# 3. IMPLICATIONS ON THE DESIGN FIRE OF THE SMOKE-MANAGEMENT SYSTEMS

## 3.1. GENERAL

PIARC report "*Fire and Smoke Control in Road Tunnels*" [7] provides extensive details on smoke management and PIARC report "*Road Tunnels: Operational Strategies for Emergency Ventilation*" [16] discusses different ventilation methodologies and operational strategies. The purpose of this chapter is to highlight the main ventilation factors in the context of design fire sizes. The prime purpose of a smoke management system is to provide tenable conditions for self-rescue without exacerbating the growth of the fire. Moreover, it is to be applied in the best possible manner to support rescue and fire-fighting.

## 3.2. LONGITUDINAL SMOKE MANAGEMENT

Longitudinal ventilation systems induce a longitudinal flow along the axis of the tunnel, and this provides an efficient smoke-management system as long as the tunnel is occupied only on one side of the fire, thus assuming that traffic downstream can proceed out of the tunnel. Smoke is blown toward the unoccupied side, so that egress can be carried out in the upwind direction. This is achieved when the longitudinal ventilation is conducted at a velocity of at least the critical velocity. Too low a velocity would result in smoke propagation upstream of the fire (i.e. back-layering).

As shown in *illustration 3*, see for example [17], the critical velocity increases rapidly with the fire size up to about 50 MW and then only increases slightly with increased heat-release rate. Consequently, for many standard tunnel applications, it may only require the provision of additional jet fans and hence there may be only a marginal increase in the capital costs required to provide for an increase in the longitudinal velocity and hence accommodate a larger fire size. Other impacts on ventilation of larger design fires were discussed in the PIARC report "*Systems and Equipment for Fire and Smoke Control in Road Tunnels*" [1].

Tests have shown that the fire-growth rate is proportional to the longitudinal air velocity (see *appendix 2* and *illustration A2.10*) and that the maximum HRR also increases with longitudinal air speed. These effects need to be considered in the design and operation of such systems: see for example reference [16].

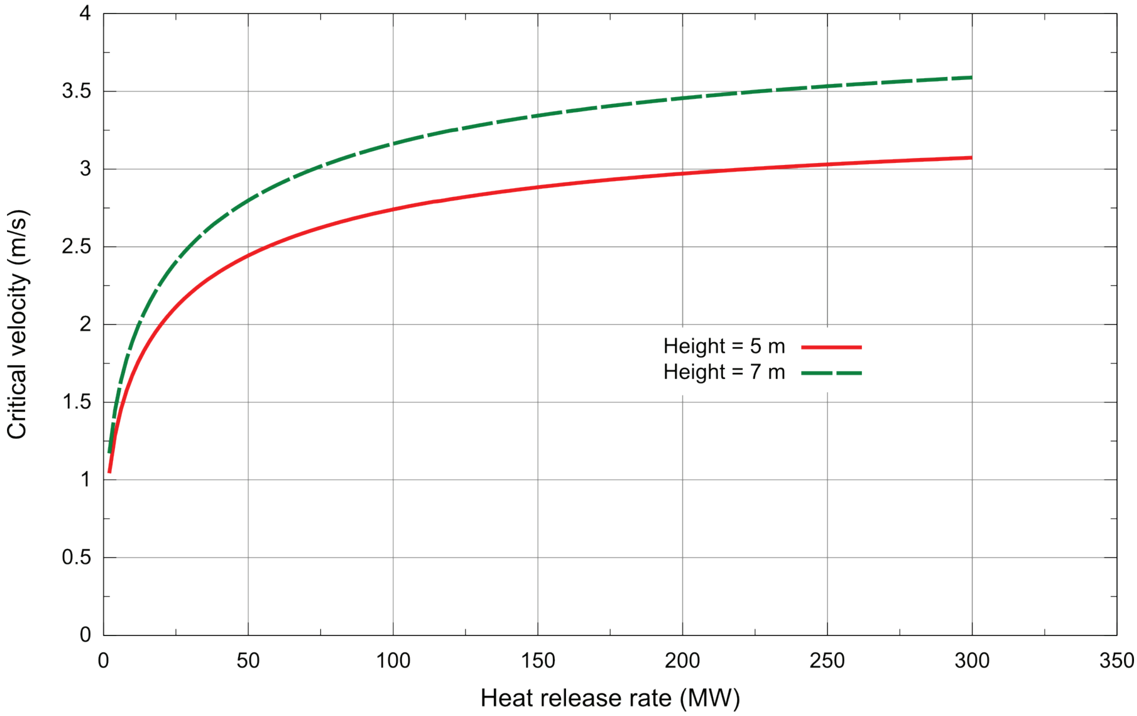


*Illustration 3 - Example of the critical velocity as a function of heat-release rate and tunnel height*

### 3.3. SMOKE EXTRACTION

Recent developments in semi-transverse smoke extraction aim at limiting the smoke spread on both sides of the fire. This enables egress away from the fire on either side. This method is essential in case of rescue from a fire in a tunnel with bi-directional traffic or traffic congestion. Some systems employ remotely controlled dampers that enable point extraction of smoke near to the fire. The construction costs for an extract system are higher than for longitudinal systems and since the required duct size increases with the heat-release rate, a larger design fire has an impact on the resulting investment costs.

The actual value for the extraction rate must consider the smoke production rate and the need for the aerodynamic management of smoke in the traffic space. Sufficient air needs to be provided in the direction of the extraction point (both upstream and downstream) to control the smoke flow and maximize the extraction efficiency. Traditionally, the dimensioning of the smoke extraction was about 150% of the smoke-production rate of the design fire, defined at a distance of 100 m from the fire (see reference [4]). This can be considered as the minimum smoke-extraction rate. Additionally, aerodynamic considerations for the management of the smoke in the traffic space apply. Taking the accuracy of the control of the longitudinal flow into account, this leads to a typical extraction rate of 2,5 to 4 times the tunnel cross section.

Ideally, the extraction system should cause air to flow in the traffic space, towards the fire on both sides, as shown in *illustration 3.2*, at a velocity proportional to the critical velocity modified by the fire heat content extracted. This confines the smoke region and increases the efficiency of extraction. Although increasing the fire size increases the extraction rate, in order to provide the amount of air required on both sides of the fire, the variation of critical velocity with fire size indicates that the requirement for extraction flow would not increase excessively for larger fire sizes. Note, however, where the extraction point is a long distance away from the smoke front, the fresh air velocity may need to be equal to the critical velocity.

*Illustration 4 - Principle of confinement*

The factors that affect the longitudinal velocity in the tunnel, such as buoyancy forces and the flow due to differences in ambient pressures at the portals, also influence smoke extraction efficiency, which deteriorates as the velocity increases. An increase in the design fire size makes this problem more severe, so it is essential to supplement the smoke extraction with a control of the longitudinal flow. Controlling the longitudinal velocity within a bandwidth of about ± 0.5 m/s is feasible but difficult.

Where the smoke-production rate exceeds the capacity of the smoke-extraction system, the action of the system still provides some improvement in the tenability conditions.