*20th International Conference on Structural Mechanics in Reactor Technology (SMiRT 20) -*
*11th International Post Conference Seminar on*
*"FIRE SAFETY IN NUCLEAR POWER PLANTS AND INSTALLATIONS"*

# WATER MIST FIRE PROTECTION SYSTEMS FOR INDUSTRIAL CABLE TUNNELS AND TURBINE HALLS

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## ABSTRACT

This paper presents full scale fire testing results on the performance of high pressure water mist fire protection technology for industrial cable tunnels and turbine halls. For cable tunnels, the fire load consisted of power and control cables placed on a tray along one wall of a simulated cable tunnel. Water mist systems were tested that either completely extinguished or rapidly suppressed the fire. For turbine hall applications, two floor-level turbine oil flowing spill fire scenarios were tested on a concrete slab. 60 l of turbine oil were pre-spilled on the slab, and additional oil was flowed to the fire at a rate of 13 l/min. The tested water mist system completely extinguished the fires.

## INTRODUCTION

Based on the probabilistic risk assessment of fires at nuclear power plants, usually some of the switchgear rooms and cable rooms are identified among the most important compartments considering nuclear safety. Additionally, big fire loads of some oil systems and transformers enable long-term fires, which are potential to cause damages of the compartment structures and to affect also neighbouring compartments.

Water is the suppressant of choice for most fires in ordinary solid combustibles. However the suitability of water for fires in electrical installations or in flammable or combustible liquids is sometimes questioned. The results presented in this demonstrate that high pressure water mist systems can be designed to provide a good fire performance for both of these applications with a water consumption that is significantly less than with standard sprinkler or water spray technology.

## EXPERIMENTAL ARRANGEMENT FOR CABLE TUNNELS

The fire suppression tests were made in simulated industrial scale cable tunnel constructed according to the industrial standard VdS 2498 [1] and located in a test hall of dimensions of 26 m by 12 m by 8 m (L x W x H). The tunnel was constructed of standard steel containers, and it had the dimensions of 1761 cm x 234 cm x 235 cm (L x W x H).

An air flow inside the tunnel was generated by a smoke scrubbing system connected to the back end of the tunnel. The system consisted of high pressure water mist nozzles installed inside the smoke extraction tube and spraying in the axial direction of the tube. The air flow inside the tunnel could be adjusted by changing the number of nozzles inside the tube and varying the nozzle pressure. An average air flow velocity of 1 m/s was applied in all tests.

The fire load consisted of five different types of typical industrial power and data cables placed in a cable tray stack. The cable arrangement on a tray of eight layers is shown in Figure 1. The full fuel package was used in the deluge extinguishing system test with a 15 min pre-burn time. In the suppression tests, the cable lengths were reduced due to shorter pre-burn times. In all tests, the cable lengths were sufficiently long to demonstrate fire suppression. A gas burner below the tray stack was used to ignite the fires.


**Figure 1** Left: photograph of the cable tray fuel package; right: schematic illustration of the cable arrangement

Temperature instrumentation is shown in Figure 2. Gas temperatures were measured 150 mm below the mid-ceiling at seven locations (TC-B01 - TC-B08) starting from the upwind end of the trays and continuing downwind at 2 m intervals Gas temperature between the top two trays at seven locations (TC-A01 - TC-A08) starting from the upwind end of the trays and continuing downwind at 2 m intervals.

