Evaluation of the possibility to use waterscreen for people evacuation from the Gran Sasso National Laboratory inside the Gran Sasso highway tunnel in case of fire

The case of The Gran Sasso National Laboratory

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General Information about the Gran Sasso National Laboratory

Geographic position

- ✓ Under the mountain of Gran Sasso - 1400 meters of rock are a perfect filter to screen huge number of particles that hit the land surface
- ✓ Alongside one of the 2 fornices constituting the Gran Sasso highway tunnel
- ✓ In the middle of 10 Km highway tunnel A24 Teramo - L'Aquila - Rome

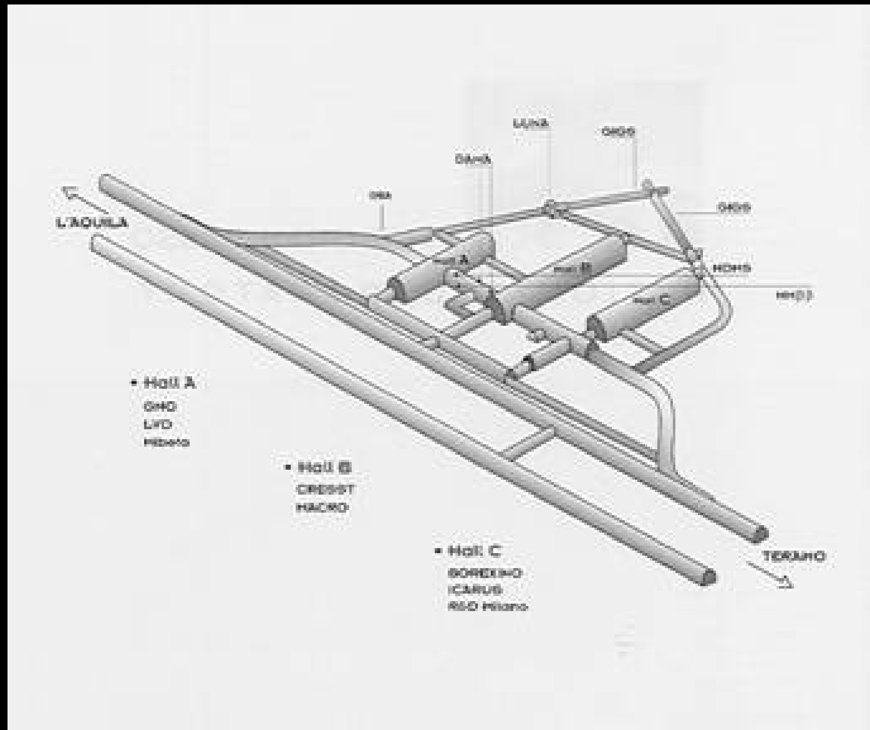
Experiments

- ✓ Neutrinos research
- ✓ Dark matter
- ✓ Double beta Decay

General Information about the Gran Sasso National Laboratory

Laboratory configuration

- ✓ 3 Big Hall (hall A, hall B, hall C) of 25.000 m3 each.
- ✓ Service tunnels
- ✓ 3 Connection tunnels (2 carriageable and 1 pedestrian) with left fornice of roadway tunnel
- ✓ 2 fornices (one Teramo direction and one L'Aquila direction)
- ✓ 18 connection tunnels (by pass) between the 2 fornices)



Critical location of LNGS inside the A24 Highway tunnel

Access

- ✓ Only from the A24 Highway tunnel through 3 connection tunnels

Position under the mountain

- ✓ In the middle of 10 Km highway tunnel A24 Teramo - L'Aquila - Rome

Emergency plan solution (approved by authority)

- ✓ Separation between LNGS and highway tunnel by means of fire resistant compartments
- ✓ Guarantee life tenability conditions inside Laboratory in case of fire in the tunnel and wait for rescue team
- ✓ But we think that it would be safer to ensure the possibility for people to evacuate in a safe area (the right fornice of the tunnel)
- ✓ The evacuation possibility can be ensured by means of a direct connection (new tunnel) between Lab and right fornice or by the USS system

Critical location of LNGS inside the A24 Highway tunnel

The fire proof separation is made up of fire proof doors with certified resistance of 180 minutes

Requirements of fire resistant compartments

- ✓ Structural Resistance (R)
- ✓ Smoke Seals (E)
- ✓ Heat Insulation (I)

but for how long time?
and under which conditions?

“Niagara “- General Description of the plant

Niagara is a cooling plant on the existing fire proof doors that separate highway from LNGS

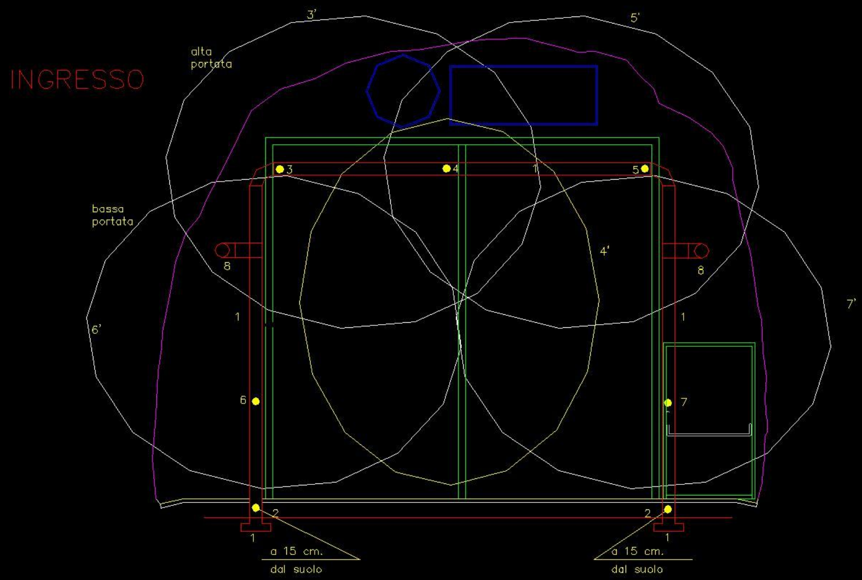
Dimensions

- ✓ Inner width 5.10 mt.
- ✓ Inner high 4.60 mt.
- ✓ Total diameter (pipe + heat insulator material and aluminium sheet) 0.30 mt.

On that pipeline 7 nozzles have been placed

- ✓ Tree on the architrave
- ✓ One at 1.6 mt from the floor on each pier (total: 2 nozzles)
- ✓ One on the basement of each pier (total: 2 nozzles)

