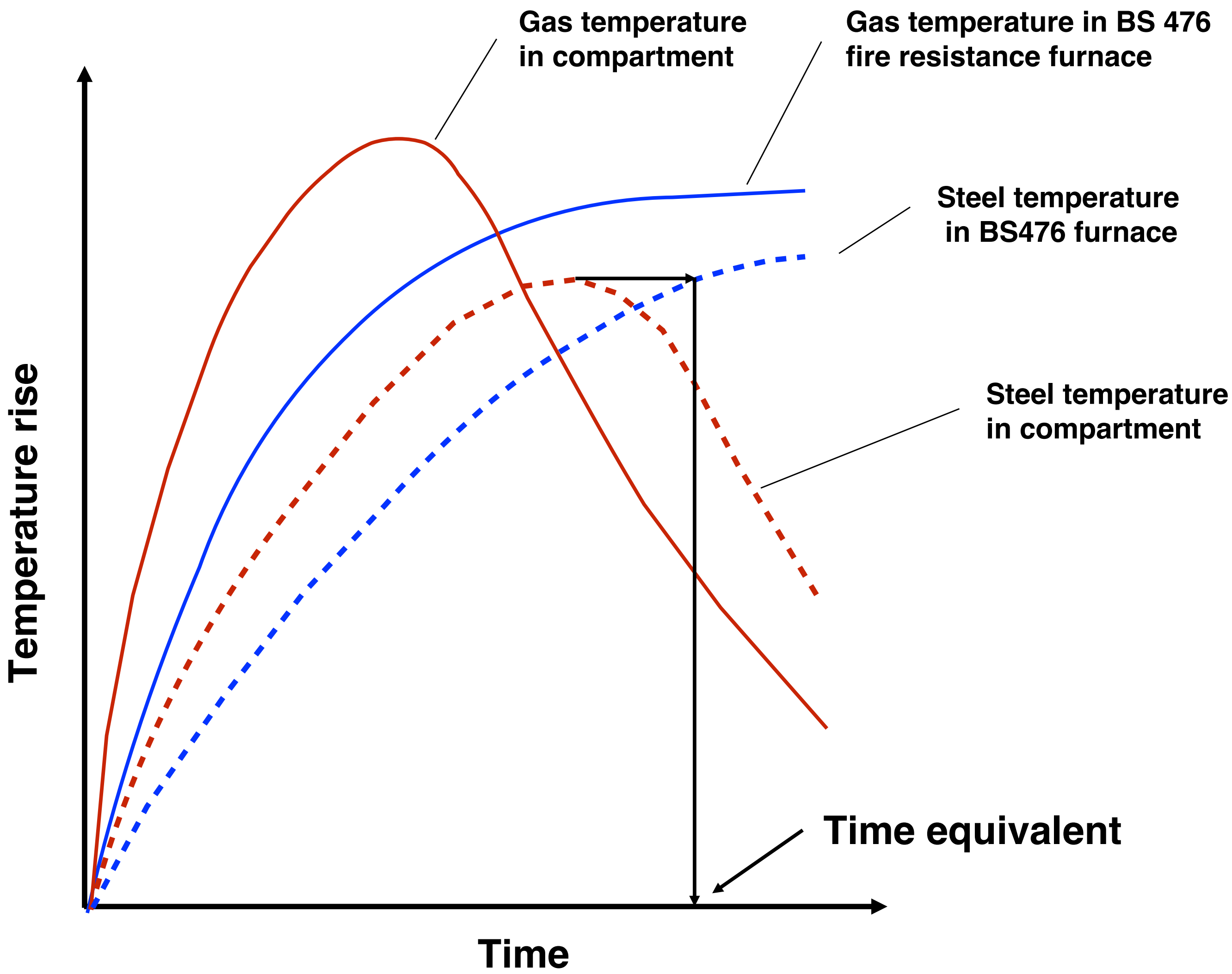
Combustion gas temperatures, front and back, 50% vent in front wall.



Combustion gas temperatures, front and back, 12.5% vent in front wall.



Time equivalent concept



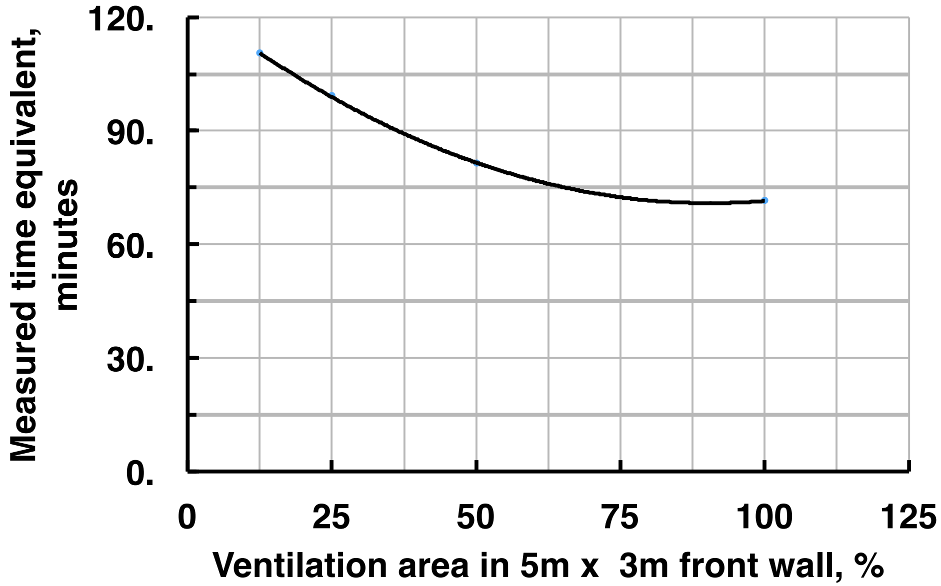
Time equivalent concept for protected steel

