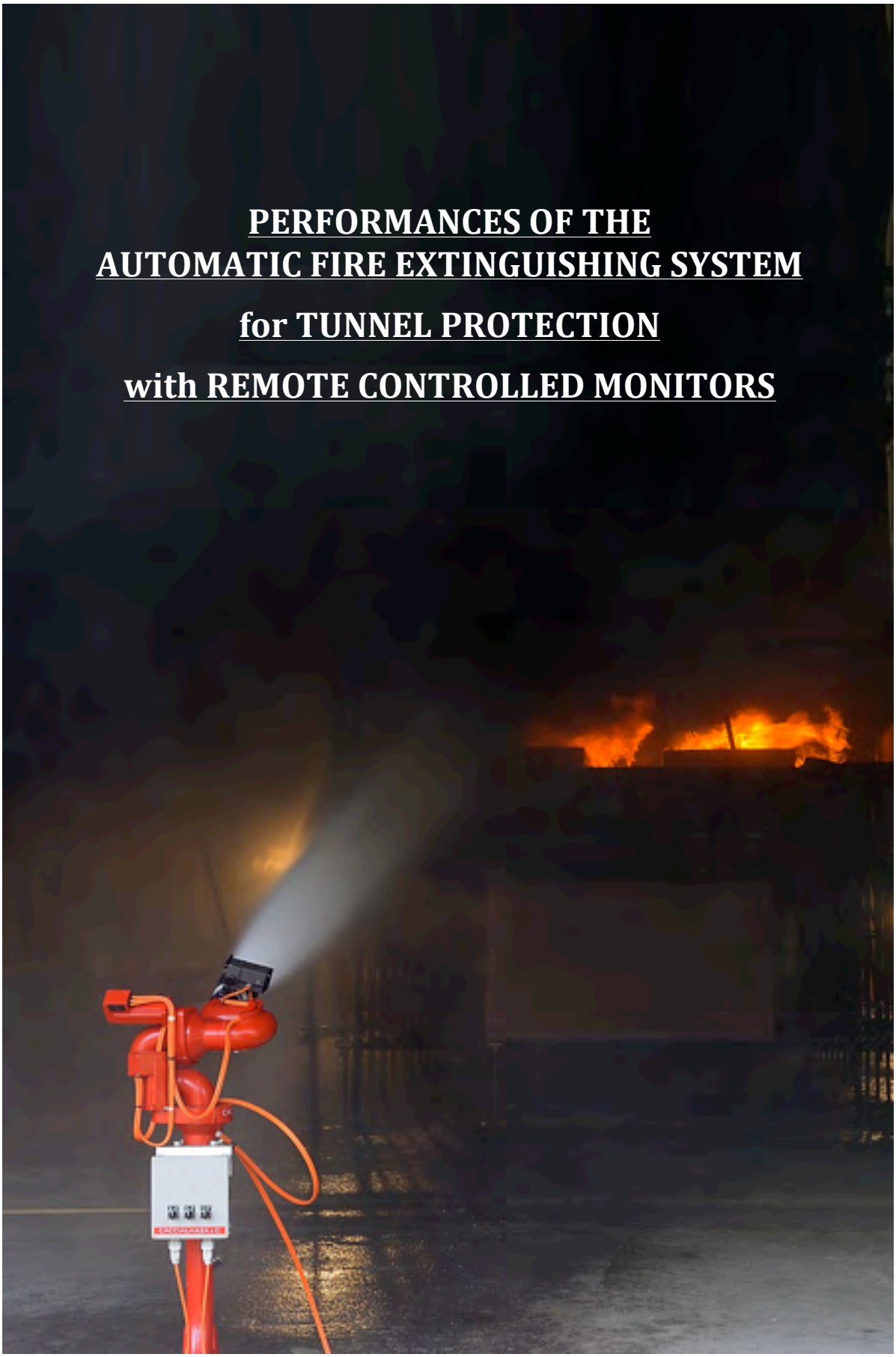
PERFORMANCES OF THE AUTOMATIC FIRE EXTINGUISHING SYSTEM for TUNNEL PROTECTION with REMOTE CONTROLLED MONITORS



General description of the system

The fire extinguishing system with remote controlled monitors represents the most efficient innovating tool provided nowadays by fire fighting technology to extinguish tunnel fires, for fully automatic / semiautomatic intervention or for remote operation from a remote Control Room.
The system is based on the proven technology of fire fighting remote controlled foam/water monitors, worldwide utilized and appreciated for the fire protection in heavy risk plants.
Monitors combine the fire extinguishing power of their water/foam jet with the utmost reliability of their operation, non toxic for people inside the tunnel.
Therefore, this system assures livable conditions inside the tunnel for all the time necessary for people to get to a safe area.
At the same time this system prevents from structural damages the fire may cause to the tunnel, with all the related economic and management advantages.
Using the results of mathematical simulations of the Fire Safety Engineering (F.S.E.) combined with evaluation of experimental data obtained by monitoring controlled fires in sample tunnels, it is possible to provide documentary evidence of the fire extinguishing efficiency in tunnels as well as of the capacity of assuring survival of people inside the tunnel.

Automatic fire extinguishing system with monitors

Description and technical data of the system

The standard version of the system consists of stations of intervention and control uniformly spaced along the tunnel at regular intervals of 42 m. Each station is equipped with a remote controlled monitor with flow rate 1.000 lt./min. with motor operated valve and protected by a cooling system, as well as with flame and temperature sensors.

The stations are interconnected to a main water / foam premix supply pipe at the pressure of about 10 bar.
At intervals of 250 m. (and however with optimized modularity considering the geometrical features of the tunnel) there are panels connecting the stations to an optical fiber bus for power supply. A similar redundant bus, always in optical fiber for power supply, ensures the interconnection of the panels as well as their connection to the control station.
The monitors are electrically remote controlled as for elevation and rotation, adjustment of the nozzle from full jet to fog jet, opening and closing of the integrated butterfly valve. Commands are sent to each monitor independently and selectively by means of a unique serial bus through a special flame resistant cable providing also power supply to the units.
Each station / monitor can be equipped with 2 IP / TV cameras for visible and infrared light pointed at both directions along the tunnel, flammable gas detectors and toxic gas detectors for monitoring dangerous situations.

Alternatively there is a version of the system with mobile remote controlled monitors on overhead trailer. This version consists in a fixed structure (overhead rail), installed at the ceiling along the tunnel, and in a number of mobile units (trailers) equipped with foam/water monitors moving along the fixed structure.

