

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:

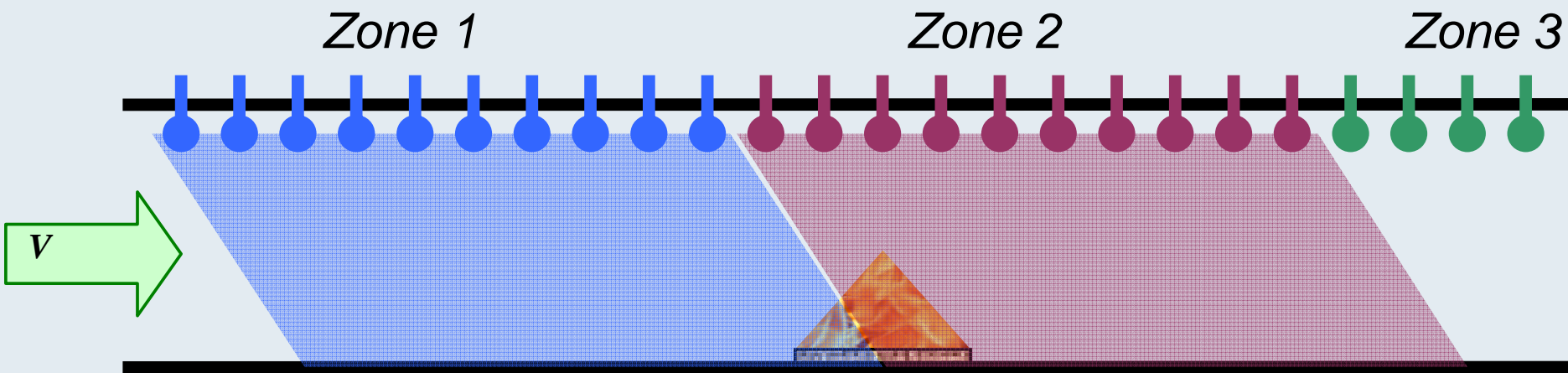
- **be supported by effective and rapid fire detection and location systems** that are optimized to ensure proper functioning of the FFFS, resulting in a highly reliable integrated system,
- **be designed to handle air velocities in the range of 10 m/s** that can result from ventilation system operation 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



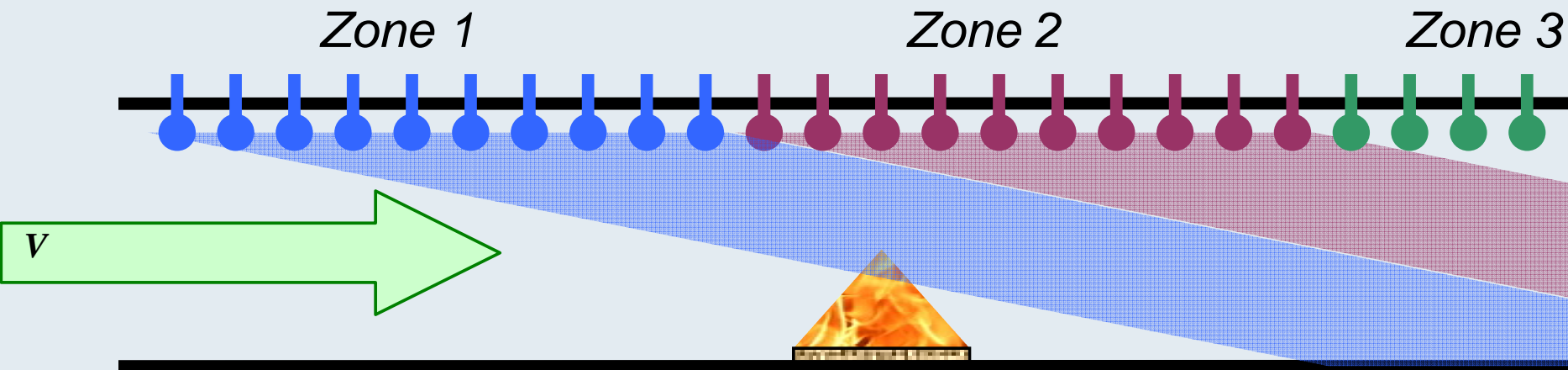
Introduction

- 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 more effective at lower ventilation velocities?

