Detailed numerical modelling of hazards from large fires in longitudinally ventilated road tunnels

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BRE

Are Road Tunnels Safe?

- Various fire accidents put tunnel fire safety in question
  - Mont Blanc 1999

  - Tauern 1999
  - St Gotthard 2001
  - …

EU Initiatives to Improve Matters

- National initiatives
- Automobile associations
- Directive on Trans-European Road Network
- Sponsored research programmes
  - Fires in Tunnels Thematic Network
  - Virtual Fires
  - …
  - UPTUN

UPTUN

- **UPgrading TUNnels**
  - ***Some 40 organisations looking at all ways to improve safety of existing road & rail tunnels***
  - ***Existing technologies***
  - ***Novel ideas***

- BRE involvement in UPTUN
  - Evacuation analysis
  - Training and dissemination
  - Fire modelling
    - *Zone modelling with FASIT/CRISP*
    - *CFD modelling with JASMINE*

Fires in Road Tunnels

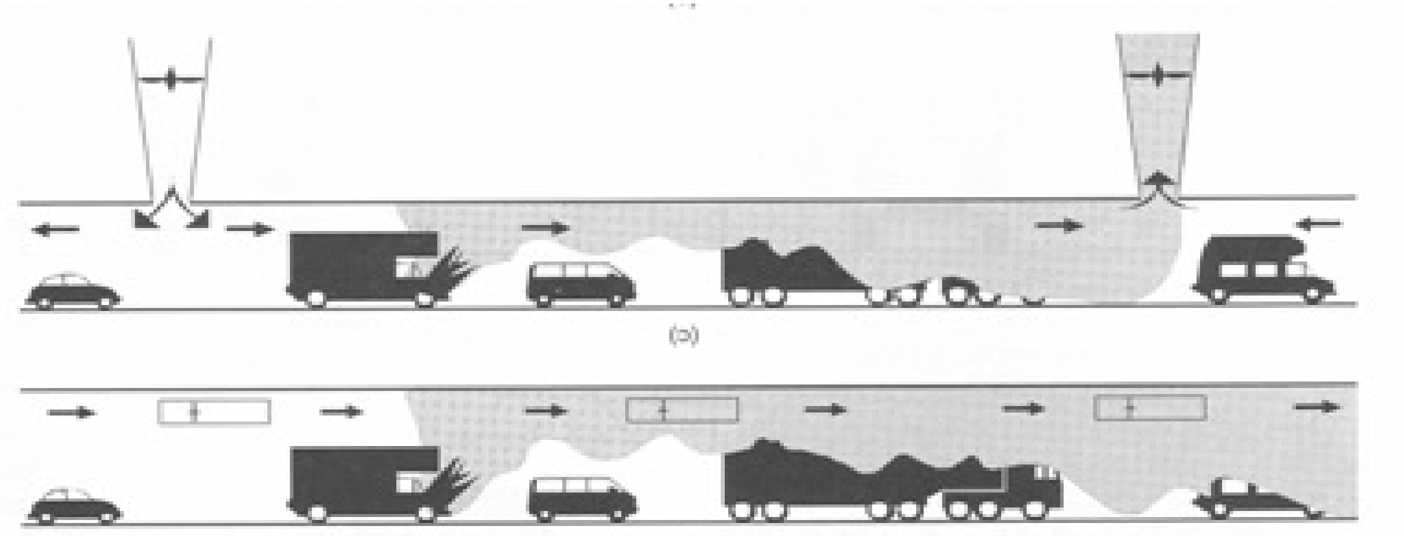
- Cars ~ 2 – 10 MW
- Tankers > 100 MW
- HGVs
    - ***30 MW?***
    - ***100 MW?***
    - ***More?***
  - UPTUN research to examine realistic HGV fire sizes

Design Fires for UPTUN

- Design fires required for UPTUN
  - Heat release rates
  - Development of hazardous conditions inside tunnel
- Information taken in part from experiments and literature
- Augmented by CFD modelling
  - To provide detailed picture of conditions
  - Transverse ventilation addressed by Instituto Superior Técnico in Portugal
  - Longitudinal ventilation addressed by BRE

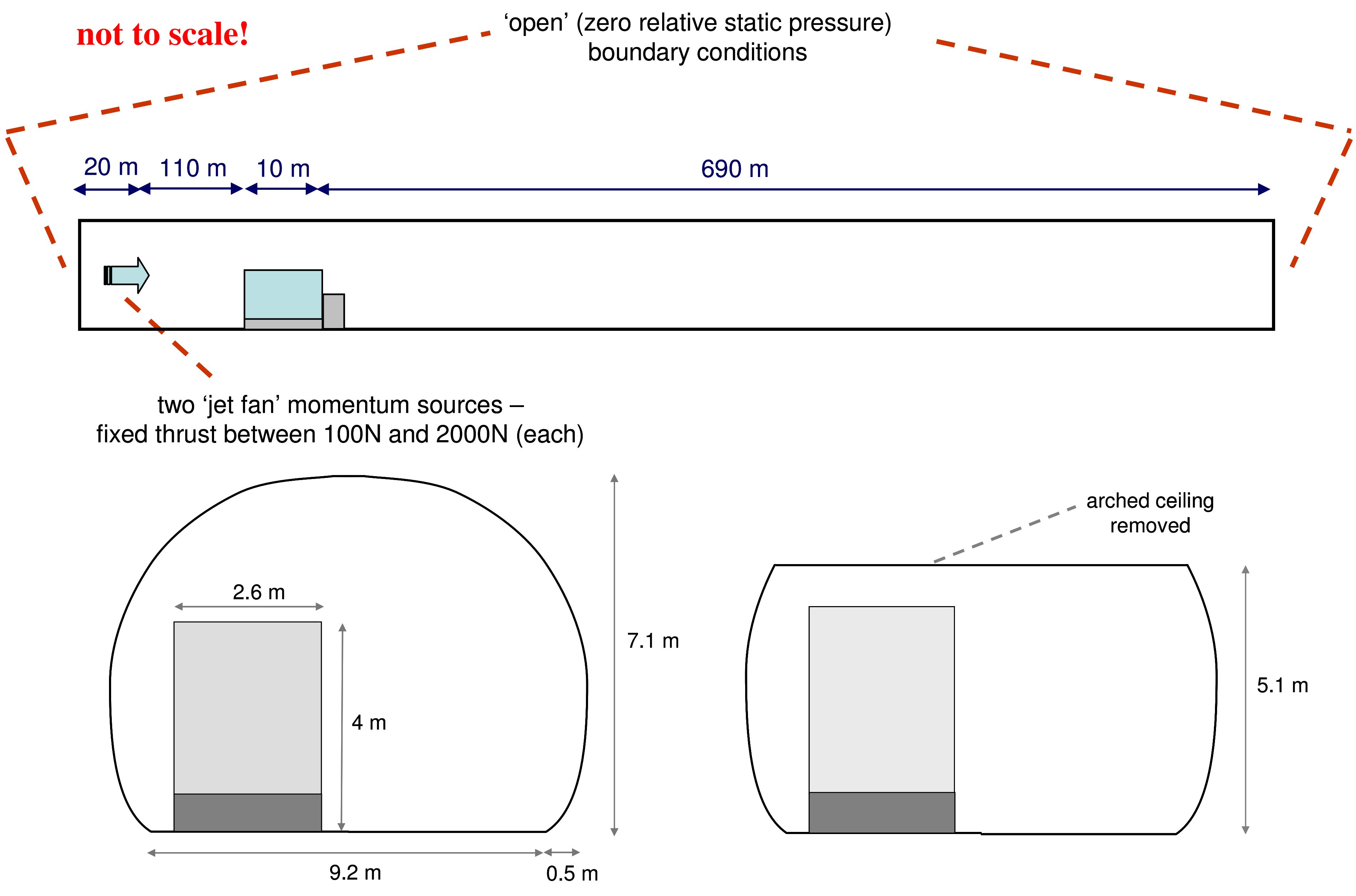
Longitudinal Emergency Ventilation

- Basic idea
  - Force all smoke & heat in downstream direction
  - Fire-fighting access and egress on upstream side



