Approximate Trajectories of Droplets from Water Mist Systems in Tunnels

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Overview

- Introduction: Why?
  - Quote from PIARC
  - Concepts and ideas
- Quick digression
  - What about “critical ventilation velocity”?
- The analytical model
  - Equations (only 4 of them)
- Results: Travel distances
  - 5 different droplet sizes, velocities up to 10ms^{-1}
- Implications for design of WM systems
  - Integrated ‘tunnel safety system’

Introduction

From PIARC "Road Tunnels: An Assessment of Fixed Fire Fighting Systems"

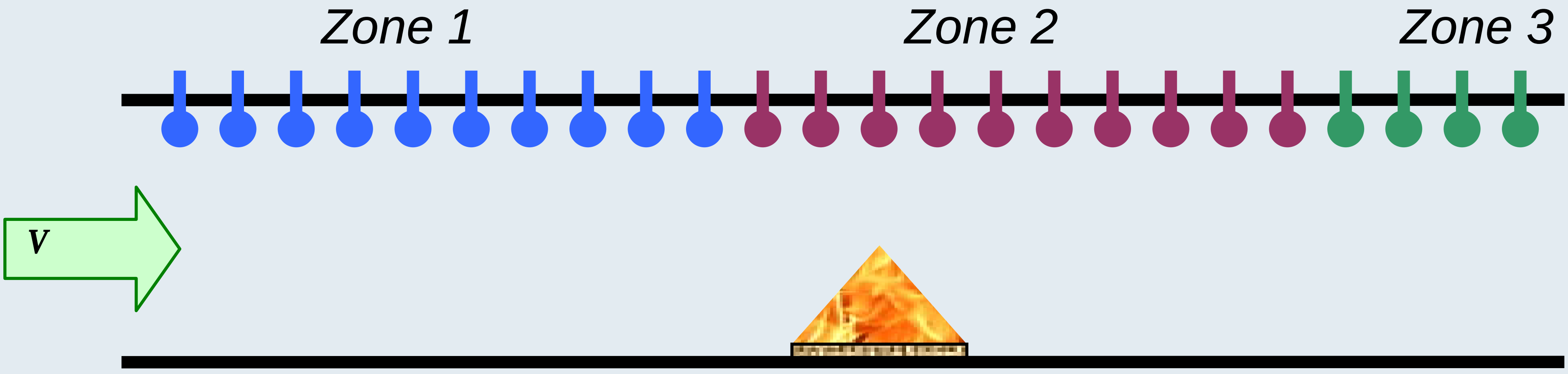
"In most cases, FFFS are not capable of extinguishing vehicle fires. The aims are to: slow down fire development, reduce or completely prevent fire from spreading to other vehicles, provide for safe evacuation, maintain tenability for fire-fighting operations, protect the tunnel structure and limit environmental pollution. To fulfil these purposes, the FFFS must:

- be supported by effective and rapid fire detection and location systems that are optimized to ensure proper functioning of the FFFS, resulting in a highly reliable integrated system,
- **be designed to handle air velocities in the range of 10 m/s** that can result from ventilation system operation or natural effects,
- be able to mitigate fire development and infrastructure damage by utilizing an agent with good cooling effect,
- have an acceptable influence on visibility, especially during the self-rescue phase,
- be able to reduce radiant heat.