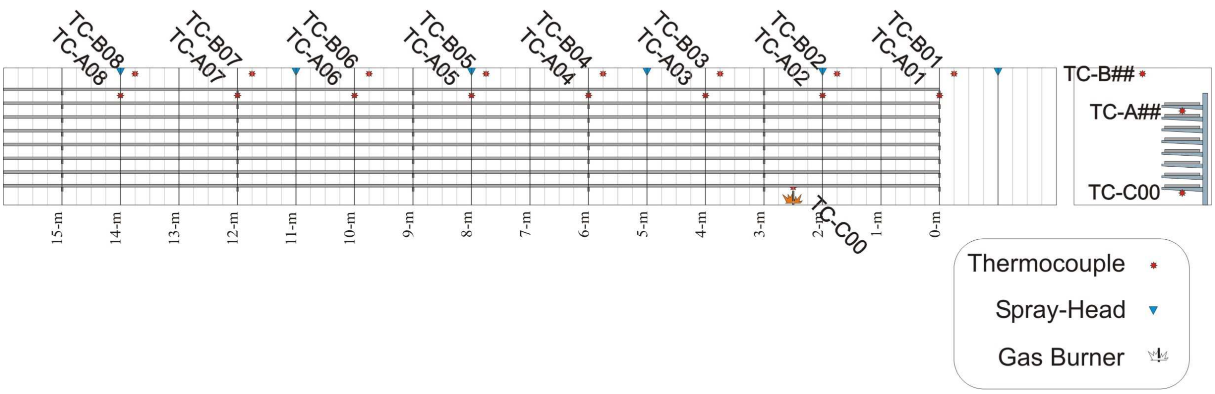


**Figure 2** Schematic side view of the thermocouple and nozzle arrangement TC-C00 denotes the burner location; air flow is from right to left

Three different high pressure water mist systems were investigated. Two of these were deluge systems, and one used automatic sprinklers. For each system, a single row of six nozzles was installed along the centreline of the container ceiling with a spacing of 3 m. The protected floor area per nozzle was 7.02 $m^2$. Table 1 summarizes the main parameters of the systems.

**Table 1** Water mist system parameters for cable tunnel tests

| System ID | System description | Nozzle K-factor [l/min/bar$^{1/2}$] | Pressure at nozzle [bar] | Flux density [l/min/m$^2$] |
|---|---|---|---|---|
| Deluge A | Deluge extinguishing system | 3.4 | 100 | 4.8 |
| Deluge B | Deluge suppression system | 2.1 | 74 | 2.6 |
| Sprinkler | Sprinkler suppression system | 2.0 | 120 | 3.1 |

**Table 2** Test programme

| Test | System | Flux density [l/min/m$^2$] | Burner HRR [kW] | Pre-burn time [min] |
|---|---|---|---|---|
| 1 | Deluge A | 4.8 | 250 | 15 |
| 2 | Deluge B | 2.6 | 250 | 5 |
| 3 | Deluge B | 2.6 | 250 | 10 |
| 4 | Sprinkler | 3.1 | 50 | N/A |

A total of four fire tests were conducted with three different water mist system designs (Table 2). In the deluge system tests all nozzles were activated manually after a pre-determined time from ignition. The burner was operated for 5 min. A pre-burn time cannot be specified for the sprinkler test as the nozzles are activated by thermally sensitive glass bulbs. Notice that the burner HRR was reduced for the sprinkler test to avoid sprinkler activation due to the gas burner flame. Furthermore, the burner was turned off upon activation of the first sprinkler.

## EXPERIMENTAL ARRANGEMENT FOR TURBINE OIL FIRES

The tests were carried out in the VTT large fire test hall. The floor area of the hall is 378 m$^2$ and it has a maximum height of 18 m. The gross volume of the hall is 6000 m$^3$. The hall is equipped with a smoke collection and cleaning system and a waste water collection system. During the tests, the ventilation was running.

The fuel used in the test was TURBINE GT 46 EP turbine oil supplied by Neste Oil Oyj, Finland. It consists mainly of hydrocarbons in the C20 - C50 range, and has a typical density of 840 kg/m$^3$ at 15 ºC, and a flash point of 230 ºC. Before the test, the fuel was pre-heated to about 70 °C to achieve a realistic fire spread rate. Ignition was performed by pouring 3 l of heptane on top of the turbine oil and manually applying a propane flame.

To protect the floor of the test hall, the fuel spill was arranged over a concrete pad measuring 3.1 m x 5.3 m x 0.1 m (high) placed on the floor of the test hall and aligned centrally with respect to the suppression system spray heads. A rim of about 3 cm in height was shaped to the pad to contain fuel and water, resulting in net dimensions of 2.8 m x 5.1 m (14.3 m$^2$) for the spill area. However, the actual size of the fuel spill was less due to a slight tilt of the pad resulting in accumulation of the fuel towards one end of the pad.

