VID Fire-Kill ApS, Svalbardvej 13, DK-5700 Svendborg,
Tel: +45 6262 1024, Fax: +45 6262 3661, www.vid.eu, SE No.: 31480604

Full scale tunnel fire tests of
VID Fire-Kill Low Pressure Water Mist Tunnel Fire Protection System in
Runehamar test tunnel, spring 2009
By Alex Palle & Carsten Palle VID Fire-Fill www.vid.eu
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Synopsis.

VID Fire-Kill together with Entreprise / Bane-Danmark did in April and May 2009 conduct a series of large full scale Tunnel Fire Tests in the Runehammer Tunnel. The tunnel is an abandon 9m wide, 6m high and 1600m long two driving lane rock tunnel located in Åndalsness on the west coast of Norway.
The fire tests involved diesel pool fires and solid class A fires with potential heat outputs of up to 100 MW. Three 20m long nozzle pipe protection sections of the VID Fire-Kill Low Pressure Water Mist Tunnel Protection System were installed in the centre line of the tunnel ceiling in the centre of the tunnel. Water Mist from the Nozzle pipes was manually release in the centre of the tunnel when the water pumps were turned on and water at 10 bar water pressure was applied to the nozzle pipe line. By using a manual system release method, the test fires were provided time to developed, and here by to test the protection system in large fires. All test fires were conducted by Sintef NBL. Sintef NBL did also conduct all measurements, data recordings and documentation of the tests and results.

It was observed, that the VID Fire-Kill Tunnel Protection System provides fast fire suppression in large tunnel fires involving hydrocarbons (diesel oil) and solid fires (Class A) with potential heat output of up to 100 MW. It was also observed that the protection system effectively cools the tunnel pipes structure and the air temperatures in the whole tunnel pipe, allowing fire fighters and rescue personal safely to enter the tunnel pipe at an early stage to rescue people and fight fires. It was also observed that the fire protection system prevented smoke backflow in the tunnel with tunnel ventilation air velocities of down to 2m/s.

Foreword.

Long infrastructure tunnels, such as train tunnels and road tunnels etc. represents very large values to the societies. The tunnel-use has large value to the societies they connect. The tunnel structures are very valuable. Tunnel fires may cost long tunnel lay-down times, and take long time to repairer damages to the tunnel structure at very high repair costs.

Also the values in forms of installations in the tunnel pipes and in vehicles and goods in tunnel pipes are high.

The fire loads in infrastructure tunnels are often very high, and infrastructure tunnels have many potential high risk points of ignition. Cars and trucks has combustion engines, here pressurized flammable hydrocarbons are transported in small pipes and flexible rubber and plastics hoses in hot vibrating engine compartments close to hot surfaces as engine blocks, exhaust manifolds and exhaust pipes etc. The vehicles are in good and bad maintenance states, and all carries fuel tanks with flammable hydrocarbons. Trucks and trains carry all kinds of goods in small and very large quantities. The vehicles are all individual controlled, and move through the tunnel pipes in high speed or close together. Each vehicle represents a high potential risk of igniting a fire in the tunnel tube.

	HRR MW	Road, examples vehicles	Rail, examples vehicles	Metro, examples vehicles	At the fire boundary
Risk to life	5	1-2 cars			ISO 834
Risk to life	10	Small van, 2-3 cars, ++	Electric locomotive	Low combustible passengers carriage	ISO 834
Risk to life	20	Big van, public bus, multiple vehicles		Normal combustble passengers carriage	ISO 834
Risk to life	30	Bus, empty HGV	Passengers carriage	Two Carriages	ISO 834
Risk to life / Risk to construction	50	Combustibles load on truck	Open freight wagons with lorries	Multiple carriages (more than two)	ISO 834
Risk to life / Risk to construction	70	HGV load with combustibles (approx. 4 tonne)			HC
Risk to life / Risk to construction	100	HGV (average)			HC
Risk to life / Risk to construction	150	Loaded with easy comb. HGV (approx. 10 tons)			RWS
Risk to life / Risk to construction	200 or higher	Limited by oxygen, petrol tanker, multiple HGVs	Limited by oxygen		RWS

The following growth rates are recommended:
Max HRR of fire $\leq$ 30MW, => gr = 10MW/min
Max HRR of fire > 30MW, => gr = 20MW/min

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Many people risks to be in an infrastructure tunnel pipe when a fire occurs. Long infrastructure tunnels have long escape routes. Vehicles or trains obstruct peoples escape routes in the tunnel pipes making evacuation in case of tunnel fires difficult. Darkness and smoke makes it hard for people to orientate, and to find their way to the escape routes or the tunnel exit.

Tunnels are long clamp spaces, with small cross section areas. The spaces quickly fill with smoke and heat from fires, quickly to turn the tunnel tube space into a life threading environments in cases of a fire in a tunnel pipe.

Long infrastructure tunnels have ventilation fan systems forcing fresh air into the tunnel pipes. The systems vent the tunnels from combustion gases from vehicles exhaust, and the ventilation systems bring oxygen to people inside tunnel pipes. Typical air velocities in modern infrastructure tunnels are 3m/s to 8 m/s, similar to 10 km/h (the speed humans can run) to 30 km/h(the peak speed of common people ridden bicycles). In elder infra structure tunnels air ventilation velocities are often as slow as 1 -2 m/s equals 3.6-7.2 km/h or common walking velocities.

Many tunnel operators plan to increase the air velocities to 8 m/s in case of fires in tunnel tubes. This way the operators hope to prevent smoke from fires from filling the tunnel pipe down stream the fire. The tunnel operators do also hope that the high air flow may cool the tunnel structure to reduce fire damages to tunnel structures, and finally it is thought that the high air flow will solute the combustion gasses from fire creating a less lethal atmosphere in the tunnel pipe down stream the fire.