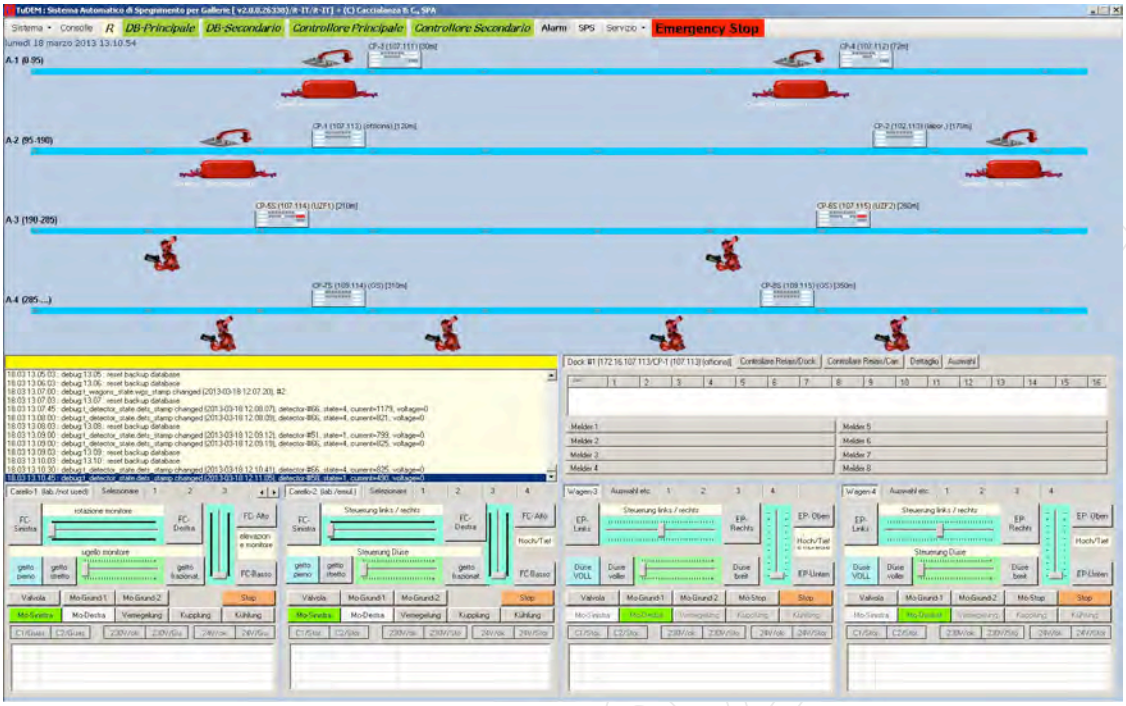
The fixed structure is equipped with the main water (or foam premix) supply pipe (working pressure ~10 bar).
In the same fixed structure are integrated the main electric power supply line and the serial bus for data transmission and it can also be equipped with the heat sensing cable and flame detectors for the fire detection.
At regular intervals (typically 42 meters) along the tunnel, docking and control stations are provided for stop and connection of the mobile units.
The docking and control stations are additionally equipped with the infrared flame detectors for the fire detection.
Each mobile unit (trailer) is equipped with 2 electric remote controlled fire fighting monitors with flow rate 1.000 lt./min., flame and temperature sensors, two IP / TV cameras for visible and infrared light, the motors for the linear movement of the unit along the rail and the electric panel with command and control devices.
In both versions the fire protection system is integrated with a water pressurizing unit and with a foam proportioning system, consisting of a pumping station (normally with electric pump and Diesel motor pump) and a displacement liquid foam proportioner.
Alternatively to the displacement liquid foam proportioning unit, a balance pressure foam proportioner with related foam concentrate pump can be used.

The dimensioning of the foam storage and proportioning system depends on tunnel length and features. Usually, for short and medium length tunnels, the same foam supply system can be used for the 2 barrel vaults of the tunnel or for 2 adjacent tunnels.
It is important to consider that in both versions of the proposed automatic extinguishing system with remote controlled monitors the extinguishing system with fire hydrant cabinets as required by law can be easily integrated.
The fire hydrant cabinets are directly connected to the monitors main water supply line with regular intervals of 126 or 252 meters (with a step multiple of the distance of the docking and control stations) and are usually equipped with a pressure reducing valve to reduce the water pressure at the manually operated branch pipes at about 4÷5 bar.
In this case the pumping station is additionally equipped with a jockey pump to maintain the main water supply line permanently at a pressure of 5 bar for the hydrant cabinets.

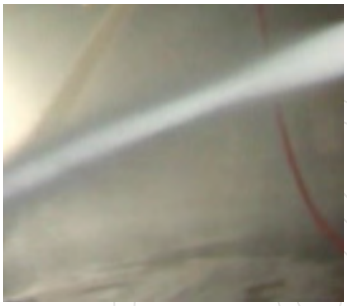
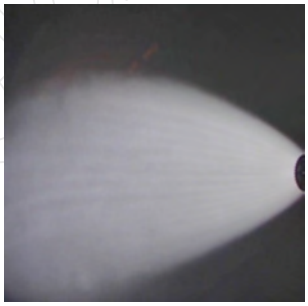
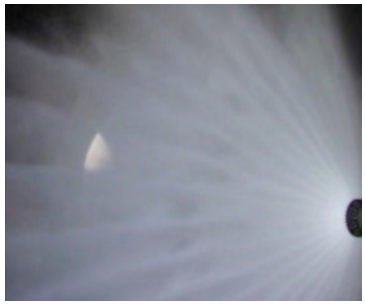
Automatic operation of the system

The automatic operation of the system is performed through a centralized main command and control panel installed in the Control Room of the tunnel or in any other technical room.

For the automatic intervention, the extinguishing system is combined with a double technology fire detection system with linear heat detectors and infrared flame detectors installed along the whole length of the tunnel.



In the system with mobile remote controlled monitors on overhead trailer, in case of detection of a fire, the two nearest mobile units with monitor (which, in stand-by condition, are positioned with constant step of about 800 m. along the tunnel) move along the rail and reach the docking and control stations closest to the fire zone.
The 2 monitors automatically connect to the main water (foam premix) supply line through a special patented coupling and start spraying water or foam with a step-less adjustable jet from full jet (for maximum throw and extinguishing power) to narrow cone and wide cone fog jet (for maximum cooling effect) as shown here below:

The connection of the mobile units to the coupling of the docking and control station automatically connect also the electric power supply and the data transmission between the mobile unit and the fixed system.
In case of longer tunnels with more than 2 mobile units, the two mobile units positioned immediately upstream and downstream the 2 units involved in the fire extinguishing intervention move to the next closer docking and control stations, connect to the feeding line and start spraying water with a wide cone fog jet (with spray angle 120°) with cooling effect to drop the temperature inside the tunnel and for containing the fire smoke. In the system with remote controlled fixed monitors uniformly spaced along the tunnel, the intervention procedure is exactly the same.

In this case, however, the monitors are fixed and uniformly installed with the required interval of 42 m. along the tunnel and therefore translation phase is not necessary. The fire detection system automatically selects the two monitors closest (upstream and downstream) to the fire and alarm area and starts the extinguishing intervention. Contemporarily, the two monitors positioned immediately upstream and downstream the 2 units involved in the fire extinguishing action are selected to start the operation with wide fog jet for cooling the heat and for containing the smoke of the fire. Obviously, all the other monitors are in stand-by and their on-off valves remain closed.

Semiautomatic operation of the system

In the semiautomatic operation the fire detection system does not control directly the extinguishing operations that start only if activated by the operator from the Control Room or from any other centralized remote control place. Optionally an additional logic automatic function can be added: if the operator does not **intervene**, after an acoustical and visual signal the extinguishing operations are anyway activated.