COMPARISON BETWEEN THE MEASURED TIME EQUIVALENT AND CALCULATED VALUES BASED UPON CIB W14(5), LAW(6), PETTERSSON(7) AND HARMATHY(8)

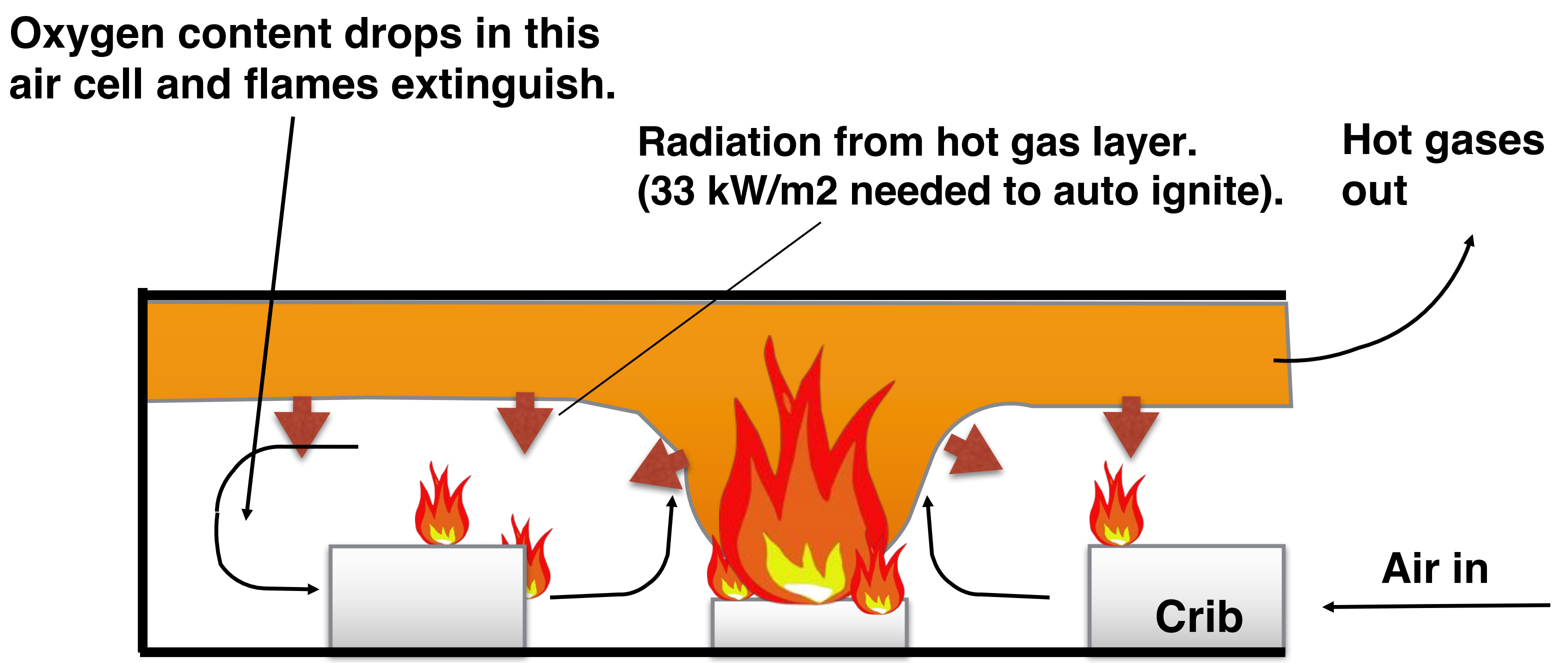
Ventilation		100%	50%		25%	12.5%			
Time Equivalent Relationship	Test 1 min	Test 2 min	Test 3 min	Test 4 min	Test 5 min	Test 6 min	Test 7 min	Test 8 min	Test 9 min
Measured	118.0	71.5	81.5	142.0	99.8	110.5	54.3	67.5	74.0
CIB W14	85.3	42.7	70.8	141.6	97.7	197.3	38.5	47.0/ 59.3	44.3
Law	79.5	39.8	55.7	111.3	79.4	109.1	34.2	43.5/ 54.8	41.2
Pettersson	109.9	55.0	91.2	182.4	126.0	254.1	49.7	55.4/ 69.8	56.8
Harmathy	45.6	29.6	59.4	106.3	98.8	342.8	48.2	31.9/ 36.8	31.2

Above data (BST Table 4) are for variously protected steel I-section elements. Does NOT apply to unprotected steel.

Large compartment fire test data (Compartment depth 23m, timber fire load density 20kg/m2, 3 cribs at back ignited first)				
	Test 2	**Test 3**	**Test 5**	**Test 6**
Ventilation of 6m wide x 3m high front wall	**100%**	**50%**	**25%**	**12.5%**
Time equivalent at back, minutes	**72.5**	**77.5**	**93**	**116.5**
Time equivalent at centre, minutes	**79.5**	**87**	**100**	**112.5**
Time equivalent at front, minutes	**62.5**	**79**	**106**	**101.5**
Average	**71.5**	**81.2**	**99.5**	**110**
Max'm protected steel temperature at back, degC	**470.5**	**506.5**	**705.5**	**639.5**
Max'm protected steel temperature at centre, degC	**505**	**572**	**742**	**623**
Max'm protected steel temperature at front,	**420**	**507.5**	**625**	**580.5**