Most infrastructure tunnels are equipped with cabinets containing hand extinguishers or hose rails for manual fire fighting. The cabinets are scattered installed in the tunnel tubes with 0.1km to 0.2 km between the cabinets. The idea is to provide people in the tunnels a possibility to fight tunnel fires them selves. For many people this would be their first time attempting to extinguish a fire. If not being successful extinguishing the fires might on the other hand cost the people valuable time to find the equipment and to try to extinguish the fire.

In April/May 2009 VID Fire-Kill and Entreprise / Bane-Denmark initiated a series of full scale tunnel fires in the Runehammar test tunnel in Åndalsness, Norway. The test fires had potential fire sizes representing fires in trucks and busses and smaller multiple car fires.
The fire test scenarios involved fires in diesel oil pools and fires in solid fuels class A. The fires were designed to have potential heat releases of up to 100MW.
The fire tests were designed and conducted by Sintef NBL. Sintef NBL did also conduct all measurements and data recordings during the tests.

The purposes with the fire test scenarios were to investigate the level of Fire Protection which an installed VID Fire-Kill Low Pressure Water Mist Tunnel Protection System is cable of supplying in large scale tunnel fires with high potential heat outputs.

The fire protection parameters which were investigated was

- The degree of fire suppression concerning heat output from fires.
- The degree of fire protection concerning temperature management.
- The degree of fire protection concerning risks of fire spreading in tunnels.
- The degree of fire protection concerning smoke management.
- The degree of fire protection concerning required ventilation conditions
- The degree of fire protection concerning visibilities and CO, CO_2 propagation.

The fire tests were conducted with the nozzle pipes from three sections of the VID Fire-Kill Low Pressure Tunnel Protection System installed in the centre line of the tunnel ceiling in the centre of the test tunnel. In

all test fires the nozzle pipes were manually activated to distribute water mist in the tunnel pipe at 10 bar water pressure.
The nozzle pipes were inside the tunnel connected to an 800m long 4" pipe connecting the nozzle pipes to the Pump system outside the tunnel. The pump system consisted of two Grundfoss CR water pumps. The total pump capacity was 90 m^3/h at 10 bar water pressure. The pump system required a power supply of 60 amps. Only fresh water with no additives was used during the fire tests.

VID Fire-Kill Tunnel Protection System.
The VID Fire-Kill Tunnel Protection System is an active fire detecting and fire suppression system.
The system is a modular built system. Each module is 18m – 20 m long and consists of two module parts.

Each system module contains:
- a supply pipe section,
- nozzle pipes with water mist nozzles
- An electric activated control valve which connects nozzle pipes to supply pipe section.
- A heat protected electric control panel with power back-up and connections to electric supply and buss line for remote control and alarm and system monitoring
- Two electric flame detectors to monitor the tunnel zone section for fires and to provide fire alarms and if necessary activate the panel to operate the section control valve to open for water to be distributed from the water mist nozzles in the fire section and its two neighbour tunnel system sections. The flame detectors are designed to provide alarm on all fires, and only to provide activation alarm signal on fires which do not move.
- A series of thermo sensors for double knock fire detection. The panel process signals from thermo sensors to a fire dependent rise of heat pattern.

System module sections are supplied as fully assembled and fully tested units from factory, ready for installation in the tunnel ceiling. The units are installed in the tunnel ceiling and flanged together to make a pipe line through the whole length of the tunnel. All electrical connections are heat protected, and monitored. All electrical connections are plug connections, making a simple and secure tunnel fire protection to install.

A variation of the system has video cameras fitted on the tunnel modules, which become active and transmit addressable pictures to a central computer when flame detectors in the protection sections activate. This allows the tunnel operators actively to decide on if it is necessary to activate the tunnel protection section system.

The section control valves are designed to stay open when activated unto manually closed from inverting the electric signal to the valves.

The VID Fire-Kill Low Pressure Water Mist Tunnel System operates with 10 bar water pressure. When activated, the tunnel protection system operate three sections of 18-20m to distribute water mist in a length of the tunnel of totally 54-60m (the system section where the fire is located, and the two neighbour sections). Three sections are necessary always to ensure that a fire is fully enclosed with the fire protection coverage.

Nozzle pipes installed in the test tunnel.

The VID Fire-Kill Tunnel Protection System installed in the Runehammar tunnel was a simplified only to be the nozzle pipes with water mist nozzles.

The test fires were arranged at a known location in the test tunnel. And the test fires should be provided time to grow large before water mist was released, to see how the VID Fire-Kill Tunnel Protection coped with large fires.

Therefore the system installed did not include the fire detection and alarm systems. Also the test tunnel already had a 4" water pipeline leading from the tunnel entrance to the centre of the tunnel.
Therefore the tunnel protection system applied in the tests did only include three Nozzle pipe sections with water mist nozzles of VID Fire-Kill Low Pressure Water Mist Tunnel System.

The 3 x 20m nozzle pipes were joined together in one pipe line, which was installed in the tunnel roof centreline in the centre of the tunnel. The Nozzle pipe line was in two places connected to the 4" water supply pipe in the tunnel, and the supply pipe was connected to the pump systems with hoses outside the tunnel. Water was taken from an open fresh water reservoir.
Two Grundfoss CR pumps were with hoses connected to the water mains pipe in the tunnel pipe. The pumps were connected to a reservoir with two dib pipes. The power supply to the pump system was 60 amps. The pumps total capacity was 1.5 m^3/min at 10 bar.

The system was manually activated by turning on the pumps.