In both tests, 60 l of turbine oil were admitted on the concrete pad as a pre-spill. Based on a visual estimate, this amount of fuel settled on an area of about 6 m$^2$ (Figure 3), corresponding to an average fuel layer thickness of 10 mm. This is in excess of the 0.7 mm – 4 mm thickness range quoted for unconfined spill fires [2], and is due to the tilt of the pad. The spill area may be used to estimate the potential size of the fire. It is well established that thick hydrocarbon pools over 1 m in diameter have a burning rate of approx. 0.05 $kg/m^2/s$ [2]. Assuming a heat of combustion of 40 MJ/kg, this corresponds to a heat release rate (HRR) of 12 MW. It should be noted however, that real spills, i.e. thin fuel layers, may burn with as little as 20 - 25 % of the HRR for a corresponding thick fuel layer [2]. The relatively thick fuel layer on the pad would support using the burning rate for thick fuel layers. In addition, boiling of the residual water on the pad tended to increase the burning rate.

**Figure 3** Left: the concrete pad with a pre-spill of 60 l of turbine oil; right: the test fire without the steel table. The maximum flame height is about 8 m

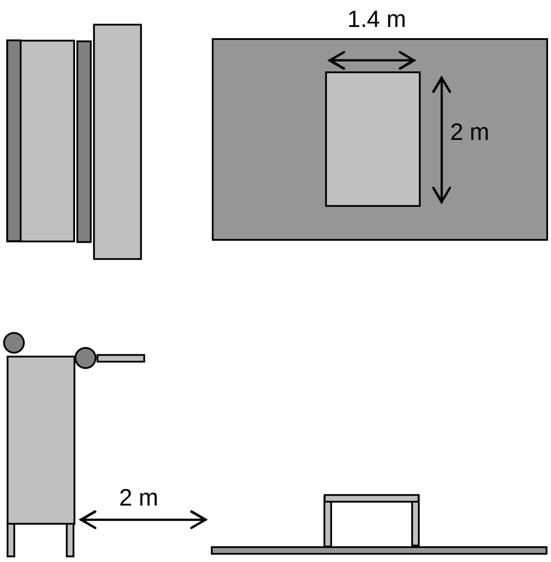


**Figure 4** Positioning of the diesel engine mock-up and steel table

To ensure that the fire would not be extinguished due to burn-out of fuel, a continuous oil flow of 13 l/min was arranged after ignition. This corresponds to a mass flow rate of 0.18 kg/s which would be able to sustain a 7 MW fire.

A diesel engine mock-up was placed next to the concrete pad to represent equipment or structures found in a turbine building (Figure 4). The mock-up is the same that is used in the fire testing protocols for total flooding by fire extinguishing systems for marine engine rooms [3]. The front surface of the mock-up was placed at 2 m distance from the short end of the concrete pad. Two tests were carried out. The first test involved a fully exposed fire. For the second fire test, a steel table measuring 1.4 m x 2 m x 0.75 m (high) was placed on top of the concrete pad (Figure 3) to simulate an obstruction between the base of the fire and the water sprays.

The temperature measurement locations and spray head lay-out is shown in Figure 5. Ceiling jet gas temperatures (T1 - T5) were measured 70 cm above the nozzle grid. Two gas temperature trees were also installed, one inside the mist (T6 - T10) and one outside the mist (T11 - T15).