“Niagara “- General Description of the plant



Nozzles distribution

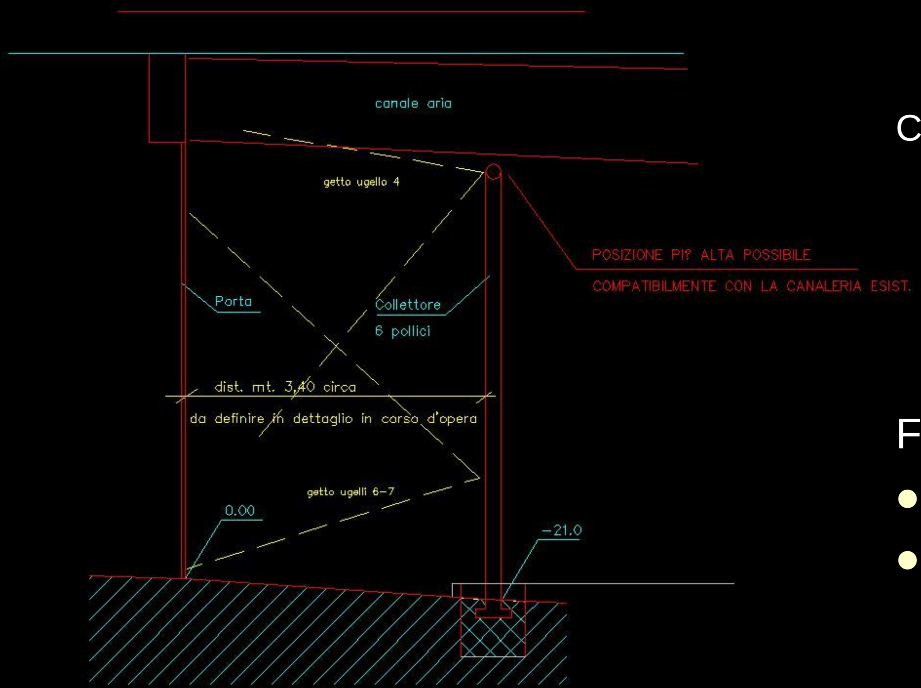
- ✓ Cone adjustable nozzles are located three on the architrave and two at 1.6m on the floor
- ✓ Fan nozzles are located on the basement

Nozzles type were

- ✓ Five Cone adjustable nozzles AISI 316 diameter ¾“ Flow rate 190 litres/min. at 4 bars
- ✓ Two fan nozzles AISI 316 diameter ½“ Flow rate 35 litres/min. at 4 bars

“Niagara “- General Description of the plant

Niagara is located 3 m far from the door to be protected



Cone adjustable nozzle have the function to cover the door area with water

Fan nozzles have the dual function:

- cooling the foundation
- clearing the water column that tends to accumulate in the piers up to 1.6 meters in height

“Niagara “- General Description of the plant

Water system adduction

- “Niagara” system uses water dripping on rock (100 litres/sec).
- Water adduction for the nozzles is via two pipes that pass through a reinforced concrete wall about 50 cm thick.
- Water is pressurized to 8 bars, by a group of 4 pumps, 1500 litres per minute each, using a 8” pipe.
- The four pumps can be operated manually or through the detection of 9 temperature sensors placed on the external face of the door.
- The 9 temperature sensors open the circuit when the temperature rises from about 14°C (constant temperature of the rock during the year) to 50°C, or by the sudden temperature increase of 2°C for minute.

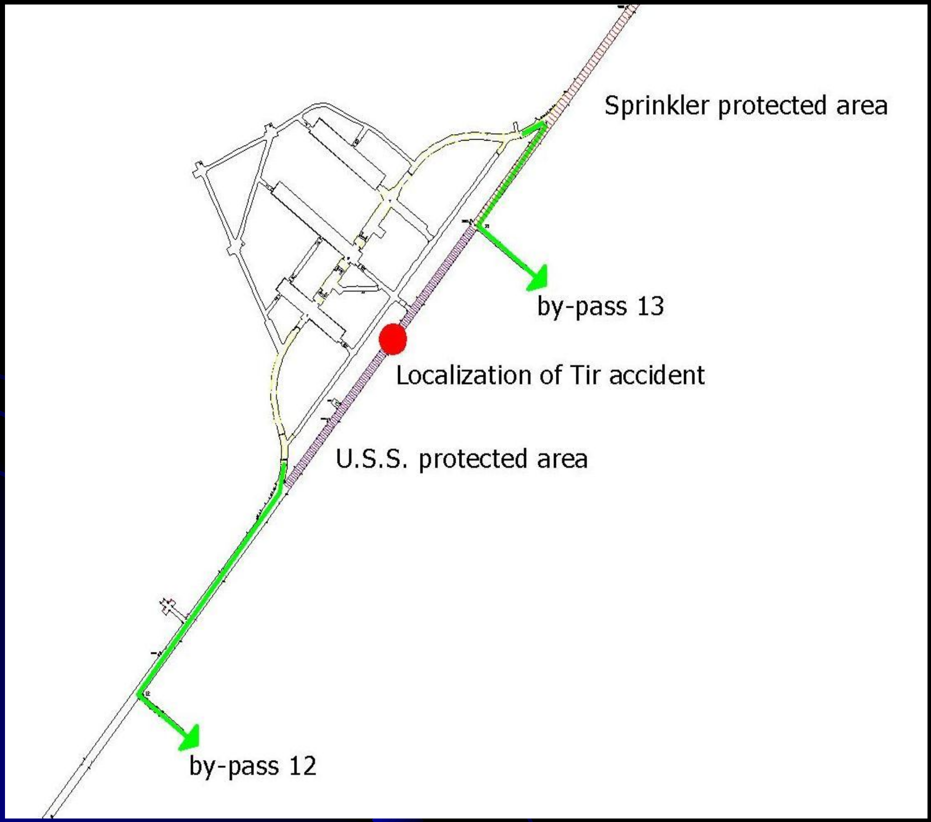
“Niagara “- General Description of the plant

Water system adduction

- The pumps that pressurize the system are eletrically powered by a redundant system and by a local and general diesel generator.
- On the water supply main circuit that serves “Niagara”, a pressure reducer calibrated at 4 bars has been installed.
- The excess of water is collected by grids interposed between “Niagara” and highway.

“U.S.S.” – Underground Safety Screen – General Description of the plant

We think that it would be safer to ensure the possibility for people to evacuate in a safe area (the right fornice of the tunnel)

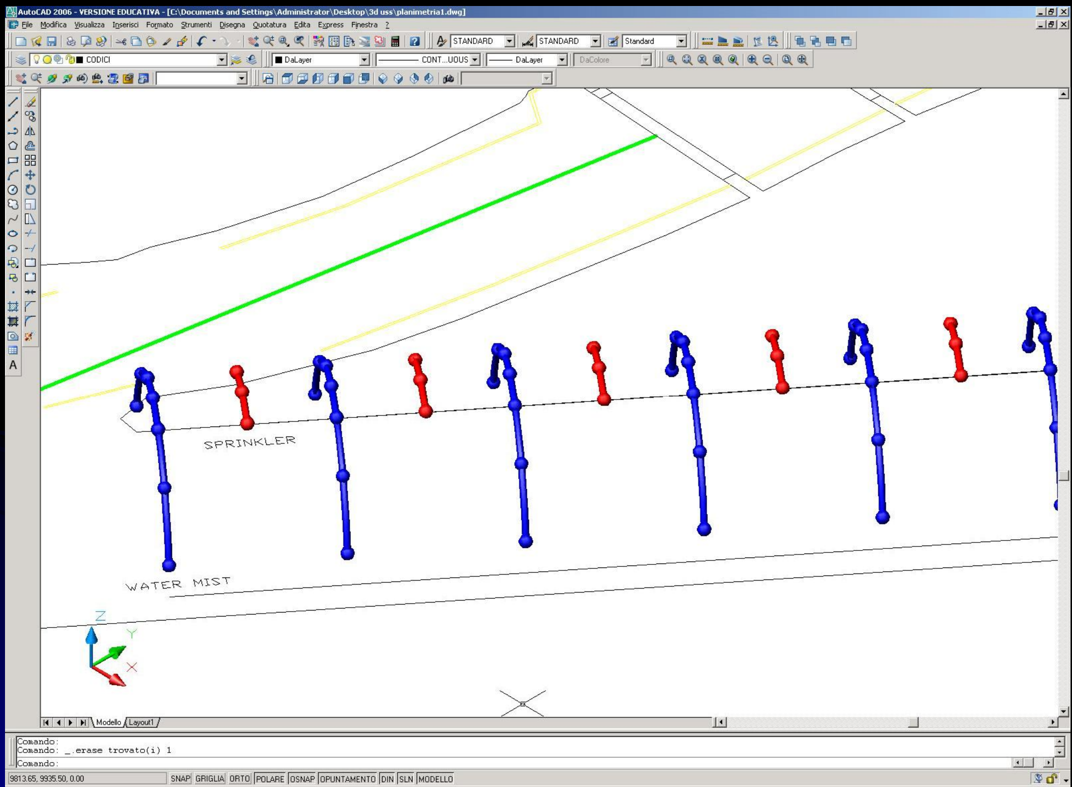


U.S.S. Protected area will cover a lenght of 250 m.