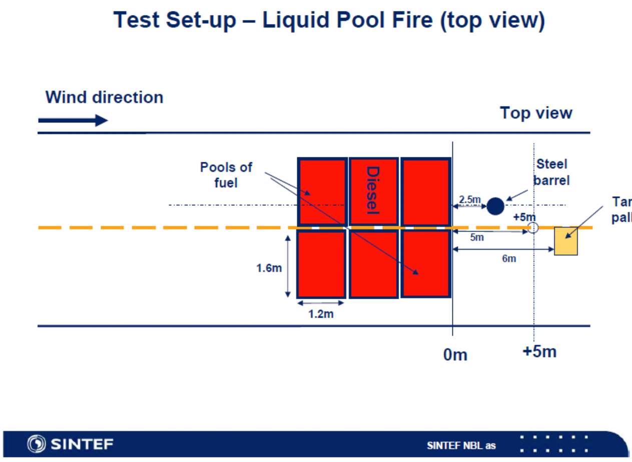
<u>The Runehammer test tunnel.</u>

The Runehammar test tunnel belongs to the Norwegian Road Authorities. The tunnel is a rock tunnel without lining. It is located in Åndalsness on the Norwegian west coast. The tunnel is a two lane road tunnel. It was a part of the Norwegian road infra structure until a landslides brought the road leading to the tunnel down into the fjord below.
The tunnel tube is 9m wide 6m high and 1600m long.
Inside the tunnel tube the original road tunnel ventilator system with two ceiling fitted ventilators are installed and functioning. The ventilators are installed approximately 200m from the tunnel entrance. The ventilator system has a capacity of 2m/s – 3 m/s depending on the outside wind conditionings. The original ventilator system was active through the whole fire test scenarios, and was never turned off.

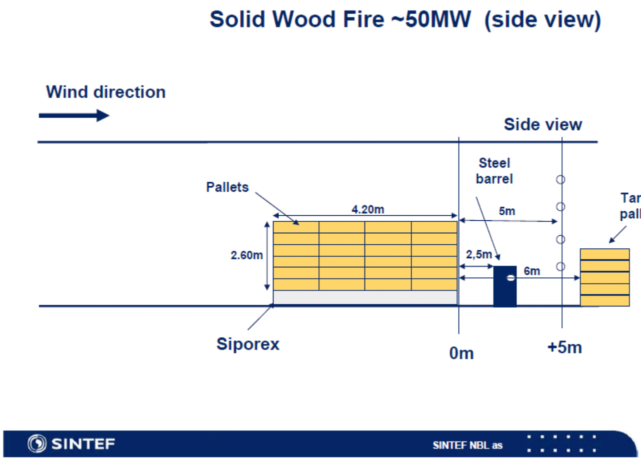
<u>Test fires and set-up of test fires.</u>

All test fire was located in the centre of the tunnel, 800m from both tunnel openings. Three fire tests were conducted. In all fire tests a target arrangement was installed down stream the test fire to show if the fire would have had the possibilities to spread to other vehicles in the tunnel.
The tests:

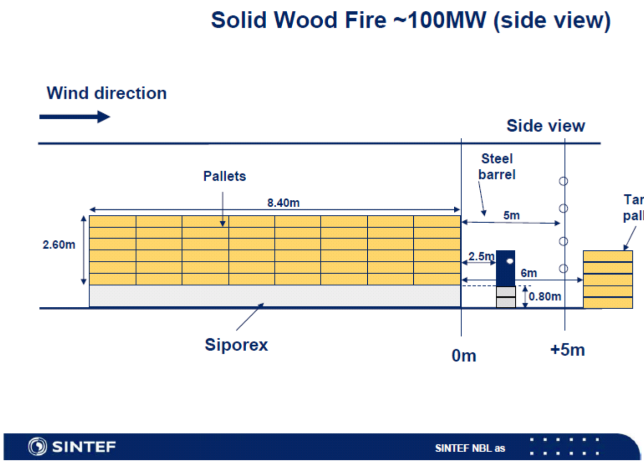
1: Diesel fire with 6 diesel pools. Each diesel pool was 2m² large and had 0,5m high sides to shield the pool fires. Prior to the fire test the diesel pools were filled with 1.5m² diesel oil. Sintef NBL estimated that the full developed fire to have a potential heat output of 30 MW. The fire was ignited with gasoline on the oil diesel surface. The fire protection system was Activated 4 minutes after igniting the fire and the temperature was 450ºC above the fire and the nozzle pipe.



2: Solid fuel Class A fire. 180 pcs. euro pallets were stacked on a concrete foundation 1m above the road. The Fire was ignited at the front of the wood pallet pile with 4 x 1litre plastic trays positioned in the wooden pallets. Sintef NBL had estimated that the full developed fire would have a potential heat output of 50MW. The fire protection system was activated 5 minutes after igniting the fire and the Temperature was 950ºC above the fire and the nozzle pipe.



3: Solid fuel Class A fire. 360 pcs. euro pallets were stacked on a concrete foundation 1m above the road. The Fire was ignited at the front of the wood pallet pile with 4 x 1litre plastic trays placed in the wooden pallets. Sintef NBL had estimated that the full developed fire would have a potential heat output of 100MW. The fire protection system was activated 6 minutes after fire ignition, and the temperature above the fire and above the nozzle pipe was more than 1000ºC