The high pressure water mist fire protection system consisted essentially of 18 spray heads (K-factor 3.9 l/min/bar$^{1/2}$) in a 3 x 6 grid with a 3.5 m spacing installed at 15 m height, and a diesel-driven piston pump unit, rated for 360 l/min at 140 bar; in the tests, the pump unit was operated at a pressure of 60 bar

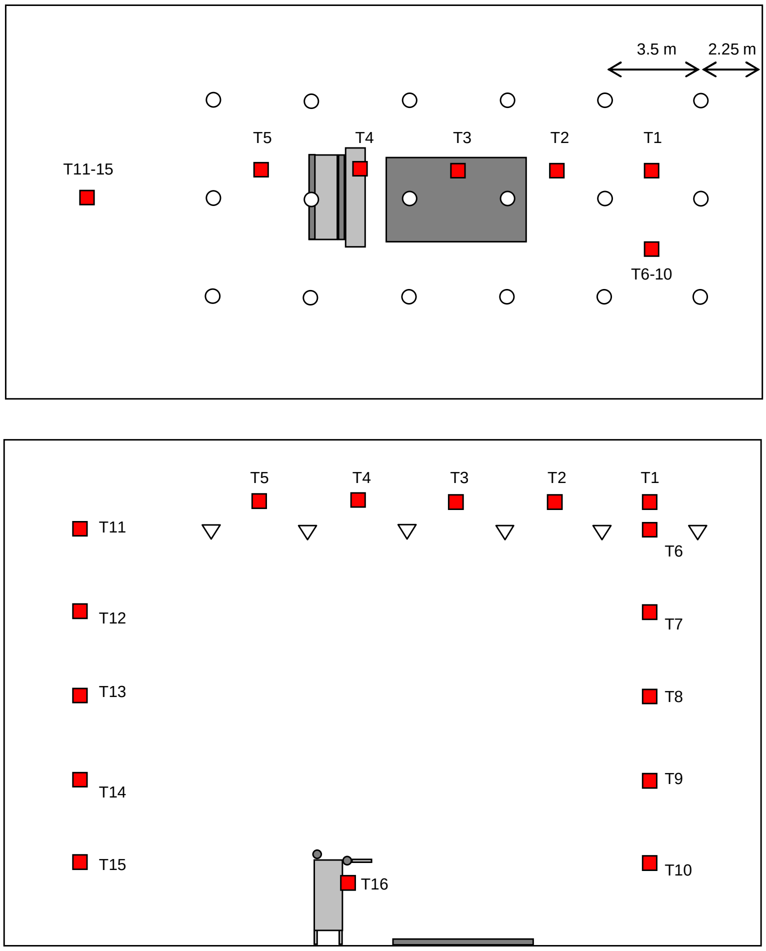


**Figure 5** Spray head and thermocouple locations

## RESULTS FOR CABLE TUNNELS

Figure 6 to 9 represent the extent of fire damage to the cables in each test. The white bars denote the cables that were installed to the fuel package, and the black portions represent the extent of fire damage (charring or melting) to the cables. The numbers indicate the horizontal dimension in metres starting from the upwind end of the cable tray. The black triangles above the trays indicate the positions of the water mist nozzles. The effect of air flow in the tunnel is clearly visible in the damage patterns.

The figures also show the position of the residual flames after test, if any. It is worth noting that the residual fire was always small, and it was located inside the area damaged by the fire, not at the edge of the damaged area. Furthermore, it was located close to the position of the gas burner. This suggests that either the steel cable trays or the copper core of the cables was maintaining the residual fire, since the fire was at the location that was exposed to the fire for the longest time, and that was best shielded from the water sprays.