Sprinkler Protected area will cover a lenght of 3 Km.

The aim of the U.S.S. System is to guarantee in case of fire inside the tunnel the human life tenability; this to allow people working in the underground lab to safely evacuate to the second parallel tunnel – considered in this case as “dynamic safe place” – through the connection by-pass nr. 12 or nr. 13

"U.S.S." – Underground Safety Screen – General Description of the plant



The two plants staggered with a constant pace between sprinkler and water mist nozzles of 2.5 m.

U.S.S. System is made up of two completely independent plants that increase the total reliability level:

- "Sprinkler" System
- "Water Mist" System

The reason why the U.S.S. System is made up of a two combined plants are:

1. Need of having a fire fighting system acting directly on fire with bigger water flux (Sprinkler System).
2. Need of having a system capable of absorbing radiative heat and scrubbing smokes produced by fire.

“U.S.S.” – Underground Safety Screen – General Description of the plant

- The total water supply available inside the laboratory is 100 l/s
- The water reaches the nozzles through two separate pipes for Sprinkler System and Water Mist System taking water directly from the laboratory or from the highway for Sprinkler System.
- With regards to Sprinkler System, water is pressurized to 8 bars by a group of 4 pumps with a range of 1500 l/min. Pressurization pumps are elettrically fed by a redundant system and generator.
- The Water Mist System is pressurized by pumping units made of 6 modules that provide a pressure between 80 and 140 bar.
- The Sprinkler System is operated by bulbs containing a heat-sensitive liquid. At 74°C, the bulbs break and water flows on a protected are of 144 sqm and a density of about 16 l/min per sqm.
- Water supplied by Sprinkler System is equal to 2357 l/min over 12 heads, that is a supply of water per head of about 196 l/min.
- The Water Mist System operates as a deluge system on the whole area of installation. Its 273 nozzles supplies 3643 l/min of water, that is a supply of water per head of about 13 l/min.

Simulations with CFD software: Description of the Model

Overview on the CFD calculation

- The software used for this CFD simulation is NIST's Fire Dynamic Simulator (Mc Grattan et al. 2001a, b)
- FDS was developed to specifically address fire-hazard scenarios
- This software predicts smoke and/or air flow movement caused by fire, wind, ventilation systems and other sources of momentum.
- To visualize the predictions generated by NIST FDS can be used Smokeview (Mc Grattan & Forney 2001c)
- FDS solves a form of the Navier-Stokes equations appropriate for low-speed, thermally driven flows of smoke and hot gases generated in a fire.
- Smokeview visualizes FDS computed data by animating time dependent particle flow, 2D slice contours and surface boundary contours. Data at a particular time may also be visualized using 2D or 3D contour plots or vector plots.

Simulations with CFD software: Description of the Model

Geometry modelling in FDS

Cell discretization

$$D^* = \left(\frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g}} \right)^{\frac{2}{5}}$$

D* : characteristic diameter of fire;
Q : heat release total rate, kW;
ρ_∞ : density at room temperature, kg/m3;
c_p : specific heat of gas, kJ/kg°K;
T_∞ : room temperature, °K

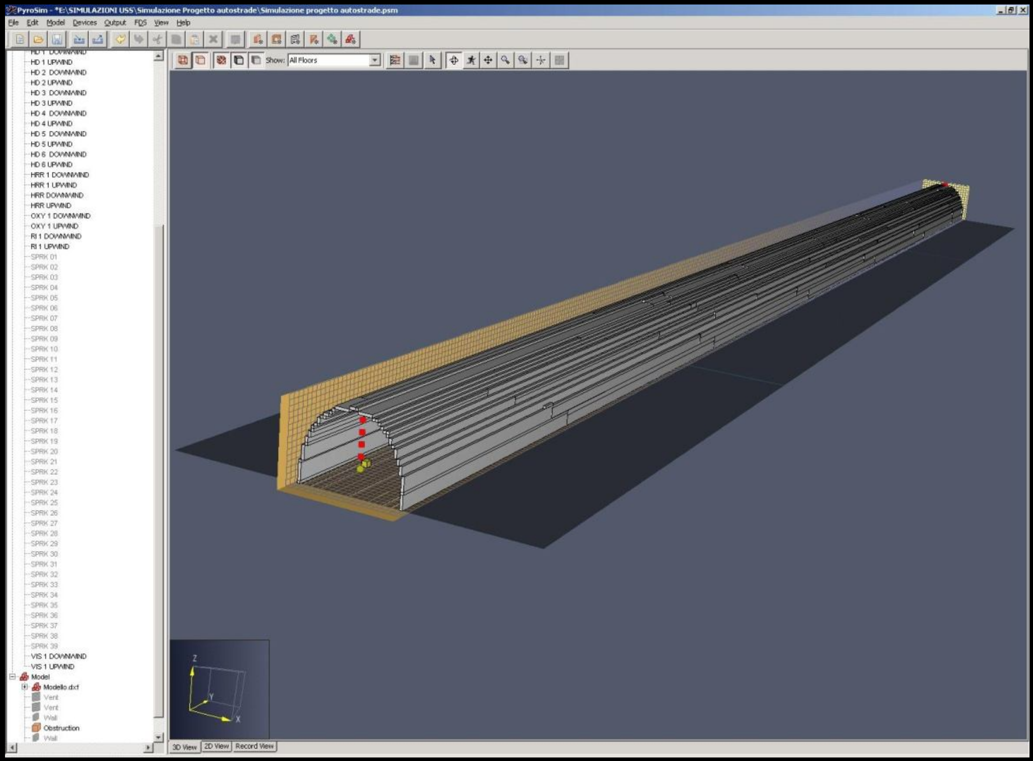
In our simulation
T=283 °K
ρ_∞=1.2 kg/m3
c_p =1.0 kJ/kg°K
Q = 200.000 kW
it results D* =8.12m.