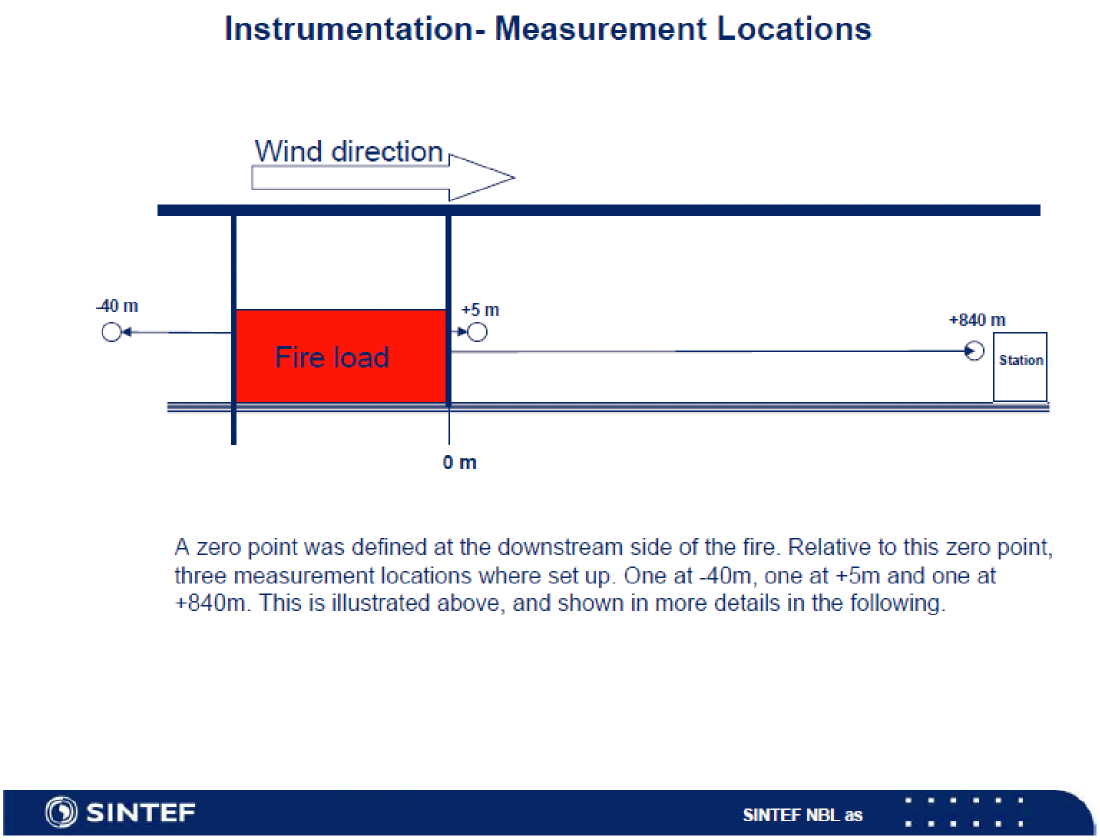


Target arrangement for fire spread from test fires.

A target arrangement to show spread of fire from the test fire was made for each fire test. The arrangement consisted of a 200 litre steel barrow, positioned 3m down stream the test fires, and a pile of 10 euro wooden pallets positioned 6m down stream the test fires. The water temperature was measured during the fire tests, and the pile of wooden pallets was inspected for fire damages after each test.

In no tests conducted did the fire spread to the wooden pallets, and the maximum temperature measured in the water was 35 ºC.

Instrumentation.



40m upstream from the test setups: Temperatures and air velocities were measured at different heights above the road.

5m down stream from the test setups: Temperatures were measures 2m, 3m, 4m, 5m, and 6m -10cm above the road.

700m down stream from the tunnel centre and 100 from the tunnel exit: Temperatures were measured 2m, 3m, 4m, 5m, and 6m -10cm above the road. And air velocities were measured in different heights, and CO, CO2, O2 were measured.

Results from fire tests.

Test Results

Test Id.	Scenario	Potential Heat Release Rate (HRR)	Time at Ignition	Time at Activation	Activation Delay	Water Pressure	Time to Extinguishing after Activation	Time to Temperature Control at +5m, after Activation	Target pallet damage
		[MW]	[hh:mm:ss]	[hh:mm:ss]	[hh:mm:ss]	[Bar]	[sec]	[sec]	
Test A	$12m^2$ pool	25-30	18:51:32	18:54:50	0:03:18	10,0	< 60	< 30	No damage
Test B	180 wood pallets	50	21:08:20	21:14:35	0:06:15	10,0	-	< 30	No damage
Test C	360 wood pallets	100	10:27:49	10:33:34	0:05:45	10,0	-	<180	No damage

Test B and Test C (180 and 360 wood pallets respectively) had HRR rate of 40MW and 50MW respectively at time of activation. Test B was close to free burning rate, while test C was on a strong increasing gradient. For a stronger ventilation rate, higher flame spread rate is expected. Consequently higher burning rate after 6 minute would be present. For Test C a 100MW free burning rate is expected, but appearing somewhat later.

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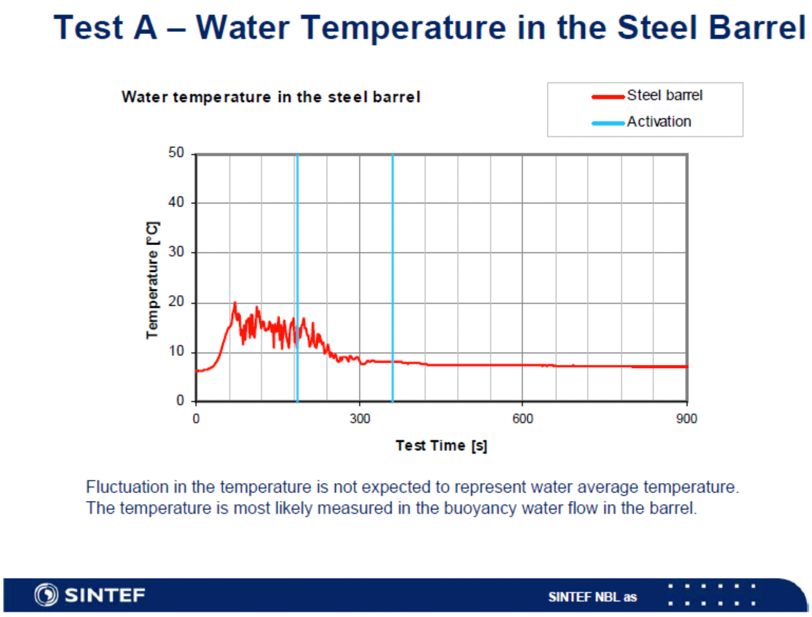
VID Fire-Kill ApS, Svalbardvej 13, DK-5700 Svendborg,
Tel: +45 6262 1024, Fax: +45 6262 3661, www.vid.eu, SE No.: 31480604

Conclusion:

Risks of fires spreading in the tunnel.

Fires having a potential heat output of up to 100MW fires will not spread to other vehicles in the tunnel tube if a VID Fire-Kill Tunnel Protection System is installed in the tunnel.

The heat from a potential 100 MW large fire did only cause a temperature increase of 20ºC to the water in the steel barrow 3m down stream the fire, indicating that a fuel tanks 3m away from a fire will not burst from heat in tunnels where a VID Fire-Kill Tunnel System is installed.



