A 3D PARAMETRIC STUDY TO ASSESS THE IMPACT OF A FIXED FIRE FIGHTING SYSTEM ON THE EVACUATION CONDITIONS IN PARIS LA DÉFENSE ROAD TUNNELS

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ABSTRACT

Techniques and technologies that aimed at limiting the risks and consequences of fires in road tunnels are regularly developed and optimized. In this context, Fixed Fire Fighting Systems are increasingly seen as a method capable of ensuring user safety and infrastructure protection.

The objective of the study presented in the paper is to evaluate in a parametric and comparative manner the influence of Fixed Fire Fighting Systems in Paris la Défense tunnels, on environmental conditions encountered by the users during their evacuation. One of the subjects is also to ensure their compatibility with other safety provisions such as the emergency ventilation system.

For this, a 3D CFD prototype representing a generic section of Paris la Défense tunnels has been developed. Several scenarios are carried out to take into account different structure geometries, different configurations of smoke extraction principles (longitudinal, transverse or natural), different types of fire size, different configurations of sprinkler systems as well as different initial longitudinal air speeds in the tunnel.

A conclusion is then drawn based on a qualitative multicriteria analysis including the sensitivity of the parameters studied on the evacuation conditions of users, distinguishing the zone close to the fire (zone of action of the sprinklers) from the zone further away.

Keywords: Fixed Fire Fighting Systems, Tunnels, Ventilation, Evacuation.

1. INTRODUCTION

Major fires in road tunnels have significant consequences for users, tunnel infrastructure, and, on a larger scale, the road network. Techniques and technologies aimed at limiting the risks and consequences of fires in road tunnels are regularly developed and optimized.

Fixed Fire Fighting Systems (FFFS) are increasingly considered as a method capable of ensuring the safety of users and the protection of infrastructure and can be used as a risk reduction measure. However, their use is not widespread for various technical, economic, political, and social reasons. FFFS may not necessarily be the most appropriate measure to adopt in all circumstances or locations.

The given study is an excerpt from a larger comparative study assessing the impact of sprinkler systems on the evacuation conditions of users for different smoke extraction ventilation configurations, different structure geometries, different types of fire sources, and different sprinkler system configurations.

The main objective was to characterize the influence of existing and projected sprinkler systems in the tunnels of PARIS LA DEFENSE on the ambient conditions experienced by people during their evacuation, to ensure their compatibility with other safety provisions such as smoke extraction or the position of emergency exits.

2. SIMULATION ASSUMPTIONS

2.1. Modelling softwares

Simulations are carried out with:

- 3D-type calculations to model the three-dimensional effects of smoke propagation and the effects of sprinkling on these smokes in relation to evacuation conditions. These simulations are carried out using FDS software (version 6).
- 1D-type calculations to calibrate the boundary conditions of 3D models. These calculations are performed using CAMATT2 software (distributed by CETU) to determine the intensity and direction of longitudinal air velocity in an unmeshed network.

2.2. Evacuation simulations

The evacuation simulations are carried out using a specific tool developed by EGIS Tunnels to meet the requirements of [3].

2.3. Geometrical assumptions

The study entrusted to EGIS aimed to comparatively assess the impact of Fixed Firefighting Systems (FFFS) on the evacuation of people in a tunnel section representative of several tunnels in PARIS LA DEFENSE. Consequently, certain elements such as road infrastructure (sidewalks, barriers) or the tunnel slope were not considered in the modeling, as they would provide specific results for a limited linear section of the tunnel.

Thus, a model aimed to simulate a long section of approximately 400 m of a tunnel in PARIS LA DEFENSE called the "Sculptors' Lane".