Manual remote control of the system with joy-sticks from the panel in the Control Room

From the main command and control panel in the Control Room it is possible to control the situation in the tunnel by means of high sensibility IP / TV cameras for visible and infrared light mounted on the mobile units or on each fixed monitor, and to operate the monitors from remote with the joy-stick controller, aiming the jet of the monitors exactly on the fire. This operation can be performed as final tuning of the automatic or semiautomatic intervention of the system or on autonomous decision of the operator in the Control Room.

In this case it is sufficient to click with the mouse the exact point on the screen where the extinguishing operation is required in order to activate immediately the positioning procedure of the mobile units and their connection to the water supply line and to the electric power and signal transmission line (version with remote controlled monitors on overhead trailer), or to activate immediately the automatic selection procedure of the involved monitors (standard version with remote controlled monitors uniformly spaced along the tunnel).

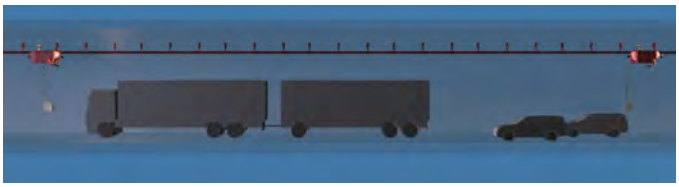
Local manual operation of the waistband radio control system

In order to optimize eventual extinguishing interventions by specialized operators and by the Fire Brigades, in addition to the remote manual control from safe area, also a local control directly inside the tunnel is foreseen.

For this purpose is available a waistband radio control unit that enables manual selection of the required monitor and the manual direct control of its functions,
besides eventual local correction of extinguishing operations in progress that have been activated by the main control panel. Like for the remote control, the movement control is carried out by means of a precision joystick and the system status data are visualized through LEDs and LCD displays on the waistband unit.

Dimensioning logic of the system

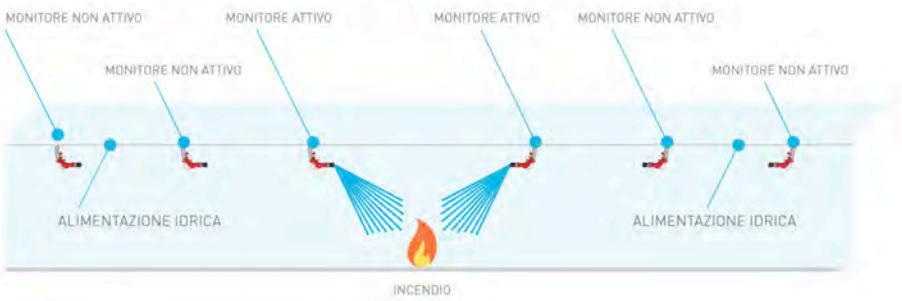
The dimensioning of the automatic fire extinguishing system with remote controlled monitors for tunnels protection has been designed to assure an intervention time of less than 4 minutes from the start of the fire to the beginning of the automatic extinguishing action. A time of less than 2 minutes is considered for the fire detection and the validation procedures.



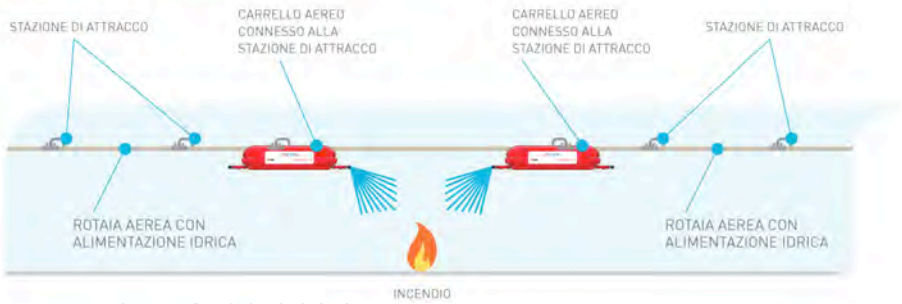
Only for the version with mobile remote controlled monitors on overhead trailer, the translation of the mobile units to reach the nearest docking station for connection to the water feeding line and start automatically the extinguishing operation requires about 1 minute.

The translation speed of the mobile unit along the overhead rail is ≥ 10 m./sec. The mutual distance of the single mobile units (trailer with monitor) in "stand-by" condition (when not working) is ≥ 500 m. up to 1 km (typical step 800 m.). In less than 1 minute the monitors are activated and positioned and the extinguishing operation can start. In case of remote joy-stick operation of the system directly from the operator in the Control Room, the time of intervention can be further reduced.

SOLUTION 1: UNIFORMLY SPACED MONITORS



SOLUTION 2: MONITORS ON OVERHEAD RAIL



Indeed, when the operator in the local or remote Control Room individuates a fire, he can immediately activate the extinguishing procedure (eliminating the time of automatic fire detection and validation), starting the extinguishing operation in less than 2 minutes. The same happens if the operator decides to activate the extinguishing operation based on an alarm from a single fire detector, after checking the situation via the IP / TV cameras for visible and infrared light, without waiting for the redundant signal of the heat sensing cable (which is normally slower).

Structure of the system (uniformly spaced monitors)

The main water (or foam premix) supply pipe is installed in elevated position at the wall along the tunnel, equipped with the main electric power supply line and the serial bus for data transmission.

Both the main electric power supply and the data transmission are carried out with a loop.
The intervention and control stations are mounted along the tunnel with a typical spacing of 42 m.
The below picture shows the panel that supervises all the functions and is installed with regular intervals of about 250 m.
Connection of monitors and flame / temperature sensors of each intervention and control station to the related panel is performed by means of an optical fiber bus and an electric power supply cable, both with a protective flame resistant sheath.
If required, to the same panel can be connected also a fire detection system with heat sensing cable, where additional fixed monitoring cameras, both for visible and infrared light, oriented to the 2 directions of the tunnel, can be interfaced.

The monitors are dimensioned for a specific water / foam flow rate of 1.000 lt./min. each, and following much higher than the total specific flow rate of any mobile unit or fixed spray system normally used for extinguishing operations inside tunnels.
The total water discharge of the remote controlled monitors system is nevertheless similar to the flow rate required for other fixed spray systems for tunnel protection, however this system allows to concentrate the full available water or foam stream exactly where required on the fire, instead of dispersing the extinguishing agent flow rate with uniform distribution along longer sections of the tunnel.