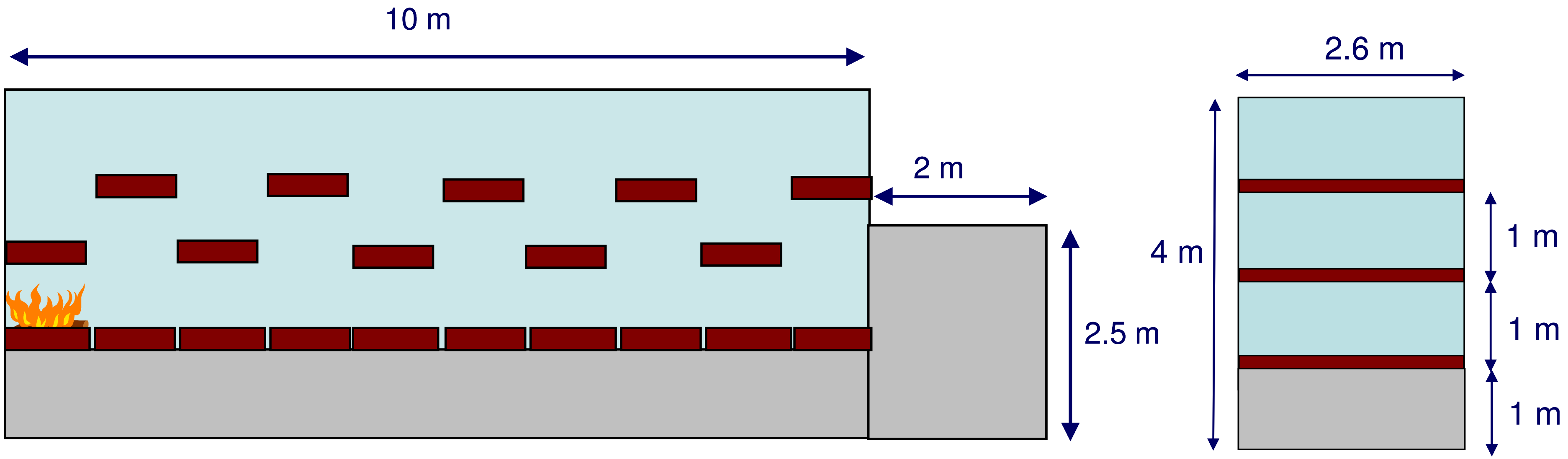
  - Required ventilation rates?
  - What about conditions downstream?

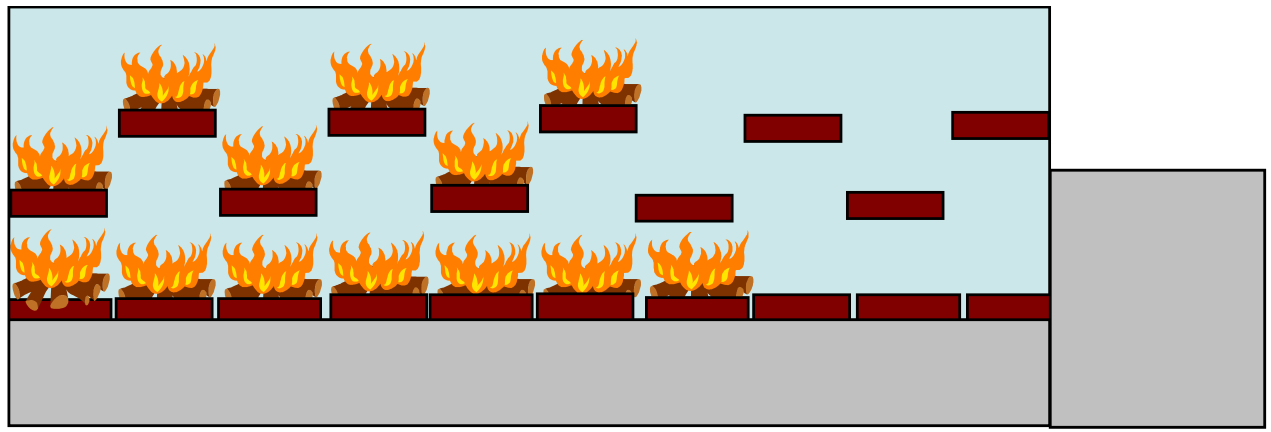
CFD Tunnel Study



HGV Fire Source

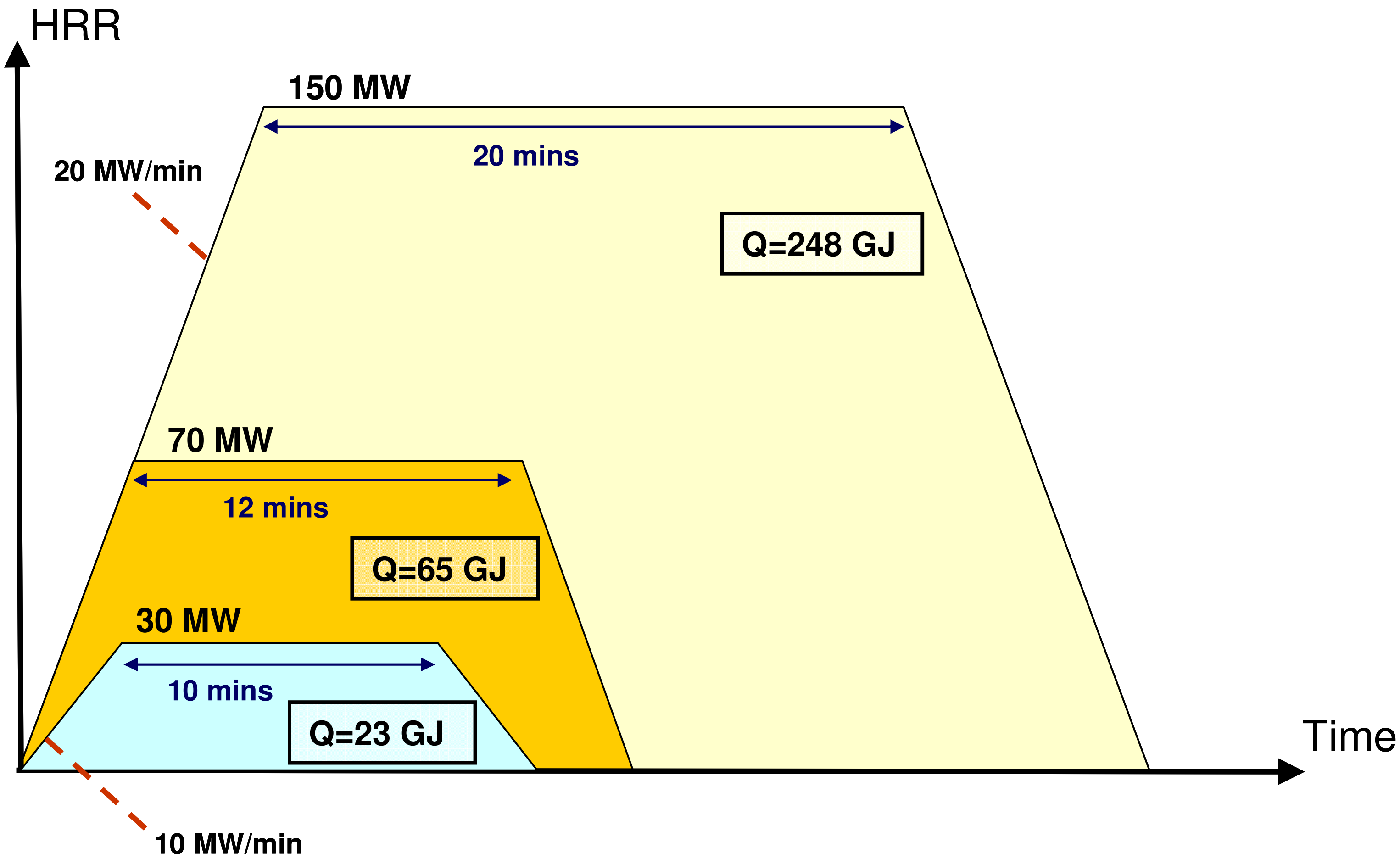
- Geometry based loosely on Runehamar tests