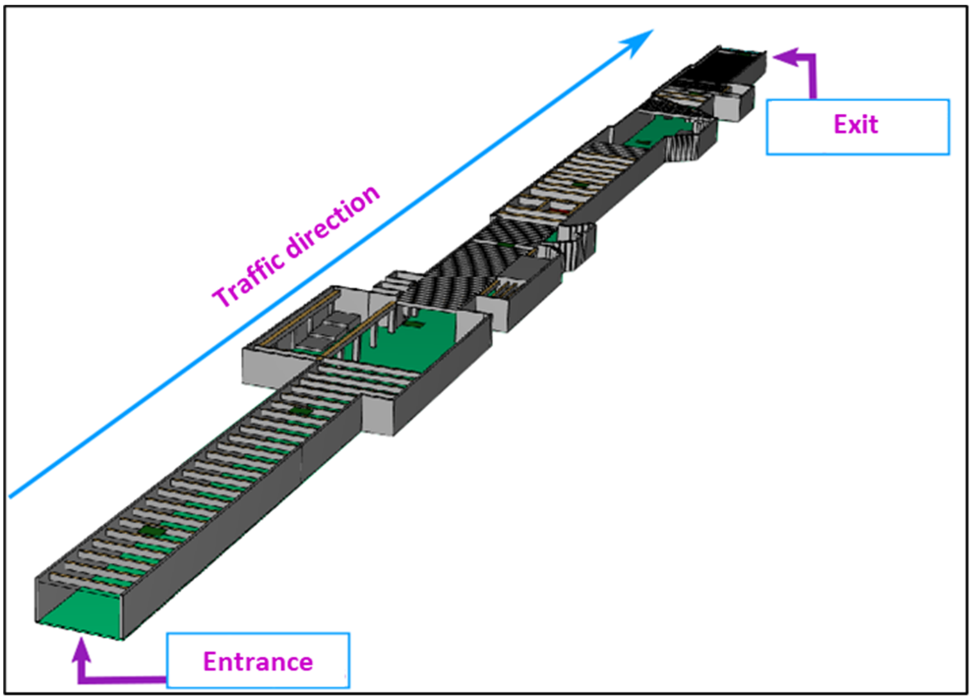

Figure 1: FDS model of the tunnel

2.4. Fire assumptions

The majority of tunnels in PARIS LA DEFENSE being restricted to vehicles weighing less than 19-ton, the ignition sources for various scenarios in this study were based on a 19-ton heavy goods vehicle (HGV).

A third-party provider commissioned by PARIS LA DEFENSE was tasked with defining the mitigation of a Fixed Fire Fighting System (FFFS) on the fire power of a 19-ton HGV.

Three types of fire sources were deemed relevant: an unmitigated source reaching 37 MW in 300s (“Scenario 1”); a mitigated source from a covered fire reaching 35 MW in 300s (“Scenario 2”); and a mitigated source from an open fire depending on the activation time of SFLIs, reaching 5,7 MW in 50s (not part of this paper).