Structure of the system (monitors on overhead rail)

An overhead rail (fixed structure) is installed at the ceiling along the tunnel, equipped with the main water (or foam premix) supply pipe, the main electric power supply line and the serial bus for data transmission as shown in the following picture.
Relevant for the system are the compact installation and the little space occupied along the tunnel vault. Along the tunnel with a typical spacing of 42 m. are mounted the docking and control stations that provide each mobile unit with water (or foam premix) supply and with electric power supply so that buffer batteries are automatically charged while the unit is connected in stand-by.
In addition to these fixed structures, the tunnel can be equipped also with wall mounted panels at regular intervals of 250 m. for connection to the fire detection system by means of heat sensing cable or flame sensors and to the monitoring cameras, both for visible and infrared light, oriented to the 2 directions of the tunnel. The mobile unit is equipped with 2 foam/water monitors (the biggest structure on the trailer) with flame and temperature sensors, with 2 IP /

TV cameras for visible and infrared light, and with the eventual

flammable gas detectors and toxic gas detectors. The monitor is also equipped with a remote controlled on-off valve for start or stop of the water or foam stream. The monitors are dimensioned for a specific water / foam flow rate of 1.000 lt./min. each, and following much higher than the total specific flow rate of any mobile unit or fixed spray system normally used for extinguishing operations inside tunnels. The total water discharge of the remote controlled monitors system is nevertheless similar to the flow rate required for other fixed spray systems for tunnel protection, however this system allows to concentrate the full available water or foam stream exactly where required on the fire, instead of dispersing the extinguishing agent flow rate with uniform distribution along longer sections of the tunnel.

System reliability

The world wide proven extinguishing capacity of the automatic fire fighting system with remote controlled monitors is combined with the highest reliability of its components, considering the particular conditions where the fire fighting intervention must be performed.

To assure the highest reliability, redundancy has been applied to all critical parts of the system, for which not only the best materials and components available on the market have been selected, but also the most updated and reliable technology of monitoring, communication and check procedures have been adopted.

In particular for the data transmission a TCP/IP system has been selected, in order to allow the direct use of already existing communication structures or future structures to be realized for the remote transmission of alarms, commands and controls to the centralized Control Rooms of the tunnel without additional costs.

The system is therefore designed to be redundant in all its features:

- extinguishing operation by means of 2 monitors on the 2 sides of the fire (1 monitor is sufficient for extinguishing the fire),
- the power supply of the docking and control stations is performed in a loop; therefore it is possible to supply separately and independently the two sides of any area involved in the fire,
- the data transmission (both via optical fibre and copper cable) is performed in a twin loop, separately and independently for the two sides of any area involved in the fire.

The extinguishing operation can work continuously without time limitation, as there are no components or resources of the system subject to exhaustion.

Easy system installation

The automatic fire extinguishing system with remote controlled monitors for tunnels protection can be easily installed in new or in existing tunnels, without need to stop the tunnel traffic during the installation works of the system.

It can be installed in motorway tunnels, railway tunnels and in underground lines.

Scenarios of Tunnel Fires

Scenario 1

The construction logic of mathematical model of the tunnel aims at the optimization of the simulation and, therefore, of the result calculation time without introducing simplifying hypotheses that might lead to less reliable results.
The examined tunnel can represent, thanks to its geometrical features, both a road and a motorway connection. In order to make dissertation easier, the tunnel is considered straight, even, 1.000 m. long, 10 m. wide and max. 7 m. high. The fire is supposed to develop in the middle of the tunnel.
The examined fire is of considerable seriousness and caused by an articulated lorry with a load that can develop a fire of the overall power of 80 MW.
The mathematical model for calculation is applied to a 100 m. tunnel segment, simmetrically located with respect to the fire ignition point.
In case of fire simulation in a tunnel with ventilation, the forced ventilation system is supposed to be always present and in operation with constant speed also during the fire. In case of forced ventilation, air speed is supposed to be 3 m./sec., in order to consider also that ventilation might be increased in case of fire, as foreseen nowadays in many tunnels.
For each scenario virtual probes have been used to determine heat and smoke effects as for Time-Temperature curve (analysis of the post-flashover for evaluation of the structure fire resistance) and visibility (analysis of the pre-flashover for evaluation of the height free from smoke and, consequently, of the conditions of a safe evacuation). In addition, possible evacuation of people inside the tunnel has been evaluated. Besides fire fighting devices required by regulations (i.e. hydrants), the tunnel is supposed to be equipped also with a remote controlled monitors system for automatic or semiautomatic remote controlled intervention.
This scenario foresees two monitors, one upstream and the other one downstream the fire, 42 m. far from each other, with a flowrate of 1.000 lt./min., each with a pressure of 8 bar at nozzle. The hydrants, 150 m. far from one another, are part of the extinguishing system with monitors and are fed by the same loop. Hydrants can be used by rescuers upon their arrival, while the remote controlled monitors system is supposed to be activated only 4 minutes after the fire beginning.

Scenario 2

The tunnel is supposed to be equipped only with the extinguishing devices required by Italian Dlgs. 264/2006.
In particular, hydrants are supposed to be placed along the entire tunnel, at regular intervals of 150 m. (this condition is stricter than what regulations require, but is in line with technical requirements of many Motorway Management Companies).
Hydrants are supposed to be connected in a loop and fed by a pumping station ensuring a flowrate of 600 lt./min. at a min. pressure of 4 bar. Extinguishing intervention is carried out by the Fire Brigades that get to the tunnel after the call.
Like in the previous scenario, fire fighting squads are supposed to be equipped with all the individual protection devices; therefore, rescuers are always able to resist to a temperature lower than 100°C and to smoke/toxic gas concentrations that decrease visibility to a value of 2 m. Consequently in this scenario fixed extinguishing devices are used by rescue squads.
As for rescue squads intervention time, Fire Brigades are supposed to start their extinguishing operations within 20 minutes after the fire beginning. Of course these times refer to an ideal, very optimistic condition.

Fire simulation

FDS (Fire Dymamics Simulator) has been developed by NIST (National Institute of Standards and Technology). The model is a CFD (Computational Fluid Dynamics), i.e. a computational fluid dynamics model of fire-driven fluid flow. FDS solves numerically a form of the Navier-Stokes equations appropriate for low-speed flow, with an emphasis on smoke and heat transport from fires. Smokeview is the visualization program that can be used to display the output of FDS.
FDS and Smokeview were released in 2000. During NIST investigations of the World Trade Center collapse it became clear that FDS needed to be completed in order to be an efficient tool for fire reconstruction. In 2005 FDS was considerably revised and was developed the new version 5 that increases the model flexibility and functionality. FDS code is universally known and appreciated thanks to the applications related to Fire Safety Engineering (FSE).

Evacuation simulation

The model used is EVAC by VTT (Technical Research Centre of Finland), distributed by NIST. This model is able to follow the behaviour of each single agent of the simulation depending on fire evolution and production of combustion products such as smoke, CO and CO2, calculated by FDS. The two models, FDS and EVAC, work together in the same calculation session.
The agents movement model is behavioural, i.e. it takes into account actions performed by people together with their movement towards one of the exits. The model enables also to assign a statistical distribution not only of times of detection, pre-movement, evacuation speed depending on the agent type chosen by the user, but also of the effects of some combustion products by means of FED (Fractional Effective Dose) calculation.