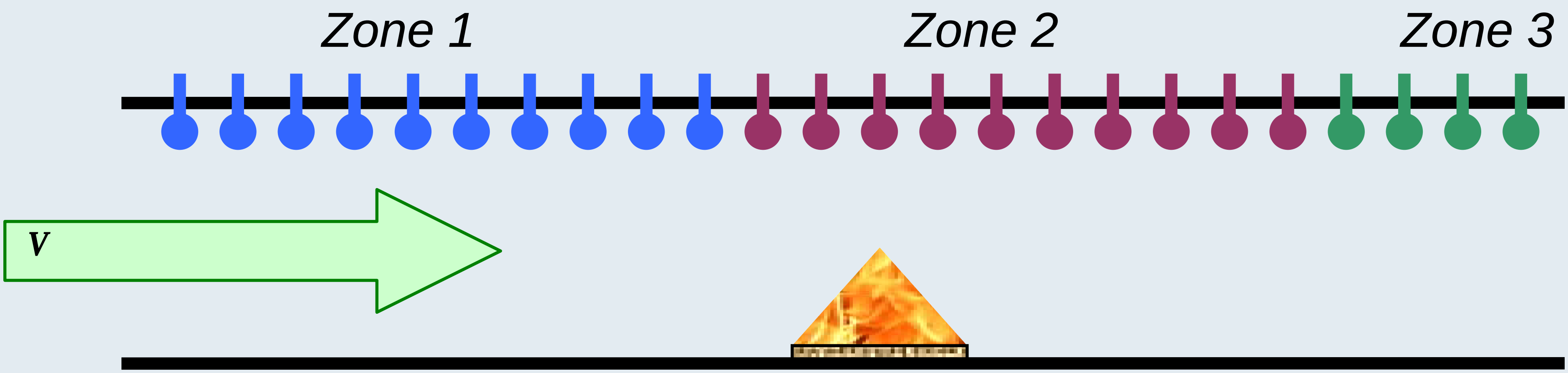
Introduction

- What this implies to me:
  - “We already have a powerful ventilation system”
  - “We understand smoke control using ventilation”
  - “We need this level of ventilation to prevent backlayering”
  - “We are not going to change the way we use the ventilation to suit the needs of the water mist”
- But what if the water mist system would be <u>more effective</u> at lower ventilation velocities?