Therefore, it is assumed an average size of the discretization at 10% D* 80cm

Simulations with CFD software: Description of the Model

Geometry modelling in FDS

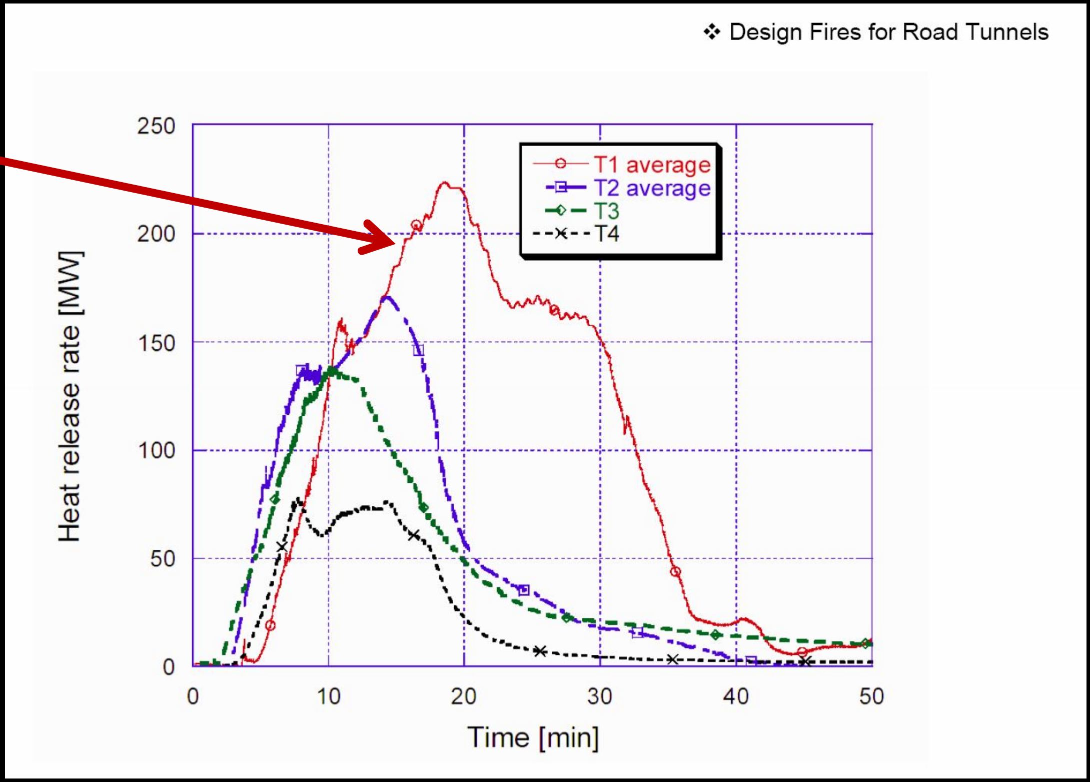
The volume is divided in one type of mesh
• on the highway tunnel the dimension of each cubic cell is 50 cm
•Total amount of cells are 120,000 cells on the 200 m part of tunnel, where the system is installed.



Simulations with CFD software: Description of the Model

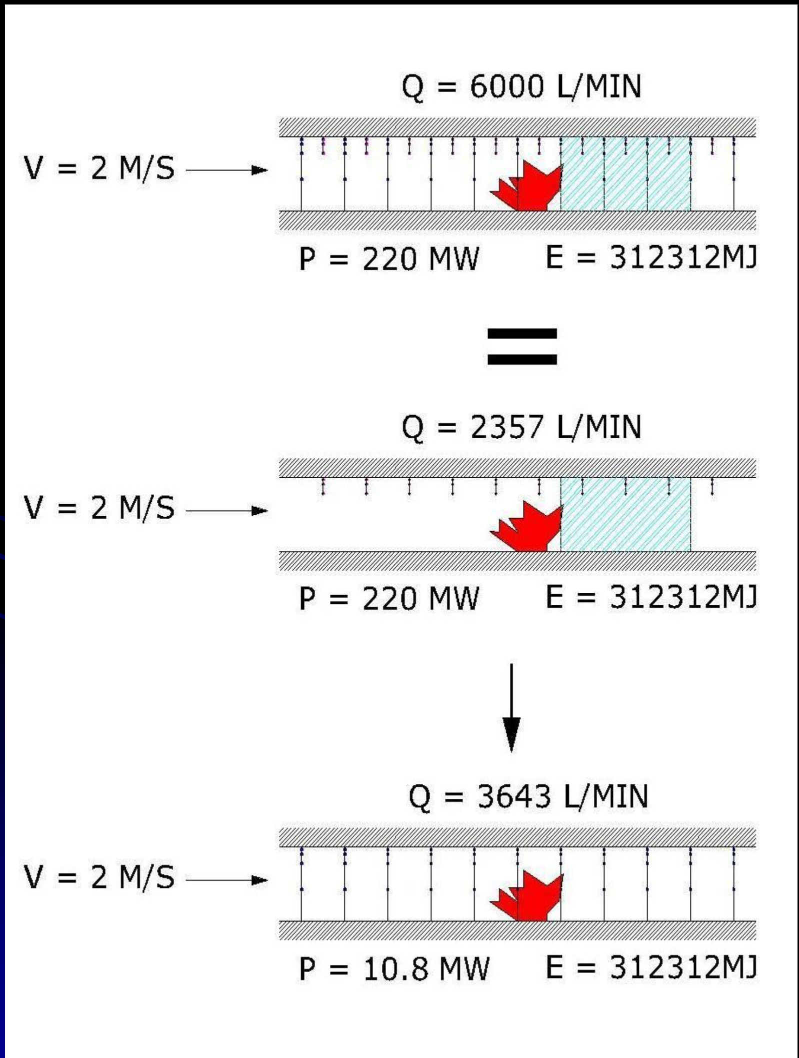
Geometry modelling in FDS

HRR Curve considered



The HRR from the four large-scale Runehamar fire tests with HGV-trailer fire load

Simulations with CFD software: Description of the Model



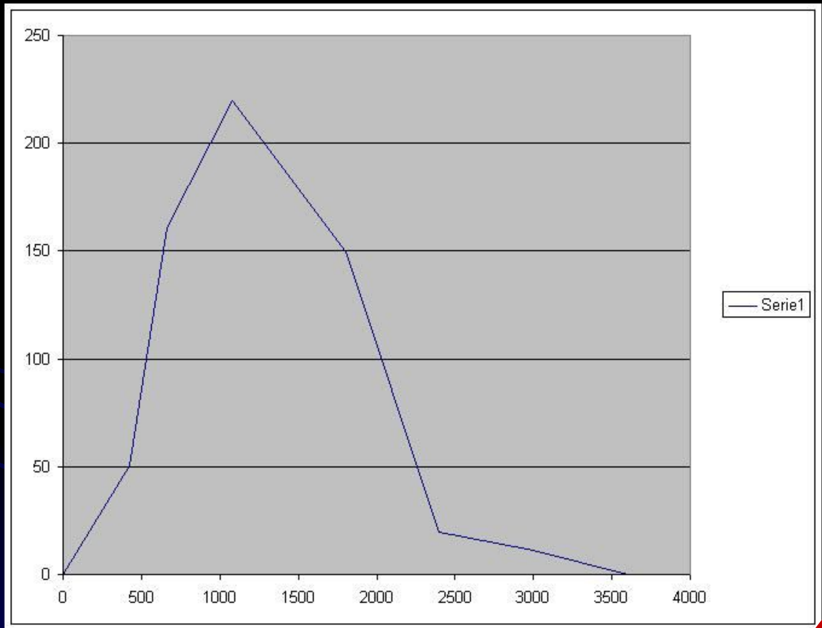
Starting conditions.