Computers used for calculation

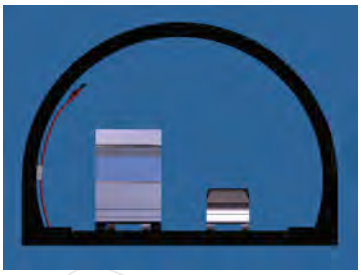
Computers with Intel Core i-7-930 processor with clock speed of 2.8 GHz have been used for calculation.
The above processor, based on Intel Bloomfield architecture and built with 45nm lithographic process, with 731 million transistors in total, consists of 4 cores able to process at the same time up to 8 threads thanks to Hyper-Threading technology and benefits from a second level chache memory in common with the 8 MB cores. Connection to motherboard is realized by means of a FCLGA 1366 socket integrating a BUS QPI towards 4.8 billion tranfers/sec. system peripherals and 3 communication channels towards as many memory banks.
Therefore, computers have been equipped with 12 GB of DDR3 RAM 1600 MHz, equally distributed on the 3 communication channels in order to maximize exploitation of processor standard band 25.6 GB/s.
Video section is based on a OpenGL compatible graphic card with 1GB video memory GDDR3.
The operating system Windows 7, 64 bit version, enables software to fully use hardware resources of these computers.
The above version not only exceeds the standard 3GB of RAM of the 32 bit systems, but also uses the 64 bits of the CPU internal parallelism (latest generation Intel platforms).

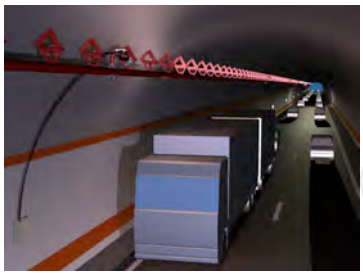
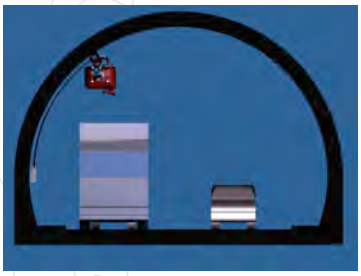
Results Visualization

Test environment

The tunnel enviromental conditions during the 4 tests are always the same, except for the presence or absence of the forced venting system in operation and, therefore, the presence or absence of the fire extinguishing system with remote controlled monitors.
The remote controlled monitors (if present) can be both in fixed distributed version and, alternatively, in mobile version on overhead rail, without any change in the results. In fact the extinguishing performances of the two above versions are the same.
The 2 series of pictures below show the 2 typical layouts for the test tunnel.





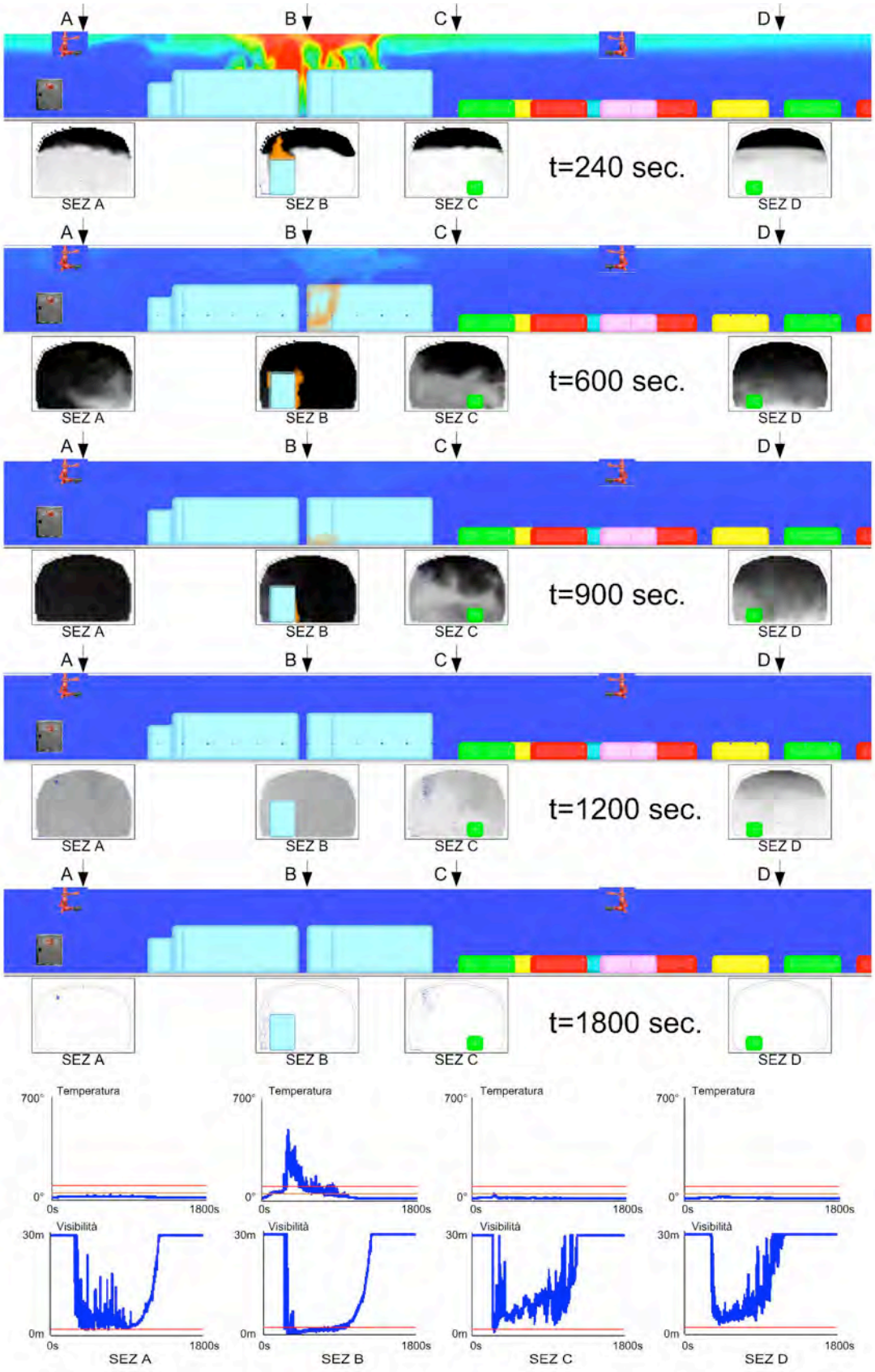
Results of the simulation without venting

Simulation results for scenario 1 (monitors installed in the tunnel) and for scenario 2 (only hydrant fire boxes installed in the tunnel) are reported on pages 12 and 13.
The simulation lasts 30 minutes (1.800 seconds) and are shown the results of the following times: 241, 600, 900, 1.200 and 1.800 seconds.
In case 1 monitors are automatically activated after 4 minutes (240 seconds), while the hydrants are activated after 20 minutes (1.200 seconds), expected time of arrival of the Fire Brigades. Obviously results before activation of the monitors are the same in both cases.
For each considered time are reported not only the tunnel longitudinal section, but also 4 cross sections with different distance from the fire ignition point. In addition, are reported the trend of the HRR curve for the 2 scenarios and the trend of temperature curves at 18 m. and 60 m. from the fire ignition point (always at the same time for both scenarios).