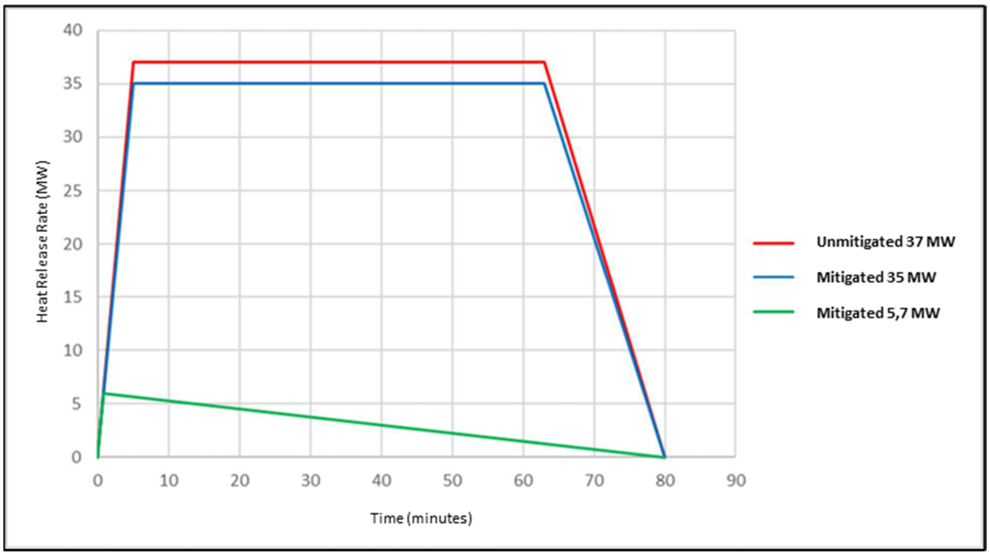

Figure 2: Heat Release Rate of fire sources

The choice of modeling the fire in the FDS software was as follows:

1) A prescribed pyrolysis model of HRRPUA type (Heat Release Rate Per Unit Area).
2) A "Simple Chemistry" combustion model, with a reactant of type $C_xH_yO_z$

The chemical reaction used for the fire was calibrated according to the production rates defined by [3].

2.5. Traffic assumptions

The low number and speed of vehicles in the structures of Paris La Défense lead to the consideration that the piston effect they generate is negligible. The traffic assumptions taken into account are 9 cars stopped upstream of the fire and 2 cars stopped downstream of it (calculated based on an average daily flow).

2.6. Aerodynamic assumptions

2.6.1. Wind effects

No counter-pressure related to the effects of external wind was taken into account in this simulation.

2.6.2. Initial air velocity

The studied tunnel having low traffic flow (2200 vehicles per day), the initial speed criterion of the air was not considered as an essential parameter for this study.

2.7. Smoke extraction assumptions

Transverse ventilation strategy is used in the tunnel. The extraction flow rate of the tunnel was set in accordance with the current French tunnel regulations [2]:

$$Q_{ext} = 80\ m^3/s + 1{,}5 \times S_{tun}$$

As the cross-sectional area of the tunnel is variable, the chosen reference section S_{tun} [m²] is the one located at the fire, which is 60,75 m². Therefore, the total smoke extraction flow rate has been set to **171** m³/s (distributed over 8 extraction points with a volumetric flow rate of 21,4 m³/s each).

2.8. FFFS assumptions

2.8.1. Characteristics of individual sprinkler

A third-party provider commissioned by PARIS LA DEFENSE recommended using a tunnel application rate of at least $10\ l/min/m^2$, with a sprinkler K factor of a minimum of $115 L/min/bar^{0,5}$ and an involved surface area of approximately 300 m², considering coverage over the entire width of the tunnel. These values have been chosen for the simulation.

The activation temperature of the sprinklers is set at 72°C with a response time index of 50 $\sqrt{(m.s)}$.

Regarding the 3D modeling, a conical-shaped spray filled entirely with water droplets was considered.