Variation of measured time equivalent with ventilation area

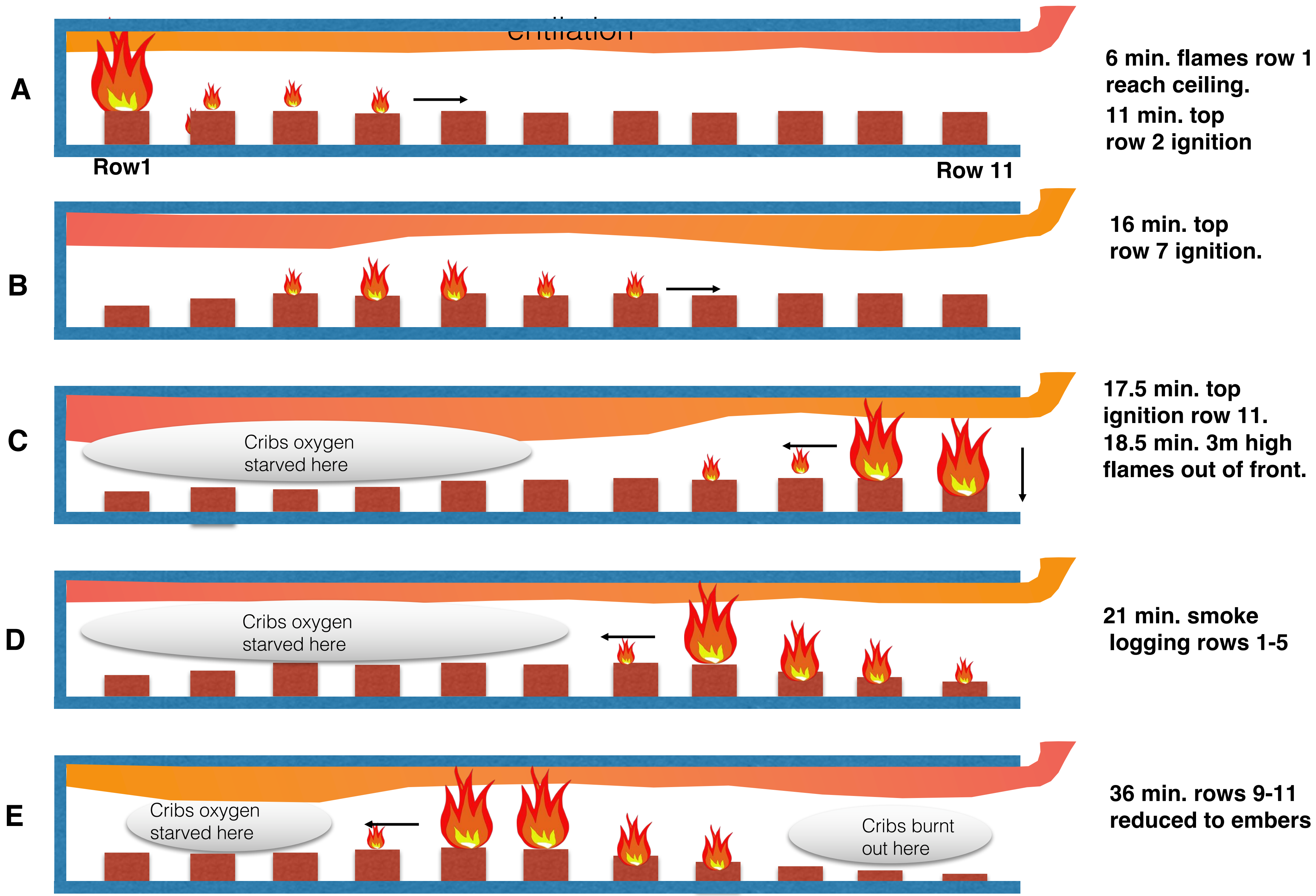


Flame spread by spontaneous ignition of upper surface of crib. This mechanism spreads fire from crib to crib and the spontaneously-ignited crib then burns downwards if it has sufficient access to air.