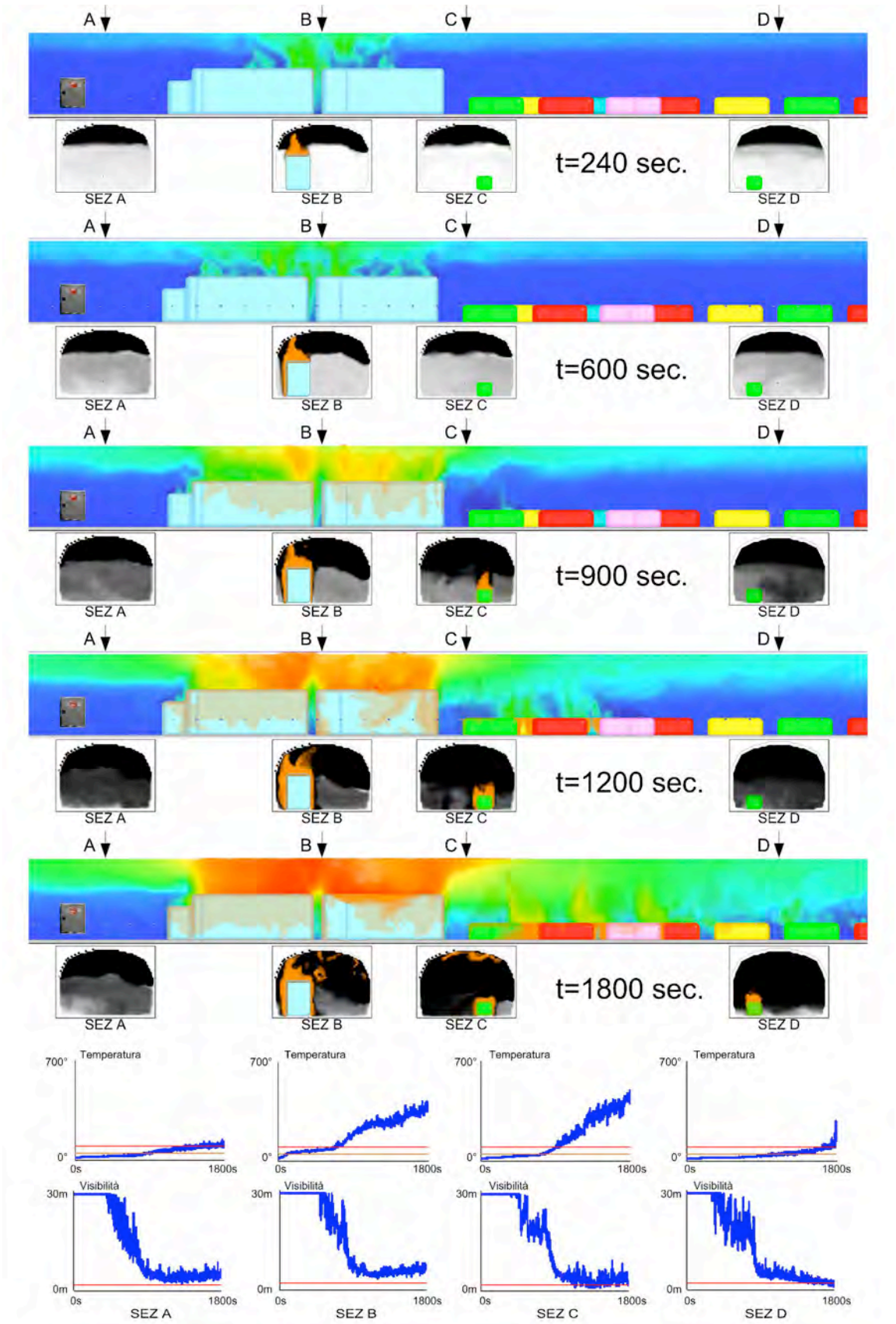
Results of the simulation with forced venting

Also in this case simulation results for scenario 1 (monitors installed in the tunnel) and for scenario 2 (only hydrant fire boxes installed in the tunnel) are reported on pages 14 and 15.
The simulation lasts always 30 minutes (1.800 seconds) and, in order to have an exact comparison, are shown the results of the same times of the previous simulation (241, 600, 900, 1.200 and 1.800 seconds).
Also the activation times of the monitors in case 1 and of the hydrants in case 2 are the same (therefore, 4 minutes and 20 minutes respectively). For each time are reported not only the tunnel longitudinal section, but also 4 cross sections with different distance from the fire ignition point. In addition, are reported the trend of the HRR curve for the 2 scenarios and the trend of temperature curves at the same distances from the fire ignition point as above indicated for both scenarios.

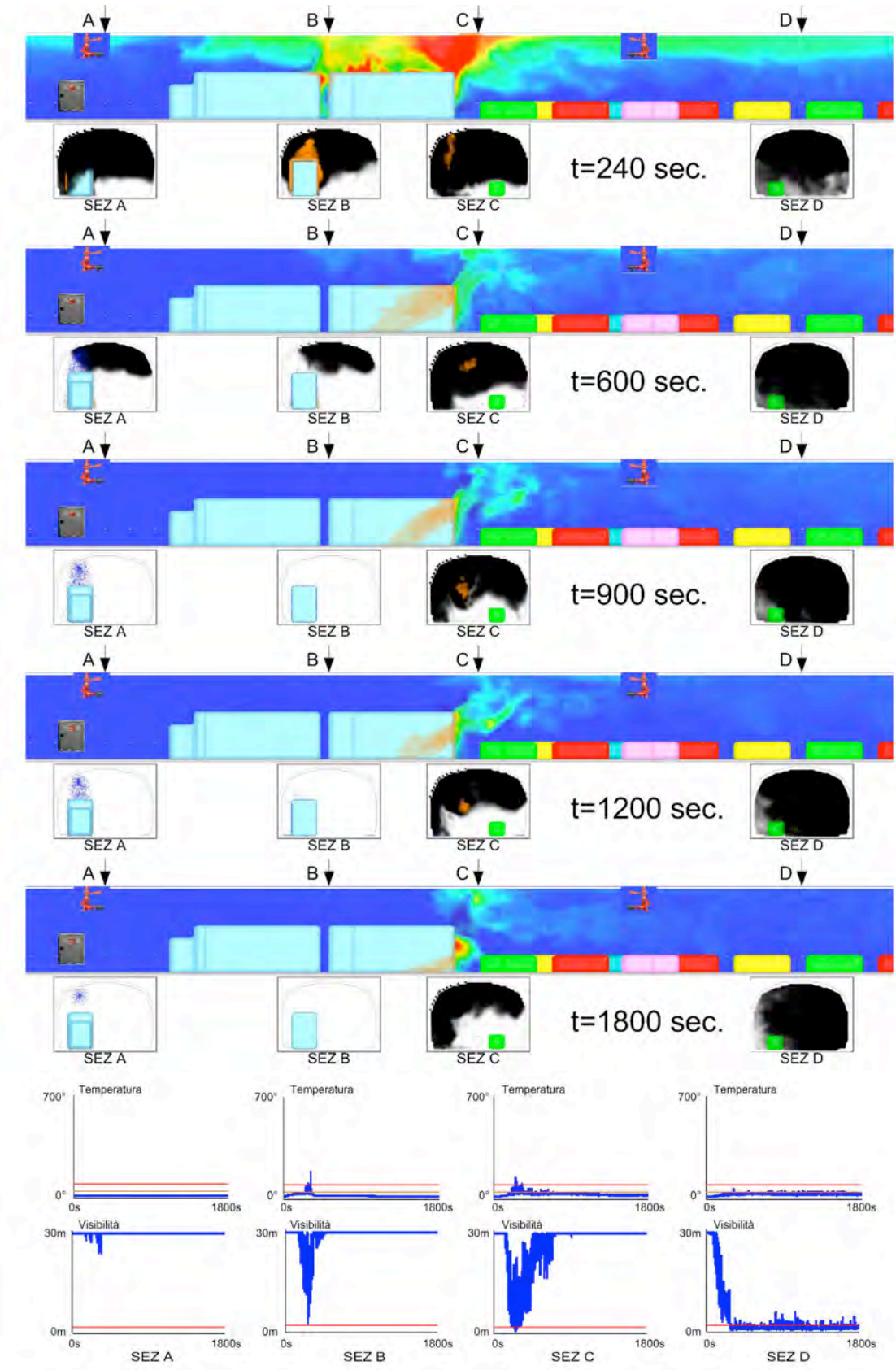
Fire in tunnel equipped with monitors without forced venting