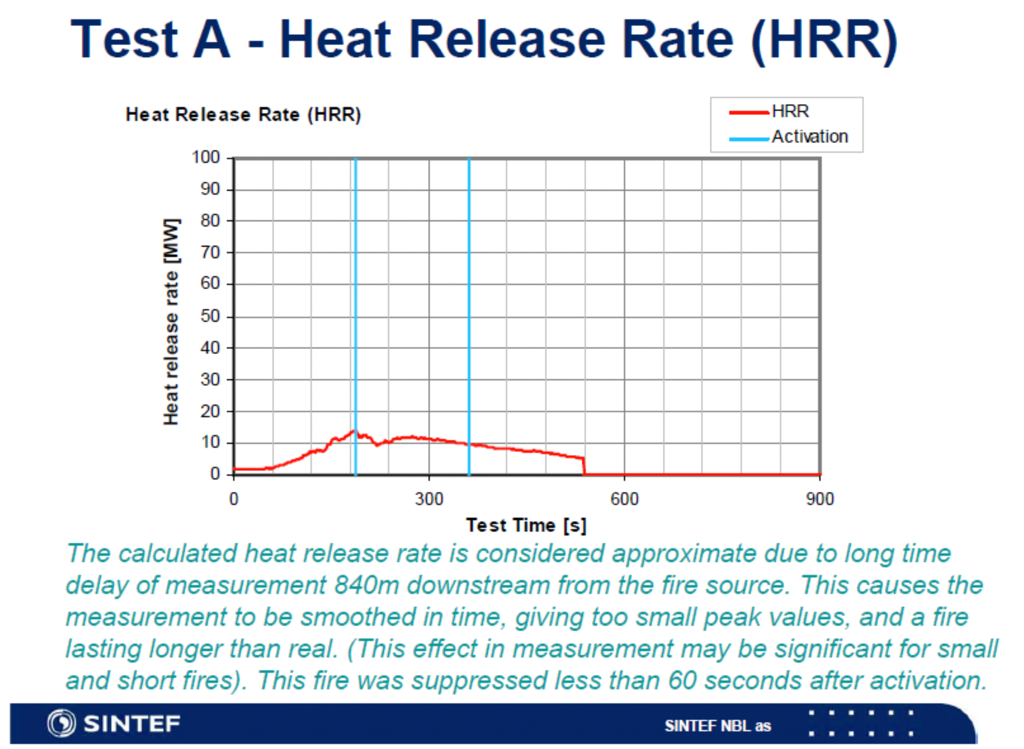
Suppression of Heat Output from the test fires.

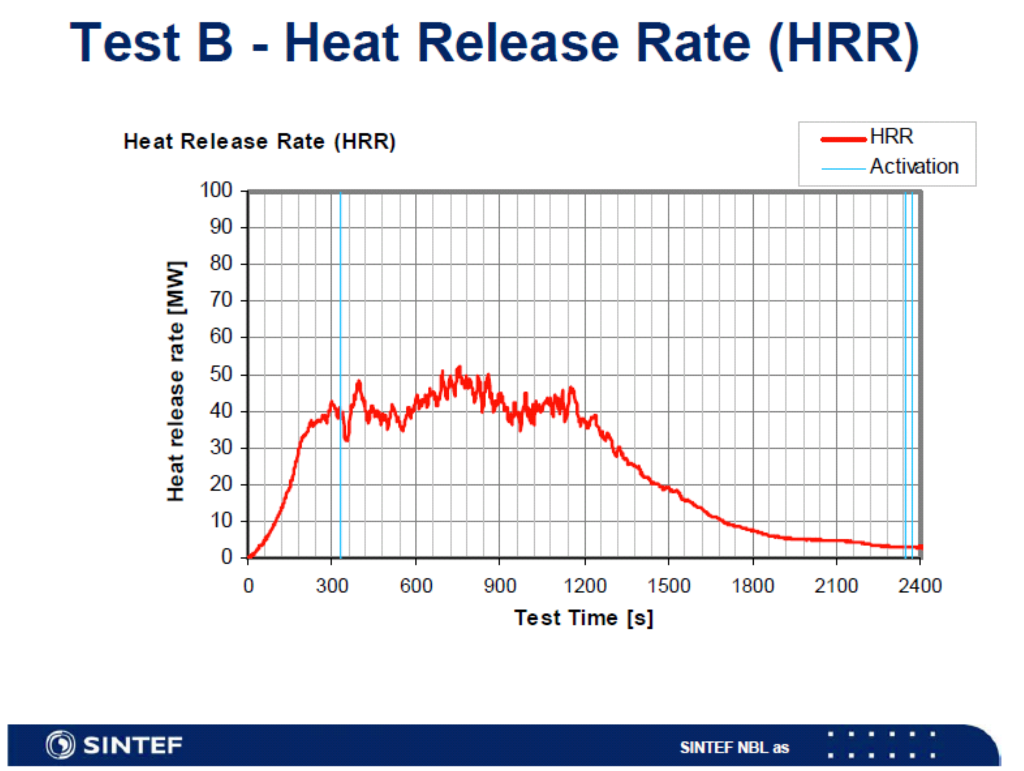
The VID Fire-Kill Tunnel Protection System extinguished the 6 x 2m² diesel pool fire within 30 sec after activation.

The VID Fire-Kill Tunnel Protection System provided fast suppression of heat out puts for both the potential 50MW and the potential 100MW solid fires.