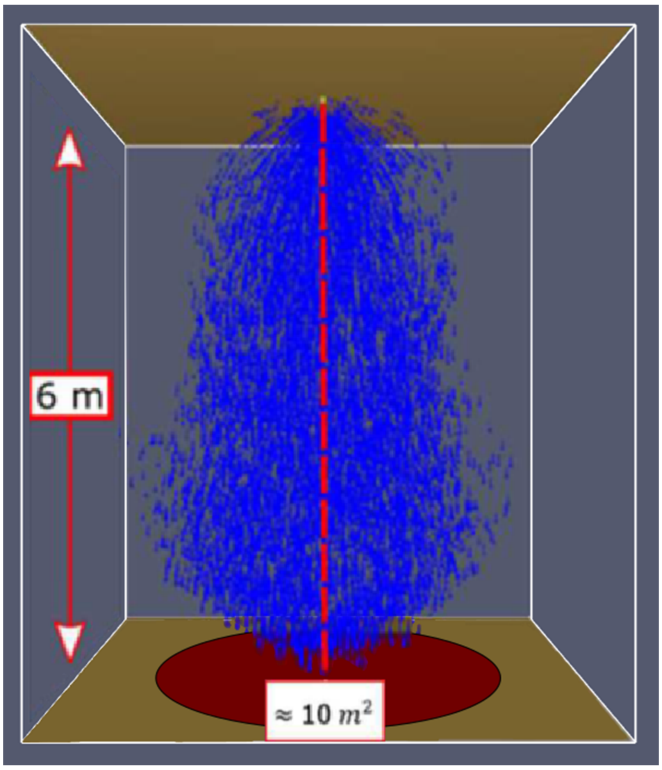

Figure 3: Individual coverage area of a single sprinkler

An individual coverage area at ground level of approximately 10 m² per sprinkler has been chosen for the entire tunnel. To achieve this :

- The two angles of the cone are set to 0° and 90°
- The discharge velocity of the droplets is set at $10\ m/s$

The operating pressure at the sprinkler head was calculated considering the formula:

$$Q = K \times \sqrt{P}\ [L/min]$$

where Q is the operating flow rate in m^3/s , K is the orifice coefficient (known as K-factor) in $L/min/bar^{0.5}$, and P is the operating pressure at the sprinkler nozzle head in bar.

The considered operating flow rate is derived from the pro-rata between the application rate imposed on each sprinkler ($L/min/m^2$) and the individual ground level coverage area ($10\ m^2$).

2.8.2. Positioning

The coverage of the modeled tunnel is ensured by 3 sprinkler heads (spaced 3.5m apart) on the transverse axis distributed throughout the entire length of the tunnel, totaling 328 sprinklers.