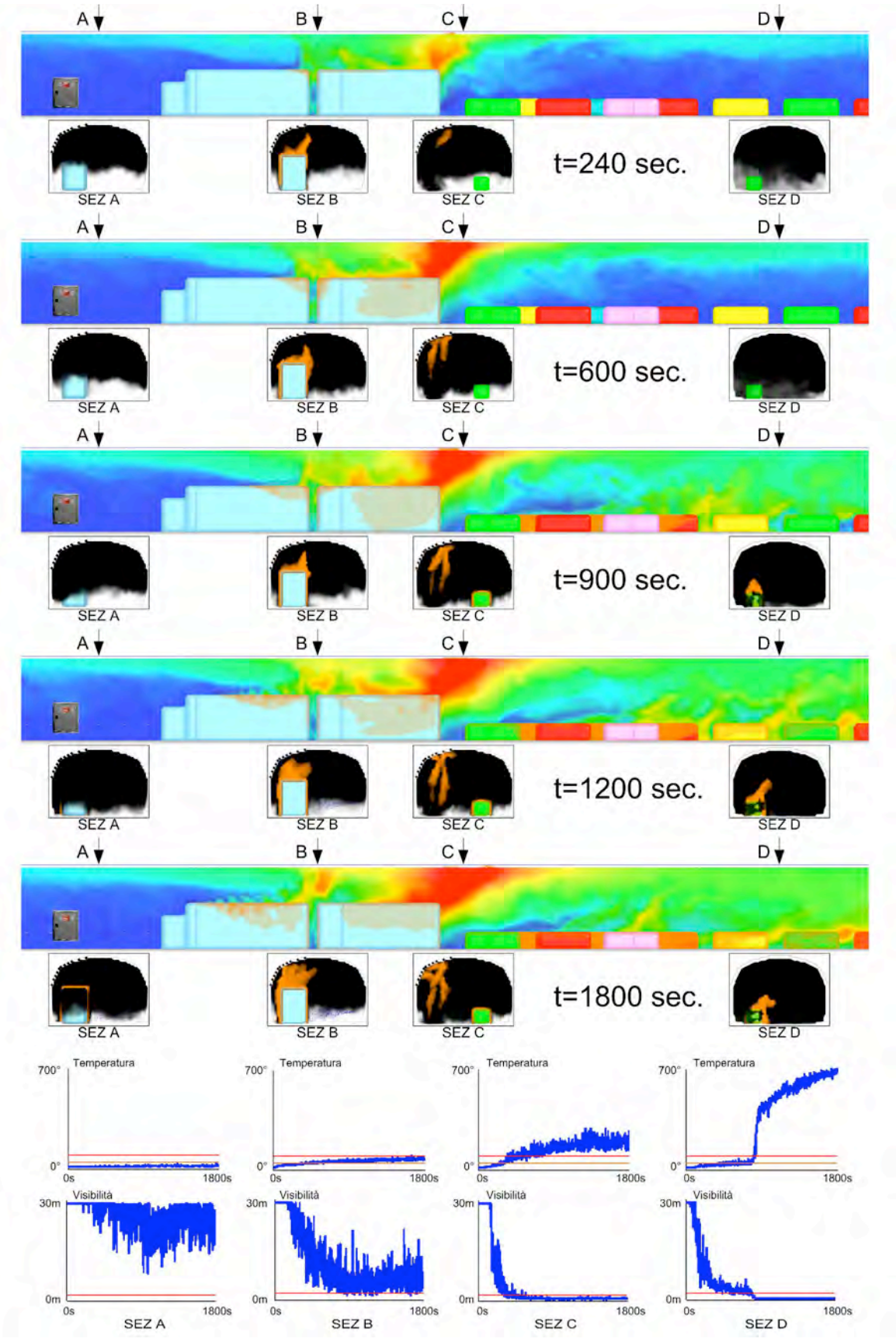
Fire in tunnel equipped only with hydrant fire boxes without forced venting



Fire in tunnel equipped with monitors with forced venting

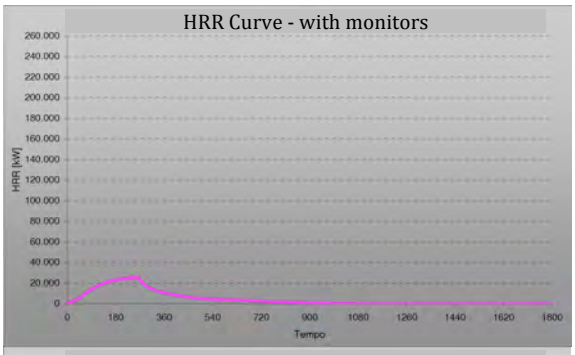


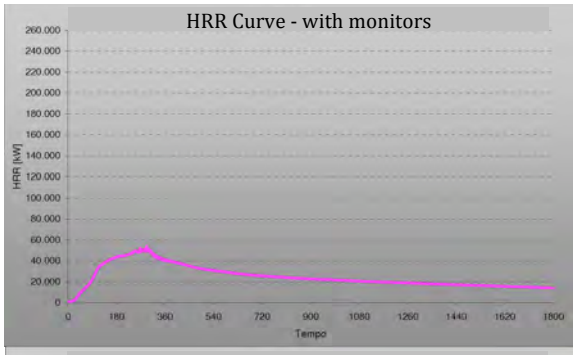
Fire in tunnel equipped only with hydrant fire boxes with forced venting