HGV Fire Source

- Heat release rate and total energy from Runehamar and elsewhere



Fuel

- Fuel treated as mixture of cellulose & polyurethane
  - Simple one-step combustion scheme

$$4CH_2O_{1/2} + 5O_2 \rightarrow 4CO_2 + 4H_2O$$

    - *Heat of combustion = 25 MJ kg^{-1}*

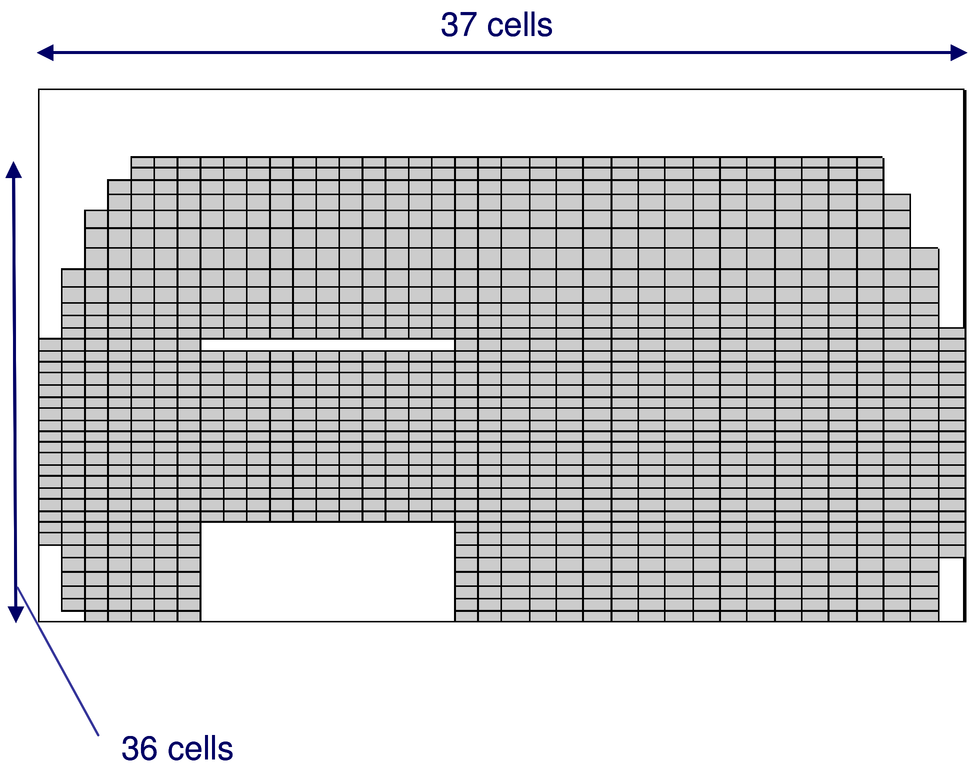
  - Assumed soot (particulate) yield of 5%
    - *Visibility then derived from empirical correlation*