3. RESULTS

3.1. 3D Slice

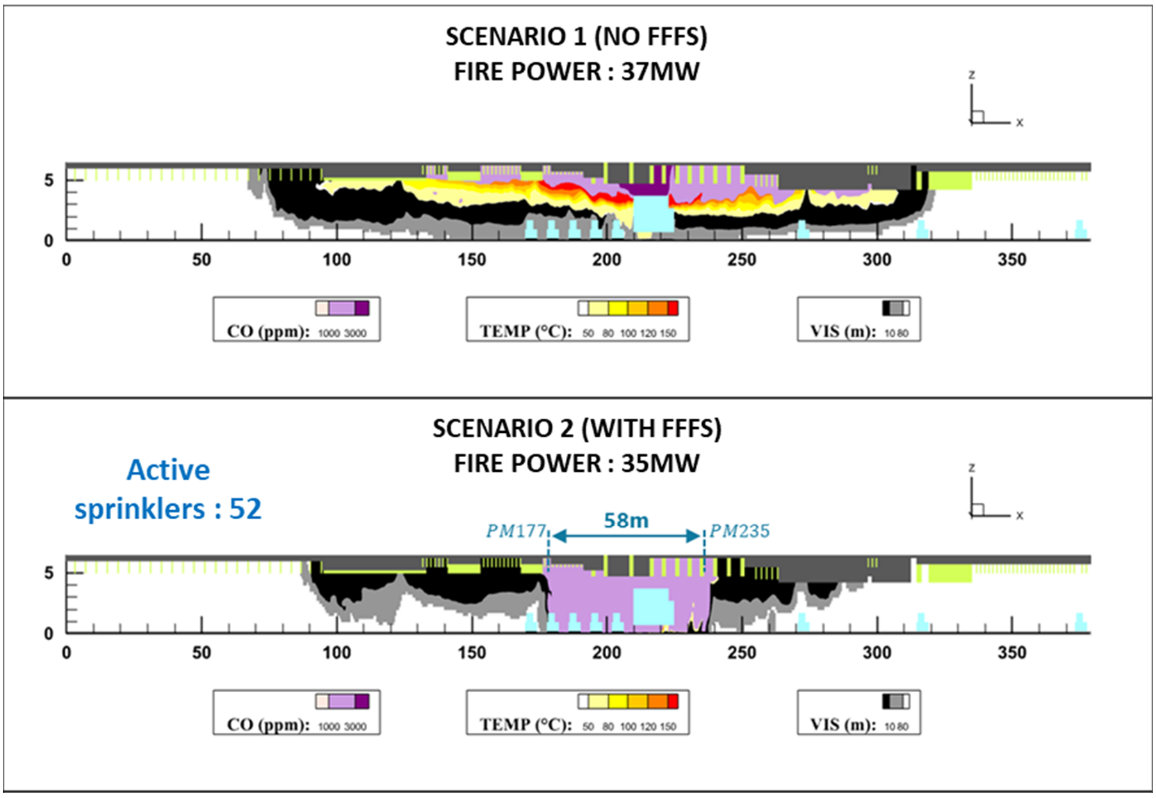

Figure 4: 3D Slice at simulation time = 600 s

The comparison between Scenario 1 and Scenario 2 revealed that the FFFS coverage area (58m at the end of the simulation, 52 active sprinklers) leads to significant degraded evacuation conditions. This is because the operating sprinklers induce smoke destratification through the entrainment effect of water droplets on the smoke layer. Consequently, the hot and toxic smoke in the upper part is destratified, increasing the CO concentration and temperature at human height while decreasing visibility.

Nevertheless, outside the SFLI coverage area, evacuation conditions are greatly improved.

The sprinklers' cooling effect also reduces the smoke propagation speed on both sides of the fire.

3.2. Space-time diagrams

The space-time diagrams below depict the state of the main section of "Voie des Sculpteurs" over time, at 1.80 meters above the ground, for the different studied scenarios. These scenarios are associated with evacuation diagrams highlighting the potential paths of individuals affected by the fire.