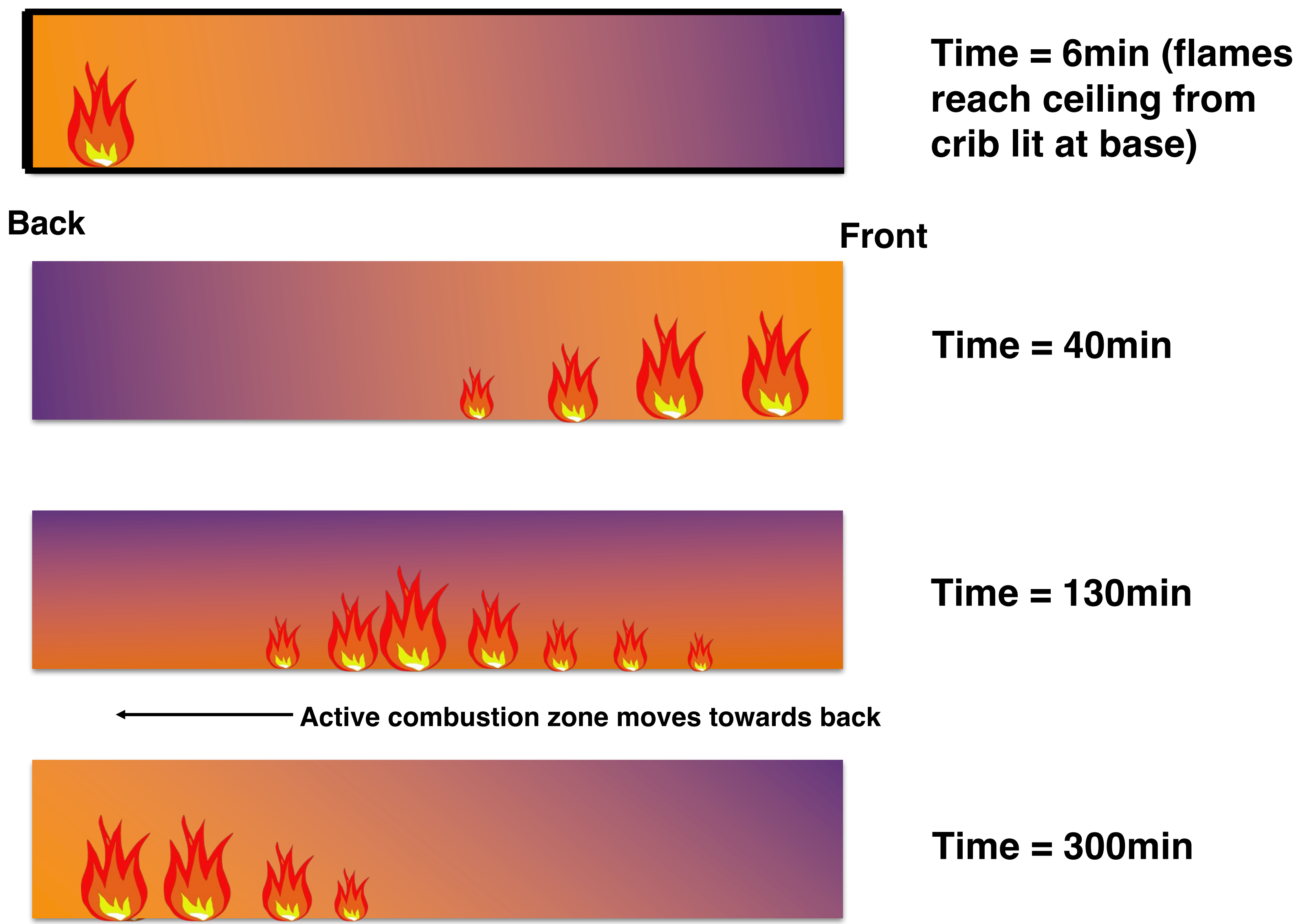
Example of spontaneous ignition of top of cribs due to radiation from hot gas layer in one of the tests

Seconds before flashover - BRE simulation of Stardust Disco disaster fire. Fire about to ‘jump’ across tops of bench seats resulting from hot gas layer radiation. Example of autoignition.

100% ventilation, 20kg/m², only row 1 cribs lit



12.5% ventilation in front wall, ignition at back

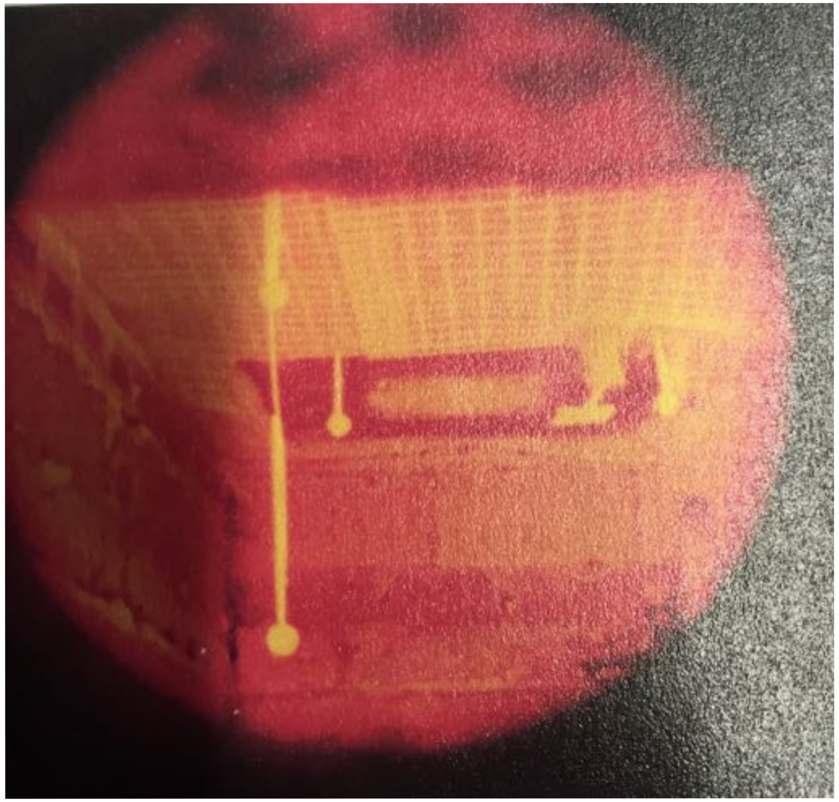


The travelling fire scenario - like a wave.