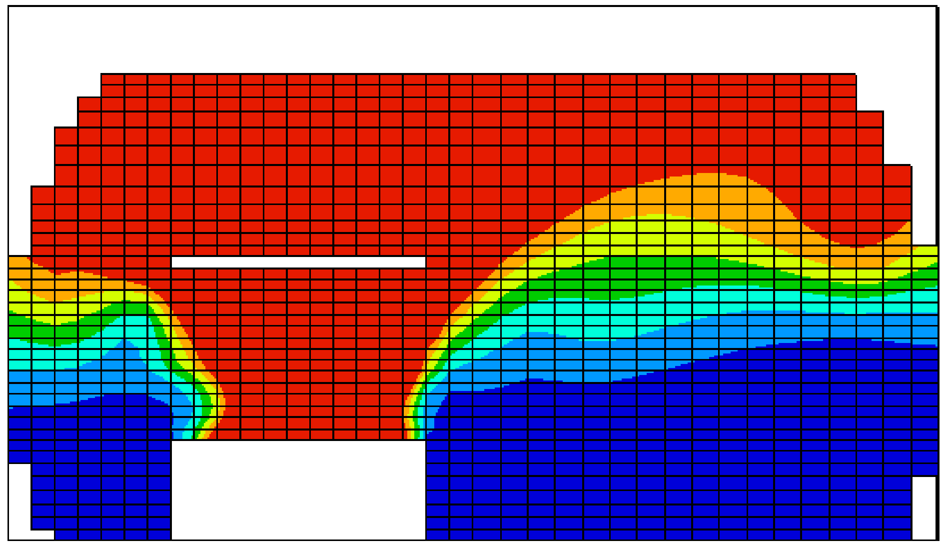
$$S = \frac{3}{Km_s}$$

    - *And CO concentration derived from assumption of fixed CO_2/CO ratio of 33:1*

CFD Mesh

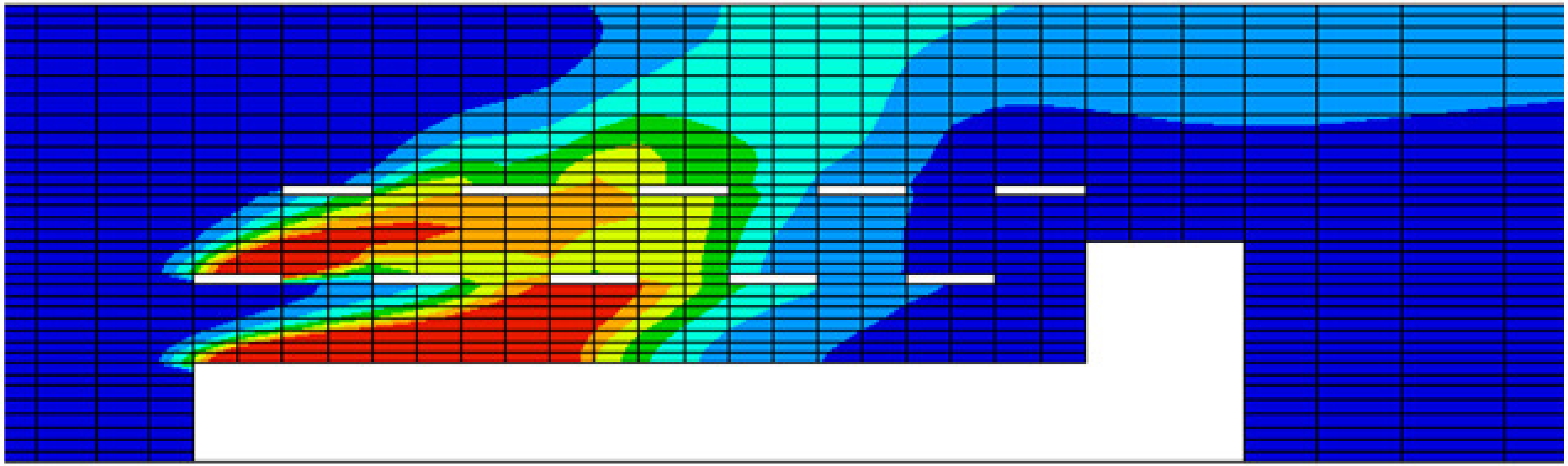
- Fine in cross-section





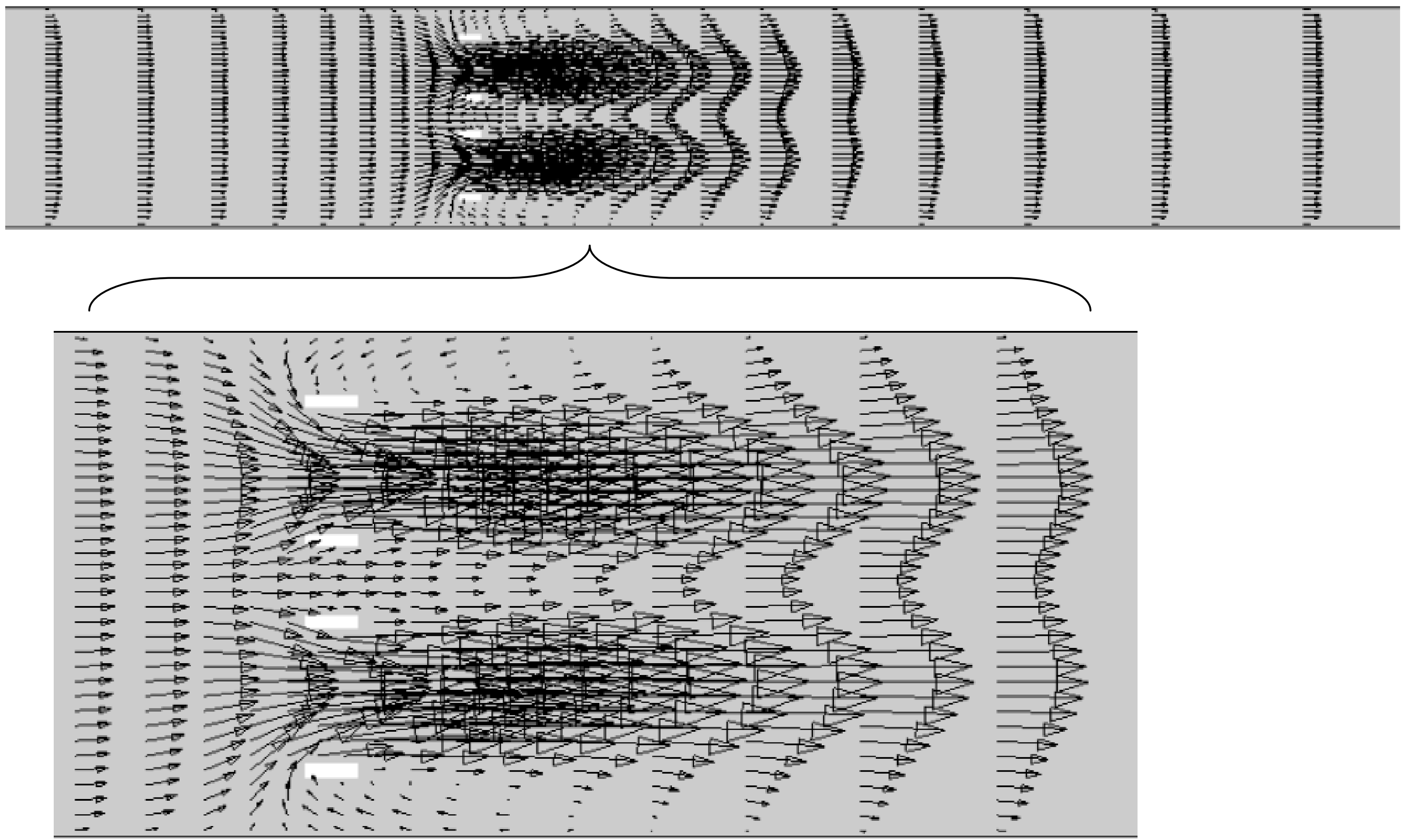
CFD Mesh

- And in vicinity of HGV



Ventilation

- <u>Fixed</u> sources of momentum 100 m upstream



Ventilation

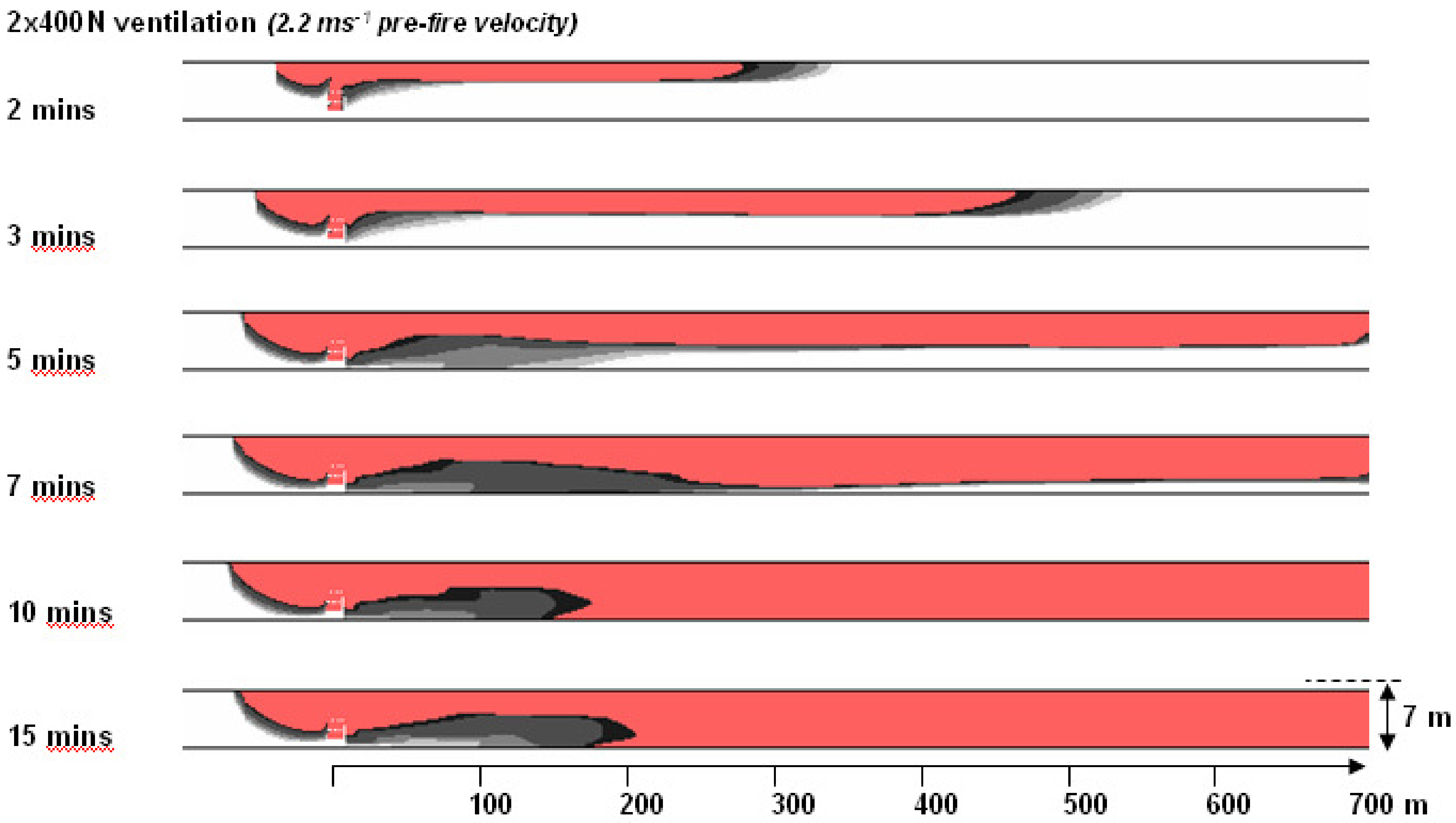
- Generate a pre-fire ‘cold flow’:

Thrust (N)*	Pre-fire longitudinal air speed (ms^{-1})	
	Arch profile	Box profile
2 x 100	1.0	1.1
2 x 200	1.5	1.6
2 x 300	1.9	2.0
2 x 400	2.2	2.3
2 x 500	2.4	2.5
2 x 600	2.7	2.8
2 x 800	3.1	3.3
2 x 1000	3.5	3.7
2 x 1500	4.3	4.6
2 x 2000	5.0	5.3

Control of back-layering

Smoke distribution for arch tunnel and 70 MW peak fire

(red → visibility < 1.5 m)