Sprinkler water flow needed to
Contain fire (HRR curve constant according to ISO/TR 13387)
Each sprinkler nozzle have a flow rate of 196 l/min at a pressure of 4 bar

Water mist flow rate and fire power (constant) used in FDS simulations
At 90 s the maximum power is equal to 10.8 MW.
Each water mist nozzle have a flow rate of 13 l/min at a pressure of 120 bar

Simulations with CFD software: Description of the Model

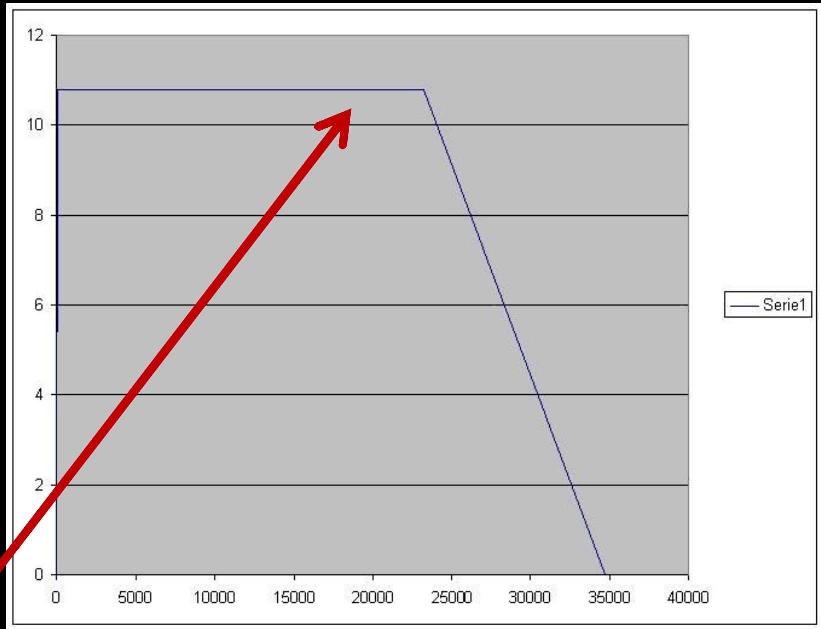
HRR Curve of the Tir accident



HRR Peak Power curve = 220 MW

Adjusted curve used in FDS program

HRR Curve of the Tir accident considering sprinkler suppression



HRR Peak Power curve = 10.8 MW
From 90 s (time activation of Sprinkler System)
To 23179 s the maximum power remains constant

Simulations with CFD software: Description of the Model

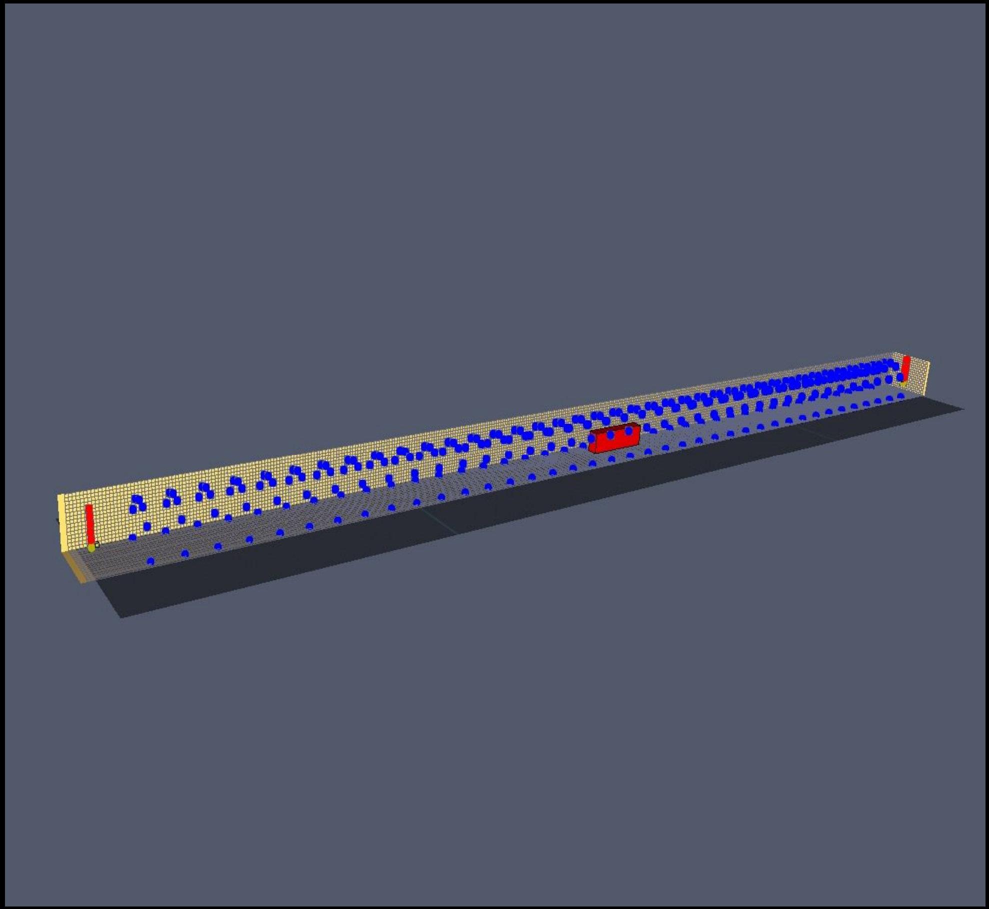
Geometry Modelling in FDS

TUNNEL MATERIALS: Adiabatic Surface
VENTILATION INSIDE THE TUNNEL: 2m/s on the “VENT” input and to be an “OPEN VENT” in output
DIMENSION OF THE RADIATING SURFACE: 146 m2
HRR PEAK POWER CURVE HGV (Hard Good Vehicle): 220MW
HRRUA Heat Release Rate for Unit Area: 1507 Kw/m2
BURNT MATERIAL: Kerosene
POSITION OF THE PROBES: Along the left fornice of road tunnel, in the proximity of Lab access and exit, has been inserted a row of probes and for each row a probe in every meter up to the keystone of the tunnel..
TYPES OF PROBES: Temperature of the gas, oxygen, carbon monoxide, carbon dioxide, visibility and radiant energy.

Simulations with CFD software: Description of the Model

Geometry Modelling in FDS

- The two row of probes in red measuring the human life tenability at different high (every meter) from the ground to the ceiling of tunnel near the entrance and the exit from the lab.
- In blue are designed the 273 water mist nozzles where each row, containing 7 nozzles, is positioned every five meters.
- The box in red simulate the position of the Tir accident with an HRR peak power curve of 10.8 MW.



Simulations with CFD software: Description of the Model

Performance levels expected   Performance levels achieved

Performance levels expected	
Visibility	10 m
Temperature	50 °C
Carbon monoxide	500 ppm
Radiation	2,2 Kw/mq
Carbon dioxide	40000 ppm
Oxygen	15 %

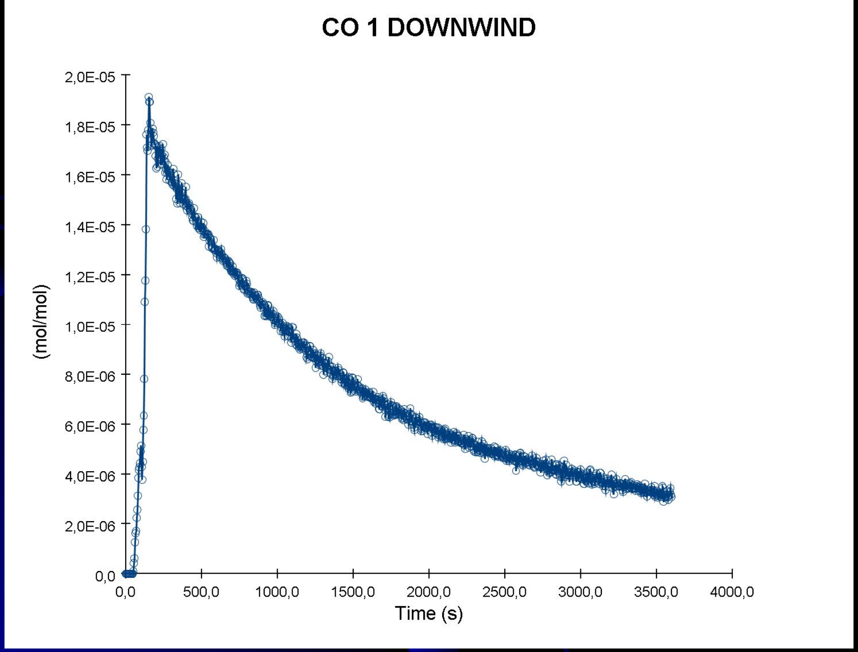
Performance levels achieved	
Visibility	8 m
Temperature	52 °C
Carbon monoxide	19 ppm
Radiation	2,15 Kw/mq
Carbon dioxide	4700 ppm
Oxygen	20,1 %

The results obtained during the simulation show that the values achieved near the exit are consistent with the values from the literature data as maximum values that allow the sustainability of human life without causing irreversible damage.