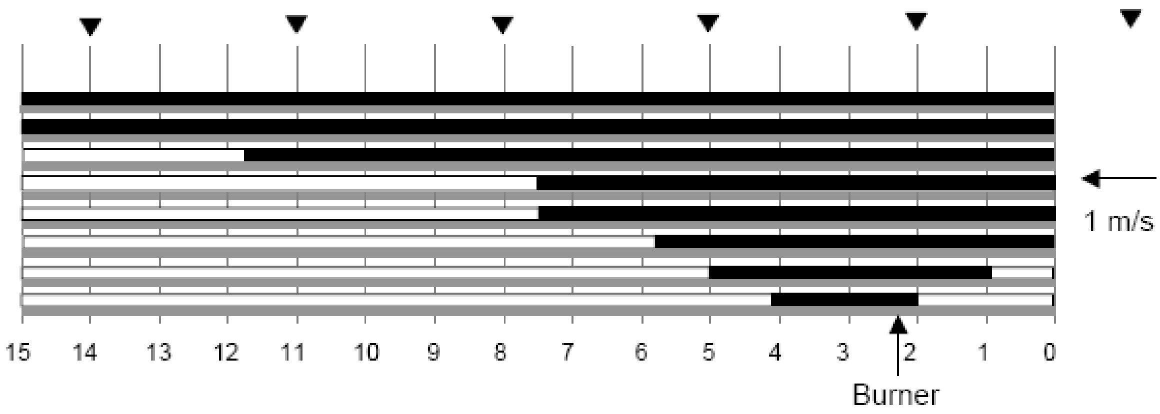


**Figure 6** Damage to the cables with 15 min pre-burn in test 1

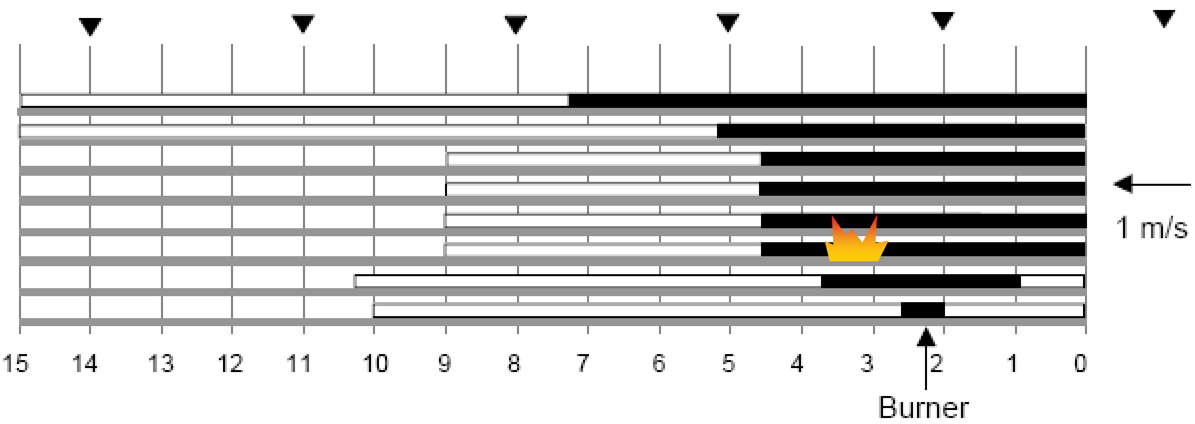


**Figure 7** Damage to the cables with 5 min pre-burn in test 2

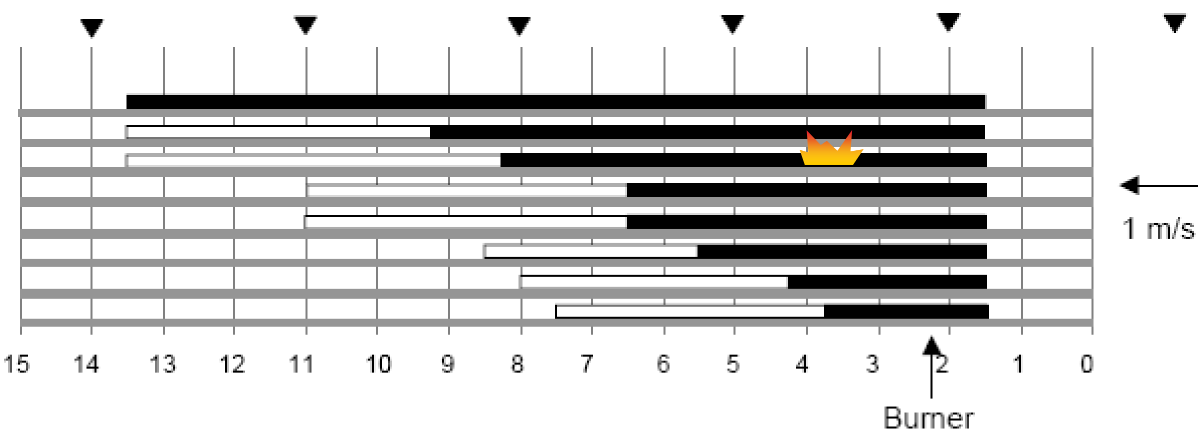


**Figure 8** Damage to the cables with 10 min pre-burn in test 3

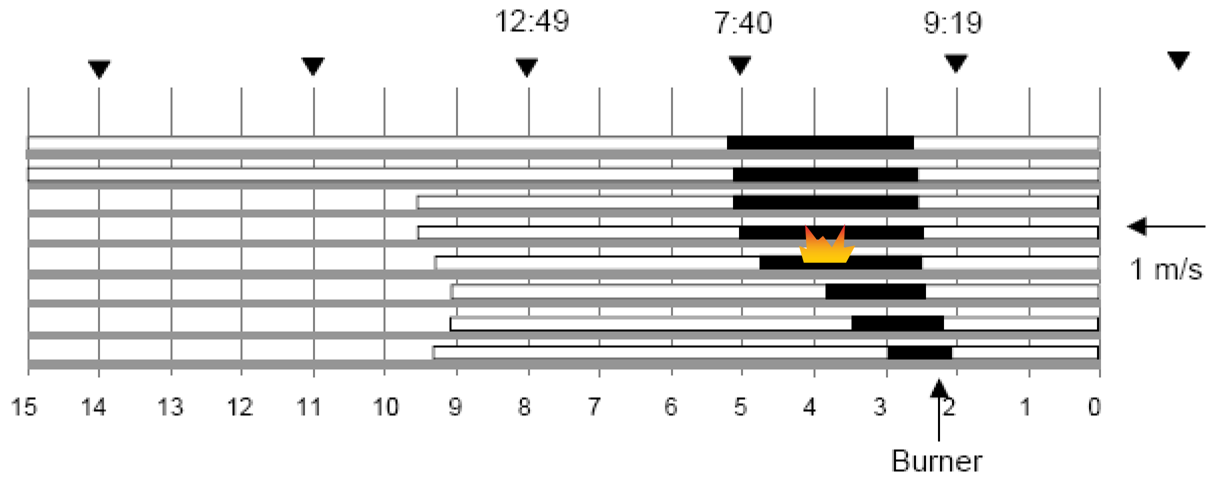


**Figure 9** Damage to the cables with automatic sprinklers in test 4; the sprinkler activation times (min:s) are determined from the moment of ignition; only three sprinklers activated

The thermocouple readings from test 1 are shown in Figure 10. The maximum temperatures observed in the tests are about 800 – 900 ºC. The first locations to achieve these temperatures are above the tray close to the position of the gas burner, and it takes about 5 min for the first thermocouple to reach this temperature. After this, other thermocouples downwind gradually approach this temperature, giving an indication on the rate of fire spread along the tunnel. A value around 800 ºC for a thermocouple represents a fully developed fire at the location of the thermocouple. Therefore, the effect of an increasing pre-burn time is primarily to affect the spread of the fire, but not the severity of the fire at a particular location.

When the water mist system is activated, temperatures fall down sharply, suggesting a rapid suppression of the fire. The investigation of the extent of the damage pattern for various pre-burn times suggests that the fire spread was effectively stopped due to the activation of the water mist system. The temperature data illustrates how water mist can provide very good thermal management in confined spaces.