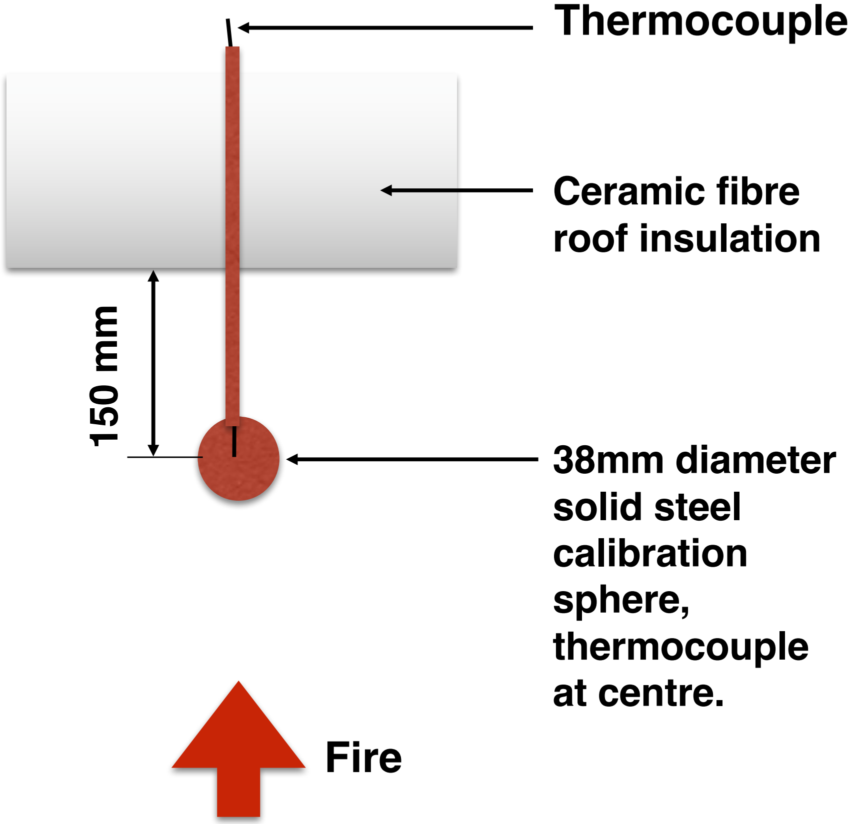
We have seen how protected steel elements behave in natural fire.

What about unprotected steel?

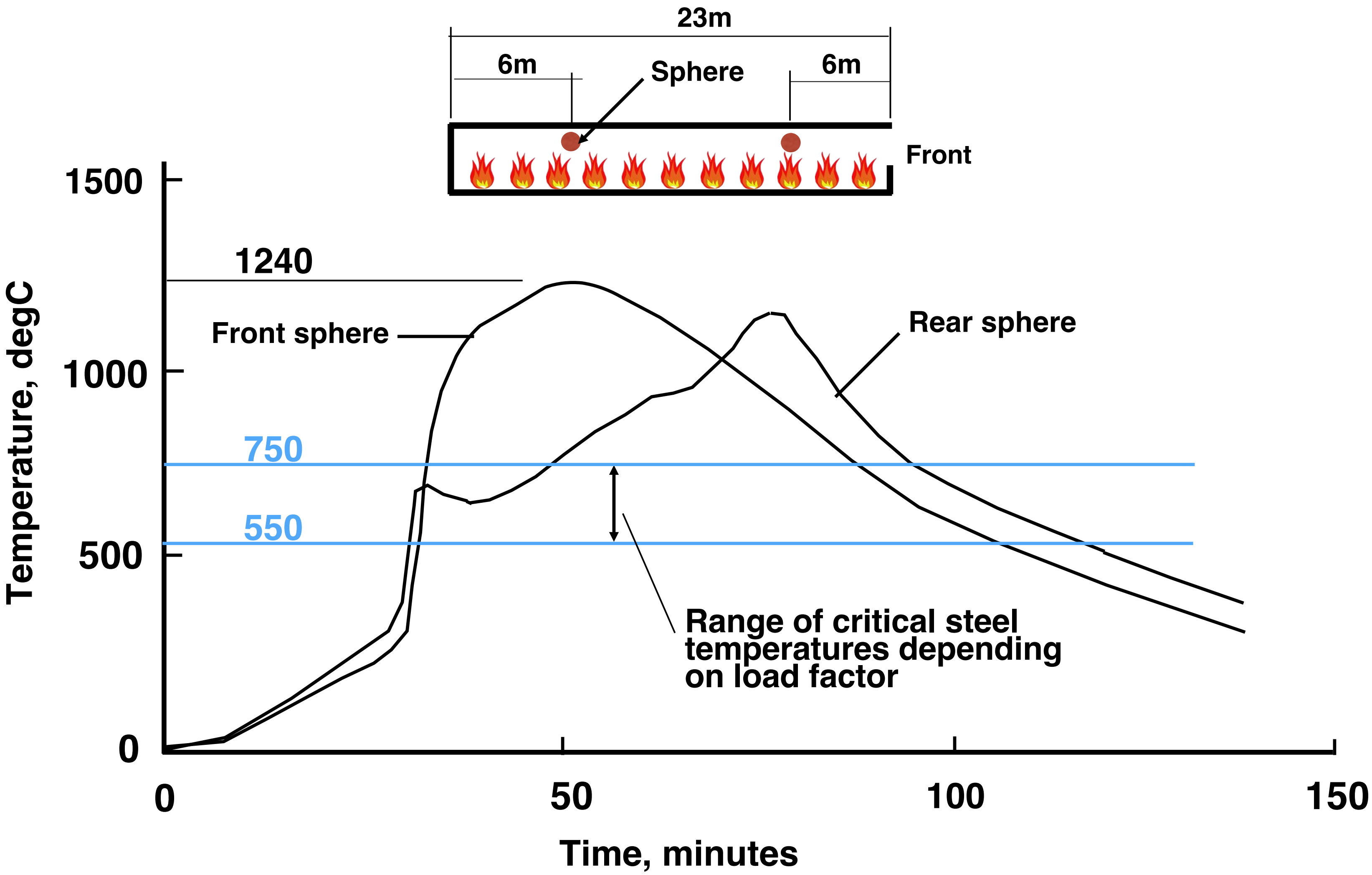
A highly emissive ‘black’ sphere measures radiative as well as conductive heat transfer.