Introduction

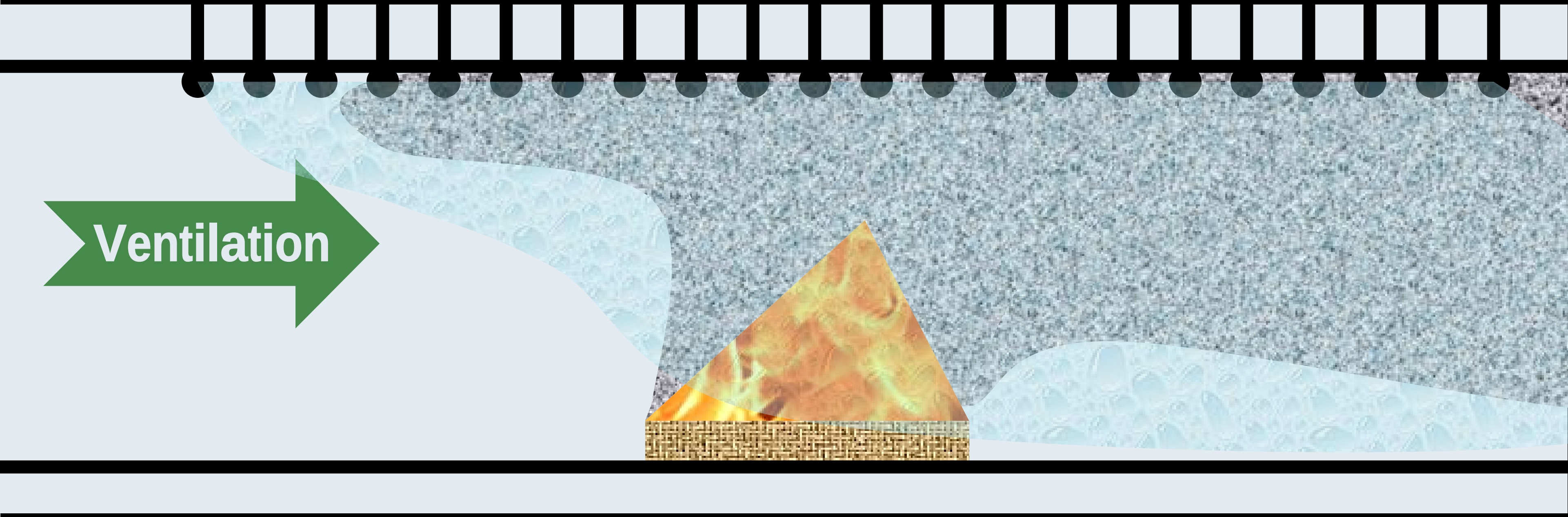


Introduction



Quick digression

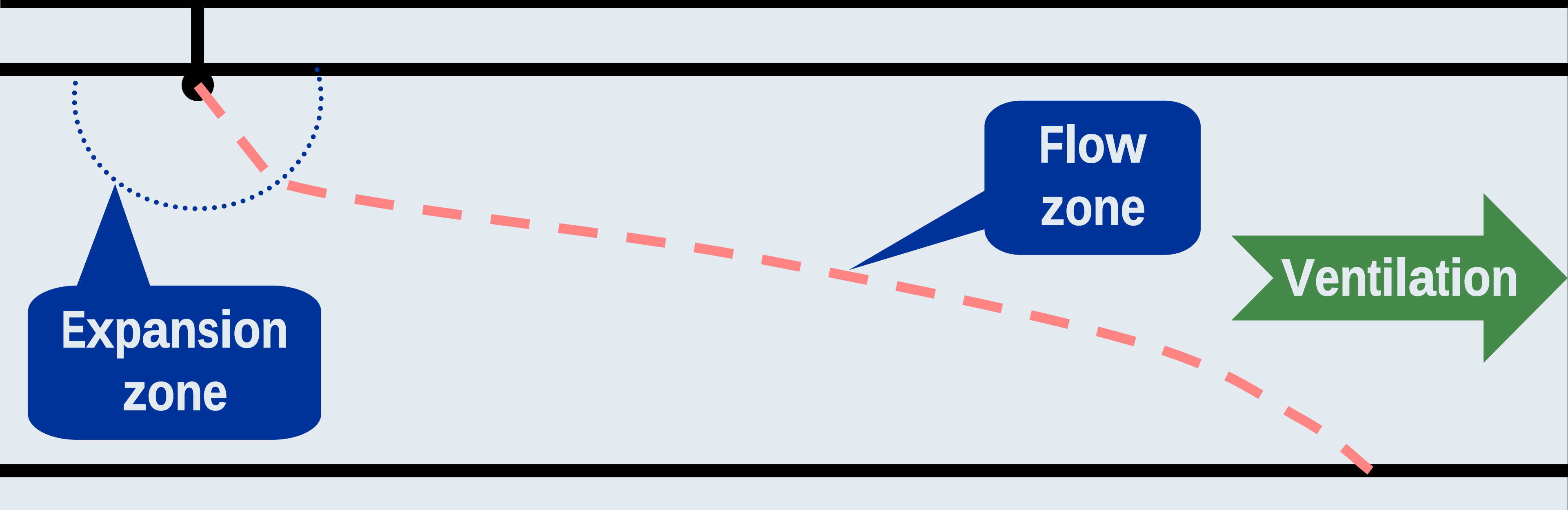
- What about "critical ventilation velocity"?



- Perhaps critical ventilation velocity is smaller with an operational water mist?
    - Would that make us do things differently?

Droplet trajectory model

- This is a **simple model**, intended to predict **approximate transport distances** – to give an indication of system performance.



- Expansion zone: droplet motion governed by exit velocity and initial angle of motion
- Flow zone: droplet motion governed by longitudinal flow

Droplet trajectory model (equations)

- Full details in the proceedings.
  - V = Droplet velocity vector
  - U = Longitudinal flow in the tunnel
  - W = Droplet velocity relative to flow
  - d = Droplet diameter
  - A_d = Area of droplet
  - m_d = Mass of droplet
  - C_D = Drag coefficient (droplets assumed to be spherical)
  - g = Gravity vector

$$\frac{d\vec{V}}{dt} = \vec{g} + \frac{1}{2} \cdot C_D \cdot \frac{\rho A_d}{m_d} \cdot \left|\vec{W}\right| \cdot \vec{W}$$