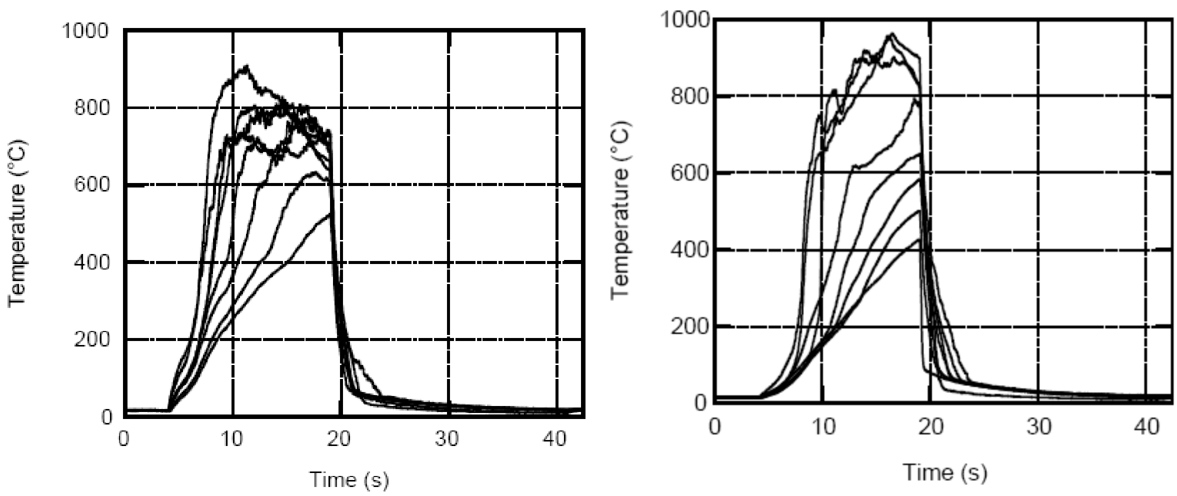


**Figure 10** Temperatures recorded in test 1; left: mid-ceiling thermocouples B01 - B08; right: tray thermocouples A01 - A08

## RESULTS FOR TURBINE OIL FIRES

The high pressure water mist system described in this report extinguished both test fires. The extinguishment times were 1 min 17 s for the exposed fire, and 3 min 27 s for the concealed fire. It should be noted that due to the continuous flow of fresh fuel to the fire, the fire was not extinguished due to burn-out.

Between the moment of HI-FOG system activation and fire extinguishment, all measured gas temperatures decreased sharply (Figure 11). This was partly due to the reduced fire size, and partly due to the high cooling efficiency of high pressure water mist. The capability of the water mist system to thermally manage the protected space is a significant safety factor in the potential case that the fire would not be completely extinguished.

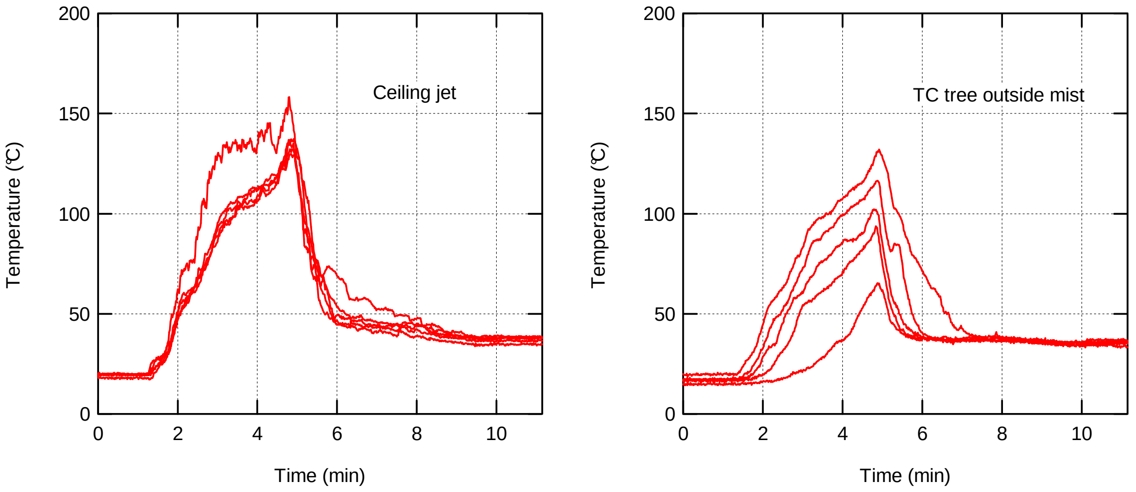


**Figure 11** Selected gas temperatures recorded in the concealed spill fire test; the fire was ignited at 1 min, and the water mist system was activated at 5 min (pre-burn time 4 min)

## REFERENCES

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