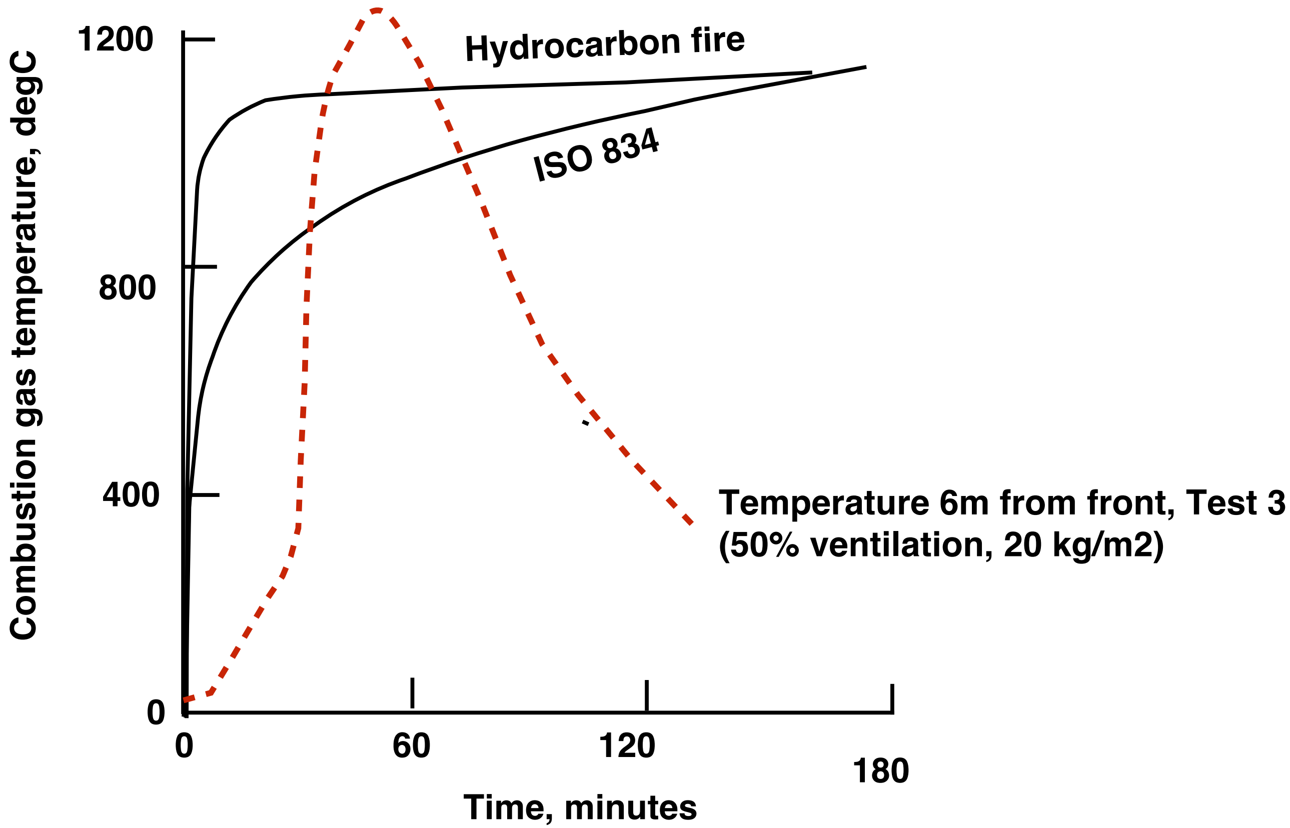
Red hot calibration spheres and plate thermometer in fire resistance floor furnace



Calibration sphere set up in large compartment fire tests



Thermal response of 38 mm diameter steel 'calibration' spheres having P/A 158 m^{-1} corresponding to a heavy steel section. Data are for Test 3.