$$\vec{\mathrm{W}} = \vec{\mathrm{U}} - \vec{\mathrm{V}}$$

$$C_D = 0.4 + \frac{24}{\mathrm{Re}_w} + \frac{6}{1 + \sqrt{\mathrm{Re}_w}}$$

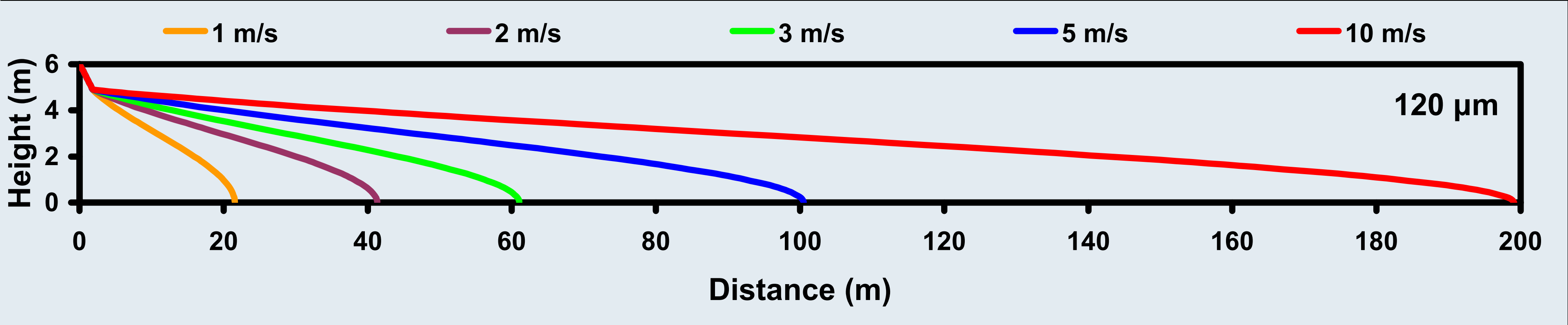
$$\mathrm{Re}_{\mathrm{w}} = \frac{\mathrm{d} \cdot \left|\vec{\mathrm{W}}\right|}{2 \cdot \nu}$$

Results: Travel distances

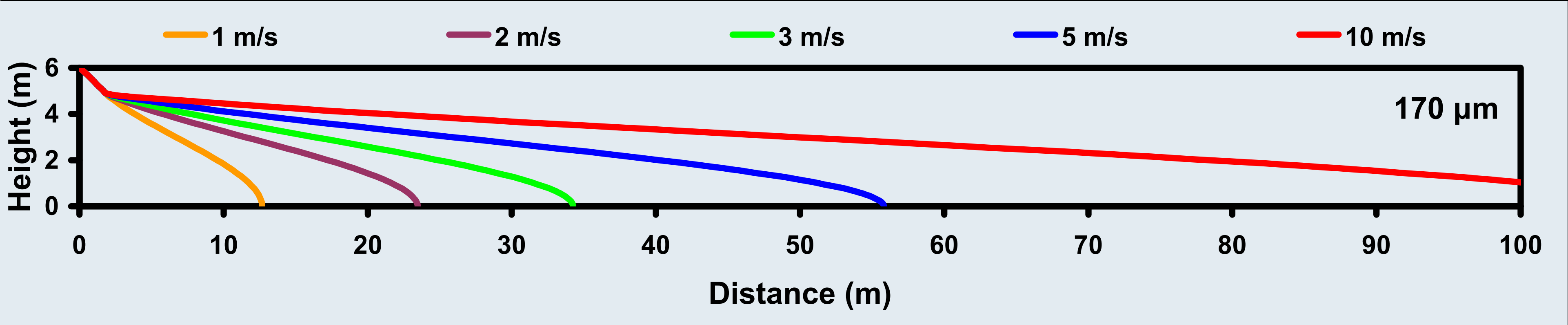
- In this study the following droplet sizes have been used:
  - 35 μm – lower limit of size
  - 90 μm – typical smaller droplet
  - 120 μm – typical larger droplet
  - 170 μm – upper limit of size
  - 300 μm – taken to represent a coalesced droplet
- Ventilation velocities considered:
  - 0.5 to 10 ms^{-1}
- All other variables have been fixed (for this paper):
  - Tunnel height (6m), Spray velocity (10ms^{-1}), spray angle (125°), expansion (2m)

Results: Travel distances

- “Typical” larger droplet size:

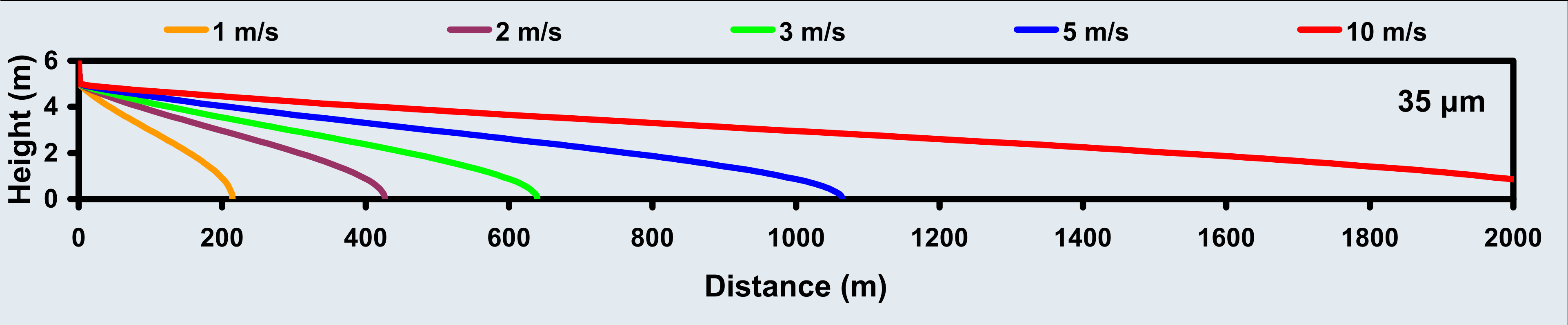


- Upper bound of droplet size:

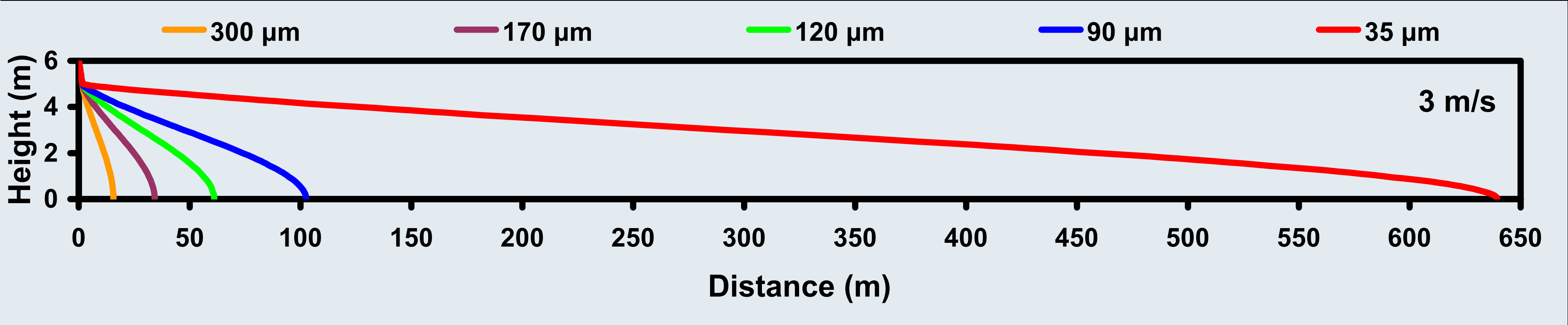


Results: Travel distances

- Lower bound of droplet size:

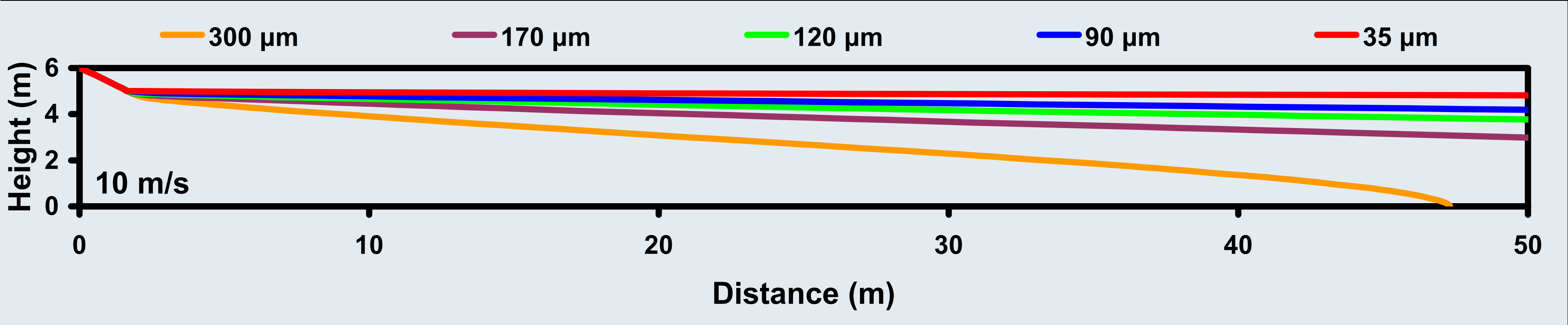


- All droplets at $3ms^{-1}$:

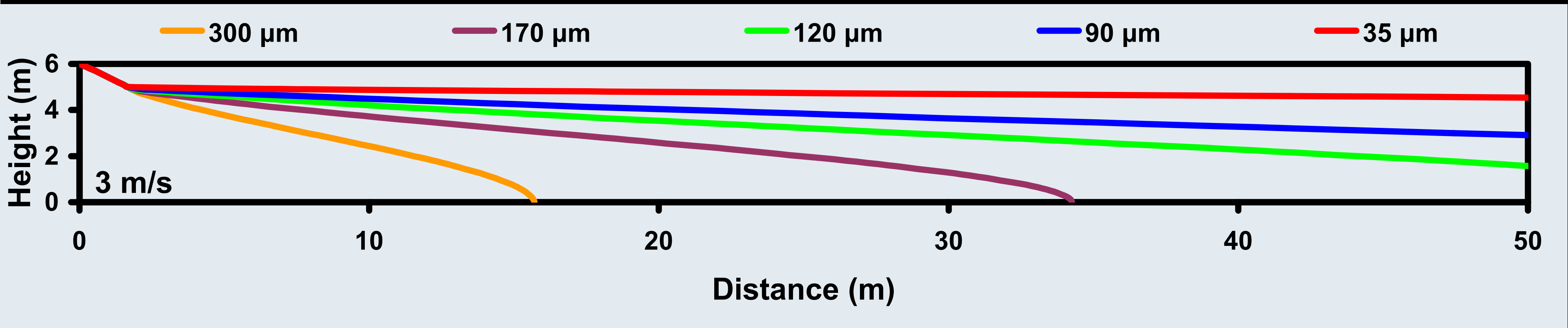


Results: Travel distances

- 50m zone with $10ms^{-1}$ flow:



- 50m zone with $3ms^{-1}$ flow:



Results: Travel distances

- Assumptions & limitations:
  - No interaction between droplets in mist
    - Corresponds to only a very sparse mist
  - Doesn't (yet) take account of buoyancy due to fire
    - This would only serve to increase transport distances
  - Doesn't (yet) take account of semi-transverse ventilation
    - Which would generally tend to slow the rate of falling and hence increase transport distances

- Comparison with other studies:
  - Robert Hart *"Numerical Modelling of Tunnel Fire and Water Mist Suppression"* PhD Thesis, University of Nottingham (UK), 2005
    - Our 'sparse mist' simple model over-predicts by **only 16%** compared to 'dense mist' full CFD simulation

Implications for design

- If the PIARC advice is used, it is clear that water mist systems are inappropriate for tunnel fire suppression.
- If the water mist is required to fight a fire at road level, within 50m of the nozzles, ventilation should be reduced to about 1 ms^{-1}.

Concluding thoughts

- We must think in terms of an integrated **'Tunnel Safety System'** rather than thinking of *'the detection system'*, *'the ventilation system'* and *'the water mist system'*. These three elements must be designed to work together as part of one integrated system.

- What are the optimum operating conditions for our integrated 'Tunnel Safety System'?