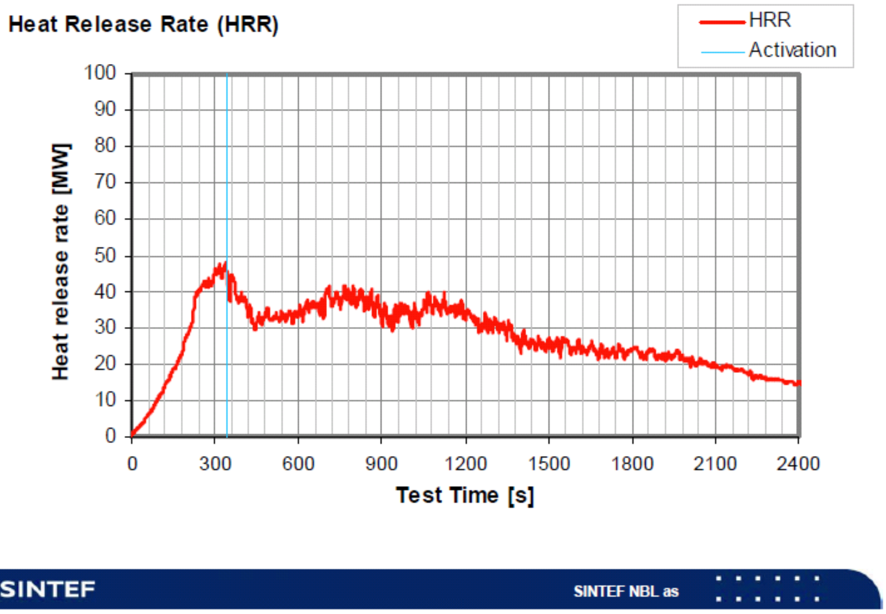
Heat outputs from fires were calorimeter method measured in single point in the tunnel tube cross section 100m from the tunnel outlet. A location 100m from the tunnel outlet is influenced by the wind conditions out side the tunnel pipe. The long distance from the test fires to the location of the measuring station for CO2, etc. 800m. The point measuring method and the location of measuring of CO2 concentrations and air velocities to calculate heat output does therefore incorporate large potential risks and large uncertainties in the calculation of heat out puts from fires.
The assumed potential heat outputs of the test fires are based upon many previous similar test fires conducted by Sintef NBL. The assumed potential heat out puts of the test fires are therefore most close to the actual heat out puts of the tests fires than what was measured and calculated during the test fires.

However the calculated values provide a good idea of the tunnel systems abilities to suppress tunnel fires heat out puts.





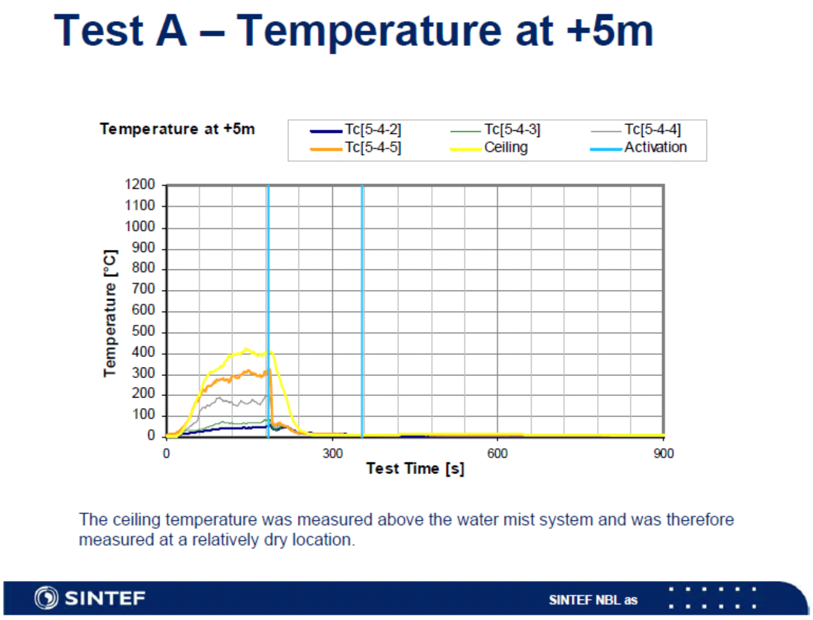
Test C - Heat Release Rate (HRR)