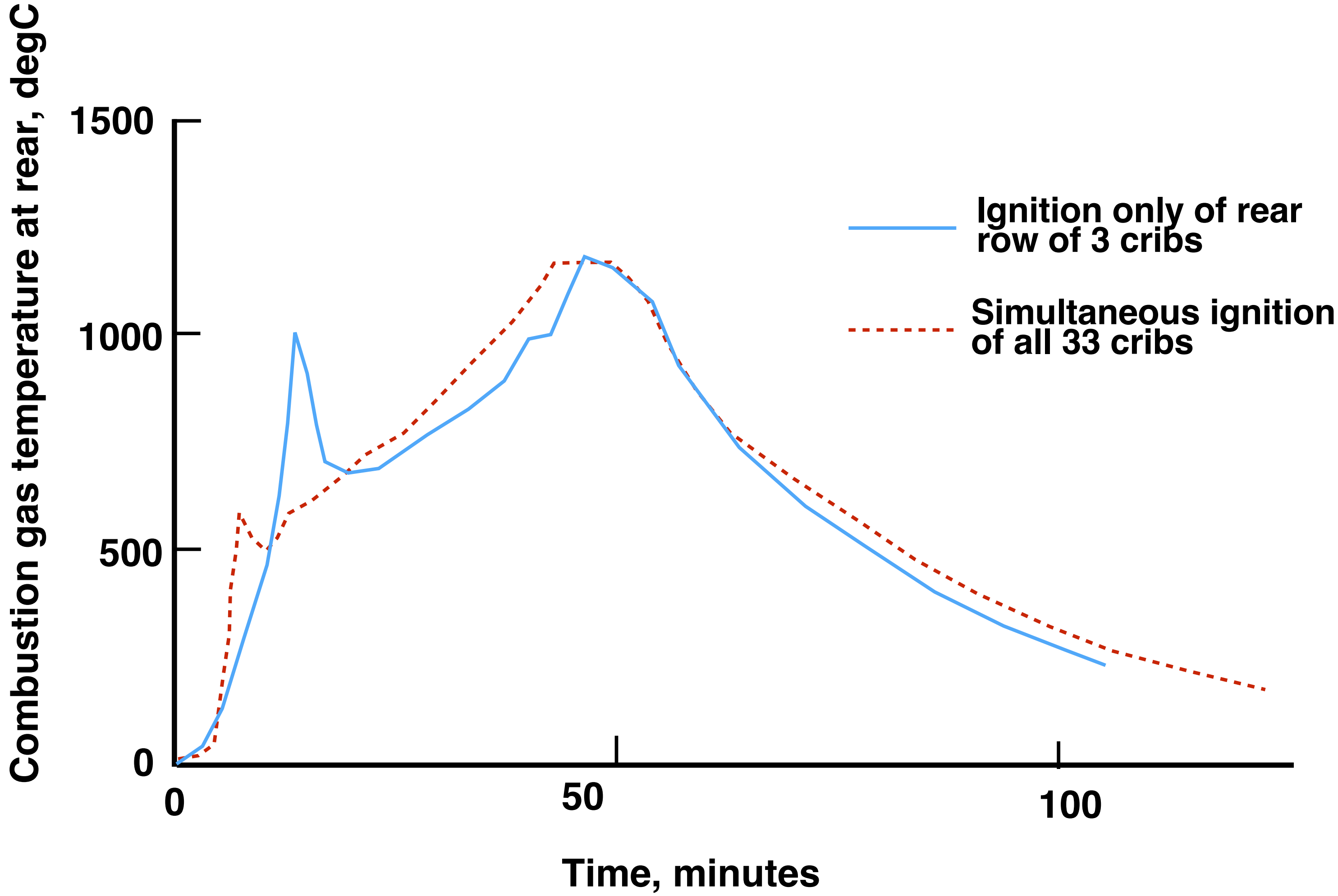


Temperature-time curves: furnace ~ natural fire (Test 3)