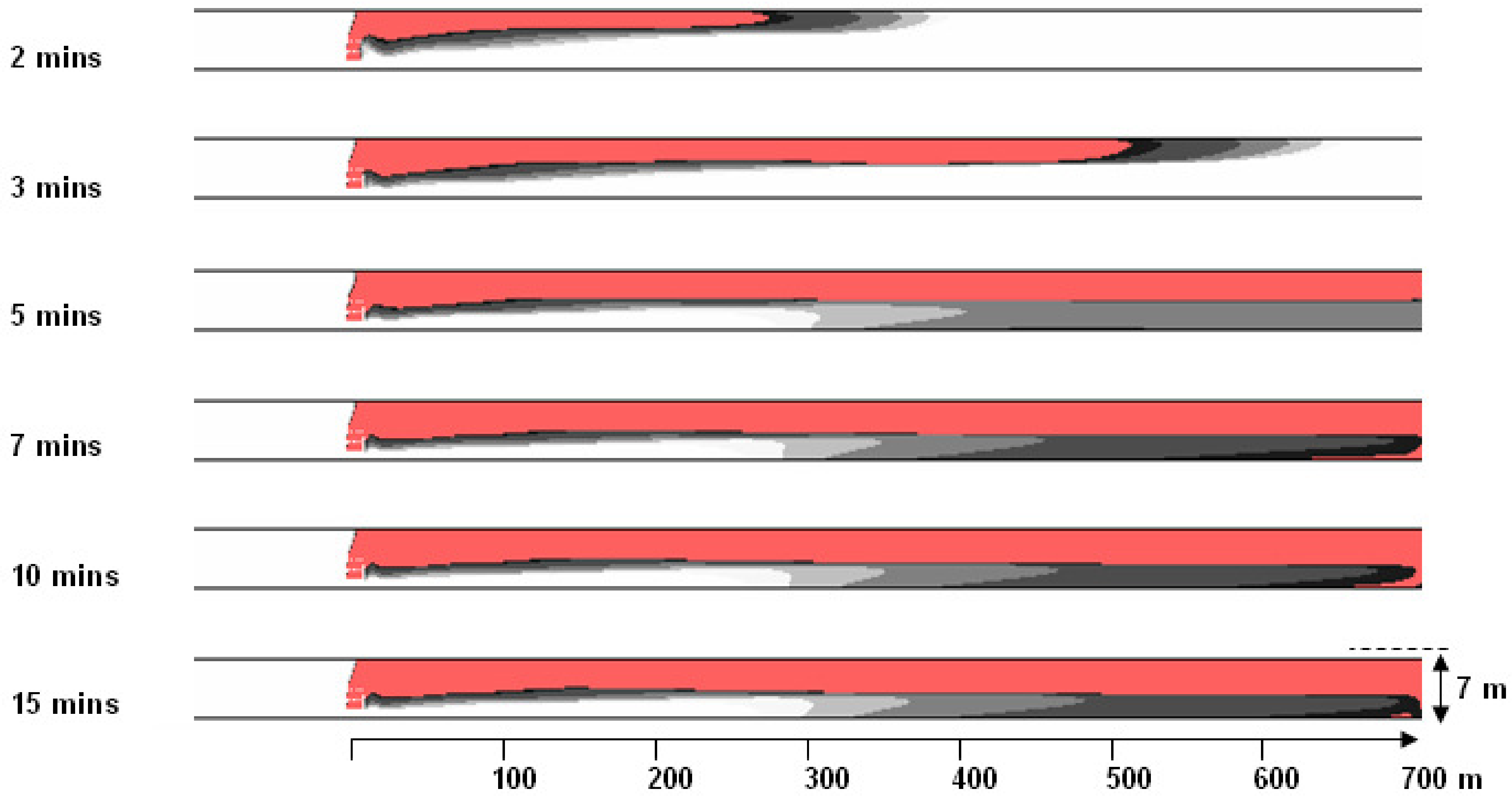


Control of back-layering

Smoke distribution for arch tunnel and 70 MW peak fire

(red → visibility < 1.5 m)

2x1000N ventilation *(3.5 ms⁻¹ pre-fire velocity)*



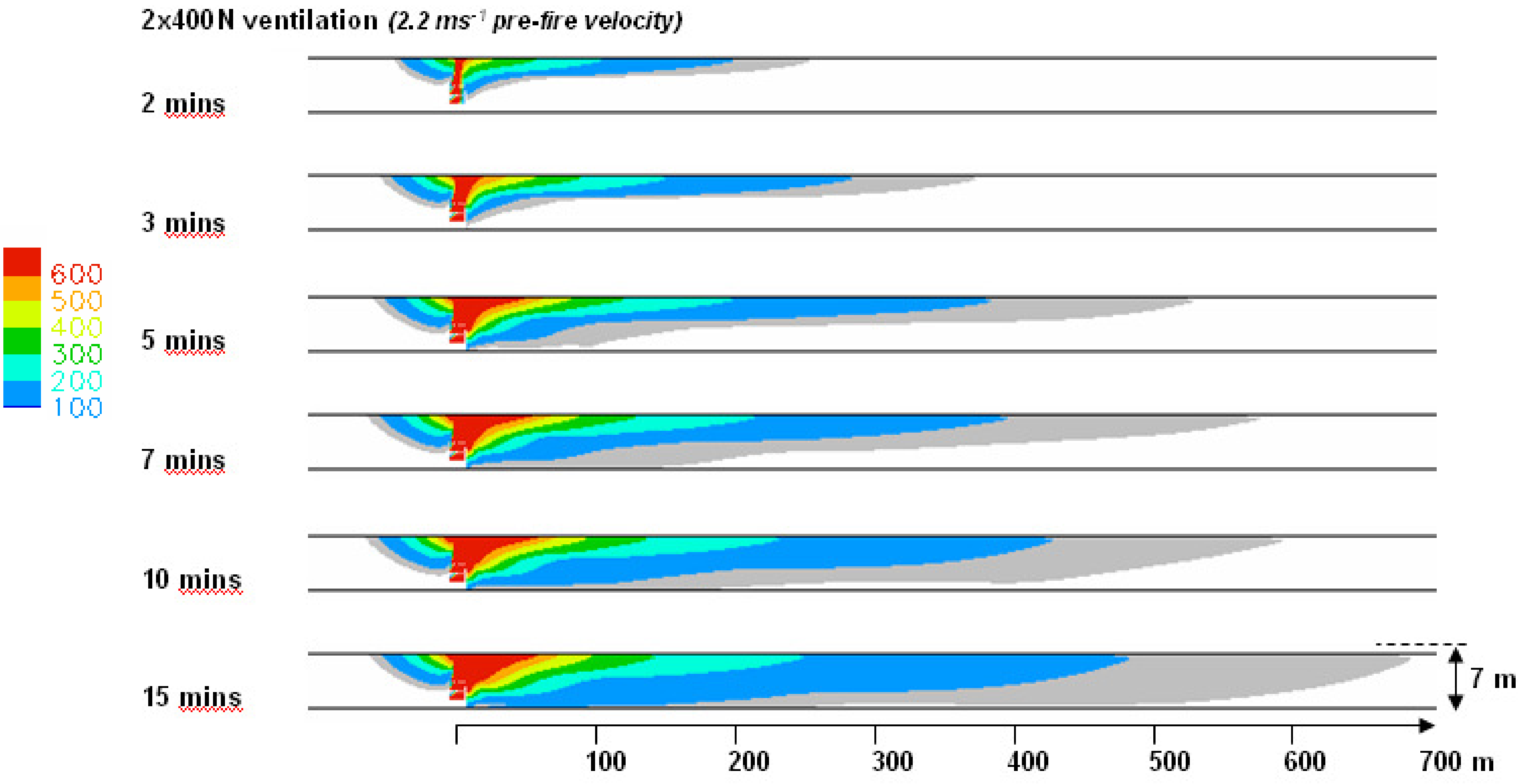
Control of back-layering

- Summary for all combinations of tunnel and fire size

Tunnel cross-section	Peak heat release rate (MW)	Ventilation rate to control back-layering ($m\ s^{-1}$)
Arch	70	3.1 → 3.5 *
Box	30	~ 2.5 **
Box	70	2.8 → 3.3 *
Box	150	~ 3.3 **