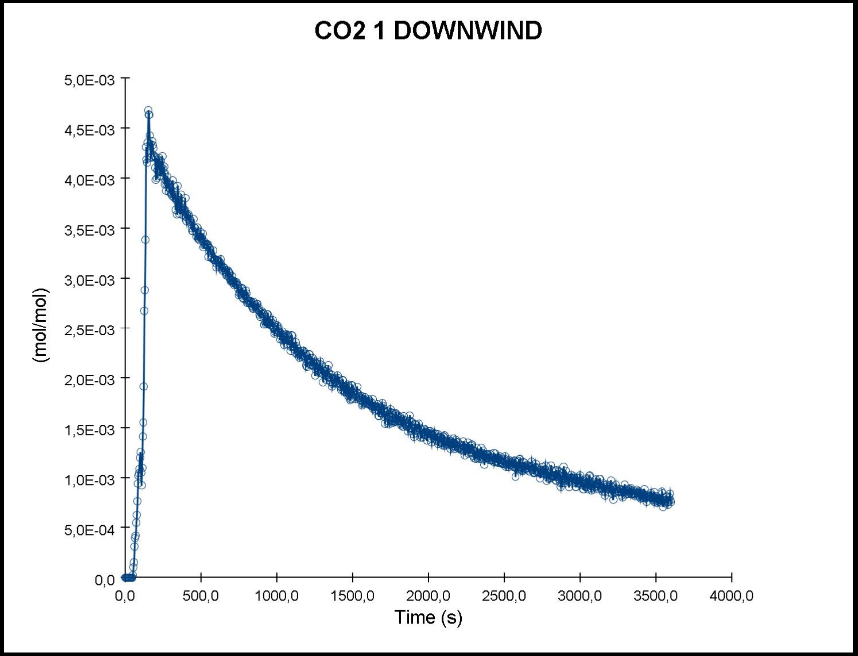
Simulations with CFD software: Description of the Model

Result Analysis

Time dependent carbon monoxide curve



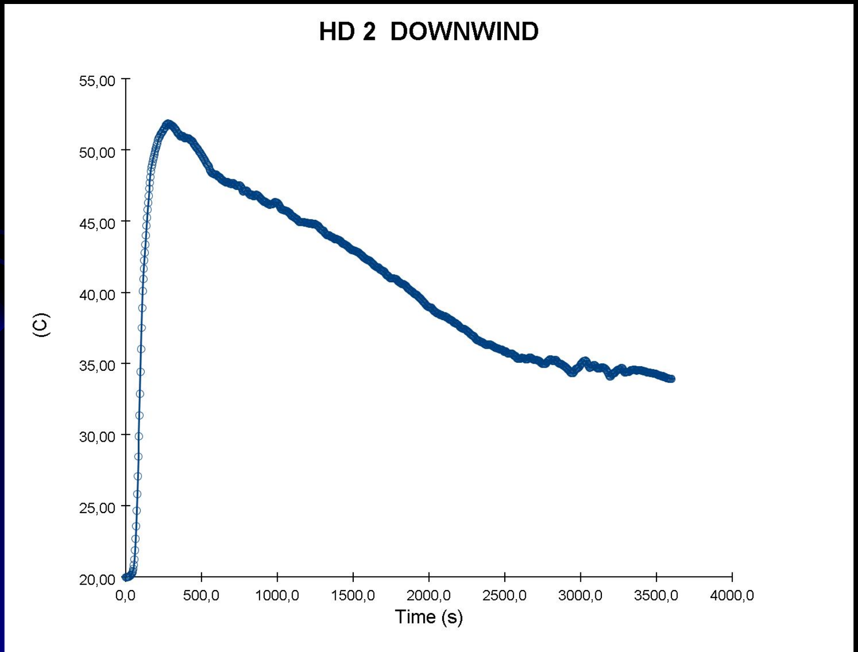
Time dependent carbon dioxide curve



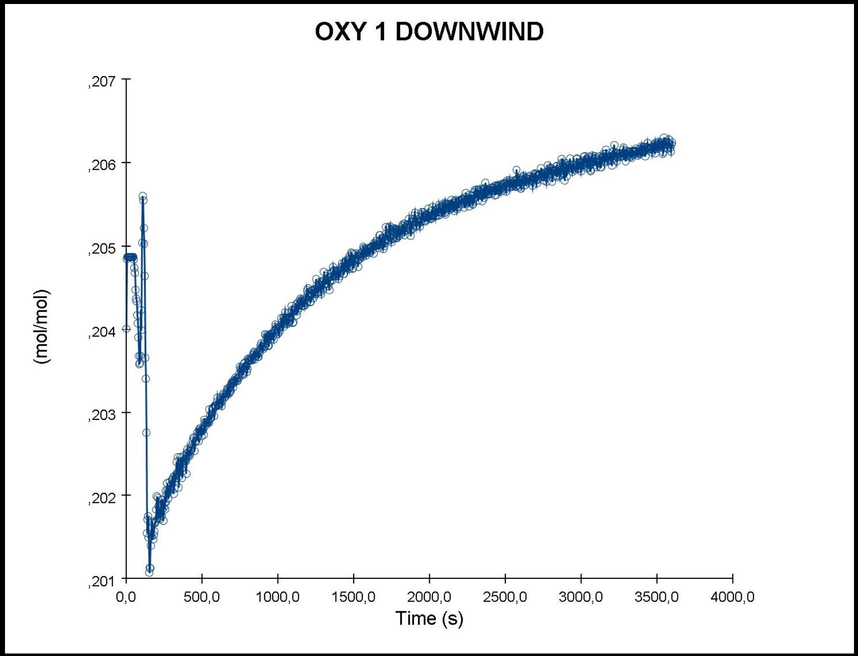
Simulations with CFD software: Description of the Model