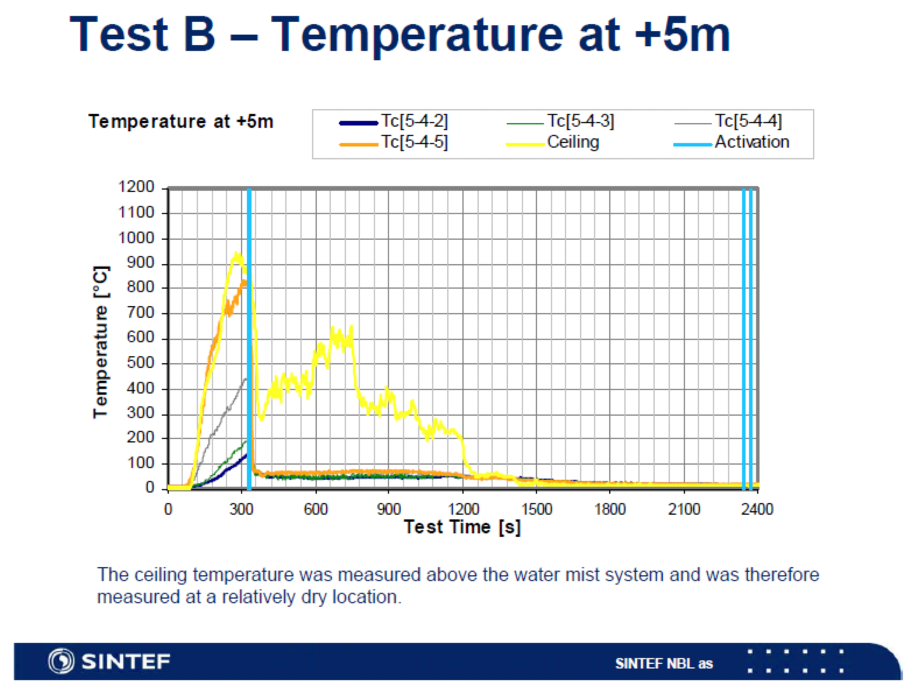


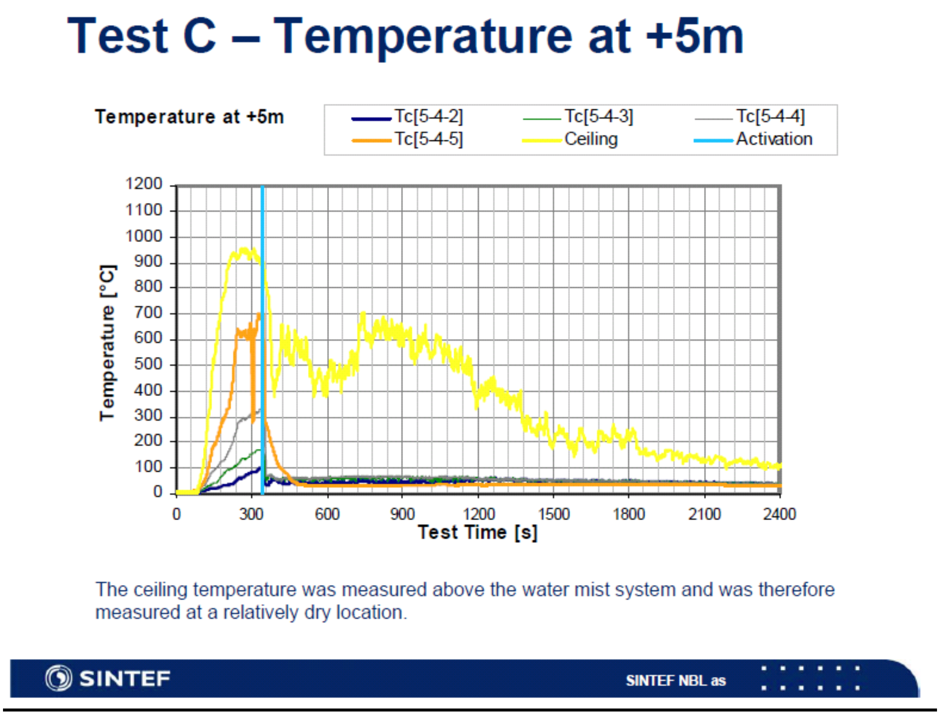
Temperaturs controle.

In all fires the activation of the VID Fire-Kill Tunnel Protection system the water mist provided an immediate drop in temperatures in the tunnel on all levels above the road.

In all test fires the fires the protection system kept the temperatures below temperatures which causes damages to concrete tunnel structures, and in all fire tests the temperatures 2m above ground was kept below 100Cº not causing harm to people in the tunnel.



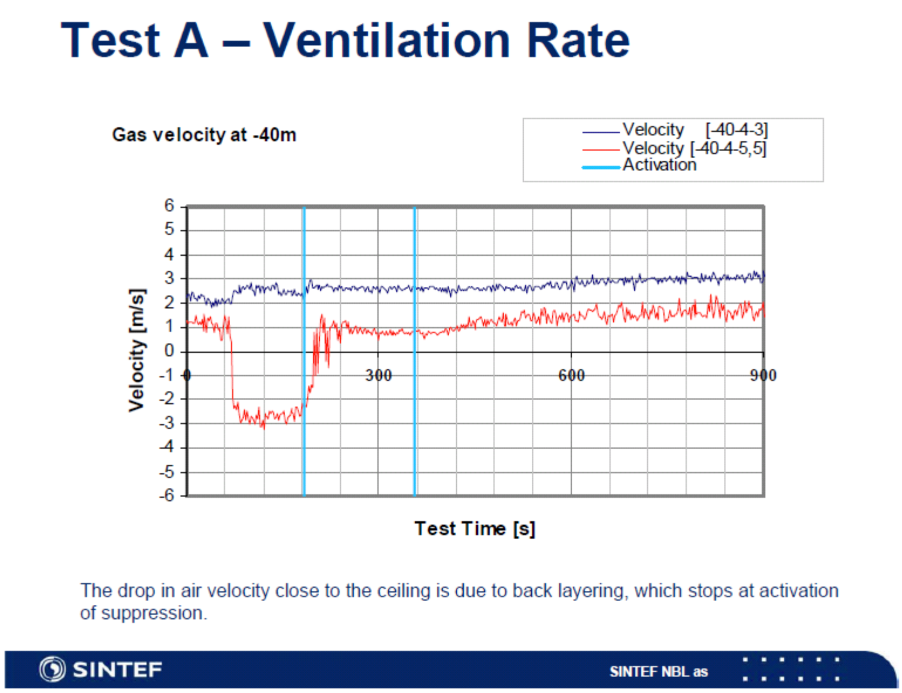




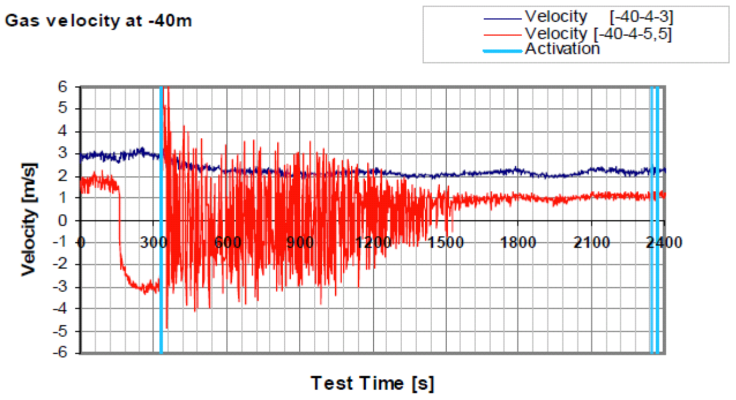
Smoke management upstream fires.

During the test-fires a smoke backflow along the tunnel ceiling was observed at the measuring post 40m upstream the fire. The smoke back flow air velocity was approximately 3m/s against ventilation with a forced air speed of 1 m/s along the ceiling.

In all fires the smoke back flow disappeared, and the air flow returned to the forced air flow of 1 m/s as soon as the VID Fire-Kill tunnel protection was released to distribute water mist in the vicinity of the test fires.