Introduction

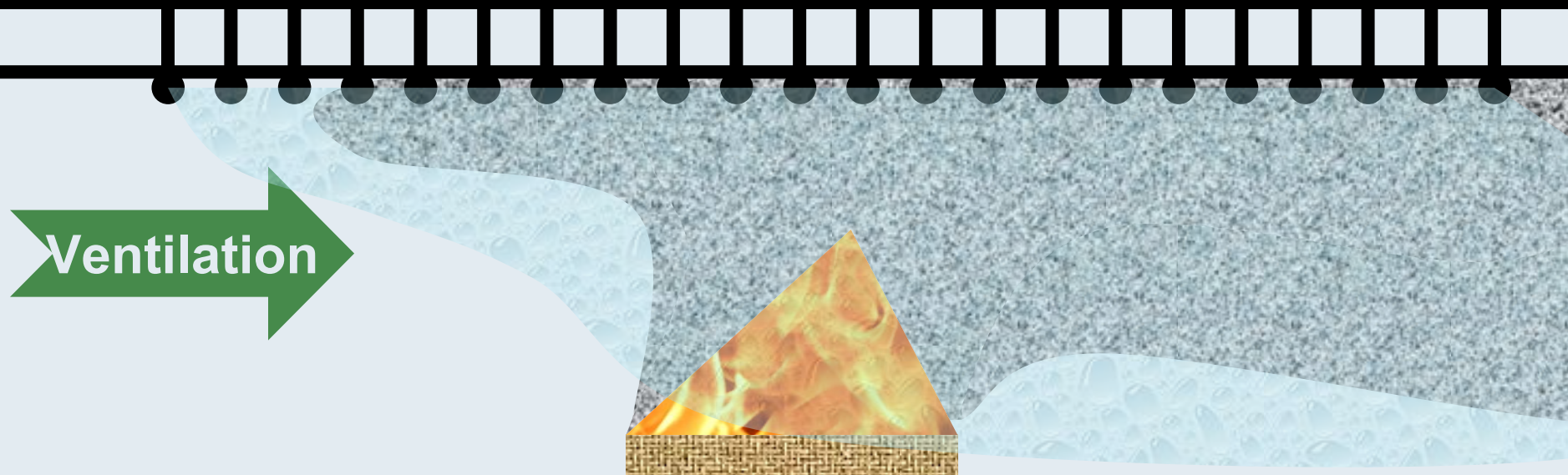


Introduction



Quick digression

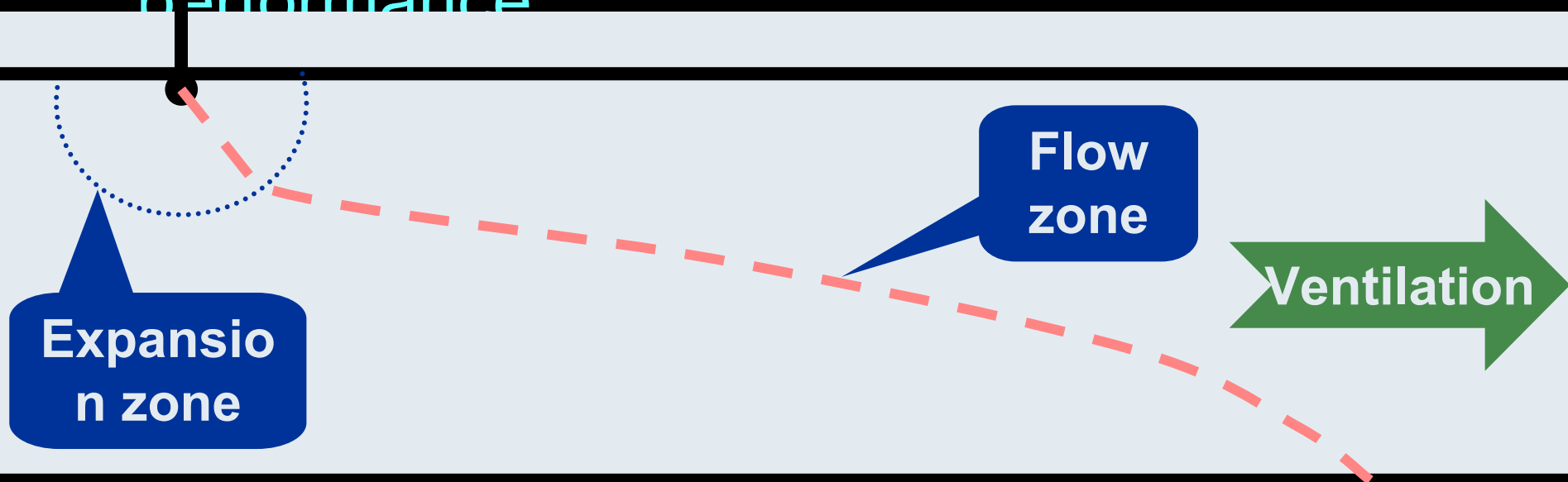
- What about “critical ventilation velocity”?