Result Analysis

Time dependent temperature curve



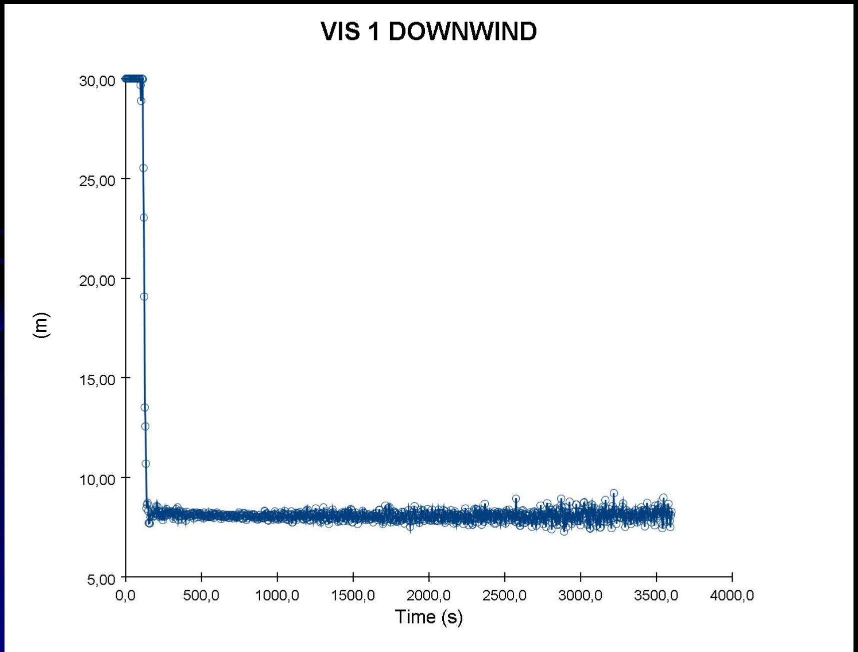
Time dependent oxygen curve



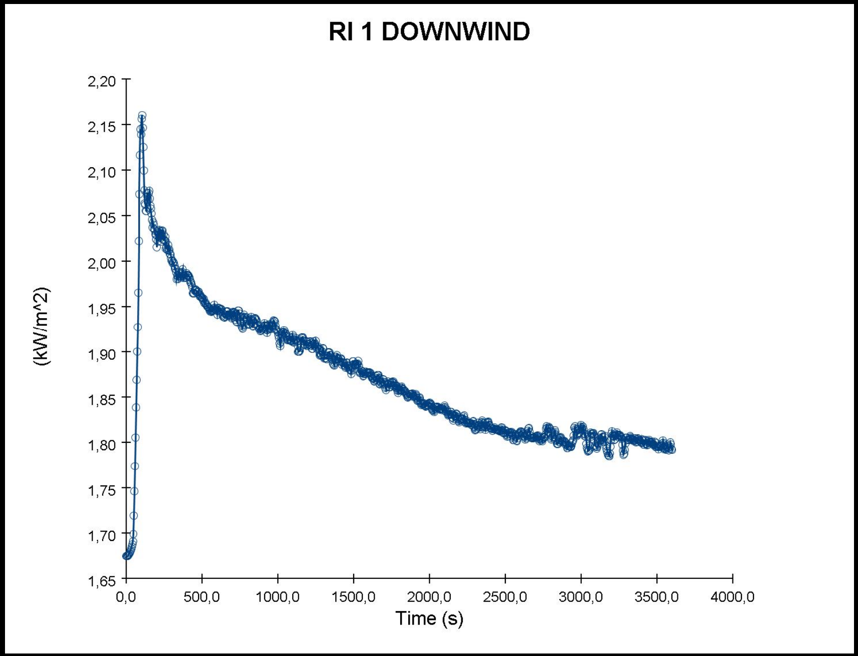
Simulations with CFD software: Description of the Model