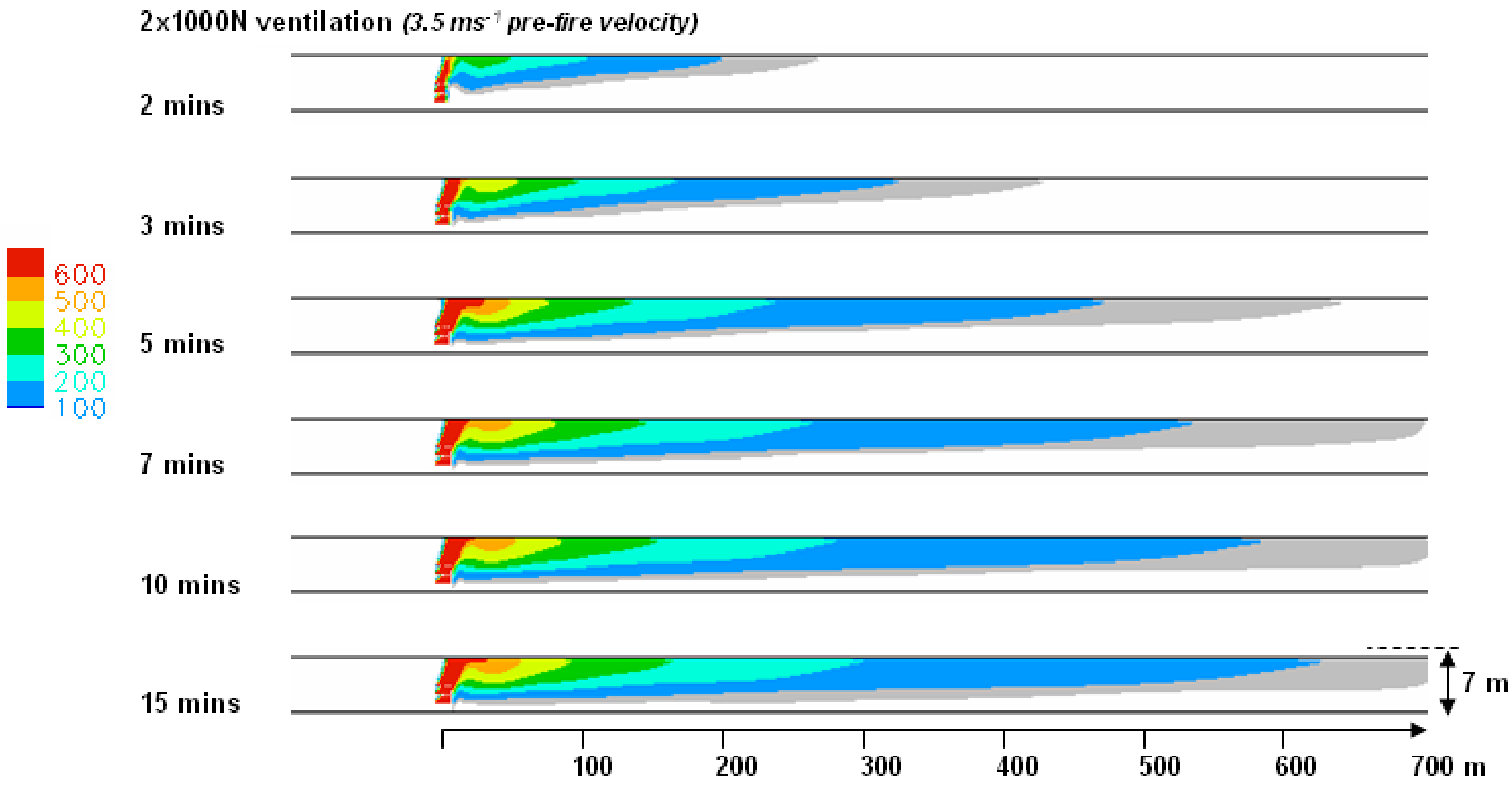
Evolution of gas temperature

Arch tunnel and 70 MW peak fire



Evolution of gas temperature

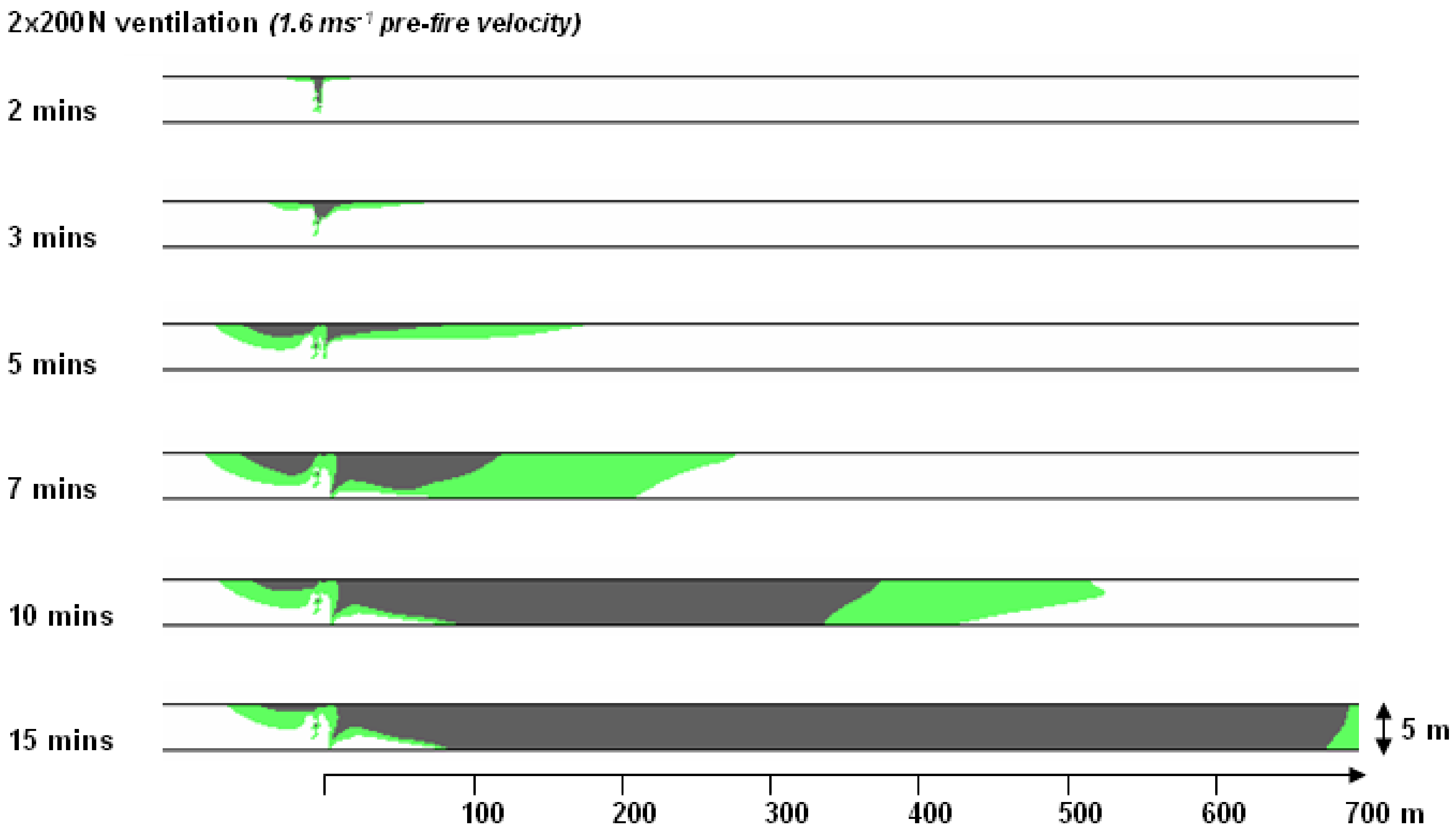
Arch tunnel and 70 MW peak fire



Evolution of CO