Test B – Ventilation Rate



The velocity close to ceiling (red curve) shows back layering until activation of fire suppression.

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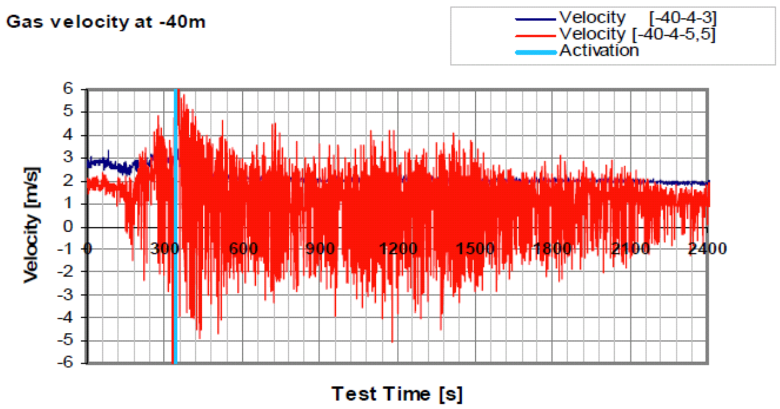
Test C – Ventilation Rate



Back layering was observed in this test as well prior to activation of fire suppression. It is not seen on the graph due to measurement errors (red curve).

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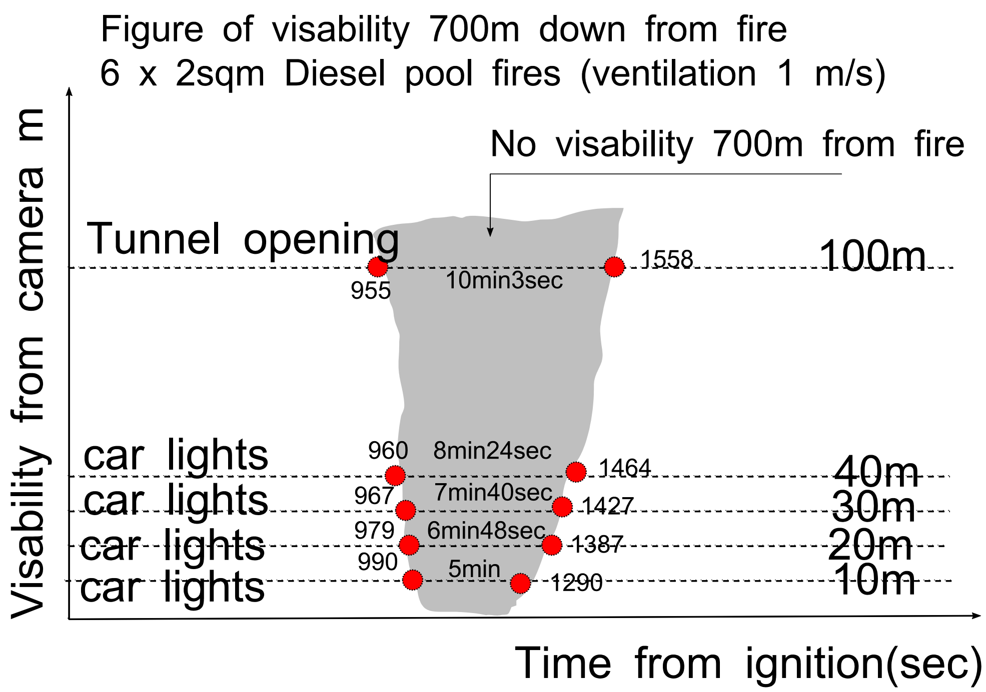
Conditions up stream fires:
During the fire tests it was possible to enter the tunnel without any kind of breathing or heat protection, and to stay in the tunnel tube as close as a few meters down stream the test fires, provided that the ventilation system was on (1m/s – 2m/s) and the VID Fire-Kill Tunnel protection system is on too.
This makes it possible for rescuing and manual fire fighting to take place at an early time in a tunnel fires in tunnels where the VID Fire-Kill Tunnel Protection system is installed.

Conditionings Down stream fires:
The Oxygen and CO and CO2 concentration was measured 100 from the tunnel outlet down stream the test fires. In no test fires did the oxygen concentration drop below 19%. The steam from evaporated water mist did therefore not cause conditions with lethal oxygen concentrations.

In test a) the 6 x 2m² diesel oil fire the visibilities 0m – 100m from the tunnel exit was recorded on video. A video camera was positioned on the road 100m from the tunnel exit, and lamps with light intensities were positioned on the road at distances of 10m, 20m, 30m, 40m and 50m from the video camera. The ventilation during the fire tests were 1-3m/s depending on the location in the tunnel and the tunnel cross section. The fire was extinguished 4 minutes after it was ignited, and the water mist was on 30min before the fire was extinguished. The video recordings showed that the visibility disappeared after 990 sec, and the visibility returned again after 5 minutes because the VID Fire-Kill Tunnel Protection System had extinguished the fire after 30 sec. and thereby stopped the smoke propagation.



Appreciations:

We like to express our gratitude to Entreprice and especially to Pierre Egon Aagard and Mette Vejle for their large interest and work in active protection of infrastructure tunnels, which has made the Runehammer fire tests possible.
We also like to express our gratitude to Sintef NBL and especially Mr. Kristen Upstad, and Mr. Are Sæby Upstad for assisting us with their vast fire knowledge, for designing the test fires, for conducting all measurements, and recording all date, and not at least driving us in and out of the tunnel during the fire tests. Without you we could not have conducted the tests.
We also like to thank veivæsnet for letting us use the Runehammar test tunnel for our tests, and especially Mr Per for your large effort setting up fire tests and removing old fuels and helping us with all small things, and for garding the tunnel entrance during test fires. Large help arranging all
Finally but not least a very large thanks you to LPG S.L, and especially Mr. Alex Palau. For many good discussions, and for being in Runehammer helping us conducting the tests.