- 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

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

$$C_D = 0.4 + \frac{24}{\text{Re}_w} + \frac{6}{1 + \sqrt{\text{Re}_w}} \qquad \text{Re}_w = \frac{d \cdot |\vec{W}|}{2 \cdot \nu}$$



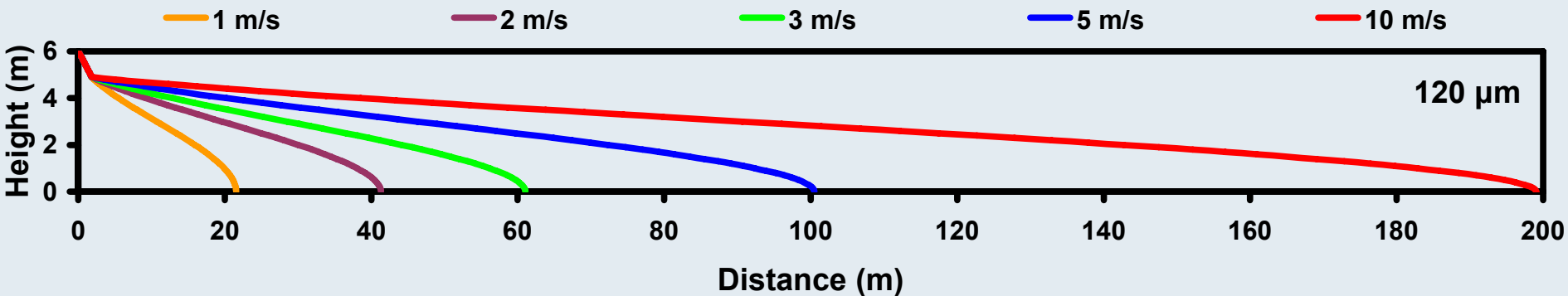
Results: Travel distances

- 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 (10 ms^{-1}), spray 10/16

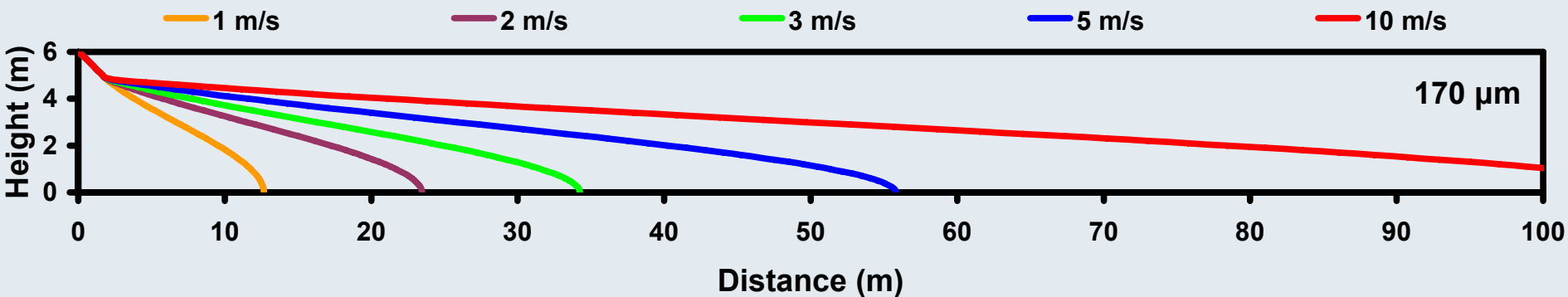


Results: Travel distances

- “Typical” larger droplet size:



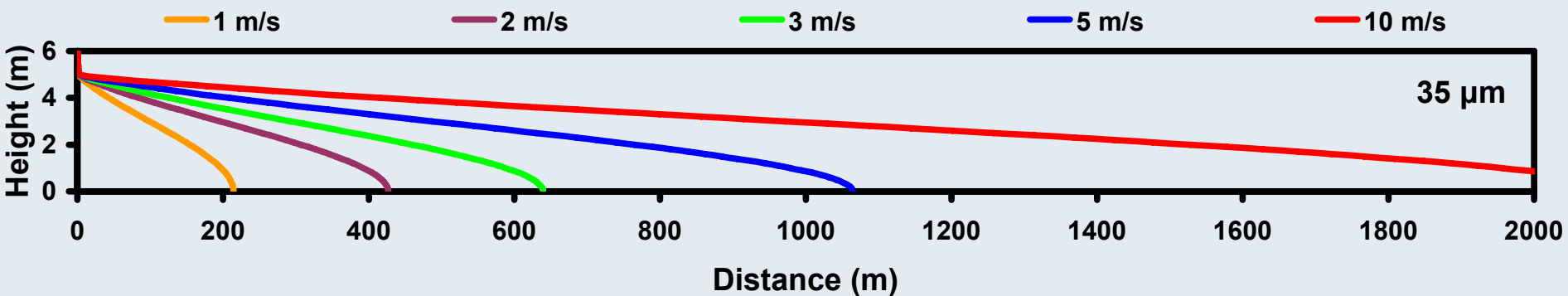
- Upper bound of droplet size:



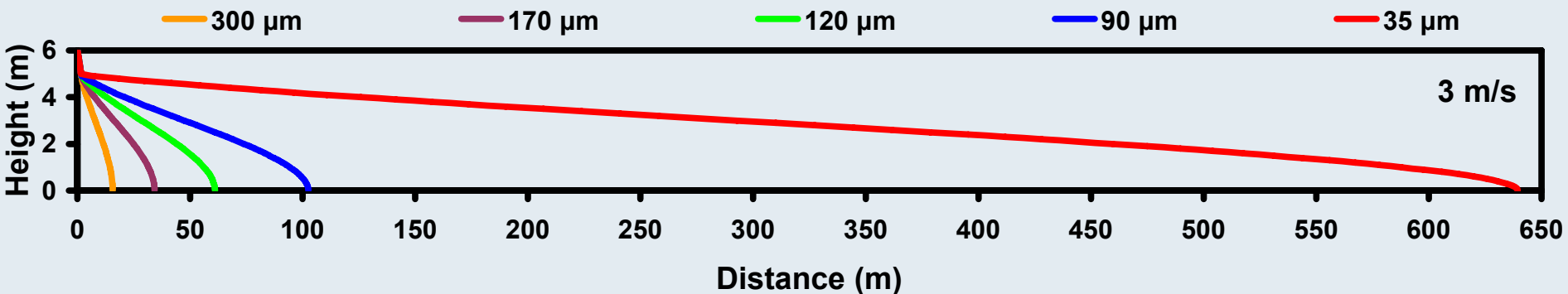


Results: Travel distances

- Lower bound of droplet size:



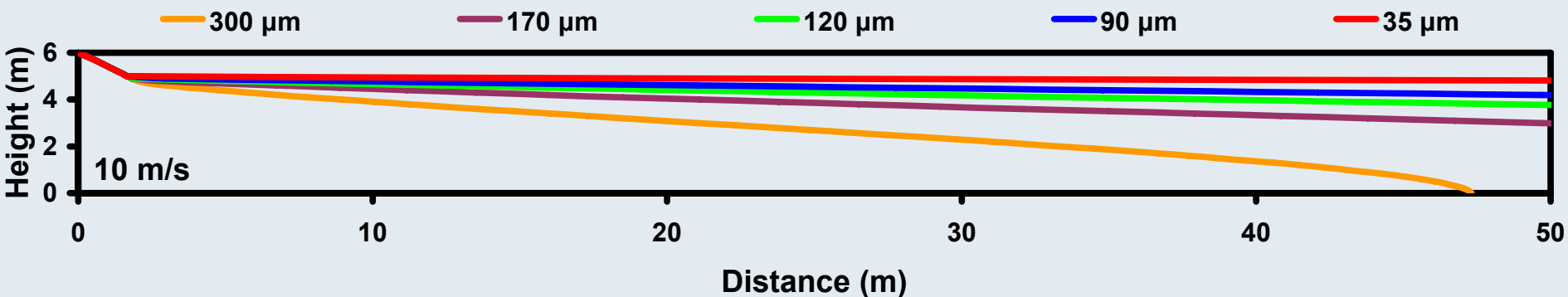
- All droplets at 3ms⁻¹:



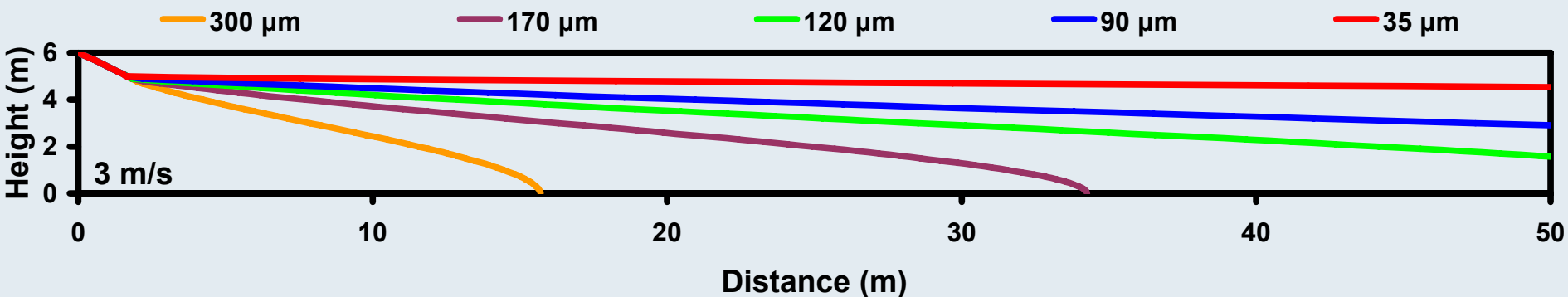


Results: Travel distances

- 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

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’?