Result Analysis

Time dependent visibility curve



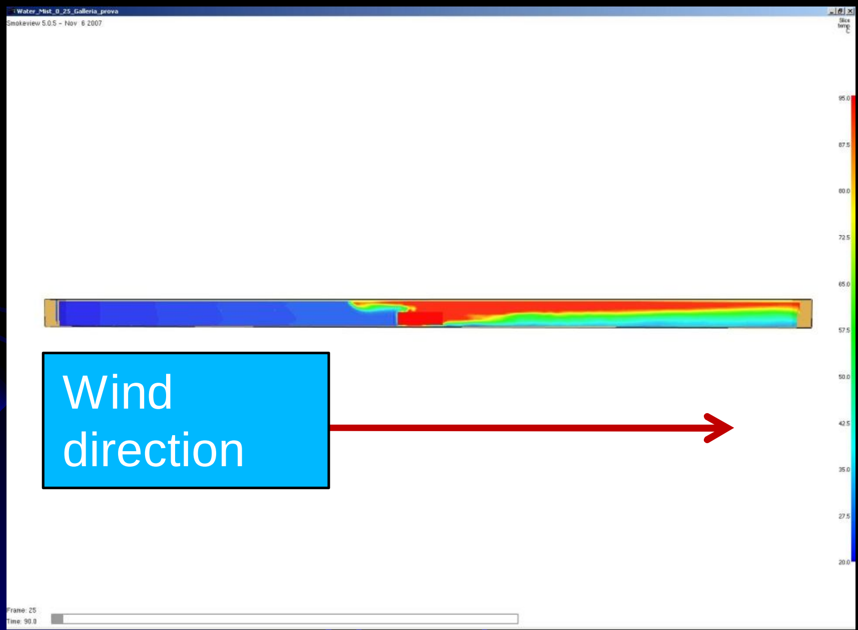
Time dependent radiant intensity curve



Simulations with CFD software: Description of the Model

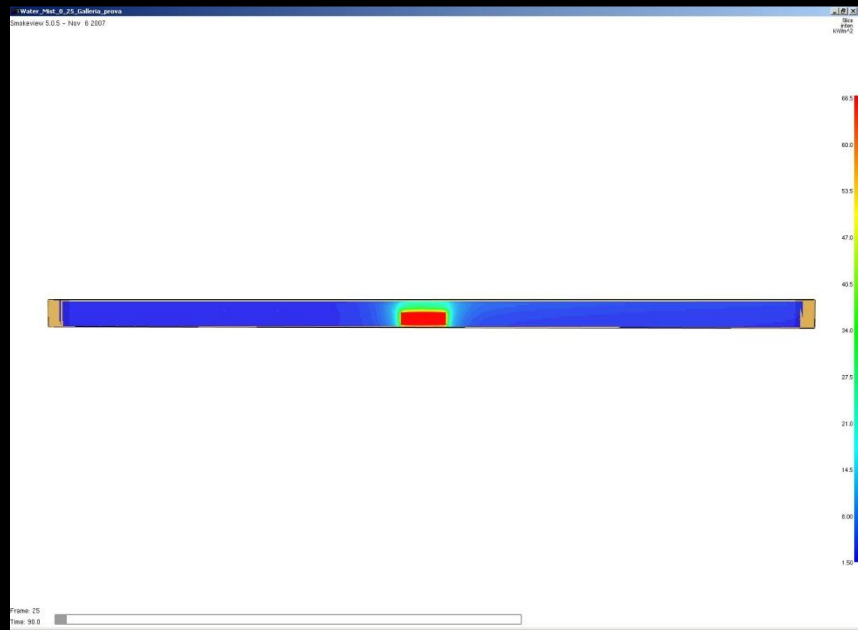
Result Analysis

Distribution of the temperature considering a wind velocity of 2m/s



Temperature

Distribution of the radiant intensity

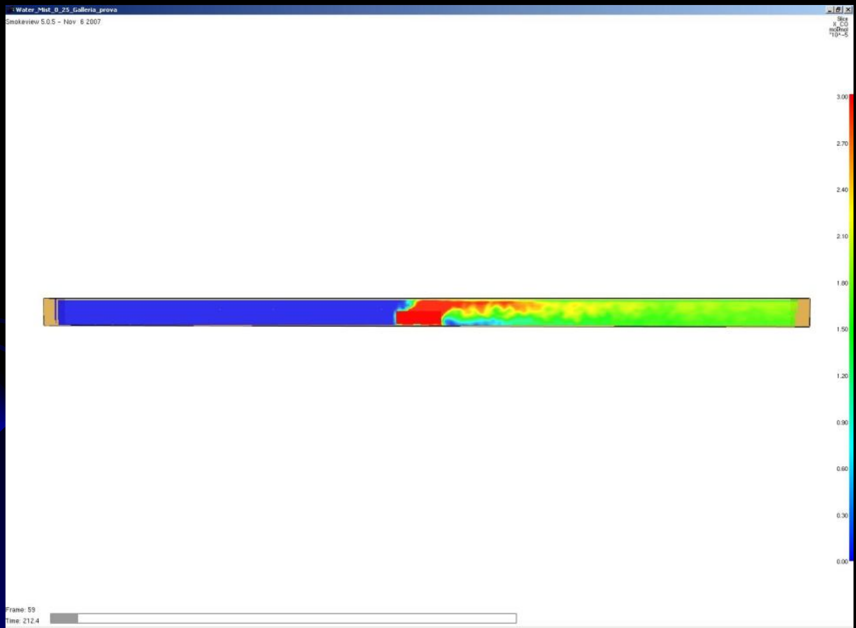


Radiant Intensity

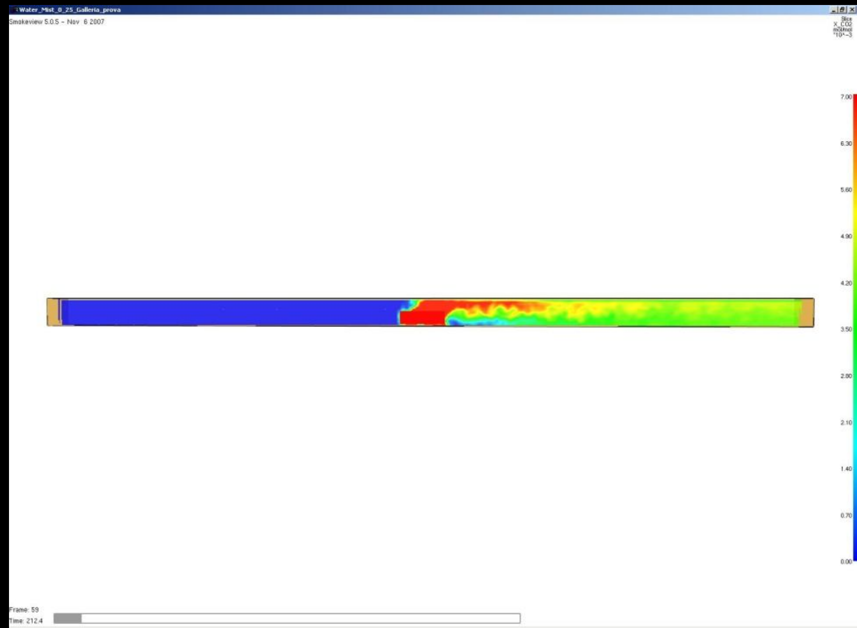
Simulations with CFD software: Description of the Model

Result Analysis

Distribution of the carbon monoxide and carbon dioxide considering kerosene as burnt material



Carbon monoxide



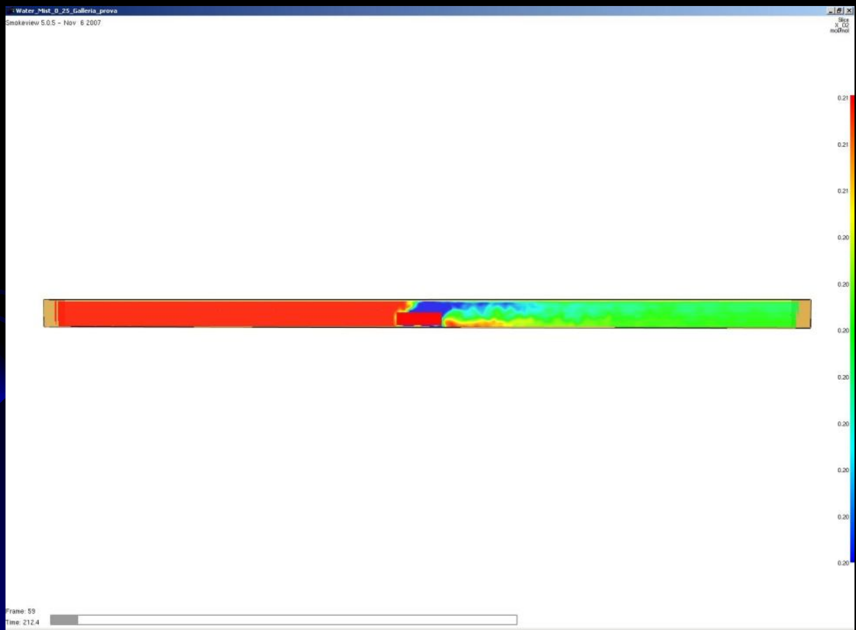
Carbon dioxide

Simulations with CFD software: Description of the Model

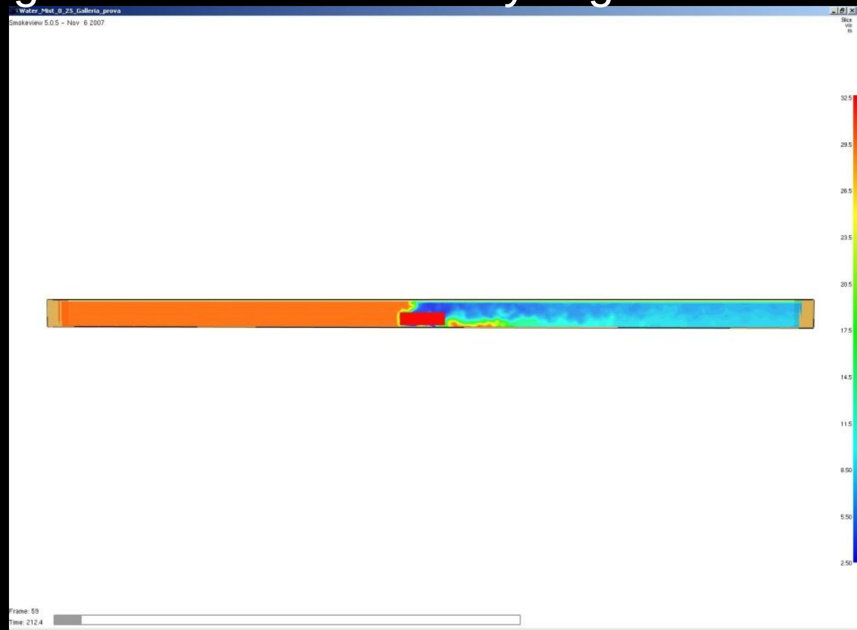
Result Analysis

Distribution of the oxygen

Distribution of the visibility.
We can see that at 2 m. from the ground floor the visibility is good



Oxigen



Visibility

Conclusions

The hybrid system USS obtained from the combination of "water mist" and "sprinkler" technologies has shown its capability to guarantee to the LNGS staff the safe escape through the tunnel without irreversible damage caused by a devastating fire (release of energy – peak of 220 MW).

To ensure this possibility it is necessary to cover with a "sprinkler" system 3 Km before laboratory.

This system, if implemeted, could be a viable alternative to the construction of a direct connection (pedestrian only) between LNGS underground tunnel and right duct (direction L'Aquila – Teramo) of Gran Sasso tunnel; at the end of this pedestrian tunnel a "dynamic safe place" woul be realized where people can safely stay waiting for rescue team, provided that two contemporary major accident inside the duct of highway tunnel are excluded.

Conclusions

In terms of estimated costs we have considered that:

1. for the construction of a direct tunnel we have need of about 5.000.000 euros.
2. For the realization of the U.S.S. System, considering that we have already a supply of water and pumping units for water mist and sprinkler, we have need of about 1.000.000 euros.

The U.S.S. system maybe a viable alternative to the realization of the direct connection between LNGS underground tunnel and right duct also in terms of estimated costs.

Thank you for your attention!

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