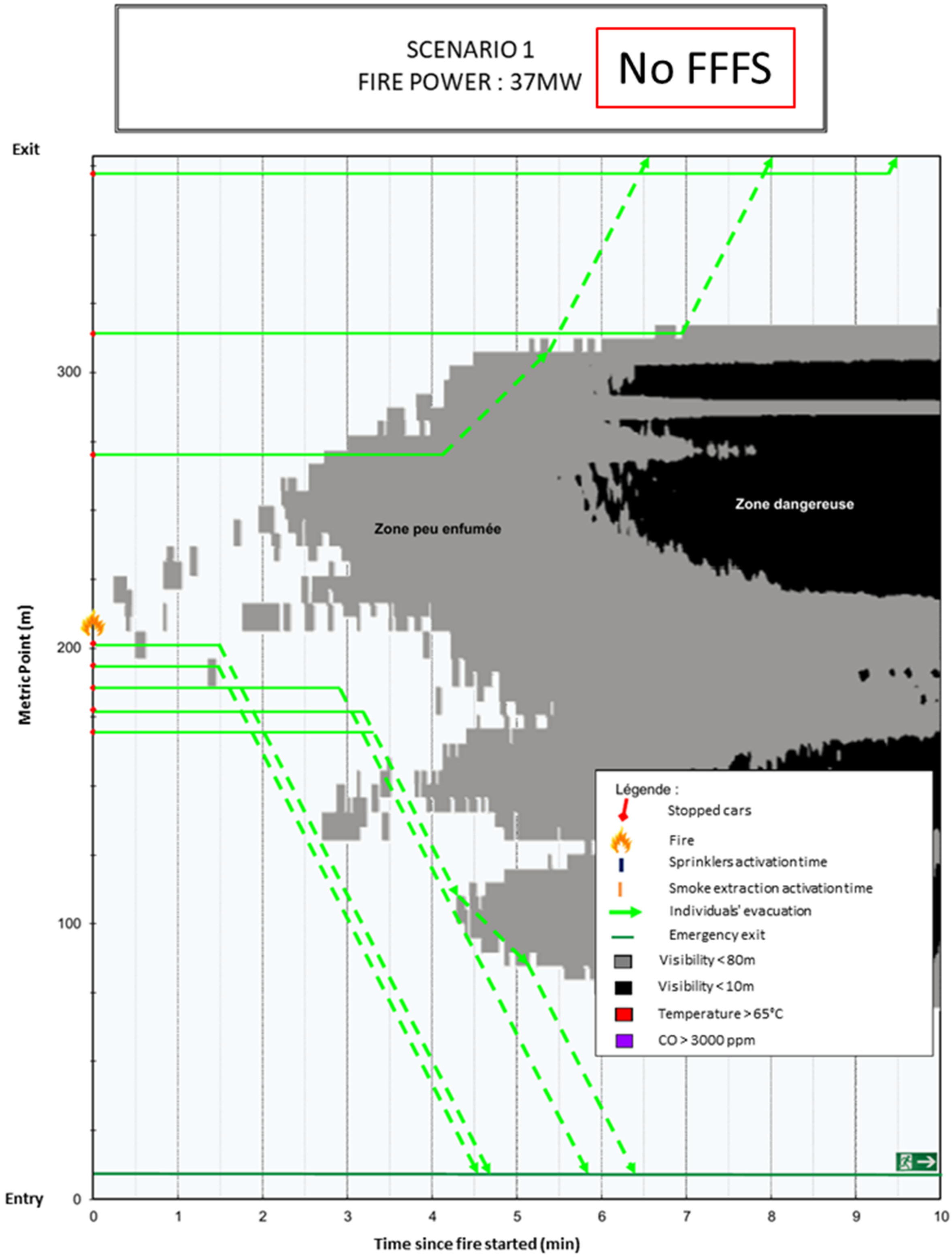

Figure 5: Space-time diagrams without FFFS

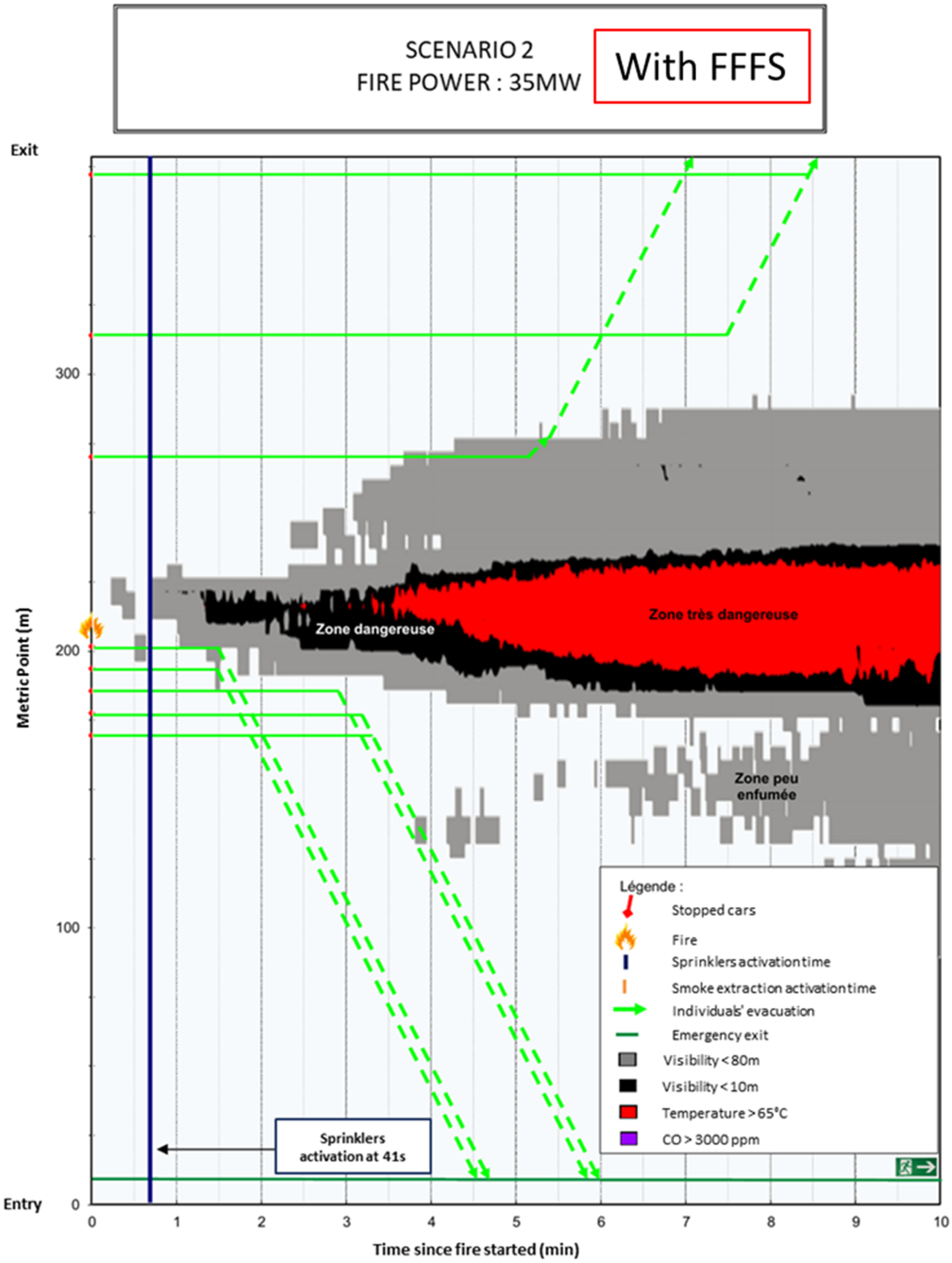

Figure 6: Space-time diagrams with FFFS

These graphs have revealed that the use of a Fixed Firef Fighting System does not worsen the evacuation of users within its coverage area as users close to the fire (within the coverage area) have sufficient time to evacuate through the emergency exits before the fire reaches high intensity.

Additionally, evacuation conditions outside this area are improved.

4. FFFS IMPACT EXTENDED STUDY

The present study was part of a larger comparative study aiming to highlight the impact of implementing a Fixed Fire Fighting System (FFFS) on the evacuation conditions of users. This was done for various smoke extraction ventilation configurations, different structure geometries, various fire scenarios, and diverse sprinkler system configurations.

In Table below is presented a multi-criteria summary making it possible to qualitatively evaluate the sensitivity of the parameters used in our study on the tenability criteria (Temperature, Radiation, CO concentration and Visibility) in the near focus zone or in the distant. In addition, a column is added to evaluate the evacuation conditions of users with the use of FFFS.