Box tunnel and 150 MW peak fire

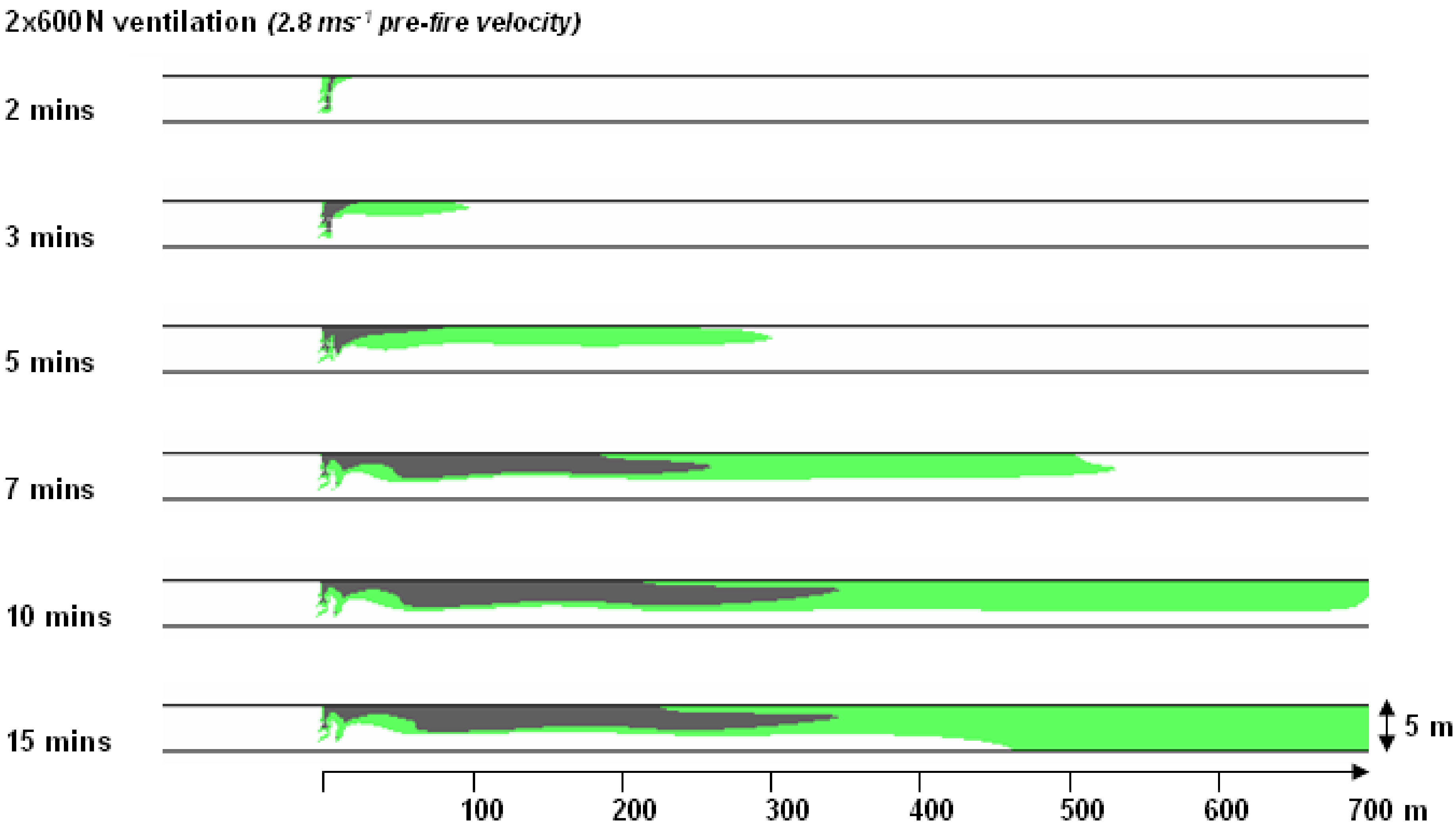
(green→1500 ppm black→3000 ppm)



Evolution of CO

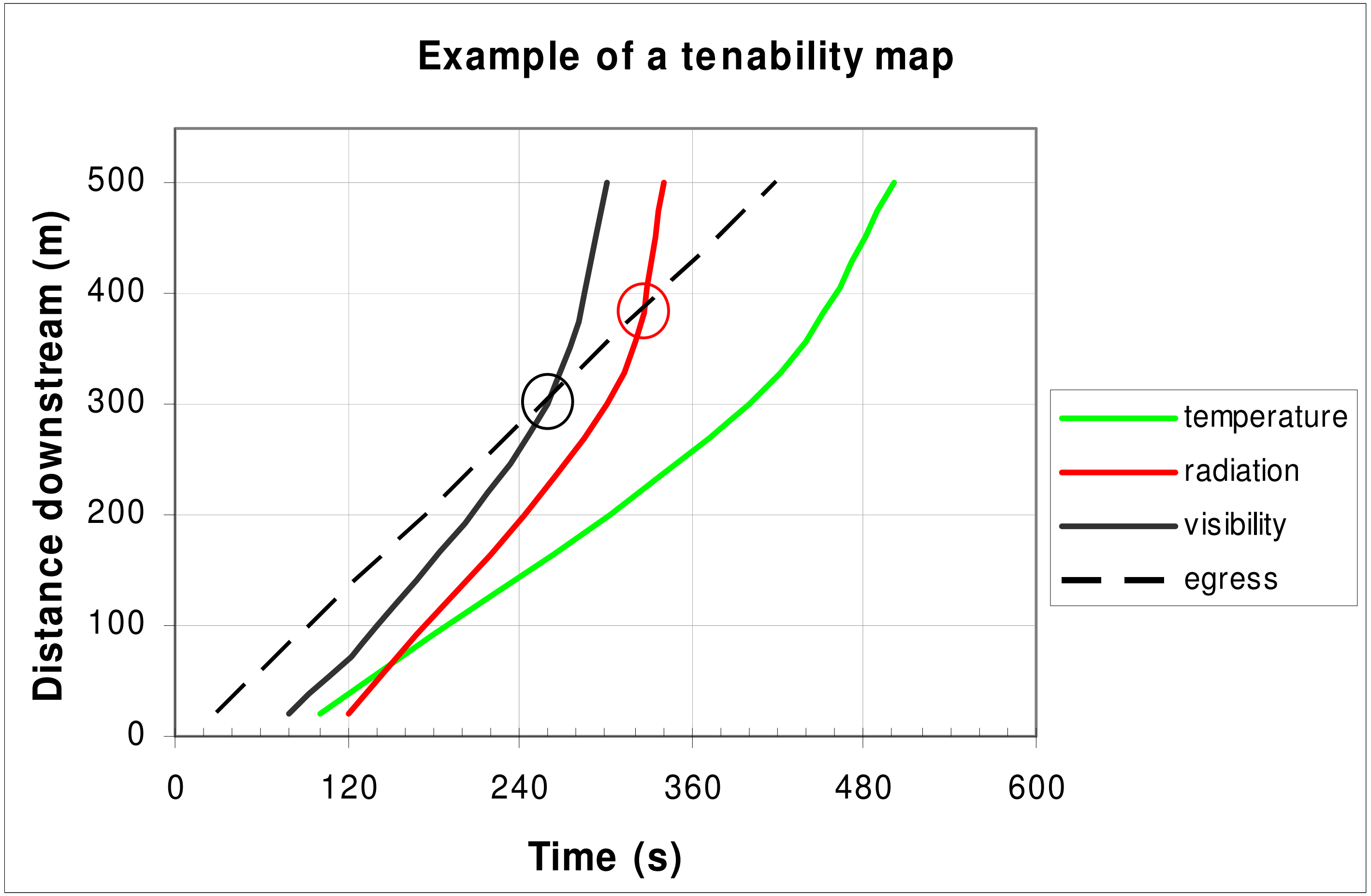
Box tunnel and 150 MW peak fire

(green→1500 ppm   black→3000 ppm)