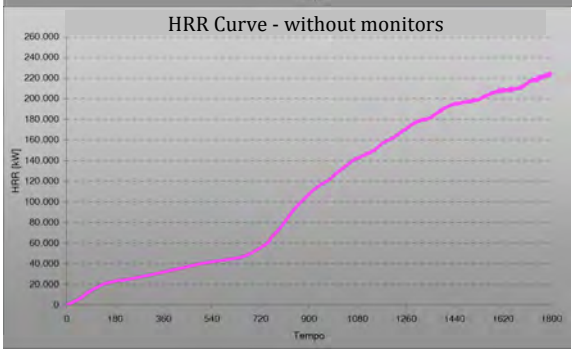


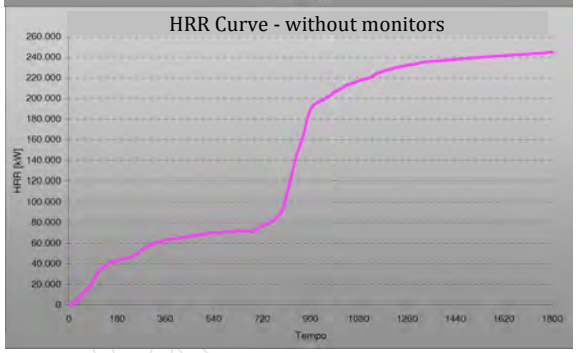
Total HRR of tunnel without forced venting

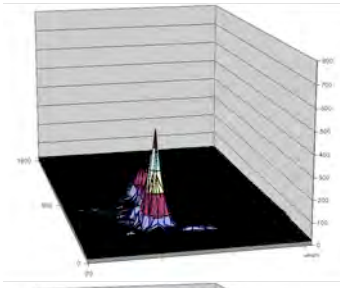
Total HRR of tunnel with forced venting





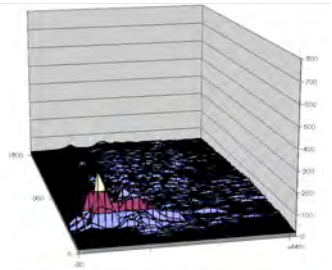


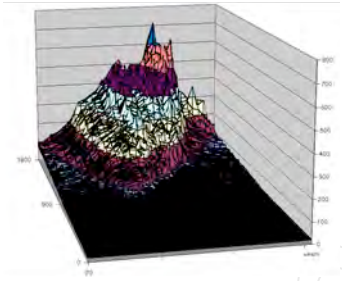




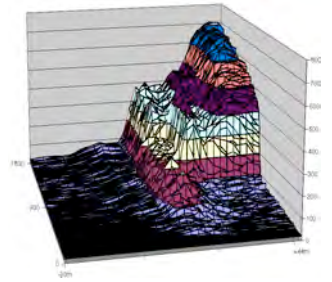
Curve of temperature trend at given height
h=1,60 mt.

With monitors

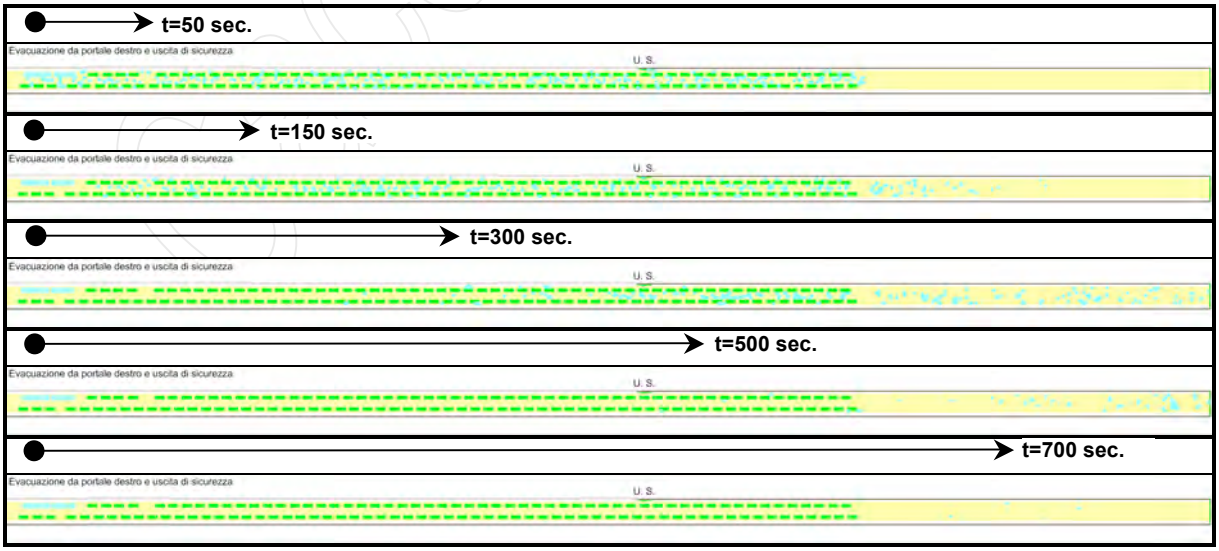




Without monitors



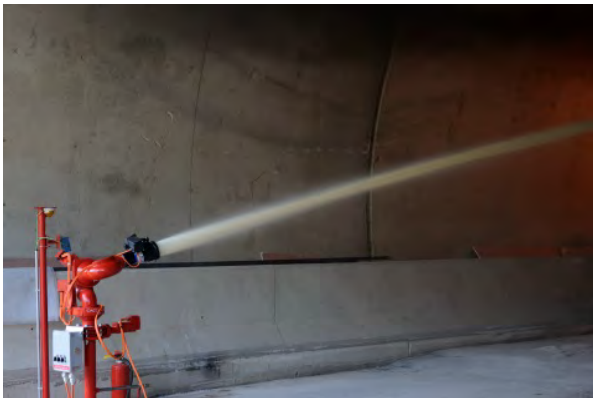
Trend visualisation



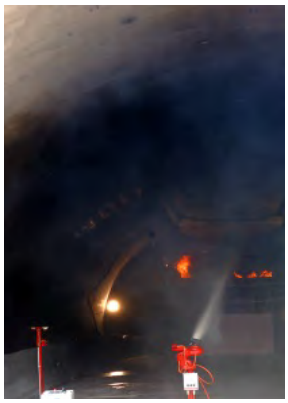
Test Results

The pictures here below shows some sequences of the tunnel tests.
The extinguishing tests have been performed in Santa Croce Tunnel - Strada dei Marmi (Carrara) and in the Test Tunnel of the Italian Fire Brigades' Training Centre in Montelibretti (Roma).

Santa Croce Tunnel - Strada dei Marmi - Carrara







Motorway Tunnel in Montelibretti (car fire)





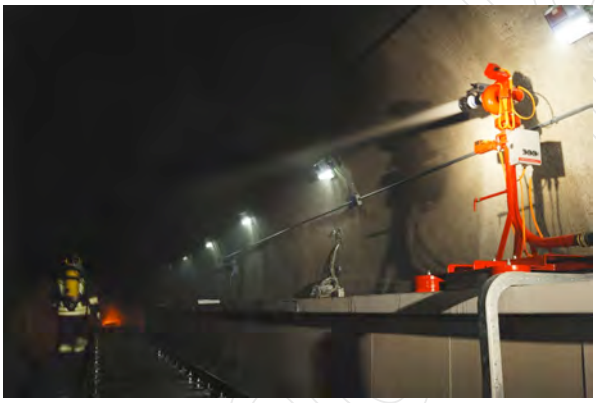
Motorway Tunnel in Montelibretti (pool fire)





Underground Tunnel in Montelibretti






The Automatic Extinguishing System for Tunnels with Remote Controlled Monitors is protected by the following Patents:

- Patent IT 0001382038 and IT 0001387359