0 : the use of the FFFS could not highlight any change
+ : the tenability criterion concerned has improved
+ + : the tenability criterion concerned has been greatly improved
– : the tenability criterion concerned has deteriorated
– – : the tenability criterion concerned has been greatly degraded

Table 1: Summary on the tenability criteria and evacuation of users

		TENABILITY CRITERION				
Type of smoke extraction	**Area**	**VISIBILITY**	**TEMPERATURE**	**TOXICITY**	**RADIATION**	**EVACUATION OF USERS**
TRANSVERSAL	**CLOSE Sprinkled Area**	--	0	-	+	+
	DISTANT Non-Sprinkled Area	+	++	++	++	++
LONGITUDINAL	**CLOSE Sprinkled Area**	-	+	0	++	+
	DISTANT Non-Sprinkled Area	0	++	++	++	++
NATURAL (without ventilation)	**CLOSE Sprinkled Area**	-	+	-	+	+
	DISTANT Non-Sprinkled Area	+	++	++	++	++

5. REFERENCES

[1] Fire Dynamics Simulator_Technical Reference Guide_Volume 1: Mathematical Model
[2] IT n°2000-63 : Annexe 2 du 25 Août 2000 relative à la sécurité dans les tunnels du réseau national
[3] Guide ESD du CETu : Fascicule 4 : Les études spécifiques de danger
[4] 2nd International Symposium on Tunnel Safety and Security: Mars 2006

6. ACKNOWLEDGEMENT

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