Comparison of severity for different ignition sites

all 33 cribs lit at same time

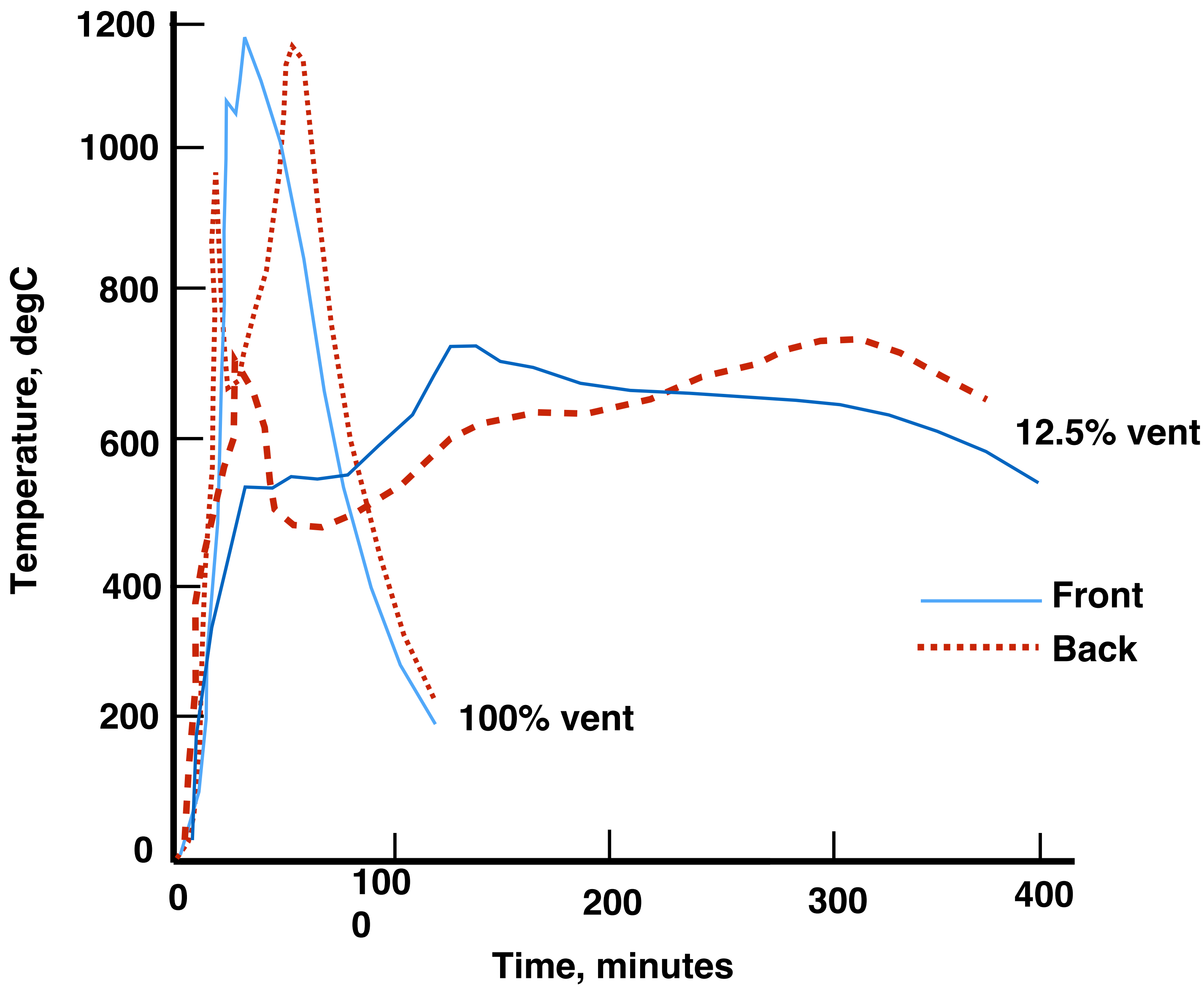
only rear 3 cribs lit



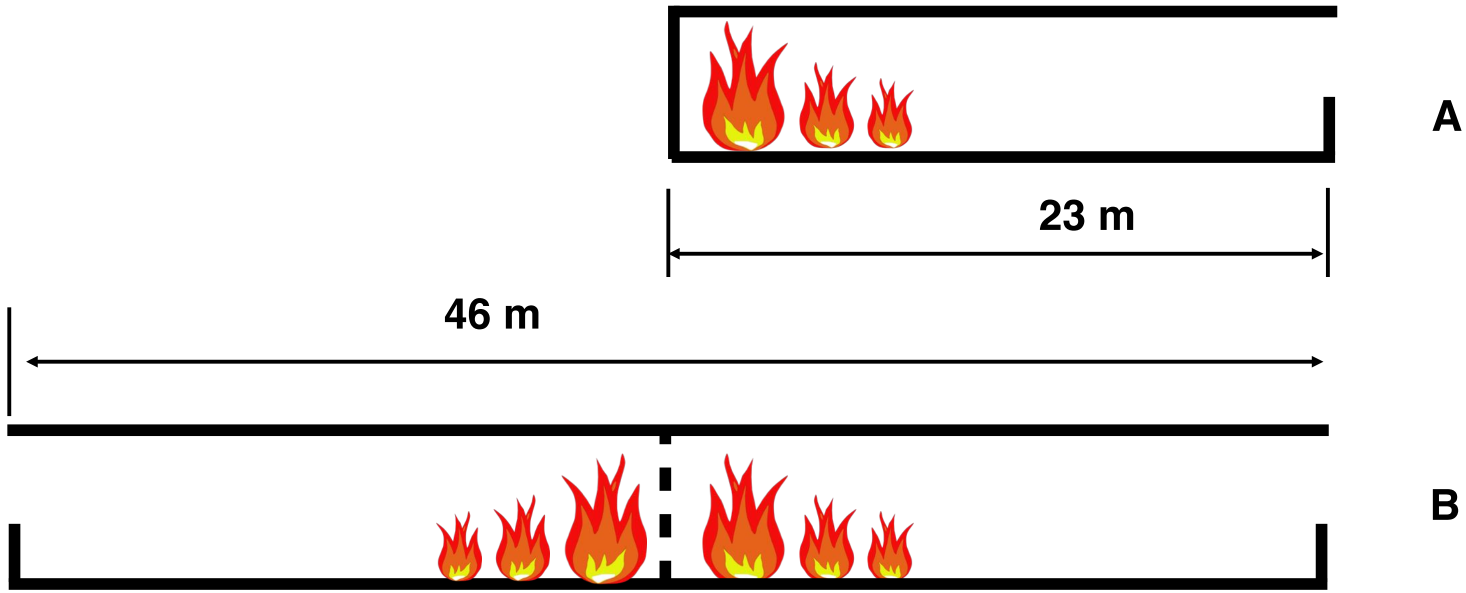
Effect of simultaneous ignition versus local rear ignition of cribs

Effect of ventilation on combustion gas temperature-time curves

Comparison of combustion gas temperatures at front and back for 100% ~ 12.5% ventilation in front wall. (20 kg/m2)



Speculation - extending compartment size



Could we say that fire growth and severity in compartment A (the tested condition) and compartment B (which has no wall in centre) would be the same assuming same ventilation opening and fire load and no through draft? I think we could.

Conclusions

In a deep, narrow, well-insulated compartment with ventilation at one narrow end (the front) and a uniform fire load spread over the floor, fire will, irrespective of where first ignited (front or back), quickly become established at the front where it has easy access to incoming oxygen, and the active combustion zone then ‘***travels’*** towards the back of the compartment.

The time equivalents are not to be confused with equivalent periods of fire resistance - time equivalent is protection-dependent.

In the 23m deep test compartment with small amount of ventilation along the top of the front wall (12.5% of the area of that wall), the active combustion zone took 3hrs to travel from front to back and the fire severity, expressed as an average time equivalent for the protected steel, corresponded to 110 minutes. With 100% ventilation (represented in a building by fire-induced collapse of storey-high glazing) the time equivalent was only 72minutes.

Time equivalent is very dependent on ventilation and on steel protection thickness. It should not be used for determining the amount of fire resistance for unprotected steel members

The reported fires are very severe, perhaps the most severe ever recorded in UK experiments with cellulosic fire loads. A steel member with P/A = 180 m-1 attained a temperature of 1260 degC

Further work is needed to determine fire spread mechanisms in large compartments.

References

1. Cooke GME, 'The severity of fire in a large compartment with restricted ventilation', IMAS 94 Conference ' Fire safety on ships - Developments into the 21st century, London, 26-27 May 1994, Proc published by the Institution of Marine Engineers.

2. Cooke GME, 'Time equivalent - is it a good measure of compartment fire severity?', Fire Safety Engineering, April 1999, pp 26-31.

3. Cooke GME, Tests to determine the behaviour of fully developed natural fires in a large compartment, Fire Note 4, Building Research Establishment, February 1998

4. Kirby BR et al, Natural fires in large scale compartments - A British Steel Technical and Fire Research Station collaborative project, British Steel Technical, Swinden Laboratories, June 1994

6. Cooke GME, Use of plate thermometers for standardising fire resistance furnaces, BRE Occasional Paper, March 1994

NB. Papers 1 & 2 are reproduced in full on Author's website: www.cookeonfire.com > About Me > Publications > Fire severity.

cookeonfire.com