Tenability Analysis

- Concept of a tenability map



Person exposed to hazardous visibility here at 300m and 260s

Person exposed to hazardous radiation level here at 390m and 320s

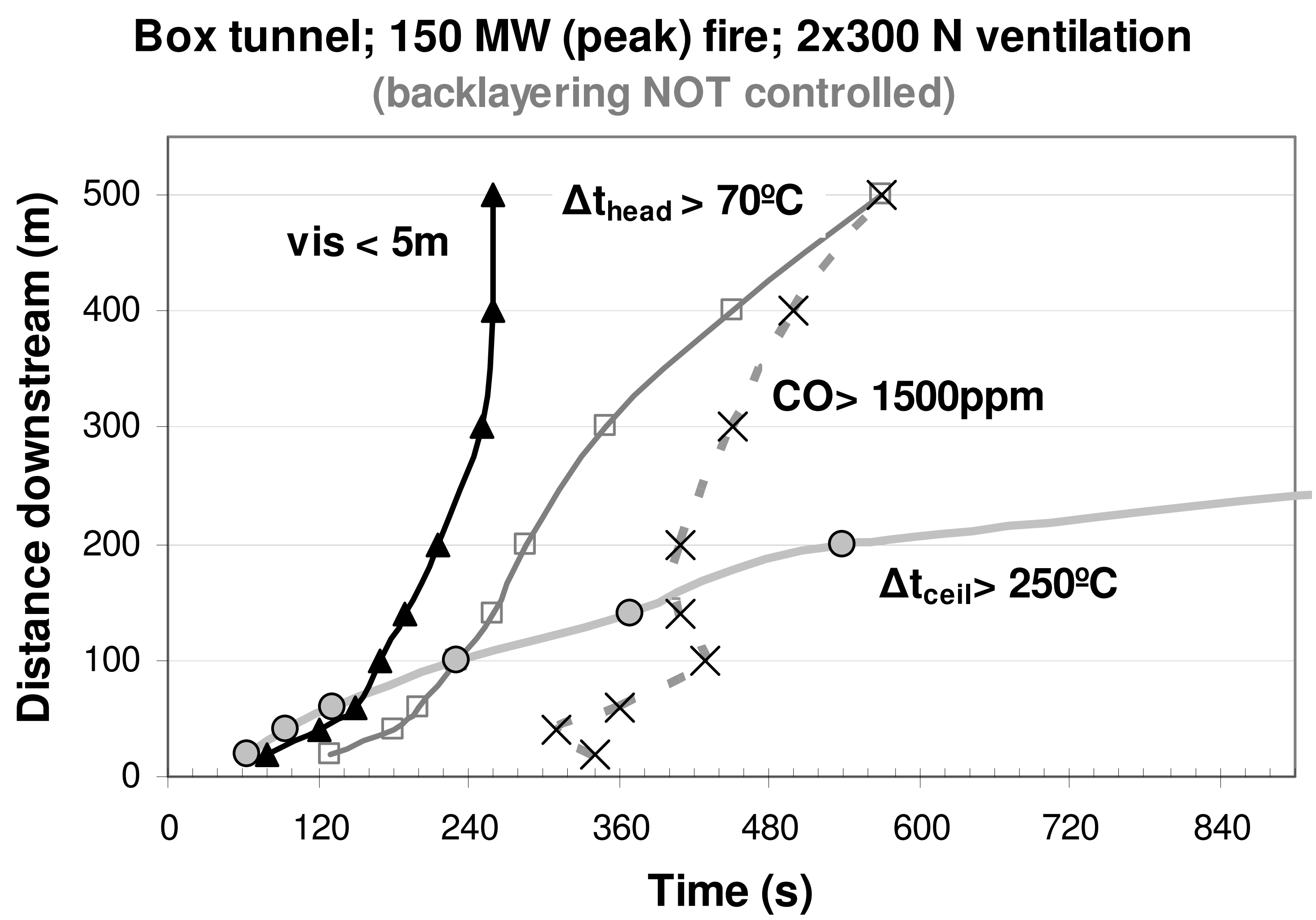
Person not exposed to hazardous gas

Tenability Conditions

- Detailed tenability analysis based on development of following selected hazard conditions:
  - Gas temperature rise of 70ºC at head height
  - Gas temperature rise of 250 ºC at ceiling
    - *~ downward radiation flux of 4 kW m^{-2}*
  - Visibility level reduced to 5 m at head height
  - CO concentration of 1500 ppm

Tenability Example

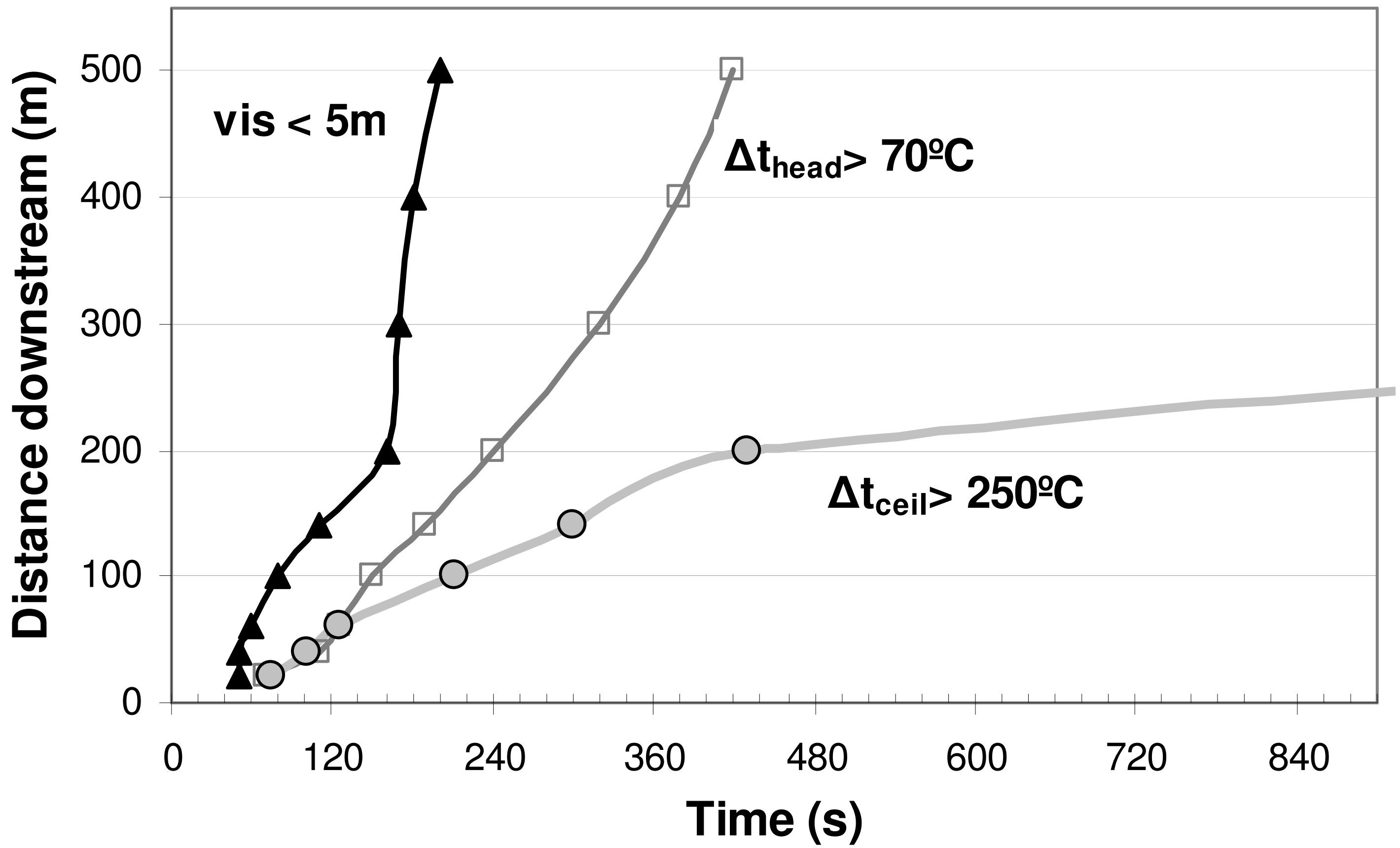
Box tunnel and 150 MW peak fire



Tenability Example

Box tunnel and 150 MW peak fire

Box tunnel; 150 MW (peak) fire; 2x800 N ventilation
(backlayering controlled)



Some Conclusions

- Ventilation providing a pre-fire longitudinal velocity of ~ 3 ms^{-1} controlled back-layering in all cases (‘critical level’)
- At ventilation rates > ‘critical level’ the smoke conditions (visibility) downstream become a serious hazard in all cases

  But for first few minutes remain tolerable in lower in lower part of tunnel

  And in first 100 m or so downstream the conditions remain less severe for the 30 and 70 MW fire scenarios

- At ventilation rates < ‘critical level’ theer is a smoke hazard upstream and it is also then worse downstream too

Some Conclusions

- At ventilation rates > ‘critical level’ the thermal hazard is significant in the first 100 m downstream in all cases

  And for the 150 MW fire scenario the region is filled with flaming gases

  For the 70 MW and 150 MW fire scenarios the thermal hazard extends well beyond 100 m (along the entire 700 m for the 150 MW fire)

- The CO hazard was negligible for the 30 MW fire scenario in all cases

  And for the 70 MW fire scenario it was only a problem where the ventilation was below the ‘critical level’

- The CO hazard was quite pronounced for the 150 MW fire scenarios

  Due primarily to the total Calorific value of the fire

  Hazard mitigated by ventilating at a high rate – but may then feed the fire with oxygen?